BIOMETEOROLOGY

BIOMETEOROLOGY

Proceedings of

The Second International Bioclimatological Congress

held at

The Royal Society of Medicine, London, 4–10 September, 1960

organized by

" The International Society of Biometeorology "

Edited by

S. W. TROMP

A Pergamon Press Book

THE MACMILLAN COMPANY
NEW YORK
1962

This book is distributed by
THE MACMILLAN COMPANY · NEW YORK
pursuant to a special arrangement with
PERGAMON PRESS LIMITED
Oxford, England

Library of Congress Card No. 61—11154

Made in Great Britain

CONTENTS*

* Papers have been grouped according to main subject, but several papers could properly be included in more than one group.

** Only written discussion papers received before 1 Dec. 1960 are included.

3rd Session

BIOCLIMATOLOGICAL CLASSIFICATION

(Chairman: Prof. J. S. Weiner)

4th Session

METEORO-PATHOLOGICAL FORECASTING

(Chairman: Mr. P. M. A. Bourke)

5th Session

URBAN BIOCLIMATOLOGY
(Chairman: Prof. J. K. Page)

6th Session

THERMOREGULATION IN ANIMALS AND MAN IN RELATION TO BIOCLIMATOLOGY*
(Chairman: Prof. H. Hensel)

* Only part of the papers submitted to this Working Group could be published in the Congress Proceedings. Other papers will be published in Vol. V, 1961 or Vol. VI, 1962 of the *International Journal of Biometeorology*.

MISCELLANEOUS BIOCLIMATOLOGICAL PAPERS SUBMITTED TO THE CONGRESS

GENERAL BIOCLIMATOLOGY

HUMAN BIOCLIMATOLOGY

BRONCHIAL ASTHMA

IONIZATION OF THE AIR

PHYSICO-CHEMICAL STATE OF THE BLOOD

ZOOLOGICAL (ENTOMOLOGICAL) BIOCLIMATOLOGY

PHYTOLOGICAL BIOCLIMATOLOGY

REPORTS OF CHAIRMEN OF SPECIALIZED WORKING GROUPS

INTRODUCTION

The second International Bioclimatological Congress was held in the chambers of the Royal Society of Medicine in London from 4--10 September 1960. The Congress was organized by the Executive Board of the International Society of Bioclimatology and Biometeorology for its 500 members representing forty–four different countries.

Bioclimatology and biometeorology have been defined by the members of this Society as "... the study of the direct and indirect interrelations between the geophysical and geochemical factors of the atmospheric environment and living organisms, plants, animals and man. The term "environment" is broadly conceived and includes micro-, macro- and cosmic environments, in so far as they affect the earth's atmosphere, and the diverse physical and chemical factors which comprise these environments. Investigations in these disciplines are conducted in nature or in the laboratory under as rigidly controlled conditions as possible to describe measurable and reproducible physical, chemical and biological factors which show a sufficiently high statistical correlation with measurable physiological and pathological processes to suggest a valid cause and effect relationship between organism and environment." (Organizational Meeting, Paris, August 1956.)

The Executive Board adopted the viewpoint that lively discussion of basic concepts, problems, and methodology leads to important cross-fertilization and growth of ideas. To this end a programme was designed which aimed at stimulating a maximum of discussion both on broad problems and on technical matters.

On each of four mornings a basic theme was discussed by three invited speakers, each covering the human, zoological, or phytological aspects of the general topic. The speakers concentrated on major unsettled issues and their possible resolution. Four main themes were selected for this Congress: *High Altitude Bioclimatology, Tropical Bioclimatology, Bioclimatological Classifications* and *Meteoro-Pathological Forecasting*. The lectures, together with discussion which each provoked, have been given in four sections of this book.

During each afternoon various Working Groups discussed very specialized bioclimatological subjects of which only some of the lectures and discussions could be published in this volume. The remaining reports will be printed in Vol. V, 1961, and Vol. VI, 1962 of the *International Journal of Biometeorology*.

The selection of the reports was not only based on the scientific standard of the reports but it was considered to be of great importance that the reader could study the different scientific approaches in different countries. Above all, those subjects were selected which, according to the editors, are most promising for the understanding of the relationship between weather and the living organism: man, animals and plants. Reports which will be published in Vol. V of the *International Journal of*

Biometeorology deal primarily with a continuation of research work reported at previous congresses.

The Executive Board of the I. S. B. B. wishes to avail itself of this opportunity of thanking the Pergamon Press Ltd. for their willingness to publish these Congress Proceedings at their own financial responsibility.

For the Executive Board of I. S. B.
Prof. FREDERICK SARGENT, II. President
Dr. S. W. TROMP, Secretary-Treasurer

IN MEMORIAM

DR. F. SAUBERER

1899—1959

Die Bioklimatologie hat einen ihrer rührigsten und begeistertsten Pioniere verloren: Dr. F. Sauberer ist nicht mehr. Am 24. Okt. 1959 raffte ihn ein Herzschlag hinweg, mitten in seiner Arbeit und viel zu früh für alle, die ihn kannten, die von seinem Rat profitierten und die seine humorvolle, menschliche Art lieben gelernt haben.

Franz Sauberer wurde am 20. Juli 1899 in Wien geboren. Nach Absolvierung der Grundschulen erlernte er vorerst das Elektro- und Feinmechanikergewerbe. Nach seiner Rückkehr aus dem ersten Weltkrieg übte er diesen Beruf an verschiedenen Stellen in der Privatindustrie aus und erwarb sich während einer 12jährigen Praxis seine fundamentalen Kenntnisse über den Bau und die Wirkungsweise von komplizierten Geräten, die ihm später, in Verbindung mit seiner akademischen Erfahrung, bei der Konstruktion von wissenschaftlichen Apparaten wertvolle Dienste leisteten. Neben seiner Berufstätigkeit besuchte Franz Sauberer das Realgymnasium als Externist und legte im Jahre 1931 die Reifeprüfung mit Auszeichnung ab. Dieser Erfolg sicherte ihm ein Stipendium an der Universität in Wien, wo er vorerst die Fächer Mathematik und Physik belegte. Eine Vorlesung von Professor Wilhelm Schmidt brachte ihn mit der Arbeitsrichtung der praktischen Meteorologie, der Lokal-, Mikro- und Bioklimatologie in Berührung, und seit jener Zeit hatte er sein eigenstes Arbeitsgebiet gefunden, zu dessen Entwicklung er während der folgenden Jahre bis zu seinem Tode unter Einsatz seiner ganzen Persönlichkeit beigetragen hat.

Noch während seiner Studienzeit, im Jahre 1936, kam Franz Sauberer an die Zentralanstalt für Meteorologie. Hier begann er, gefördert durch Prof. Wilhelm Schmidt, der seine außergewöhnlichen Fähigkeiten bald erkannte, mit seiner experimentellen Dissertation über die Strahlungsbilanz verschiedener Oberflächen. Seine Studien auf diesem Gebiet führten ihn u.a. an die Biologische Station in Lunz am See, wo er mit dem Leiter des Institutes, Prof. Franz Ruttner in Kontakt kam. Die von diesem Manne ausgehende begeisternde Atmosphäre für die limnologische Forschung ergriff auch Franz Sauberer. Ein deutsches Forschungsstipendium ermöglichte ihm, in der Folgezeit einen längeren Aufenthalt an der Biologischen Station, wo er umfassende Studien über die physikalische Limnologie, vorwiegend über das Eindringen der Strahlung in natürliche Gewässer betrieb. Die Konstruktion zahlreicher, für die Strahlungsmessungen unter Wasser geeigneter Apparate weisen auf diese Zeit zurück. Später konnte er seine Untersuchungen an Gewässern, teilweise gemeinsam mit O. Eckel, auch auf Seen in der Umgebung

Berlins und gemeinsam mit seiner Frau auf die Kärntner Seen ausdehnen. Eine Zusammenstellung dieser an Gewässern unter besonderer Berücksichtigung der Strahlungsmessung unter Wasser durchgeführten Untersuchungen wurden gemeinsam mit F. Ruttner im Jahre 1942 in Buchform veröffentlicht. Dieses Werk wurde von ihm in Zusammenarbeit mit namhaften Limnologen des In- und Auslandes durch *»Empfehlungen für die einheitliche Durchführung von Strahlungsmessungen für limnologische Zwecke«* auf den heutigen Stand erweitert.

Der Strahlungsforschung mit der er seine wissenschaftliche Laufbahn begonnen hatte, blieb F. Sauberer auch während des Krieges und nach Kriegsende treu, wenn ihn auch die Lösung apparativer Fragen auf anderen meteorologischen und bioklimatischen Gebieten immer wieder nebenher beschäftigte. In rascher Folge erschienen nach Kriegsende Arbeiten über meteorologische Strahlungsmessungen, wie der Sonnenstrahlung, der Globalstrahlung, der Gegenstrahlung und der Ausstrahlung, in sich geschlossene Teilarbeiten, die er noch ein Jahr vor seinem Tode in einem erstmaligen Versuch einer Strahlungsklimatographie von Österreich zusammenfassen konnte. Der Untersuchung der Strahlungsverhältnisse im Hochgebirge waren Messungen während mehrerer Jahre im Sommer und Winter gewidmet. Vor allem war es jedoch das Grenzgebiet zwischen Meteorologie und Biologie, das Franz Sauberer faszinierte. Die Auswirkungen der verschiedenen Strahlungsvorkommen in der Atmosphäre auf das Leben, auf das Wachstum der Pflanzen, auf die Reflexion von Bodenüberzügen, die Veränderung des Strahlungsklimas in Siedlungen und Wohnungen beschäftigten ihn durch alle Jahre seiner Forschertätigkeit. Seine Arbeiten über die Wechselbeziehungen zwischen der Strahlung und den Pflanzen sind in seinem, gemeinsam mit O. Härtel herausgegebenen Buch über *Pflanze und Strahlung* (1959) niedergelegt. Jahrelange Studien über die Strahlungsverhältnisse in der Großstadt, das Strahlungsklima in Straßen und Plätzen, hergeleitet aus Messungen und Berechnungen, wurde im Teil »Strahlung« des gemeinsam mit F. Steinhauser und O. Eckel veröffentlichten dreibändigen Werkes über *Klima und Bioklima von Wien* zusammengefaßt (1955, 1957, 1959). Seine lokalklimatischen Untersuchungen erstreckten sich auf die Niederschlagsverteilung in Gebirgslagen (Lunz) und auf zahlreiche Untersuchungen über Standorteignungen für Wohn- und Industriegebiete, die zum Teil in Gutachtenform vorliegen.

Im Jahre 1945 kehrte F. Sauberer nach den Kriegswirren umgehend an die Zentralanstalt zurück. Er leitete das Institut in dieser schweren Zeit und sorgte für die Aufräumung der ärgsten Zerstörungen. Nach der Rückkehr des damaligen Direktors gründete er die Bioklimatische Abteilung, die er von 1945 bis zu seinem Tode als Abteilungsvorstand leitete und ausbaute.

Im Jahre 1948 schuf er, größtenteils aus eigenen Mitteln ein für die bioklimatische Fachrichtung eigenes Organ, die Zeitschrift *Wetter und Leben*, die er, unter ständigen Zuschüssen aus eigener Tasche über die Krisenzeiten hinwegrettete und seit Beginn als verantwortlicher Redakteur leitete.

Obwohl Dr. F. Sauberer keine offizielle Lehrstelle an der Universität bekleidete, kamen doch immer wieder Schüler und Interessenten aus dem In- und Ausland um sich Rat für ihre Untersuchungen zu holen und ihre Forschungsunternehmungen mit ihm zu besprechen. Zur Verbreitung der Bioklimatologie und zur Kontaktaufnahme mit Botanikern, Zoologen und Medizinern rief Dr. Sauberer Bioklimatische Diskussionsabende ins Leben, in denen eine ideale Synthese dieser Grenzwissenschaft gefunden wurde. In zahlreichen populären Vorträgen wandte er sich an breiteste Kreise und hat es immer wieder verstanden, freiwillige Mitarbeiter aus allen Schichten zu werben. Seine beiden kleinen Bände *Einführung in die Meteorologie* und *Wetter, Klima und Leben* wenden sich an den interessierten Laien, der letztere bietet aber auch in seiner geschlossenen Übersicht dem Wissenschaftler eine gute Einführung in die Fragenkreise der Bioklimatologie.

Österreich ehrte die Leistungen Dr. Sauberers durch die Verleihung des Haitinger-Preises der Österreichischen Akademie der Wissenschaften und des Theodor Körner-Preises als Anerkennung für seine Leistungen auf dem Gebiet der Strahlung.

Das wissenschaftliche Werk Dr. F. Sauberers umfaßt nahezu 100 Publikationen, in denen eine Fülle von Gedanken und Erkenntnissen auf dem weiten Gebiet der Bioklimatologie niedergelegt sind. Untrennbar mit der wissenschaftlichen Kapazität des Mannes war jedoch für alle, die ihn persönlich kannten, seine eigenwillige Persönlichkeit verbunden, die durch ihre auffallende Bescheidenheit und humorvolle Güte jedermann zum Freund gewann. Das Andenken Dr. F. Sauberers wird in der internationalen Bioklimatologie und besonders an seinen einstigen Wirkungsstätten in Wien und Lunz unvergessen bleiben.

Dr. INGE DIRMHIRN

PROF. DR. HELLMUT BERG
1908—1960

AM 2. März 1960 verstarb im Alter von 51 Jahren unerwartet auf einer Excursion in die Allgäuer Berge Prof. Dr. Hellmut Berg, Direktor des Meteorologischen Institutes der Universität Köln, an einem Herzinfarkt.

Geboren am 2. November 1908 in Bretten (Baden), studierte Berg in Karlsruhe und Heidelberg Meteorologie, Astronomie und Physik. Anfang 1931 promovierte er zum Dr. phil. nat. mit der Dissertation »Ein Beitrag zur Struktur eines Warmlufteinbruches«. Nach Abschluß seines Studiums war Berg als Meteorologe an der Flugwetterwarte Hannover und ab 1934 als Leiter der Wetterflugstelle Köln tätig. Im Jahre 1937 erwarb er an der Universität Heidelberg den Grad eines Dr. phil. nat. habil und erhielt 1938 eine Dozentur für Meteorologie an der Universität Köln. Während des Krieges war Berg als Regierungsrat und später als Oberregierungsrat Leiter einer Wettererkundungsstaffel und der Wetterberatungszentralen Antwerpen und Düsseldorf.

Nach der Rückkehr aus der Kriegsgefangenschaft leitete er zunächst die Wetterwarten Rötgen und Mönchen-Gladbach. Als ihm im Jahre 1947 von der Universität Köln eine Diätendozentur angeboten wurde, schied er aus dem Deutschen Wetterdienst aus und widmete sich von da an ganz der Lehre und Forschung. Er vertrat an der Universität Köln die Meteorologie und Geophysik und hielt auch Vorlesungen über Teilgebiete der Ozeanographie. Auf seine Initiative hin wurde 1949 das Meteorologische Institut der Universität Köln gegründet, das sich dank seiner Schaffenskraft aus kleinsten Anfängen zu einer bekannten Lehrstätte entwickeln konnte. Er verstand es bei allen Institutsangehörigen trotz wachsender Studentenzahl ein enges Zussammengehörigkeitsgefühl zu wecken und zu wahren. Es war eine grosse Familie, deren Haupt er war. Zu ihm konnte jeder zu jeder Zeit kommen und fand bei ihm Hilfe durch Rat und Tat. Mehr als 30 Studenten, darunter 14 Doktoranden, trauerten am Grabe ihres Lehrers und Freundes.

Wir haben in Professor Berg einen Wissenschaftler verloren, der sein umfassendes Wissen in mehr als 150 Veröffentlichungen und Monographien darlegte und damit seinen internationalen Ruf begründete. Einen besonderen Namen erwarb sich Berg durch seine Arbeiten in der Biometeorologie. Auf Grund seines Wissens um diese Disziplin wählte ihn die International Society of Bioclimatology and Biometeorology 1956 zu ihrem Vizepräsidenten. Der Tod riß ihn aus vollem Planen und Schaffen. Ein geplanter Institutsneubau mit moderner Ausrüstung ließ ihn die Lösung mancher Probleme erhoffen. Eine Reihe Arbeiten waren geplant oder auch bereits begonnen, deren Durchführung sein allzufrüher Tod verhinderte. Sein Sterben riß hier eine Lücke, deren Bedeutung für Forschung und Nachwuchsbildung nicht abzuschätzen ist.

Aber in Berg ging auch ein Mensch von uns, dessen lauterer Charakter und dessen Hilfsbereitschaft ihn überall Freunde erwerben liess. Wer das Glück hatte, als Mitarbeiter oder Schüler diesen impulsiven Mann näher kennen zu lernen, der voller Schwung und Frohsinn stets mitten im Leben und Arbeiten stand, dem wird die Erinnerung an eine vorbildliche und liebenswerte Persönlichkeit bleiben. Wir trauern mit seiner Familie um den Menschen und um den Wissenschaftler Berg, der zu früh von uns scheiden mußte.

Dr. Phil. Günther Band

PROF. PIERRE DELORE

Le Professeur Pierre Delore (Lyon, France) est décédé le 30 Juin 1960 après une longue et douloureuse maladie.

Médecin des Hôpitaux, il s'orienta très tôt vers l'étude des problèmes sociaux que pose l'évolution de la médecine moderne. Aussi, aux activités normales de la Chaire d'Hydrologie thérapeutique et de Climatologie dont il était titulare à la Faculté de Médecine, avait-il ajouté l'Ecologie sociale. A côté de nombreux travaux médicaux et biologiques, il fut l'un des principaux promoteurs du climatisme social dont, en 1958, il présida le Deuxième Congrès International, à Briançon. Il était membre du Conseil Supérieur du Thermalisme et du Climatisme auprès du Ministère de la Santé Publique.

Dr. M. Megard

WILLIAM WESLEY HICKS
1884—1960

William Wesley Hicks grew up in California, attended Stanford University but because of lack of funds never completed his electrical engineering studies to receive a degree from Stanford. Nevertheless, he was recognized by his associates as an outstanding engineer and a pioneer in electric heating. He founded the Wesix Electric Heater Co. in 1920 and became a successful electrical manufacturer by 1927.

In 1939 Wesley Hicks became interested in air ionization as an environmental factor affecting health and comfort. He financed a Fellowship for graduates in electrical engineering at Stanford University and enlisted the aid of Professor Hugh Skilling to investigate the air ions from electric heaters and to find techniques to measure and control ions.

Following World War II, he devoted a large portion of his own time and his personal fortune to study air ionization. This work is undoubtedly the greatest sustained effort by any American to scientifically establish a basis for the many claims of biological and physiological effects of air ions on man. Wesley Hicks was an inspiring leader, a promoter, and an engineer. He encouraged scientists to undertake a difficult task; he never became discouraged where most men would have gladly turned to something else. Wesley Hicks liked to accomplish the unusual and was reluctant to follow the popular beliefs of the time. It was due to his great financial aid that I. S. B. B. could organise two of its congresses.

His appreciation for scientific methods and his respect for those people who understood the practical aspects of achievement was one of his greatest attributes. As a result he won the friendship of many of the world's most outstanding teachers and scientists.

Wesley Hicks lived to see electric space heating, which he pioneered through his company, become an accepted standard for the best in comfort and convenience in modern living. He did not live long enough to see air ionization control reach common acceptance as a natural law of man's environment; but he saw enough to be confident that this would happen.

William Wesley Hicks died at his home in San Francisco on 8, December 1960.

J. C. Beckett

ADDRESS BY THE PRESIDENT OF THE INTERNATIONAL SOCIETY OF BIOMETEOROLOGY: WHITHER BIOMETEOROLOGY?

Prof. Fred. Sargent II, M. D. Dept. of Physiology, Burrill Hall, University of Illinois, Urbana (Ill.) U. S. A.

THE members of this Society must give serious thought to the question, whither biometeorology? I must speak out frankly with the thoughts I have given to this question, for a critical self-appraisal has been long overdue.

Interest and research in biometeorology is worldwide and has been steadily growing and expanding. Of this fact the creation of this Society is sufficient proof. With this growth an unfortunate division in research activity has occurred. One group of workers, primarily biologists, emphasizes organ and organismic process of reaction and adjustment to the physical environment. The other group, principally meteorologists, emphasizes the physical environmental factors which appear to effect the organism. The former call themselves environmental physiologists and the latter bioclimatologists or biometeorologists. Actually bioclimatology is a branch of ecology and is that science which studies both the effects of geophysical and geochemical elements of the atmospheric environment on organisms and also the manner in which living things react and adjust to these elements. Bioclimatological investigation should be ecological and both these viewpoints should be integrated, for these antipodal orientations have frequently resulted in poor application of meteorology, particularly when the biologist goes into the field, and unfounded speculation about physiological mechanism when the meteorologist seeks to explain the action of the environment on a living organism. In point of fact neither viewpoint devotes adequate attention to the relative importance of the atmospheric environment; it, after all, is just a small part of the total environment in which organisms live. The first task of our Society should be to bring meteorologist and biologist together for examination and discussion of significant mesological problems. Through congresses such as the present one a forum for this collaboration can be provided.

This splintering has brought about a number of basic problems which must be solved for the future healthy growth of biometeorology. In fact their solutions comprise the second major task for our Society. What are the problems and how might we attempt to solve them?

First, there are few technical journals devoted to biometeorology. Because of its interdisciplinary nature, the majority of publications in the field are widely scattered in all manner of meteorological biological, and medical journals. The several biometeorological journals now appearing have not attempted to keep abreast of the growing literature either in the form of abstracts or classified references. Several of the abstracting services (notably *Meteorological Abstract and Bibliography* and *Biolo-*

gical Abstracts) have special sections devoted to bioclimatology, biometeorology, and so on, but their coverage is far from complete primarily because few scientists have volunteered to assist the editors of these services in preparing abstracts and because considerable expense is involved in printing each abstract.

A second problem, closely related to the first, is the scarcity of critical and authoritative reviews of either biometeorology as a whole or of special biometeorological problems. What are the basic concepts and broad generalizations which can be documented by sound evidence? What are the significant problems which are now supported only by folklore and impression and remain to be critically evaluated by careful field or laboratory investigation? In short, what is fact and what is fancy? To separate the facts and distill the generalizations biometeorologists must make a searching self-appraisal. Such evaluations must be published in regular technical journals and in monographs. Such critiques must be topics for national and international meetings where both meteorologists and biologists can participate.

Here lies the third problem. Since few biometeorologists are adequately trained in both meteorology and some branch of biology, it is necessary for many problems to be investigated by a team. Collaboration may be active between meteorologist and biologist or one may merely seek advice from the other. Generally, however, there has not been sufficiently close association, and serious problems have arisen ranging from instrumentation through type of environmental data collected to physiological or meteorological interpretation of observations. Both specialists must understand each other and should seek to work together more closely.

The modern trend for the traditional boundaries between physical and biological sciences to breakdown has resulted in a great increase in interdisciplinary sciences, e. g. biochemistry, biophysics, and bioclimatology. In some cases graduate training in interdisciplinary areas has kept pace with the trends in research. In bioclimatology training has not and young men interested in this area are not properly prepared. What is really needed is a rather radical revision of graduate training. There should be developed strong, carefully planned, and integrated courses leading to a major in environmental biology. Since so many problems facing scientists in the future involve working not only in isolation but also in teams, the graduate training must include experience with team work on interdisciplinary problems as well as the traditional independent research.

These revisions in current graduate training must be incorporated into realistic programs of the future, which are sufficiently flexible that they can be adapted both to individual students and also to the changing demands in professional areas. We must recognize the Ph.D. for what it has become, a symbol for proficiency in a specialized scientific area, not a symbol for broad scholarly ability to philosophize and generalize. However, in our training we must seek to make possible programs which not only result in competent technical specialists, but also much needed generalists.

My impression is that facts are accumulating at a faster rate than are generalizations. Unless we make an effort to collate these facts, science will not continue to grow at the healthy rate it has exhibited in the past. "Science is not a mere accumulation of facts; facts become knowledge only when incorporated into a conceptual scheme" (von Bertalanffy (1), p. 70). In bioclimatology we are not even certain of many of the facts.

The rapid growth of the literature of science and the appearance of more and more specialized journals have grave implications (2). The accumulation of data outpaces one's ability to make broad generalizations. As von Bertalanffy ((1), p. 71) expresses it: "It may well be that in many biological fields we know not too few facts but too many facts and that the very accumulation of an enormous amount of data hampers the discovery of the necessary theoretical schemes". Then there is further narrowing of the technical journal, more jargon, accentuated fragmentation of scientific fields, and increasing bewilderment among scientists about the whole aspect of Nature.

Perhaps even more important is the fact that inability to make sound generalizations accentuates the gap between scientist and layman (3). The anti-intellectualism of modern times, in part, stems from this development and makes for serious misunderstanding. Humanists must understand science so that it can be effectively assimilated into the total culture of mankind. The problems of our Society are, in the larger sense, those of the scientific community generally.

These problems are challenging! What can be done about them to assure a steady and sound development in bioclimatology?

Support should be given existing abstracting services. More volunteers must be enlisted to increase the coverage of the scattered current literature. Annotated bibliographies on special areas should be prepared to encompass the older literature. If our Society could assume some editorial responsibility for preparing abstracts, sufficient money would be saved the abstracting services so that a much larger number of items could be published. Most scientists would not gainsay the great service abstracts provide in research and teaching.

Supplementing this work the *Journal* of our Society should enlarge both in scope and detail the classified lists of references which have to date been published only at irregular intervals. This work can best be initiated by our technical committees in collaboration with the Editorial Board.

Frankly I am against starting new publications as some members have proposed. Support of existing journals is far the wiser course for the present. In this way we can make the greater contribution to documenting and digesting the tide of scientific literature.

A program of publication of authoritative and critical reviews by carefully selected investigators should be initiated. The ultimate responsibility for this program should rest with the Editorial Board. Our several technical committees should propose topics and authors and the Board should make the final choices and invite the contributions. For some years to come such critical reviews should constitute the major portion of the pages published in our *Journal*. Primarily through this effort will the theoretical concepts of biometeorology emerge.

For the past four years our Editorial Board has not been sufficiently aggressive and our technical committees have concerned themselves with mainly insular problems. Our Secretary has carried the major burden of the *Journal.* I suggest that, if the Editorial Board prefers to limit its activity to reviewing manuscripts, we form a Publications Committee and charge it with the task of developing policy and initiating programs along the lines I have proposed. Some of the ideas which I have presented today were unanimously approved in Vienna in 1957. None from the membership has since come forward. These are the facts, gentlemen. I propose that together we get at the job.

REFERENCES

1. L. von Bertalanffy, *Problems of Life. An Evaluation of Modern Biological and Scientific Thought* (Edited by Torchbook) Harper, New York (1960).
2. F. R. Cragle, Increase of biological serials — a destructive trend? *Am. Inst. Biol. Sci. Bull.* 13—14 Feb. (1960).
3. G. Holton, Modern science and the intellectual tradition. *Science* **131,** 1187—93 (1960).

MEMBERS OF THE EXECUTIVE BOARD OF I. S. B.

President: Prof. F. Sargent: Physiologist, Dept. of Physiology, 524 Burrill Hall University of Illinois, Urbana, Ill., U.S.A.

Vice president: Mr. M. P. A. Bourke: Meteorologist, ass. Director Meteorological Service, Dublin, Eire.

Dr. H. Boyko: Botanist, The Negev Institute for Arid Zone Research, Beersheba, Israel.

Prof. M. Fontaine: Physiologist, Lab. de Physiologie Générale, 7 Rue Cuvier, Paris V, France.

Secretary-treasurer: Dr. S. W. Tromp: Geophysicist, Bioclimatological Research Centre, 54, Hofbrouckerlaan, Oegstgeest (Leiden), The Netherlands.

Advisory members: Prof. J. L. Cloudsley-Thompson: Entomologist, Dept. of Zoology, Univ. of Khartoum, Sudan.

Dr. W. G. Wellington: Entomologist, Forest Biol. Lab., 409 Federal Bld., Victoria B.C., Canada.

Prof. Sh Itoh: Physiologist, Dept. of Physiology, School of Medicine, Hokkaido Univ., Sapporo, Japan

CHAIRMEN AND SECRETARIES OF THE PERMANENT STANDING COMMITTEES OF I. S. B.

1. Committee for the Study of Biometeorological Aspects of "Human Diseases", with special reference to Asthma and Bronchitis.
   Chairman: Dr. D. Ordman (South Africa). Address: The South African Institute for Medical Research, Hospital Street, P. O. Box 1038, Johannesburg, South Africa.

2. Committee of "Ecological Climatography".
   Chairman: Dr. H. Boyko (Israel). Address: 1 Ruppin Street, Rehovot, Israel.

3. Committee of "Instrumentation".
   Chairman: Dr. J. F. Griffiths (Kenya). Address: E.A. Meteorological Dept., Private Bag, Nairobi, Kenya (E. Africa).

4. Committee for the Study of the Biological Effects of various Types of "Ionisation of the Air"
   Chairman: Dr. J. H. Kornblueh (U.S.A.). Address: New Horizons, Welsh Rd. at Verree, Bustleton; Philadelphia 15 (Pa.), U.S.A.

Secretary: Mr. John C. Beckett (U.S.A.). Address: Palo Alto Engineering Co., 620 Page Mill Road, Palo Alto, California, U.S.A.

5. Committee of "Nautical Biometeorology" with a Special Subcommittee of "Cargo Bioclimeteorology".
Chairman: Prof. F. Molfino (Italy). Address: Istituto medicina del Lavoro, Ospedale San Martino, Genova, Italia.
Secretary: Prof. V. Parodi (Italy). Address: Istituto Medicina del Lavoro, Università, Genova, Italia.

6. Committee for the Study of "Chemical Tests" to be used in Biometeorological research in general and in Cosmic Biometeorology in particular.
Chairman: Prof. Dr. G. Piccardi (Italy). Address: Istituto di Chimica Fisica, Via Gino Caponi 9, Firenze, Italia.
Secretary: Mrs. Eng. C. Capel-Boute (Belgium). Address: Lab. d'Electrochemie, Université, 50 Av. F. D. Roosevelt, Brussels, Belgium.

7. Committee for the Study of "Tropical Biometeorology"
Chairman: Prof. W. V. Macfarlane (Australia). Address: The John Curtin School of Med. Research, The Australian Nat. Univ., Dept. of Physiology, Box 4, G.P.O. Canberra, Australia.
Secretary: Mr. J. P. Nicolas (France). Address: Dept. of Geography, Institut Français d'Afrique Noire, Dakar, Senegal, W. Africa.

8. Committee for the study of "Solar Radiation" in relation to Biometeorology.
Chairman: Prof. N. Robinson (Israel). Address: Solar Physics Lab., Israel Inst. of Technology, P.O. Box 4910, Haifa, Israel.
Secretary: Dr. Inge Dirmhirm (Austria). Address: Bioklim. Abt., Zentral Anstalt f. Meteorologie, Hohe Warte 38, Wien 19, Austria.

9. Committee of "Engineering Biometeorology" (including Urban- and Architectural Biometeorology).
Chairman: Prof. J. K. Page (Gr. Britain). Address: Dept. of Building Science, Univ. of Liverpool, Brownlow Hill, Liverpool 3, Gr. Britain.

10. Membership Committee.
Chairman: Prof. A. N. Dingle: Meteorol. Lab., Dept. of Civil Eng., 5060 Eng. Bld., Univ. of Michigan, Ann Arbor, Michigan, U.S.A.
Dr. H. Brezowski: Medizin-meteorol. Beratungsstelle, Badstr. 15, Bad Tölz, Bavaria, Germany.
Prof. P. Urbain: Climatologist, Institut d'Hydrologie et de Climatologie, 1 Rue Victor Cousin, Paris V, France.

LIST OF PARTICIPANTS

A) OFFICIAL DELEGATES

World Meteorological Organization	MR. P. M. AUSTIN BOURKE. President of the Commission for Agricultural Meteorology of W.M.O.
Food and Agriculture Organization of the United Nations	MR. G. PERRIN DE BRICHAMBAUT. Crop Production and Improvement Branch, Plant Production and Protection Div. of the F.A.O.
United Nations Educational, Cultural and Scientific Organization	MR. M. BATISSE Arid Zone Unit, Dept. of Natural Sciences of Unesco.
Académie des Sciences de l'Institut de France	PROF. MAURICE FONTAINE.
Czechoslovak Academy of Agricultural Sciences	DR. ROBERT INTRIBUS.
The American Phytopathological Society	PROF. RICHARD D. SCHEIN.
The Entomological Society of America	DR. WALTER R. HENSON and DR. EDWIN W. KING.
The Meteorological Office, Air Ministry, London	MR. R. W. GLOYNE, MR. P. J. MEADE and MR. H. C. SHELLARD.
The Royal Netherlands Meteorological Institute (Div. of Climatology)	DR. H. J. DE BOER
The Hungarian Meteorological Society	DR. M. KÉRI

B) REGULAR MEMBERS OF THE CONGRESS

NAME	ADDRESS
DR. D. ASSMANN (physician)	Dr. Conertstrasse 10b, Dresden N-6, Germany.
DIPL. ING. F. W. BEHMANN (engineer)	Kerckhoff-Institut, Bad Nauheim, Germany.
DR. E. BETZ (physiologist)	Physiol. Inst., Marburg/Lahn, Germany.
DR. H. J. DE BOER (physicist)	Representative of the Royal Netherlands Meteorological Service, De Bilt, The Netherlands.
DR. W. BIANCA (agric. engineer)	Dept. of Physiology, Hannah Dairy Research Inst., Kirkhill, Ayr, Scotland, Great Britain.
DR. K. BISA (physician)	Inst. für Aerobiologie, Grafschaft, Hochsauerland, Germany.
DR. J. BLIGH (physiologist)	Institute of Animal Physiology, Babraham Hall, Babraham, Cambridge, Great Britain.

IR. A. J. W. BORGHORST (electrical engineer)	Lab. voor Natuur Kunde, Landbaum bouwhogeschool, Wageningen, The Netherlands.
DR. H. BORTELS (microbiologist)	Inst. f. Bakteriologie, Königin Luisestr. 19, Berlin-Dahlem, Germany
MR. R. J. BOUCHET (plant physiologist)	Stat. Centrale de Biocl. Agric., Route de Saint-Cyr, Versailles (S. 20), France.
MR. M. P. A. BOURKE (agric. meteorol.)	Representative of the World Meteorological Organization, President of the Commission for Agricultural Meteorology of the World Meteorological Organization, Deputy-Director Meteorol. Service, 44, Upper O'Connell Street, Dublin, Eire.
MRS. DR. E. BOYKO (biologist)	1 Ruppinstreet, Rehovot, Israel.
DR. H. BOYKO (biologist)	1 Ruppinstreet, Rehovot, Israel.
DR. A. BRAUER (physician)	Niederdorf (über Geldern) 22a, Germany.
DR. J. BREBNER (physician)	Chief Medical Officer, Kuwait Oil Co. Ltd., Burgan House, 105 Wigmore Street, London W. 1, Great Britain.
PROF. K. J. K. BUETTNER (meteorologist)	Dept. of Meteorology, Univ. of Washington, Seattle 5, Wash. U.S.A.
DR. H. B. CARTER (veterinarian)	Animal Breeding Research Org., 6 S. Oswald Road, Edinburgh 9, Scotland, Great Britain.
DR. H. CAUER (phys. chemist)	Marienplatz 2/6, Bochum, Germany.
MISS DR. T. CHIEMPRASERT (physiologist)	Dept. of Physiology, Faculty of Medicine and Siriraj Hospital Bangkok, Thailand.
MR. M. CRAWFORD	Director Commonwealth Bureau of Animal Health, Veterinary Lab., Weybridge, Surrey, Great Britain.
DR. J. A. CROCKET (allergologist)	Baird Street Hospital (Asthma Clinic), 35 Baird Street, Glasgow C4, Scotland, Great Britain.
DR. TH. R. A. DAVIS (physician)	U.S. Army Medical Research Laboratory, Fort Knox, Kentucky, U.S.A.
MR. W. J. DERKSEN (physicist)	Lab. voor Natuur- en Weerkunde, Landbouwhogeschool, Duivendaal 2, Wageningen, The Netherlands.
PROF. A. N. DINGLE (meteorologist)	Meteorol. Lab., Dept. of Civil Eng., 5060 E. Engineering Bldg., Univ. of Michigan, Ann Arbor, Mich. U.S.A.
FRL. DR. INGE DIRMHIRN (meteorologist)	Bioklim. Abt., Zentral Anstalt f. Meteorologie, Hohe Warte 38, Wien 19, Austria.
DR. F. L. DUNN (physician)	London School of Hygiene and Tropical Medicine, Keppel Street, London W.C.1, Great Britain.
MR. R. DURAND (plant physiologist)	Stat. Centr. de Biocl. Agricole, Route de Saint-Cyr, Versailles (S. 20), France.
PROF. E. B. EDNEY (zoologist)	Dept. of Zoology, Univ. College of Rhodesia & Nyasaland, Salisbury, S. Rhodesia.
MR. P. C. EKERN (soil physicist)	Pineapple Research Institute of Hawaii, P.O.B. 3166, Honolulu 2, Hawaii, U.S.A.
DR. W. A. FAIRBAIRN (forest-ecol.)	Dept. of Forestry, 10 George Sq., Edinburgh, Scotland, Gr. Britain.
DR. W. FILEWICZ (physician-pomol.)	The Grange, East Malling, Kent, Great Britain.

DR. J. D. FINDLAY (physiologist)	Dept. of Physiology, The Hannah Dairy Research Inst., Kirkhill, Ayr, Ayrshire, Scotland, Great Britain.
DR. N. E. FLITTERS (entomologist)	Bioclimatic Cabinet Invest., Entomology Res. Division, Agricultural Research Serv., U.S. Dept. of Agriculture, P.O. Box 1033, Brownsville, Texas, U.S.A.
ING. B. GIVONI (architect)	Building Research Station, Technion, Haifa, Israel.
DR. E. M. GLASER (physiologist)	Dept. of Physiology, The London Hosp. Medical College, Turner Street, London E. 1, Great Britain.
MR. R. W. Gloyne (meteorologist)	Representative of the Meteorological Office, 26 Palmerston Place, Edinburgh 12, Scotland, Great Britain.
DR. K. GOLENHOFEN (physiologist)	Physiologisches Institut, Deutschhausstrasse 2, Marburg/Lahn, Germany.
PROF. J. GRAYSON	Dept. of Physiology, University College, Ibadan, Nigeria.
PROF. J. GUELFI (physician)	Vice-Président de la Fédération Thermale et Climatique de Bretagne, Directeur du Centre Anticancéreux régional, Pontchaillou, Rennes, Ille-et-Vilaine, Bretagne, France.
FRL. DR. ELSE HAINE (zoologist)	Forschungslab. f. Angewandte Entomologie im Museum Alexander Koenig, Koblenzerstr. 150—164, Bonn am Rhein, Germany.
DR. M. I. HALHUBER (physician)	Medizinische Univ. Klinik, Tempelstrasse 11, Innsbruck, Austria.
DR. R. J. Hamburger (physician)	National Aviation Medical Centre, Kampweg 3, Soesterberg, The Netherlands.
SIR JOHN HAMMOND, (physiologist)	School of Agriculture, Luord Road, Cambridge, Great Britain.
DR. R. HELLON (physiologist)	Department of Anatomy, University Museum, S. Parks Road, Oxford, Great Britain.
PROF. H. HENSEL (physiologist)	Physiologisches Institut, Deutschhausstrasse 2, Marburg/Lahn, Germany.
DR. W. R. HENSON (entomologist)	206 Osborn Zoological Laboratory, Yale University, New Haven 11, Conn., U.S.A. Representative of the Entomological Society of America.
PROF. A. B. HERTZMAN (physiologist)	Dept. of Physiology, St. Louis Univ., St. Louis, U.S.A.
PROF. W. HESSE (agric. meteorol.)	Direktor Inst. f. Agrarmeteorol. der Universität Leipzig, Fichtestrasse 28, Leipzig S-3, Germany (D.D.R.).
DR. J. C. D. HUTCHINSON (veterinarian)	Sheep Biology Laboratory, P.O. Box 144, Parramatta N.S.W., Australia.
DR. D. L. INGRAM (physiologist)	Physiology Dept., The Hannah Dairy Research Inst., Kirkhill, Ayr, Ayrshire, Scotland, Great Britain.
DR. R. INTRIBUS (agric. meteorol.)	Research Institute for Forest Management Slovenska Akad. Vied, Lesnicke Lab., Pracovisk nam 37, Zvolen, Czechoslovakia. Representative of the Czechoslovak Academy of Agricultural Sciences.
DR. H. JUNGHANS (forest meteorologist)	Institut f. Forstliche Meteorologie und Klimakunde, Techn. Hochschule Dresden, Tharandt, Germany D.D.R.
DR. H. JUNGMANN (physician)	Wrangelpark 11, Hamburg/Othmarschen, Germany.
PROF. DR. H. JUSATZ (physician)	Geomedizinische Forschungsstelle, Heidelberger Akad. d. Wissensch., Kaiserstrasse 14, Heidelberg, Germany.

DR. I. KÉRDÖ (physician)	Staatliches Institut für Rheuma und Bäderwesen, Frankel Leó-u. 25/29, Budapest II, Hungary.
DR. M. KÉRI (meteorologist)	Biometeorological Section of the Hungarian Meteor. Inst., Kitaibel Pál u. 1., Budapest II, Hungary.
DR. D. MC. K. KERSLAKE	R.A.F. Institute of Aviation Medicine, Royal Aircraft Establishment, Farnborough, Hants, Great Britain.
PROF. O. KETUSINH (physiologist)	Department of Physiology, Faculty of Medicine and Siriraj Hospital, Bangkok, Thailand.
DR. E. W. KING (entomologist)	Department of Entomology and Zoology, Clemson College, Clemson, S.C. U.S.A. Representative of the Entomological Society of America.
DR. A. Q. C. KLOMP (physician)	Juliana van Stolbergstraat 3, Schiedam, The Netherlands.
DR. H. G. KOCH (forest meteorol.)	Meteorologisches Institut, Friedrich-Schiller Univ., Schillergässchen 2, Jena/Thüringen, Germany D.D.R.
DR. I. H. Kornblueh (physician)	Dept. of Physical Med. and Rehabilitation, The Graduate Hospital Univ. of Pennsylvania, Philadelphia 46, Pa, U.S.A.
DR. W. S. S. LADELL (physiologist)	Medical Div. Chemical Defence Exper. Establishm., Porton near Salisbury, Wilts., Great Britain.
DR. H. E. LANDSBERG (meteorologist)	U.S. Weatherbureau, Dept. of Climatol., Washington 25 D.C., U.S.A.
DR. CH. S. LEITHEAD (physiologist)	School of Tropical Medicine, Pembroke Place, Liverpool 3, Great Britain.
PROF. R. R. LEMAIRE (physiologist)	Laboratoire de Physiologie, Ecole Nat. de Médécine et de Pharmacie de Dakar, Dakar, Mali).
PROF. LINSER (dermatologist)	Hautklinik der Humboldt Univ., Berlin, Germany.
DR. I. A. M. LUCAS	Rowett Research Institute, Bucksburn, Aberdeen. Scotland, Great Britain.
PROF. C. P. LUCK (physiologist)	Dept. of Physiology, Makerere College, Box 2072, Kampala, Uganda, E. Africa.
DR. M. A. MACDONALD (anim. physiol.)	MacDonald College of McGill University, MacDonald College, P.O. Box 258, Quebec, Canada.
MR. J. A. MACLEAN (engineer)	Physiology Dept., The Hannah Dairy Research Inst., Kirkhill, Ayr, Ayrshire, Scotland, Great Britain.
PROF. A. MÄDE (agric. meteorol.)	Eichenweg 5, Halle/Saale, Germany D.D.R.
PROF. R. MARGARIA (physiologist)	Laboratorio di Fisiologia, Universita di Milano, Via Mangiogalli 32, Milano, Italy.
PROF. R. A. MCCANCE (physiologist)	Dept. of Experimental Medicine, Tennis Court Road, Cambridge, Great Britain.
MR. R. E. MCDOWELL	Dairy Cattle Research Branch, Agricultural Research Center, Beltsville, Md., U.S.A.
DR. W. MENGER (physician)	Seehospiz Kaiserin Friedrich, Benekestrasse, Norderney, Germany.
MISS DR. IRENA MODLIBOWSKA (biologist)	The Grange, East Malling, Kent, Great Britain.
DR. L. E. MOUNT (animal physiologist)	Institute of Animal Physiology, Babraham, Cambridge, Great Britain.

PROF. D. MÜCKE (physician)	Physiologisch-chemisches Institut, Leninallee 70, Leipzig C. 1, Germany (D.D.R.).
DR. J. MUNRO (veterinarian)	Hill Farming Research Organisation, Glensaugh, Laurence Kirk, Kincardineshire, Great Britain.
MR. J. P. NICOLAS (geographer-climatol.)	Institut Français d'Afrique Noire, Dakar, Mali
MISS BERTHE NONN (meteorologist)	10 Avenue Constant Coquelin, Paris VII, France.
DR. M. NOSEK (meteorologist)	Masaryk University, Geographical Institute, Department of Climatology and Meteorology, Janáckovo nam 2a, Brno V, Czechoslovakia.
DR. H. OLDIGES (physician)	Institut f. Aerobiologie, Grafschaft, Hochsauerland, Germany.
DR. C. B. OLLERENSHAW (animal-physiologist)	The Veterinary Laboratory, New Haw, Weybridge, Surrey, Great Britain.
DR. D. ORDMAN (physician)	The South African Institute for Med. Research, Hospital Street, P.O. Box 1038, Johannesburg, Union of South Africa.
Prof. J. K. PAGE (archit.-engineer)	Department of Building Science, Univ. of Liverpool, Liverpool, Great Britain.
PROF ING A. J. PASCALE (agric.-meteorologist)	Facultad de Agronomia y Veterinaria, Avda San Martin 4453, Buenos Aires, Argentina.
DR. J. PASZYŃSKI (geographer)	ul. Kazimiersowska 69 m. 14, Warszawa, 12, Poland.
DR. S. PATERSON	Lundbacken 6, Lerum, Sweden.
DR. H. PECHERT (veterinarian)	Forschungsstelle für Tierhaltung, 15 Knaü/Thür., Kr. Pöszneck, Germany (D.D.R.).
MR. M. PELEG (civil eng.)	Technion Israel Inst. Technology, P.O. Box 4910, Haifa, Israel.
MR. G. PERRIN DE BRICHAMBAUT	Representative of the Food and Agricultural Organization (Crop Production and Improvement Branch, Plant Production and Protection Div.), via delle Terme di Caracalla, Rome, Italy.
PROF. J. P. PICHOTKA (physiologist)	Physiol. Institut d. Humboldt Univ., Hessische Strasse 3/4, Berlin N. 4, Germany.
DR. ZOFIA PIÈSLAK (agric. meteorolog.)	Section Agrométéorologie, Institut Hydrologique et Météorologique, Rue Podleśna 61, Varsovie 32, Poland.
PROF. DR. H. PLEISZ (forest meteorologist)	Institut f. Forstliche Meteorologie und Klimakunde, Techn. Hochschule Dresden, Tharandt, Germany D.D.R.
DR. ENG. B. PRIMAULT (forest-engineer)	Institut Suisse de Météorologie, Krählbühlstrasse 58, Zürich 7/44, Switzerland.
DR. K. A. PROVINS (physiologist)	Department of Human Anatomy, University Museum South Parks Road, Oxford, Great Britain.
DR. J. D. PULLAR (physiologist)	Physiology Dept., The Rowett Research Inst., Bucksburn, Aberdeen, Scotland, Great Britain.
DR. E. T. RENBOURN (physiologist)	Director Clothing and Stores Experim. Establ., Ministry of Supply, R.A.F., Farnborough, Hants, Great Britain.
PROF. P. W. RICHARDS (botanist)	Dept. of Botany, Memorial Buildings, Univ. College of N. Wales, Bangor Caernarvonshire, Wales, Great Britain.
MR. G. W. ROBERTSON (meteorologist)	Agro-meteorological Section, Plant Res. Institute, Central Experimental Farm, Ottawa, Canada.

PROF. N. ROBINSON (physicist)	Solar Physics Laboratory, Israel Inst. of Technology, P.O. Box 4910, Haifa, Israel.
PROF. F. SARGENT II (physiologist)	Department of Physiology, 524 Burrill Hall, University of Illinois, Urbana, Ill., U.S.A.
PROF. R. D. SCHEIN (botanist)	Representative of the American Phytopathological Society. Department of Botany and Plant Pathology, The Pennsylvania State University, University Park, Pa., U.S.A.
DR. R. SCHINDLER (veterinarian)	Bernhard-Nocht-Institut für Schiffs- und Tropenkrankheiten, Bernhard-Nocht-Strasse 74, Hamburg 4, Germany.
DR. H. SCHRÖDTER (agrar-meteorol.)	Agrarmeteorologische Forschungsstelle, Ermslebenerstrasse 32, Aschersleben, Germany (D.D.R.).
DR. H. B. SCHULTZ (agric. engineer)	Department of Agricultural Engineering, 622 East 8th Street, Davis, Cal., U.S.A.
DR. J. A. SEALANDER, JR. (biologist)	Zoology Dept., Univ. of Arkansas, Fayetteville, Arkansas, U.S.A.
MR. H. C. SHELLARD (meteorologist)	Representative of the Meteorological Office, M.O.3, Headstone Drive, Harrow, Middlesex, Great Britain.
DR. K. H. SIMON (forest meteorologist)	Inst. f. Forstliche Meteorologie, Humboldt-Univ. z. Berlin, Schicklerstrasse 5, Eberswalde, Germany D.D.R.
DR. B. SLAVÍK (botanist)	Institute of Biology of the Czechoslovak Academy of Science, Na cvičišti 2, Praha 19, Czechoslovakia.
DR. J. SLOMKA (biologist)	Bioclimatological Laboratory of the Mammals Research Institute, Polish Academy of Sciences, Bialowicza, Poland.
PROF. G. B. SPURR (physiologist)	Clinical Physiology, University of Tennessee, 62 S. Dunlap, Memphis, Tenn., U.S.A.
DR. E. STEPHAN (veterinarian)	Inst. f. Tierzucht u. Haustiergenetik der Univ. Giessen, Gleiberweg 123, Giessen/Lahn, Germany.
DR. PH. STOUTJESDIJK (biologist)	Biologisch Station, Oostvoorne (Z. H.), The Netherlands.
PROF. TH. STEGENGA (animal physiologist)	Prof. Ritzema Bosweg 34, Wageningen, The Netherlands.
DR. K. SYMON (physician)	48 Šrobárova, Praha 12, Czechoslovakia.
MR. W. E. A. TAYLOR (biologist)	82, George Street, London W. 1, Great Britain.
DR. S. W. TROMP (geophysicist)	Bioclimatological Research Centre c.o. Dept. Interne Geneeskunde, Akademisch Ziekenhuis, Leiden, The Netherlands.
DR. P. UHLÍŘ	Pisecká 2, Praha 12, Czechoslovakia.
DR. W. UNDT (meteorologist)	Zentralanstalt für Meteorologie, Hohe Warte 38, Wien 19, Austria.
DR. K. UNGER (agric. meteorol.)	Deutsche Akad. d. Landwirtsch., Inst. f. Pflanzenzüchtung, Rosenbergstrasse 23, Quedlinburg, Germany (D.D.R.).
PROF. P. URBAIN (climatologist)	71, Rue du Cardinal Lemoine, Paris V, France.
MR. K. UTAAKER (meteorologist)	Universitett I Bergen, Geofysik Inst., Bergen, Norway.
DR. O. VAARTAJA (entomologist)	Canada Agriculture Research Station, University Post Office, Saskatoon, Sask, Canada.

Dr. A. Vandenplas (agric. meteorol.)	Institut Royal Météorologique, 3 Ave. Circulaire, Uccle-Bruxelles 8. Belgium.
Dr. G. Voigt (meteorologist)	Inst. f. Med. und Biologie, Bereich Physik, Lindenbergerweg 70, Berlin-Buch, Germany.
Miss Z. Waloff (biologist)	Anti-Locust Research Centre, 1 Princes Gate, London S.W. 7, Great Britain.
Dr. W. Warmbt (meteorologist)	Radebeul 5, Altwahnsdorf 2a, Germany (D.D.R.).
Dipl. Ing. E. Wedler (physicist)	Institut für Meteorologie und Geophysik der Freien Universität Berlin, Podbielskiallee 62, Berlin-Dahlem. Germany.
Dr. W. H. Weihe (physiologist)	Hochalpine Forschungsstation, Jungfraujoch, Bühlplatz 5, Bern, Switzerland.
Prof. J. S. Weiner (physiologist)	Department of Human Anatomy, University Museum, South Parks Road, Oxford, Great Britain.
Dr. H. G. Wenzel (physiologist)	Max-Planck-Institut f. Arbeitsphysiologie, Rheinlanddamm 201, Dortmund, Germany.
Dr. G. C. Whittow (physiologist)	Department of Physiology, The Hannah Dairy Research Institute, Kirkhill, Ayr, Scotland, Great Britain.
Prof. C. M. Williams (anim. physiologist)	Dept. of Animal Husbandry, Univ. of Saskatchewan, Saskatoon, Saskatchewan, Canada.
Dr. O. Wilson (physiologist)	Svanegatan 5, Lund, Sweden.
Dr. Yabuki (meteorological agro-ecologist)	Lab. of Meteorological Agroecology College of Agriculture, Univ. of Osaka, Sakai City, Osaka, Japan.
Prof. N. Yagi (biologist)	Faculty of Sericulture and Textile, Shinshu University, Ueda, Nagano Pref., Japan.
Mr. R. G. Yeck (veterinarian)	Leader, Livestock Environmental Investigations Agric. Engr. Bldg. Columbia, Missouri, U.S.A.
Dr. G. Zabka (botanist)	Department of Botany, State Univ. of Iowa, Iowa City, Iowa, U.S.A.
Dr. M. Batisse	U. N. E. S. C. O. — Paris — France.
Mr. W. Vincent Blockley	130 Ocean Way, Santa Monica, California, U. S. A.
Dr. L. A. Canaan (physician)	Park Boulevard, Massapequa Park, New York, U. S. A.
Mrs. Eng. C. Capel-Boute (civil engineer)	Lab. d'Electrochémie et Métallurgie, Univ., 50 Av. F. D. Roosevelt, Brussels, Belgium.
Captain Alexander Cumming	c/o Medical Research Council, Hampstead, London, Great Britain.
Mr. J. C. Dickinson	Scientific and Techn. Dept., Int. Wool, Secretariat, Dorland House, 18—20 Regent Street, London S. W. 1, Great Britain.
Mr. Jacques Dreyfus	Centre Scientific de Technique du Bâtiment, 4 Avenue du Recteur Poincaré, Paris 16, France.
Prof. F. E. J. Fry	Ontario Fisheries Research Lab., Dept. of Zoology, Univ. of Toronto, Toronto 5 (Ontario) — Canada.
Col. J. L. Gordon	Prof. of Army Health, Royal Army Med. College Millbank, London S. W. 1, Great Britain.
Dr. J. G Griffiths (veterinarian)	University College of Wales, The Institute of Rural Science, Penglais, Aberystwyth, Wales, Great Britain.
Dr. N. H. Hayes	Army Operational Research Group, Broadoaks, Parvis Road; West Byfleet, Surrey, Great Britain.

MR. SABURO YOKOYAMA	305—5 Saginamiya Nakano, Tokyo, Japan.
CAPT. ROBERT J. T. JOY (physician)	United States Army, Medical Research Lab., Fort Knox, Kentucky, U. S. A.
PROF. DR. M. KÜLEY (physician)	Istanbul Tip Fakültesi, 3 Ic, Hastaliklari Kliniği, Istanbul, Turkey.
MISS JUDITH V. LASZLO	Geographer Anti-Locust Research Centre, London, Great Britain.
DR. J. ST. LAWRENCE (physician)	Empire Rheumatism Council field Unit, Clinical Sciences Building, York Place, Manchester, Great Britain.
MISS JOYCE J. MAGOR	Geographer Anti-Locust Research Centre, London, Great Britain.
COL. C. W. MAISEY	Dept. Dir. Army Health, H. Cl. Eastern Command War Office, Lansdowne House, Berkeley Square, London W. 1. Great Britain.
MR. THOMAS A. MARKUS (architect)	Pilkington Brothers Ltd., Glass Manufacturers, St. Helens, Lancashire, Great Britain.
MR. F. N. MARZULLI	Army Chemical Centre, Edgewood, Maryland, U. S. A.
PROF. V. OLGYAY (engineer)	School of Architecture, Princeton University, Princeton, N. J. U. S. A.
MR. C. W. PARCE	Parce Engineering Co., Harlingen, Texas, U. S. A.
MAJ. G. POWER	Dept. Army Health, Lansdowne House, Berkeley Square, London W. 1., Great Britain.
DR. F. REYNHAM (physician)	Edmonton, Alberta, Canada.
DR. P. ROPEZ	Royal Victoria Hospital, Montreal 2, Canada.
H. COL. G. W. RITCHIE	Ass. Prof. of Army Health, Royal Army Med. College, Millbank, London S. W. 1., Great Britain.
MRS. J. M. SEEKINGS	Science I, The War Office, Whitehall, London E. 1, Great Britain.
MR. J. L. H. SIBBONS	Department of Geography, The University, Sheffield 10, Great Britain.
DR. E. SOHAR (physician)	Hospital Tel-Hashomer, Tel-Hashomer, Israel.
DR. M. STAQUET (physiologist)	24, Rue du Monastère, Bruxelles, Belgium.
DR. PAUL WEBB	Box 51, Yellow Springs, Ohio, U. S. A.
DR. MICHEL WARD	London Hospital, Whitechapel, London E. 1, Great Britain.
MR. D. VAN ZUILEN (engineer)	Instituut voor Gezondheidstechniek T. N. O., Koningskade 12, Den Haag, The Netherlands.

1st Session

HIGH ALTITUDE BIOCLIMATOLOGY

Chairman: Prof. Max J. Halhuber

PHYSIOLOGICAL ASPECTS OF LIFE AT EXTREME ALTITUDES

RODOLFO MARGARIA and PAOLO CERRETELLI
Lab. of Physiology, University of Milano, Milano, Italy.

Abstract—Life at high altitudes meets many unfavourable conditions, the most important being the reduced partial pressure of oxygen.

A long process of adaptation, called acclimatization, takes place in man at high altitudes: this concerns all the body functions and enables man to survive and to carry on a certain, though limited, activity.

In this paper the mechanisms of control and regulation of respiration that take place both in acute and chronic hypoxia, are described, with particular emphasis on the nervous chemoreflexogenic mechanism; some features of the respiratory mechanics of the acclimatized subject are also described.

Data are given on the cardiocirculatory function at altitude (heart rate, blood pressure) and on the Hb content during the process of acclimatization. The relative changes of O_2 absorption by the lungs, its transport to the blood and its utilization at the muscle level are discussed in relation to the capacity to perform muscular exercise.

Résumé*—Des conditions très difficiles, desquelles la plus importante est la réduction partiale de la pression de l'oxygène, charactérisent la vie humaine aux grandes altitudes.

Un long procès d'adaptation qui intéresse toutes les fonctions du corps et qui est appelé acclimatation, rend possible la vie et une certaine activité, bien que limitée.

Pendant cette tractation on décrit les méchanismes de control et régulation de la respiration pendant hypoxie aiguë et chronique, en particulier les méchanismes d'origine chemoréflexogénique; on décrit aussi quelques charactéristiques de la méchanique respiratoire du sujet acclimaté.

En outre on donne des résultats qui concernent la fonction cardiocirculatoire (fréquence cardiaque, pression du sang) et changements du sang en conséquence d'un prolongé séjour à l'altitude.

Enfin on a parlé des rélatifs changements de l'absorption d'oxygène par les poumons, son transport dans le sang et son utilisation au niveau des muscules en connection avec la capacité d'accomplir de l'exercice musculaire.

Auszug—Das Leben der Menschen auf grossen Höhen unterliegt verschiedenen ungünstigen Bedingungen, wovon die wichtigste der verminderte Teildruck des Sauerstoffs ist.

Ein progressiver Anpassungsprozess, der sich auf sämtliche organische Funktionen erstreckt und Akklimatisierung genannt wird, erlaubt es jedoch dem Menschen auch unter diesen Umständen zu leben und selbst eine beschränkte Tätigkeit zu entwickeln.

In der vorliegenden Arbeit werden Steuerung und Regelung der Atmungstätigkeit bei akuter und chronischer Sauerstoffarmut besprochen, besonders wenn sie chemoreflexbedingt sind, sowie einige Eigenschaften der Atmungsmechanik des Akklimatisierten.

* The Editor gratefully acknowledges the collaboration of Mlle Berthenonn (Paris), who prepared all of the French abstracts of the Congress Proceedings.

Ferner enthält die Arbeit verschiedene Angaben über die Leistung der Kreislauforgane, das Blutbild und über die Auflösungskurve des Blutes für den Sauerstoff im Akklimatisierten.

Schliesslich wird die Frage erörtert in welchem Ausmass die chronische Sauerstoffarmut eine körperliche Tätigkeit zulässt, unter Berücksichtigung der verschiedenen Anforderungen des praktischen Lebens.

Many unfavourable conditions are met at high altitudes; however, life is possible through a long process of adaptation that includes all organic functions called acclimatization. Through such complex functional adaptations man may survive and even carry on productive activity whereas unacclimatized men would succumb.

The most important of these unfavourable conditions is the reduced partial pressure of oxygen. The problem of life at high altitudes was tackled towards the end of the last century by many physiologists, but in the last 20—30 years it has been studied with renewed interest in view particularly of the application to the medical aspects of aviation and mountaineering.

Besides a limited number of individuals, aviators and mountaineers, who may benefit from high altitude physiology, a great number of individuals ordinarily live at high altitude. In some places in the world in fact, where the climatic conditions are particularly favourable, large communities live at altitudes of 4000—5000 m above sea level. Besides, a number of people with impaired circulation or respiration, live at sea level in a kind of anoxic condition which is very similar to that experienced by healthy people at altitude. Recently the possibility has been discussed of acclimatizing possible occupants of manned satellites to hypoxia, in order to allow a lower pressure in the capsule, and consequently lead to a decreased weight of the satellite.

REGULATION OF RESPIRATION IN ACUTE AND CHRONIC HYPOXIA

It has been well-known for some time (Pflüger, 1958; Loewy, 1890; Boycott and Haldane, 1908) that in acute and chronic hypoxia, pulmonary ventilation increases.

In acute hypoxia hyperventilation and the inherent reduction of the alveolar P_{CO_2} take place only at levels of hypoxia such as are met by breathing 12—14 per cent oxygen at sea level (P_{I,O_2} = ca. 85 mm Hg). The acclimatized subject reacts a little differently to hypoxia as shown in the diagram of Fig. 1 constructed from the data of Rahn and Otis (1949); the acclimatized subject in fact shows: (a) a greater alveolar ventilation V_A; and (b) the hyperventilatory reaction is evident at much partial lower pressures of oxygen.

As it is evident, the difference between the respiratory response to anoxia in the acclimatized and in the non-acclimatized subject confers to the former a greater resistance to anoxia, for the result is an increased oxygen pressure in the alveoli and in the blood, and a greater saturation of the haemoglobin with oxygen; all this occurs at the expense of the decrease of the CO_2 pressure; this gas is not so vitally important as O_2.

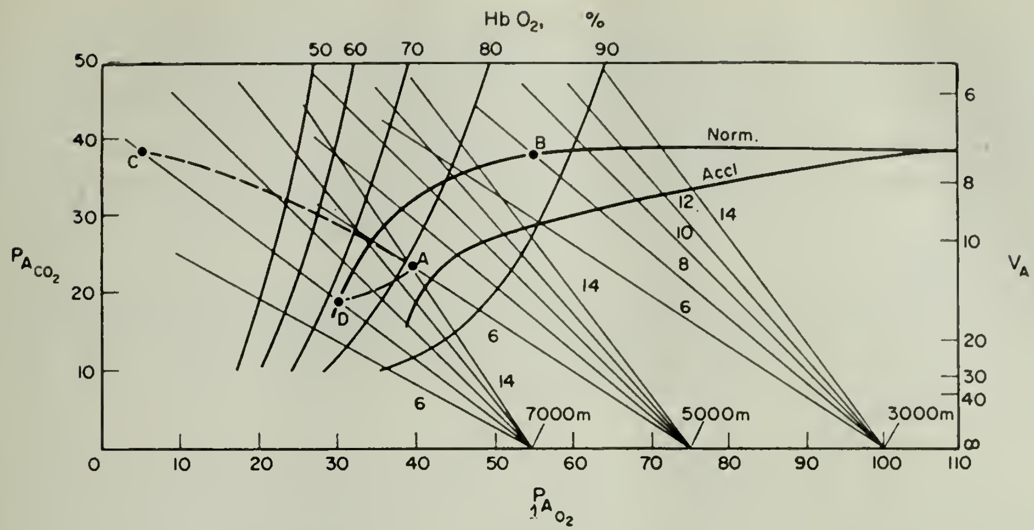


FIG. 1. Difference in alveolar air composition between man acutely exposed (Norm.) and acclimatized at various altitudes (Accl.) (from Margaria, 1955)

MECHANISMS OF HYPERVENTILATION IN HYPOXIA

The mechanism of hyperventilation in hypoxia has been the object of extensive investigations. The finding at the beginning of the century of a lowering of plasma bicarbonate at altitude (Agazzotti, 1904, 1905) has led some authors to believe that in hypoxia, a condition of acidosis develops, which leads to hyperventilation. Zuntz *et al.* (1906) indicated in the formation of acid metabolites, the condition causing acidosis and hyperventilation. Boycott and Haldane (1908) thought that this metabolite was mainly lactic acid; its characteristic slow disappearance from the blood would also be responsible for the slow return to normal of pulmonary ventilation in the passage from altitude to sea level. Douglas *et al.* (1913) and Barcroft *et al.* (1914) on the other hand could not find any lactic acid in the blood during hypoxia.

One of the first and most active supporters of the H^+ ion as the only physiological stimulus to respiration is Winterstein (1911). His hypothesis, however, did not fit in with the fact that at altitude the blood CO_2 decreases, namely that acapnia ensues (Mosso and Marro, 1904; Sundstroem, 1919; Barcroft *et al.*, 1922), and hyperventilation occurs at the same time as alkalosis. Therefore, to overcome this contradiction, Winterstein put forth the hypothesis that, in spite of the blood alkalosis, the intracellular fluid in the respiratory centre would suffer a decrease of pH, owing to the local formation of acid metabolites.

In 1927 Heymans showed the existence of chemoceptors in the carotid body and in the aortic arch, which could be stimulated by CO_2 and by hypoxia: further evidence was given by the finding of a stream of impulses in the carotid nerve elicited by such stimuli (Samaan and Stella, 1935; Bogue and Stella, 1935). The activity of these chemoceptors may give a satisfactory reason for the hyperventilation in hypoxia. At sea level the activity of the chemoceptors is very limited; in fact, on shifting from air to oxygen, pulmonary ventilation decreases very little (Dripps and Comroe, 1947; Loeschke, 1953) and a slight decrease of the impulses in Hering's nerve also is observed (von Euler *et al.*, 1939). In acute hypoxia, on the contrary, a tonic stimulation of the chemoceptors is very evident, and it appears to be of vital importance on shifting from acute hypoxia to breathing pure oxygen pulmonary ventilation is suddenly lowered to half its previous value. During acute hypoxia an increase of the electric activity in the carotid sinus nerve is also observed (Heymans and Rijlant, 1933).

The suppression of the carotid chemoceptors by cutting Hering's nerve abolishes the hyperventilatory response to hypoxia, and the animal may succumb for dyspnoea: the evidence of a chemoreflexogenic stimulus to respiration in acute hypoxia is thus well-supported.

On the contrary, an agreement is not yet reached on whether such a stimulus also persists in chronic hypoxia, namely in the subject acclimatized to altitude. In this case in fact, if oxygen is given, or if the subject is brought back to sea level, hyperventilation persists: this led to the belief that in the acclimatized subject, the hyperventilation is not sustained by the chemoreflexogenic hypoxic stimulus, but by an increased sensitivity of the respiratory centre to the normal chemical stimuli to respiration, i.e. CO_2 and H^+.

This hypothesis was supported by the data of Bjurstedt (1946) who found that the effect of oxygen breathing on ventilation is very evident in acute hypoxia, but that it subsides progressively to become practically nil after 8 h of anoxia. Åstrand (1954), however, found that a chemoreflexogenic control of ventilation, as judged by the effect of the sudden administration of oxygen on the frequency of the impulses from the carotid body chemoceptors, is well evident even in chronic hypoxia.

In man, Rahn and Otis (1949), have shown on the subject acclimatized to hypoxia, a hypersensitivity of the respiratory centre to CO_2 and H^+: in accord with Bjurstedt (1946), they think that the claim for a chemoreflexogenic control of respiration in this condition is no longer necessary. Åstrand (1954), however, found that during exercise a very evident decrease of ventilation takes place when the acclimatized subject is shifted from air to oxygen breathing.

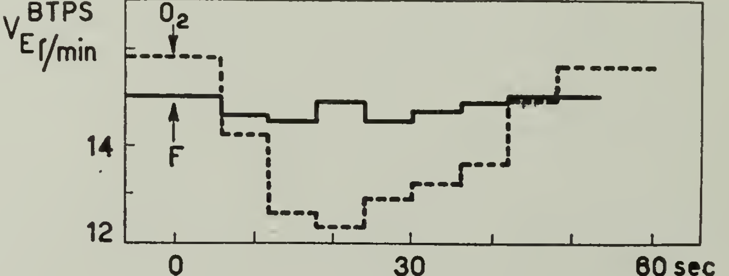


FIG. 2. The effect of a single V_T of oxygen on ventilation (average five subjects at rest after 60 days at 5000–7000 m above sea level). Between the eighteenth and the twenty-fourth second from O_2 administration V_E decreases about 22 percent. F, control: a single V_T of ambient air was given

Dejours (1959) has investigated the activity of chemoceptors by giving a single breath of oxygen; this reaches the arterial blood and the chemoceptors in the arterial blood in only a few seconds: the eventual ventilation changes that may take place in this short time are certainly due to the action of oxygen on these formations, without

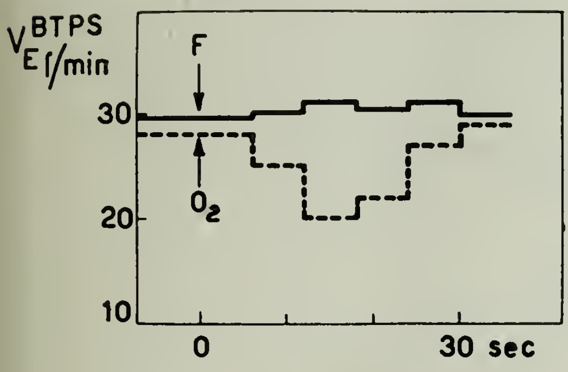


Fig. 3. The effect of a single V_T of oxygen on ventilation (average three subjects performing a step test after 60 days at 5000—7000 m above sea level). Between the twelfth and the eighteenth second from O_2 administration V_E decreases about 29 per cent. *F*, control: a single V_T ambient air was given

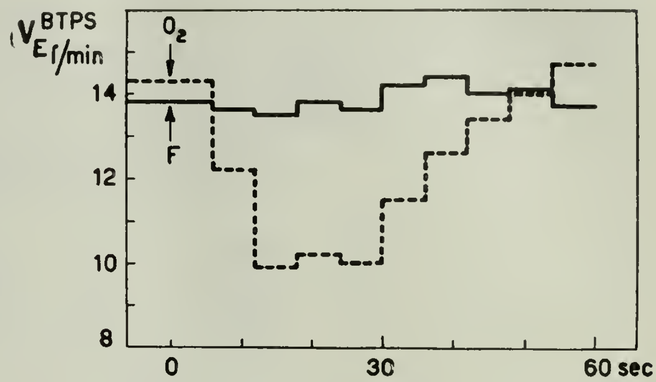


Fig. 4. The effect of a single V_T of oxygen on rest ventilation (average four subjects breathing 11 per cent O_2 in N_2 at sea level). Between the twelfth and the eighteenth second from O_2 administration V_E decreases about 31 per cent. *F*, control: a single V_T of O_2 in N_2 was given

the interference of other eventual mechanisms that may have a longer time factor. With this technique he found that in the acclimatized subject a single breath of oxygen induces a temporary depression of the ventilation of about the same order

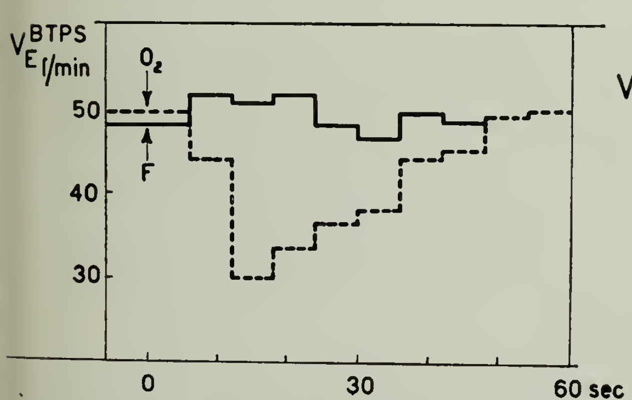


Fig. 5. The effect of a single V_T of oxygen on ventilation (average four subjects walking at a steady state on a treadmill breathing 11 per cent O_2 in N_2). Between the twelfth and the eighteenth second from O_2 administration V_E decreases about 38 per cent. *F*, control: a single V_T of 11 per cent O_2 in N_2 was given

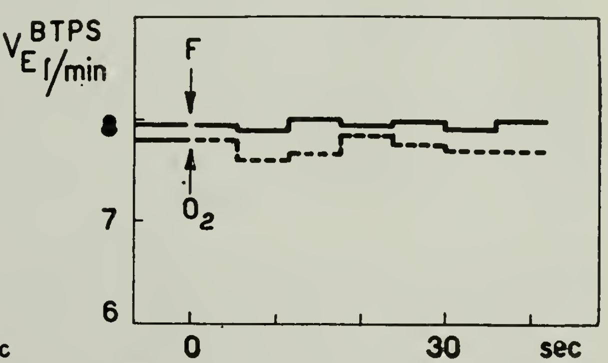


Fig. 6. The effect of a single V_T of oxygen on rest ventilation (average three subjects breathing air at sea level). Between the sixth and the twelfth second from O_2 administration, V_E decreases about 3 per cent. *F*, control: a single V_T of ambient air was given

of magnitude as in acute hypoxia. Similar experiments have been performed recently during a Himalayan expedition by Cerretelli (1959) at higher altitudes (from 5000 to 7000 m) and after a 60-days acclimatization. In Fig. 2, the effect of a single breath of oxygen is shown (average of five subjects), the reduction of the pulmonary

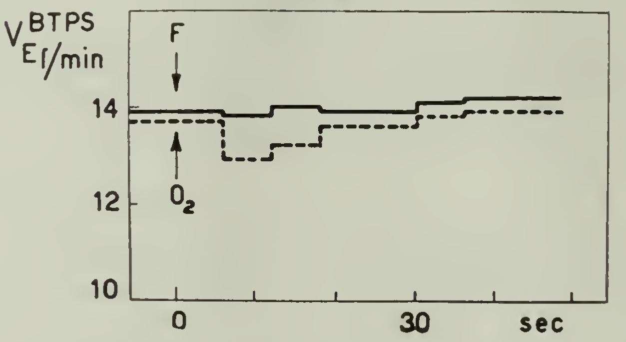


Fig. 7. The effect of a single V_T of oxygen on ventilation (average three subjects walking at a steady state on a treadmill, breathing air at sea level). Between the sixth and the twelfth second from O_2 administration, V_E decreases about 7 per cent. *F*, control: a single V_T of ambient air was given

ventilation having a peak of 22 per cent after about 20 sec. Fig. 3 shows the same experiment during exercise; the peak of the reduction is 29 per cent and it takes place earlier, at about the fifteenth second.

In acute hypoxia, both at rest and during exercise, the same results are obtained (Figs. 4 and 5). Figs. 6 and 7 show the effect of a single breath of oxygen at rest and during exercise in man at sea level.

In these experiments, the most peculiar observation is that the reduction of ventilation on shifting from hypoxia to oxygen breathing is permanent in the non-acclimatized and transitory in the acclimatized subject. This observation may be explained on the hypothesis of the presence of a chemoreflexogenic hypoxic stimulation of the respiratory centre in both acclimatized and non-acclimatized subjects; however, in the acclimatized subject the removal of the hypoxic stimulus and the consequent hypoventilation gives rise to an additional stimulus to respiration whose effects are manifest after a certain delay.

We think that this mechanism consists in the H^+ increase in the blood that takes place only in the acclimatized subject in the following manner: acute hypoxic subjects are in conditions of acapnic alkalosis due to hyperventilation; during the hypoxia this alkalosis is compensated in the first hours or days by alkali elimination through the kidney, until the pH of the blood is back to normal. The hypoventilation following the first few breaths of oxygen leads to an increase of the blood CO_2 and therefore to an acidosis; this takes place only after about 60 sec, this being the time necessary for an appreciable amount of CO_2 to accumulate in the blood and to be distributed into the tissues; in non-acclimatized individuals the hypoventilation does not induce acidosis, but only a return to normal of the blood and tissues pH. This is clearly seen in the blood data in Table 1, calculated from the charts given by Dill *et al.* (1937) and Rahn and Fenn (1955) for man at sea level and residents at altitude (4100 m).

Table 1. Respiratory parameters of a normal and of an acclimatized subject at sea level and in hypoxia. (In the last column the parameters are given for acclimatized subjects, when ventilation is such as to induce a value of 7.40 for the blood pH

Normal		P_{A,O_2} P_{I,CO_2} P_{A,CO_2}	Acclimatized		
150	60	P_{I,O_2}	60	150	150
98	77	Hb O_2	73	97.5	99
101	36	P_{A,O_2}	37	103	120
40	20	P_{A,CO_2}	20	40	25
6.0	12.0	$\dot{V}_A$	12.0	6.0	10.0
0.0175	0.035	$\dot{V}_A/\dot{V}_{O_2}$	0.035	0.0175	0.029
7.41	7.61	pH	7.46	7.30	7.40
0.8	0.8	R	0.8	0.8	0.8

Determinations are being made at this Institute to describe the effect of a sudden shift from hypoxia to oxygen breathing in subjects: (a) with reduced alkaline reserve, e.g. after ingestion of ammonium chloride, a condition similar to that found in acclimatized subjects, and (b) after ingestion of bicarbonate.

RESPIRATORY MECHANICS

Pulmonary volumes change in the course of acclimatization. Hewett in 1875 found a decrease of vital capacity (V. C.) after a few days at 3000 m at sea level, and this finding has been confirmed by Bert (1878), Mosso (1898), Zuntz (1896), Fuchs (1908), Viale (1919), Grollman (1930), Schneider (1932), Verzàr (1933, 1945), Rahn and Hammond (1952) among others. The data given by these authors, however, covers a wide range, a decrease from 4 to 50 per cent, presumably in relation to different altitudes and to different degrees of acclimatization.

Vital capacity does not seem to change immediately at altitude. Recently Rahn and Hammond (1952), using a decompression chamber, measured the vital capacity for a few minutes at 3000, 4300, 5500 m. The same experiments were made after breathing oxygen at the same pressure; a decrease of V.C. of only 4 per cent was found. A 7 per cent reduction was found in an experiment at 12000 m above sea level while breathing oxygen.

Durig (1911) after 3 weeks at 4400 m above sea level found a reduction of 15 per cent of V. C. in four subjects.

Tenney *et al.* (1953) during a 7-days stay at Mount Evans (4260 m above sea level) found a reduction in the vital capacity which reached its peak on the third day, to resume its normal value by the end of the week. From the first day the residual volume was increased up to 20 per cent, and it remained high on the following days. During a Himalayan expedition Cerretelli (1960) found in seven subjects after 30 days between 3800 and 5000 m above sea level a reduction of V. C. of 9.84 per cent $\pm$ 4.34, and after additional 30 days between 5000 and 7500 m above sea level, a reduction of 12.54 per cent $\pm$ 3.80 (Fig. 8). The same values were found if the test

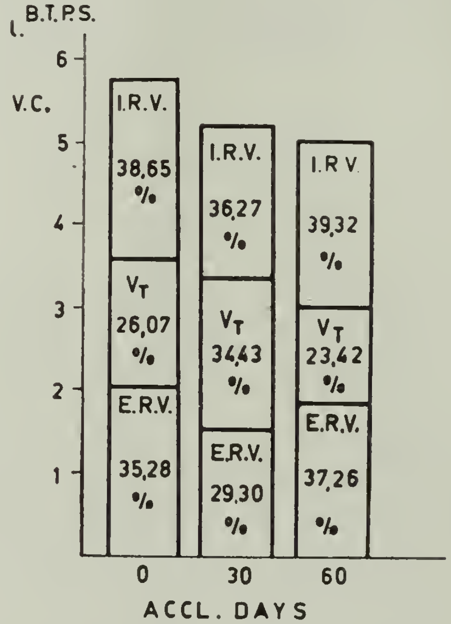


Fig. 8. The effect of acclimatization on vital capacity and its components

was performed during oxygen administration. Such a reduction of V. C. in the acclimatized subject may possibly be due to an increased inspiratory tonus (Verzàr, 1945; Peyser *et al.*, 1950); a more inspiratory average position of the chest gives reason also for the increased lung volume in normal respiration, and the increased residual volume (Tenney *et al.*, 1953).

The increase of the average pulmonary volume has been also called "functional emphysema", and it has a considerable physiologic importance in levelling off the changes in concentration of the respiratory gases in the alveoli and in the blood, as due to the respiratory movements. In conditions of chronic hypoxia this could be particularly useful, because in anoxic conditions the feed-back control of the respiratory centre seems to operate in an emergency condition. Nielsen (1936) and Rahn and Otis (1949), claim that in acute anoxia the sensitivity of the respiratory centre to normal chemical stimuli, CO_2 and H^+, is increased; Margaria (1941), however, found that anoxia does not change the sensitivity of the respiratory centre to CO_2, as defined by $dV_E/dP_{A,CO_2}$.

Another aspect of particular interest with regard to the respiratory mechanics in the acclimatized subject, is given by the changes of the maximal exercise ventilation (M.E.V.) during acclimatization. Christensen (1937) found an appreciable reduction of the M.E.V. at 5300 m above sea level and Cerretelli (1960), in five subjects acclimatized to about 5000 m found a reduction of 22 per cent. Pugh (1958) however, in similar conditions of acclimatization, found an increase of about 20

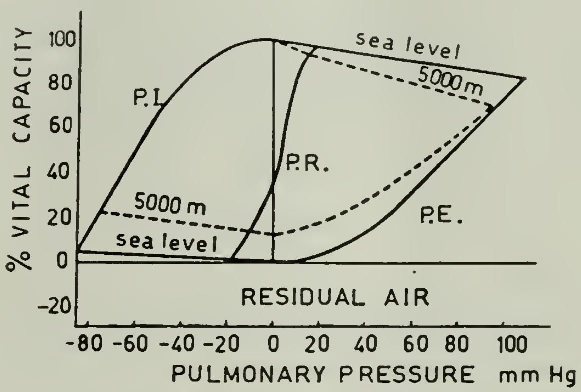


Fig. 9. The effect of acclimatization on the pressure—volume diagram of the chest and of the lungs. The area included in the interrupted line is about 0.75 of the total

per cent, which he attributed to the reduced air density and consequently to the reduced resistance of the airways. Pugh's data on ventilation, however, have been collected by an indirect method.

Many factors may influence M.E.V. in chronic hypoxia. In particular the factors that tend to reduce M.E.V. are:

(a) The reduced air pressure leads to a reduction of the area of the pressure—volume diagram for the respiratory apparatus, i.e. of the maximal potential work of a single breath (Rahn *et al.*, 1946). This effect, as evidenced in Fig. 9, is due to the greater changes of volume of the air in the lung by the same absolute pressure change, i.e. by the steeper incline of the upper and lower lines.

(b) The possible reduction of V.C. implies a further reduction of the area included in the pressure—volume diagram besides that described in (a) (Fig. 9).

(c) Hypoxia is presumably an important factor in the reduction of the working capacity of the respiratory muscles, as it is for all other muscles of the body, particularly during strenuous muscular exercise. A tendency to an increase of M. E. V. on the other hand is given by (d).

(d) The reduction of the work involved in overcoming turbulence in the airways, for a given air flow; this decrease is due to the decrease of the air density (Otis and Bembower, 1949), and it implies a reduction of the total respiratory work.

This last factor is not quantitatively very important. In fact Cotes (1954) using a decompression chamber found an inciease of about 15 per cent of the maximum breathing capacity (M.B.C.) at 410 mm Hg. A short period of hypoxia, however, does not appreciably reduce the working capacity of the respiratory muscles, nor are appreciable changes induced in the pulmonary volumes or in their ratios (Rahn and Hammond, 1952). Particularly in subjects at rest, the sum of the other factors (a), (b) and (c) prevails considerably, and a decrease of the M.E.V. at altitude results, and is thus responsible for the 22 per cent reduction at an altitude of 5000 m, as reported by Cerretelli (1960).

Factor (c) may not modify the M.B.C., but certainly helps to reduce the M.E.V. The decrease of 12.5 per cent of the vital capacity in acclimatized subjects, together with the reduction due to factor (a), amply explains a 25—30 per cent reduction in the area of the pressure—volume diagram of the respiratory apparatus, which is of the same order of magnitude as the reduction of the M.E.V. found by Cerretelli.

HEART

1. *Heart Frequency at Rest*

Anoxia has a twofold effect on vagal cardioinhibitory centre: impulses from the chemoceptors in the circulatory tree lead to a reflex inhibition of the centre; this, however, may be stimulated, and the heart frequency reduced, through a direct effect of anoxia on the centre. In mild anoxia, the first reflex mechanism prevails, in severe anoxia the direct central mechanism is predominant (see Margaria, 1943). In acute hypoxia, an increase of heart frequency is already evident at an altitude of about 2000—3000 m; it increases further to reach a maximum at about 7000 m; in more severe anoxic conditions, bradicardia develops, which is rapidly followed by loss of consciousness.

During the acclimatization process at altitude, tachicardia subsides and a normal sea level heart frequency value is reached again (Mosso, 1898; Durig, 1909; Schneider, 1921; Barcroft, 1922; Hingston, 1925; Hartmann, 1936). At high altitude, even the subject at rest is bradicardic ("acclimatization bradicardia", Hartmann, 1933). This condition was subsequently confirmed by Hartmann *et al.* (1941), Wyss-Dunant (1955) and Cerretelli (1960); in experiments on five subjects after 60 days acclimatization at 5000 m, Cerretelli found a reduction of 8.5 per cent of the heart frequency at rest.

2. *Minute Volume of the Heart at Rest*

A subject acclimatized to altitude, has not a different minute volume from the man living at sea level; Rotta *et al.* (1949) found the same values using the method of catheterization of the right side of the heart.

Grollman (1930) using the acetylene method found a 50 per cent increase in the minute volume in the first few days at 4300 m, which returned to normal in about 9 days. This author emphasizes a correlation between the return of the minute volume to normal values and the increase of blood haemoglobin that takes place at the same time. Christensen and Forbes (1937) described similar behaviour in the heart minute volume; they deny, however, that a significant correlation exists with the increase of haemoglobin. Asmussen and Consolazio (1941) found after 3—4 days at 4300 m a 40 per cent increase of the minute volume that subsided to normal values after a few days.

Electrocardiographical and radiological examinations seem to indicate that at altitude a slight myocardial hypertrophy takes place (Rotta, 1947; Kerwin, 1944); the cardiac diameters are slightly increased. This finding, however, does not seem to find support in more direct data on the changes of the weight of the heart of animals that have been kept at low barometric pressure for a prolonged time (Rotta, 1943; Moore and Price, 1948; Lintzel, 1928). On the other hand, myocardial hypertrophy in chronic hypoxia is hardly accounted for by a greater increase in the work of the heart.

In fact, in spite of the increased cellular blood elements, blood pressure, both systolic and diastolic, is not increased (Ward 1908; Hingston, 1925; Grollman, 1930; Rotta, 1947); however, Cerretelli found a slight decrease of blood pressure in twelve subjects, of about 10 mm Hg in both systolic and diastolic pressure after 60 days at 5000 m. Because of anoxia, the possibility of performing hard work in emergency conditions is decreased for the heart in the same way as for any other muscle of the body. Therefore, the condition that would justify sustained prolonged work that might lead to myocardial hypertrophy is lacking.

The pulse rate is increased in acute hypoxia, probably as a consequence of an increased arterial tone; in the acclimatized subject it has the same value as in residents at sea level (Wiesinger and Steiman, 1943; Wiesinger and Abbühl, 1944; Dalla Torre, 1944; Delius *et al.*, 1942).

3. *Heart Frequency and Minute Volume during Exercise*

A given standard exercise requires a higher heart frequency before acclimatization; after acclimatization, however, for moderate exercise, the increase of frequency is the same as at sea level (Mosso, 1898; Douglas *et al.*, 1913; Schneider, 1916; Schilling *et al.*, 1956, Brendel, 1956). Christensen and Forbes (1937) have shown that the oxygen consumption per heart beat, does not change with altitude in the acclimatized subject.

The maximal heart frequency observed during exhaustive exercise is appreciably lower at altitude (about 150) than at sea level (about 180) (Barcroft, 1925; Christensen 1937; Åstrand and Åstrand, 1958; Cerretelli, 1960).

Rushmer (1959) found at sea level that heart frequency is proportional to minute volume: if this also holds true for acclimatized subjects at altitude, a decrease of the same order as for heart frequency is to be found for the minute volume. Such an impairment of the heart function is to be attributed to the impending anoxia, and not to secondary changes of the body functions. The administration of pure oxygen at altitude, therefore, immediately increases the maximum oxygen consumption and the maximum heart rate.

BLOOD

Hypoxia constantly induces an increase in the number of erythrocytes and in the amount of haemoglobin. This was shown by Bert (1882) and by Viault (1892) and confirmed subsequently by many authors. Such an increase during the earliest part of hypoxia is due mainly to mobilization of the erythrocytes from reservoirs in the body, particularly from the spleen (Barcroft, 1926; Binet, 1927; Kramer and Luft, 1951) and possibly to an increased plasma concentration (Asmussen and Consolazio, 1941; Hurtado *et al.*, 1945; van Liere, 1942; Grant, 1951).

In the earliest phase at altitude the erythrocytes increase is only 10—15 per cent (Margaria and Sapegno, 1928), but it is much more pronounced in the latest phase of acclimatization; in residents at altitude, it may reach about 60 per cent and it may lead to an impairment of the circulation (Monge, 1935). Up to 5 per cent or more reticulocytes are present (Barcroft *et al.*, 1922; Talbott and Dill, 1936; Hurtado *et al.*, 1945). The blood volume does not increase appreciably, while the plasma volume and the concentration of the plasma proteins are the same as at sea level (Margaria and Sapegno, 1928; Hurtado *et al.*, 1945; Hill *et al.*, 1936; van Liere, 1942; Huey and Holmes, 1950). An increased erythropoesis can be shown also through biopsies of bone marrow (Merino and Reynafarje, 1949) and, indirectly, by studying the iron metabolism by administering a radioactive isotope (Reynafarje, 1958).

The increased erythropoesis and the consequent polycitemia, in man living at altitude, seems to be due to a factor present in plasma: Loeschke and Schwartzer (1939) by injecting into the rabbit blood serum from a man living at altitude, were able to obtain a significant increase in the number of erythrocytes; the average life of the erythrocytes, however, is not appreciably changed at altitude (Berlin *et al.*, 1954).

The Oxygen Dissociation Curve of the Blood

Douglas *et al.* (1913) could not find any appreciable change in the oxygen dissociation curve of the blood of individuals after a permanent residence at 4300 m above sea level, when the CO_2 tension was the same as in alveolar air.

Of course this tension was lower than in residents at sea level. This finding showed that the haemoglobin has the same functional behaviour in residents at altitude as in residents at sea level, in spite of a different CO_2 tension of the blood.

Barcroft *et al.* (1922) during the Anglo-American expedition to Peru found a shift to the left in the oxygen dissociation curve of human blood after a few weeks at 4300 m above sea level. This was interpreted as due in part to the greater alkalinity of the blood, and possibly to other factors independent of the pH (Barcroft, 1925).

Barcroft's data, however, could not be confirmed by other investigators; Dill *et al.* (1931) in experiments on subjects who had spent 4 days at 4200 m above sea level, could not find significative changes for a given blood pH.

Salazàr and Hurtado (1944) analysed the oxygen dissociation curve for blood: (a) on seventeen residents at sea level; (b) on twelve subjects in acute hypoxia (2 h after reaching a height of 4540 m above sea level); (c) on twelve permanent residents at this altitude; and finally (d) on eight high altitude residents immediately

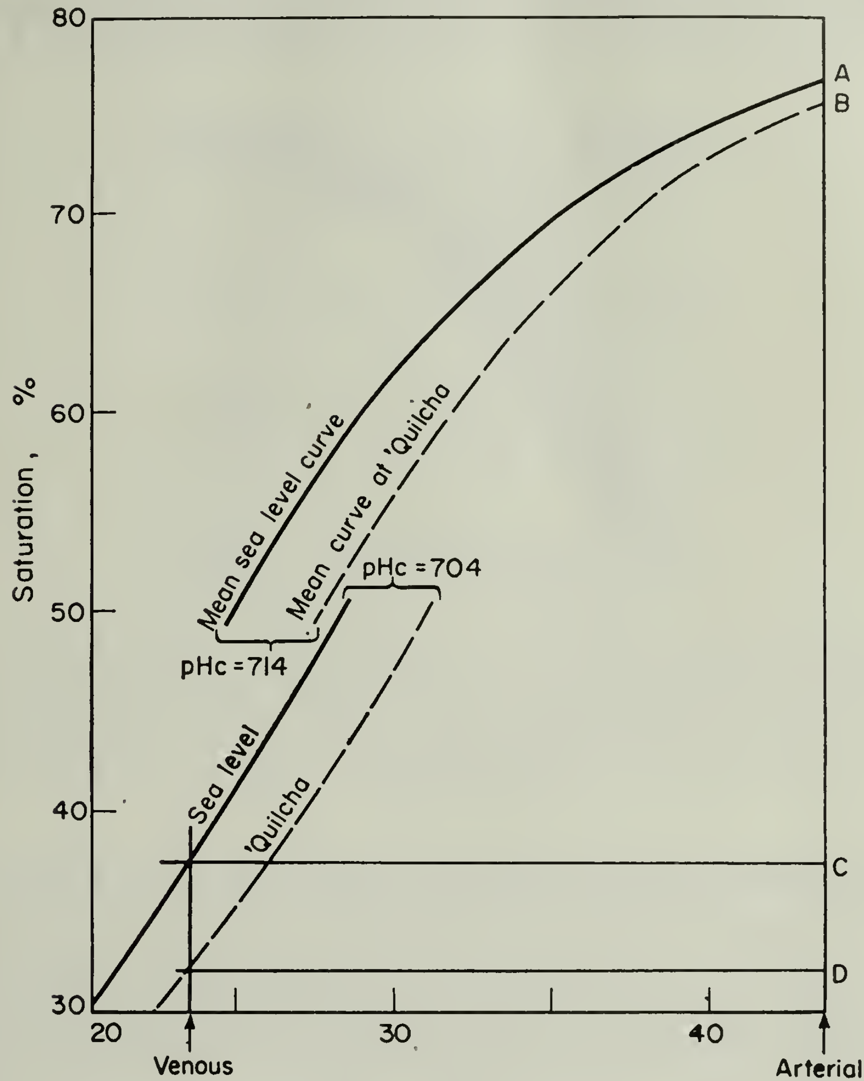


Fig. 10. The effect of acclimatization on the O_2 dissociation curve (from Keys *et al.*, 1936)

after reaching sea level. At the actual value of blood pH, the blood dissociation curves were the same in all cases. A very slight, probably unsignificant, shift to the right of the oxygen dissociation curve, was found for the residents at altitude. The same conclusion was reached previously by Keys *et al.* (1936) on a slightly lower number of subjects during the Chile expedition of 1935 (Fig. 10).

Hall (1936) obtained dialized haemoglobin from subjects living at sea level and at altitude. The oxygen dissociation curve of these two haemoglobins did not differ significantly, and this shows that prolonged hypoxia does not induce changes in the haemoglobin molecule.

Hall *et al.* (1936) found that the affinity for oxygen of sheep's blood does not change after permanent residence of the animal at an altitude of 5300 m above sea level. The blood of animals of similar species, such as llama and vicuña, that permanently live at high altitudes, has a much greater affinity for oxygen (Fig. 11). This

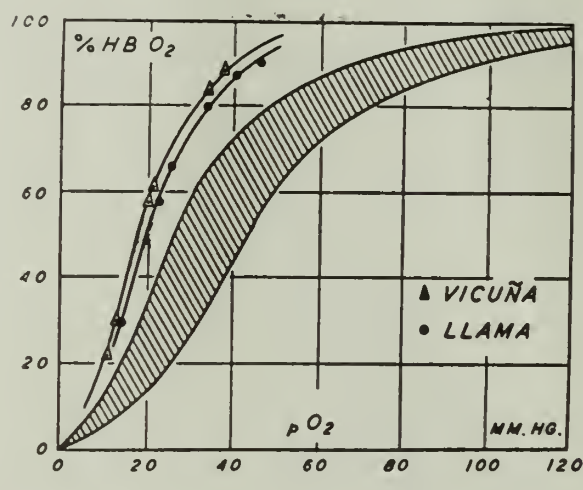


FIG. 11. The oxygen dissociation curves of the llama and vicuña at body temperature (39°) and $pH_e = 7.1$ compared with the range for eight lowlanders. These eight range from man to sheep, the intermediate six being the horse, dog, rabbit, pig, peccary and ox. The visacha, a native rodent of high altitudes, has an oxygen dissociation very near that of man (from Hall *et al.*, 1936)

affinity remains the same if these animals are taken down to sea level, and even if they are born in captivity and reside permanently at sea level. This characteristic seems therefore not to be directly related to the altitude. Hall *et al.* also found an affinity for oxygen in the haemoglobin of birds living at high altitude, greater than that found for sea level birds by Christensen and Dill (1935) and by Morgan and Chichester (1935).

In conclusion, anoxia will not change the way that the structure of the haemoglobin molecule is synthesized in the various animals. The chemistry of haemoglobin is a characteristic which is bound to the animal species, and it is completely independent of external factors.

The hypothesis that in anoxia the body could synthesize a haemoglobin with a greater affinity for oxygen was considered particularly after Barcroft *et al.* (1934) found that foetal haemoglobin has a greater affinity for oxygen than maternal haemoglobin. The foetus lives in conditions of relative anoxia and the change from the foetal to adult haemoglobin takes place progressively after birth. Evidently this change is not related to changes in oxygenation of the body tissues.

The finding that the oxygen dissociation curve of the blood at the same pH value in man living at sea level and at altitude is identical, is rather astonishing, in view of the great difference of the CO_2 in the blood in the two cases, and in view of the effect of the CO_2 on the O_2 dissociation curve of the blood. Margaria and Green have shown since 1933 that the dissociation curve of horse haemoglobin for oxygen is very appreciably shifted to the right when, without change of pH and ionic strength,

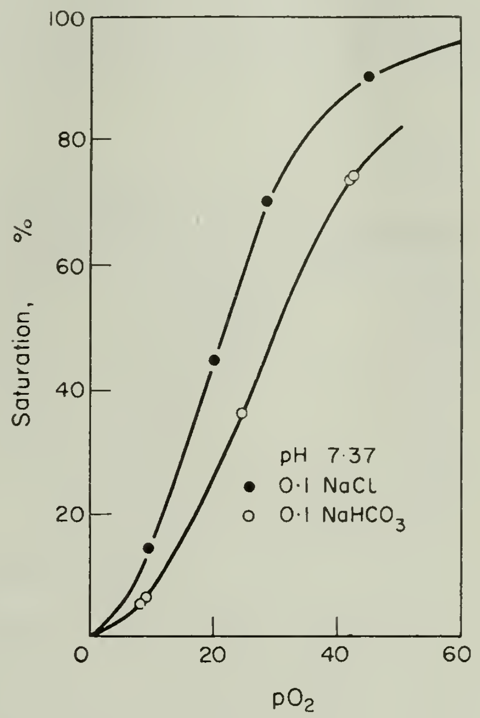


FIG. 12. Oxygen dissociation curves of haemoglobin in NaCl and $NaHCO_3$ at the same pH and ionic strength (0.1 m) (from Margaria and Green, 1933)

the electrolyte is shifted from NaCl to $NaHCO_3$—CO_2 (Fig. 12). This effect (later confirmed repeatedly) is due, at least in part, to the combination of CO_2 with haemoglobin in a carboaminic compound (Ferguson and Roughton, 1934; Margaria, 1952). At altitude, $P_{A,CO_2} = 20$ mm instead of 40 mm as at sea level, and the pH is the same; one would thus expect the oxygen dissociation curve of the blood at altitude to be shifted to the left, in accordance with Barcroft's claim (1922).

The data of Dill *et al.* (1931), Keys *et al.* (1936) and Salazàr and Hurtado (1944), however, give support to the hypothesis that the Margaria and Green effect on horse haemoglobin may not have an equivalent in human haemoglobin, or alternately that some other factor is present that may be responsible for the tendency of the oxygen dissociation curve of haemoglobin to shift to the right. As a matter of fact, the physicochemistry of human haemoglobin is not so well known as that for haemoglobin of other species, probably owing to the greater difficulty of obtaining large amounts of protein in a pure crystallized state. Possibly a quantitative analysis of the Margaria and Green effect on human haemoglobin may bring a solution to this problem.

ENERGY METABOLISM

Maximum oxygen consumption is reduced both in acute hypoxia and in the acclimatized subject (Margaria, 1930; Christensen, 1937; Åstrand, 1954; Pugh, 1958, among others); the impairment seems greater in the acclimatized subjects, particularly at very high altitude (see Fig. 13). The capacity to perform work in anaerobic

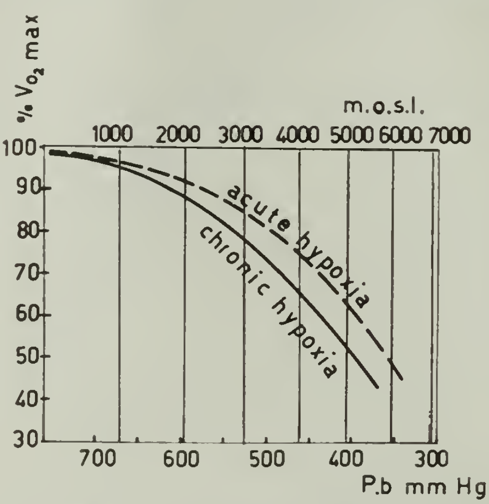


Fig. 13. Maximum oxygen intake at altitude

conditions ought to be independent of altitude, i.e. from the degree of hypoxia. Actually the lactic acid figures during maximum work are lower at altitude than at sea level, and this is presumably an index of a lower capacity to perform anaerobic work.

The first phase of the recovery process, due to the discharge of the lactic acid debt, does not seem to change in hypoxia (Cerretelli, 1959; Figs. 14 and 15). The slow recovery process identified with the discharge of the lactic acid debt, which is correlated more to oxidative processes, seems on the other hand, to be reduced in hypoxia (Margaria, 1928).

The mechanical efficiency of muscular exercise is obviously the same at altitude as at sea level (Christensen, 1937; Ewig, 1931; Herheimer, 1933; Schilling *et al.*, 1956).

The energetic efficiency of respiration such as defined by kcal/l., namely by the ratio of energy expenditure to pulmonary ventilation, is appreciably lower both in acute as in chronic hypoxia, owing to hyperventilation, which is present at all levels of exercise (Bainbridge, 1931; Christensen, 1937; Åstrand, 1954). The higher pulmonary ventilation at altitude, at a given rate of work, has evidently a compensatory significance in the decrease of P_{I,O_2} and is due to the additional hypoxic stimulus to respiration. This mechanism has obviously a limitation, owing to the maximal values of $\dot{V}_E$ that can be attained; in fact, at an altitude of 5000 m a maximal value of ventilation of about 120 l./min, is reached, with an oxygen consumption of about

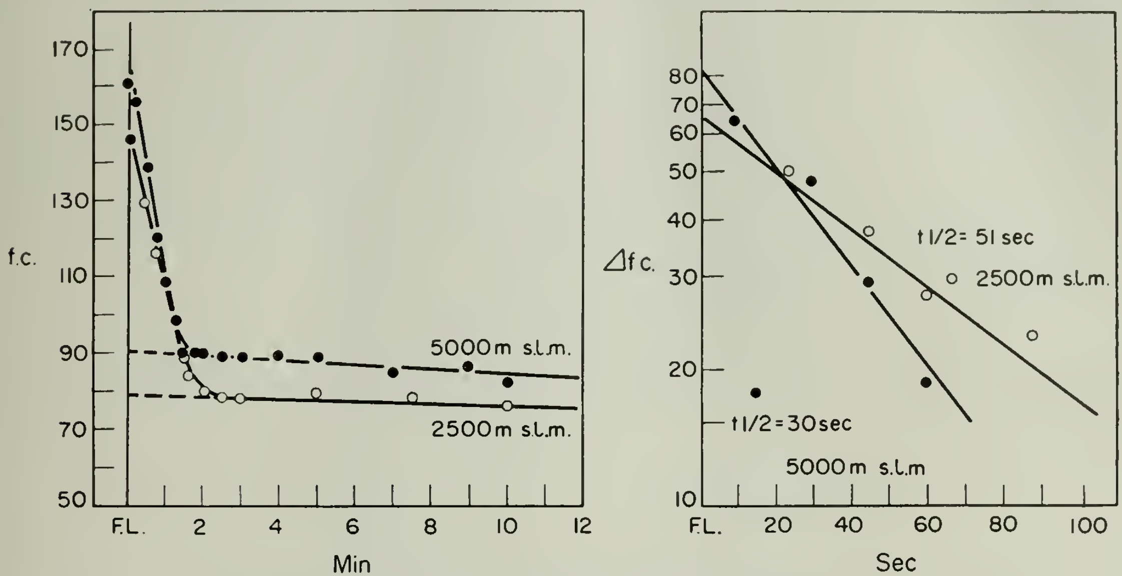


Fig. 14. Kinetics of recovery of c.f. after standard exercise (city resident) (from Cerretelli, 1960)

2 l./min, the same value that is obtained at sea level with a much higher oxygen consumption.

This maximum ventilation during exercise (M.E.V.) does not seem to be lower in acute hypoxia, at least up to an altitude of 4000 m (Åstrand, 1954) or 4700 m.

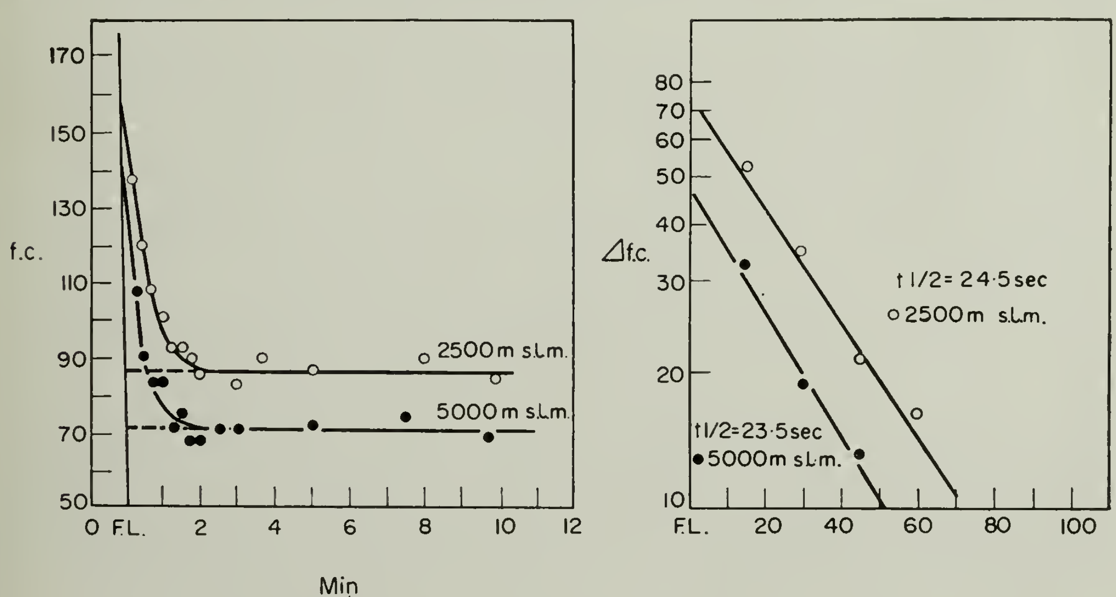


Fig. 15. Kinetics of recovery of c.f. after standard exercise (alpine guide) (from Cerretelli, 1960)

At higher altitudes, however, (5000 m) Christensen (1937) found an appreciable reduction of M.E.V. which was recently confirmed by Cerretelli (1959). In the acclimatized subject the latter author found a reduction of M.E.V. of less than 0.8 the values previously found in the same subject at sea level. Such a reduction of M.E.V. at very high altitude may explain the lower working capacity of the acclimatized subject, as compared to the subject exposed to acute hypoxia (Fig. 12).

The oxygen saturation of arterial blood is not lowered appreciably at sea level, during heavy exercise; at altitude it may instead be very appreciably lower (Riley and Houston, 1947). The alveolo-capillary P_{O_2} gradient is correspondingly increased during hard work at altitude (Liljenthal *et al.*, 1946); one consequence is a lower saturation of arterial blood with oxygen at altitude, which is partly compensated by the increased haemoglobin content of the blood.

In experiments with five subjects kept at an altitude of 5000 m Cerretelli (1960) found a reduction of the maximum oxygen consumption of up to 0.44 the value obtained at sea level. The maximum oxygen consumption is given by the well-known formula:

$$\dot{V}_{O_2}^{max} = \Delta\,\text{sat.} \times \text{cap.} \times G = \dot{V}_A(F_{I,O_2} - F_{A,O_2}) \tag{1}$$

$$0.44 = 0.42 \times 1.32 \times 0.8 = 0.8 \times 0.55$$

$$0.44 = 0.76 \times 1.32 \times 0.44$$

where Δsat. is the difference in the percentage saturation of haemoglobin with oxygen between the arterial and the venous point, cap. is the capacity of the blood for O_2, G is the minute volume of the heart, $\dot{V}_A$ is the alveolar ventilation in l./min in STP, F_{I,O_2} and F_{A,O_2} are the fractions of oxygen in inspired and in alveolar air, respectively.

By this formula, the possible corresponding fraction values at altitude are obtained. For the respiratory parameters, no problem arises. The decrease to 0.8 of $\dot{V}_A$ comes from direct observation, and therefore the value $F_{I,O_2} - F_{A,O_2}$ must be reduced to 0.55 the value at sea level.

This parameter, which is evidently the energetic efficiency of respiration, in litres of oxygen per litre of alveolar ventilation, is marked with a thick line on the abscissa of Fig. 16, where values of P, proportional to F, are plotted.

The data of the circulatory parameters have been calculated on two different assumptions. A first assumption is made that the oxygen consumption in the tissues, i.e. the amount of oxygen going through the capillary membrane in the unit time, is proportional to the blood capillary—tissue oxygen gradient. Furthermore, a second assumption is that, at maximum work, P_{O_2} in the tissues is approaching 0, and therefore the average P_{O_2} capillary may be assumed as the oxygen gradient. The average tissue capillary P_{O_2} at sea level can be approximately calculated with the empirical Barcroft's formula

$$P_{O_2}\,\text{cap.} = P_{O_2}\,\text{ven.} + \frac{P_{O_2}\,\text{art.} - P_{O_2}\,\text{ven}}{3}$$

when a given saturation is given for the arterial blood (95 per cent) and for the venous blood coming from the active tissues (30 per cent), as 39 mm Hg. From the two assumptions above, at altitude the average tissue capillary P_{O_2} must be $39 \times 0.44 = 17$ and from this value the arterial and the venous point may easily

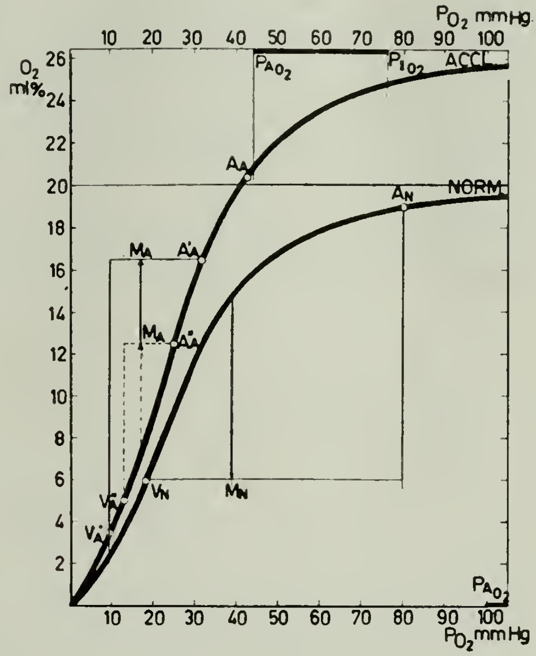


FIG. 16. O_2 dissociation curve of the blood of sea level residents (N) and of the same subjects after 60 days residence at 5000—7000 m (A); O_2 capacity of the blood increases from 20 to 26.4 ml.
A_N and $V_{N'}$ assumed arterial and venous points during heavy exercise at sea level. M_N average tissue capillary P_{O_2}, as calculated from Barcroft's formula. $M_A = 0.44\ M_N$: average tissue capillary P_{O_2} at altitude, 0.44 being the reduction of the maximum oxygen consumption at altitude. A'_A, V'_A arterial and venous points during heavy exercise at altitude, calculated on the assumptions: (a) $M_A = 0.44\ M_N$; (b) stroke volume is not influenced by altitude and the heart minute volume is decreased as the heart frequency to 0.8. $A''_{A'}$, V''_A same as above, except assumption (b) is changed to: (b) arterio-venous O_2 difference in vol. % is not changed as effect of altitude. The heavy line on the abscissa defines $P_{I,O_2}-P_{A,O_2}$ at altitude and this is the energetic efficiency of the respiration

be calculated, if a value is assumed for one of the two unknown variables, namely the arterio-venous percentage saturation gradient of haemoglobin with oxygen and the heart minute volume, the increase of the blood capacity for oxygen being known, as determined at 1.32 the sea level value. Assuming that the stroke volume does not change from sea level to altitude, and that the changes of G, the heart minute volume, are due only to heart frequency, which is decreased to 0.8 the value at sea level, the difference in percentage saturation turns out to be 0.42 and the corresponding arterial and venous points are those shown in Fig. 16 as A''_A and V''_A. The value of saturation for the arterial point so calculated is evidently too low, and this shows that the assumption involved in this calculation, i.e. that the stroke volume is not decreased as an effect of altitude, and that the heart minute volume is decreased only as an effect of the decreased frequency, is not tenable.

Much more reasonable is the other assumption that the arterial venous oxygen difference in ml/100 ml of blood is about the same at altitude as at sea level; on this assumption the arterial point turns out to be 12 mm lower than the alveolar point; this is probably already too big a value, and probably at altitude the heart minute volume is reduced to even less than 0.44 the sea level value, as indicated in the formula above.

These considerations point to the necessity of more investigations with more modern and more refined techniques on the circulatory conditions at altitude. Reliable data in this field are still lacking, in contrast with the deeper knowledge of the respiratory function.

REFERENCES*

AGAZZOTTI A. (1904) *Arch, Ital Biol.* **42,** 14.

AGAZZOTTI A. (1905) *R. C. Accad. Lincei* **14,** ser. V, 180, 256, 706.

ASMUSSEN E. and CONSOLAZIO F. (1941) *Amer. J. Physiol.* **132,** 555.

ASTE SALAZÁR H. and HURTADO A. (1944) *Amer. J. Physiol.* **142,** 733

ÅSTRAND P. O. (1954) *Acta Physiol. Scand.* **30,** 335.

ÅSTRAND P. O. and ÅSTRAND I. (1958) *J. Appl. Physiol.* **13,** 75.

BAINBRIDGE F., BOCK A. and DILL D. B. (1931) *The Physiology of Muscular Exercise.* Longmans Green, London.

BARCROFT J., CAMIS M., MATHISON C. G., ROBERTS F. G. and RYFFEL J. H. (1914) *Philos. Trans.* B **206,** 49.

BARCROFT J., BINGER V., DOGGARD F., HARROP G. A., MEAKINS J. C. and REDFIELD A. C. (1922) *Philos. Trans.* **211,** 351.

BARCROFT J. (1925) *The Respiratory Function of the Blood.* Cambridge University Press.

BARCROFT J., ELLIOT E. H. K., FLEXNER B. L., HALL F. G., HERKEL W., MCCARTHY F. E., MCCLURKIN T. and TALAAT M. (1934) *J. Physiol.* **83,** 192.

BERLIN N., REYNAFARJE, C. and LAWRENCE J. (1954) *J. Appl. Physiol.* **7,** 271.

BERT P. (1878) *La Pression Barométrique.* Paris.

BERT P. (1882) *C. R. Acad. Sci. Paris* **94,** 805.

BINET L. (1927) *C. R. Soc. Biol., Paris.*

BJURSTEDT A. G. H. (1946) *Acta Physiol. Scand.* **12,** Suppl. 38.

BOGUE J. Y. and STELLA G. (1935) *J. Physiol.* **83,** 459.

BOYCOTT A. and HALDANE J. (1908) *J. Physiol.* **37,** 355.

BRENDEL W. (1956) *Pflüg. Arch. Ges. Physiol.* **263,** 227.

CERRETELLI P. 1959. *Comm. II world and IV Europ. Congr. Aeron. and Space Med., Roma.*

CERRETELLI P. (1959) *Boll. Soc. ital. Biol. sper.* **34,** 24 bis, 1920.

CERRETELLI P. (1960) *Int. Z. angew. Physiol. einschl. Arbeitsphysiol.* In press.

CERRETELLI P. (1959) *Communicazione al II Congr. Mond. e IV Europ. di Med. Aeronaut. Spaz., Roma.*

CERRETELLI P. In press.

*For various technical reasons the lists of references in the Congress Proceedings have not been unified. Each author was allowed to use his own reference system.

Christensen E. H. (1937) *Skand. Arch. Physiol.* **76,** 88.
Christensen E. H. and Dill D. B. (1935) *J. Biol. Chem.* **109,** 443.
Christensen E. H. and Forbes W. (1937) *Skand. Arch. Physiol.* **76,** 75.
Cotes J. E. (1954) *Proc. Roy. Soc.* B **143,** 32.
Dalla Torre L. (1944) *Helvet. Physiol. Acta* Supp. **3,** 119.
Dejours P. *et al.* (1959) *Rev. Fr. Études cl. Biol.* **4,** 2.
Delius L., Opitz E. and Schoedel W. (1942) *Luftfahrtmed.* **6,** 213.
Dill D. B., Edwards H. T., Főlling A., Obert S. A., Pappenheimer A. M. Jr. and Talbott J. H. (1931) *J. Physiol.* **71,** 47.
Dill B. D., Christensen E. H. and Edwards H. T. (1936) *Amer. J. Physiol.* **115,** 530.
Dill D. B., Edwards H. T. and Consolazio W. V. (1937) *J. Biol. Chem.* **118,** 635.
Douglas C. G., Henderson L. J., Haldane J. S. and Schneider E. C. (1913) *Philos. Trans.* B **203,** 185.
Dripps R. D. and Comroe J. H. (1947) *Amer. J. Physiol.* **149,** 277.
Durig A. (1909) *Physiol. Ergebn. der im Jahr 1906 durchgeführten M. Rosa Exped.* Vienna.
Durig A. (1911) *Denkschr. Akad. Wiss. Wien* **86,** 350.
Euler U. S. von, Liljestrand G. and Zotterman Y. (1939) *Skand. Arch. Physiol.* **83,** 132.
Ewig W. and Hinsberg K. (1931) *Z. Klin. Med.* **115,** 732.
Ferguson J. K. W. and Roughton F. J. W. (1935) *J. Physiol.* **83,** 68.
Fuchs R. (1908) *Sond. aus den Sitzungsberg d. Physikal Med. Soz. in Erlangen* **40,** 204.
Grant W. (1951) *Amer. J. Physiol.* **164,** 226.
Grollman A. (1930) *Amer. J. Physiol.* **93,** 19.
Hall F. G. (1936) *J. Biol. Chem.* **115,** 485.
Hall F. G., Dill D. B. and Guzman Barròn E. S. (1936) *J. Cell. Comp. Physiol.* **8,** 301.
Hartmann H. (1933) *Z. Biol.* **93,** 391.
Hartmann H. (1936) *Luftfahrtmed.* **1,** 2.
Hartmann H. Hepp G. and Luft U. (1941) *Luftfahrtmed.* **6,** 1.
Herxheimer H., Kost R. and Ryjaczek (1934) *Arb. Physiol.* **7,** 308.
Hewett F. (1875) *Brit. Med. J.* **2,** 667.
Heymans C., Bouckaert J. J. and Dautrebande L. (1931a) *Arch. int. Pharmacodyn.* **40,** 54, 292.
Heymans C., Bouckaert J. J. and Dautrebande L. (1931b) *C. R. Soc. Biol., Paris* **106,** 48.
Heymans C., Bouckaert J. J. and Dautrebande L. (1931) *Arch. int. Pharmacodyn.* **41,** 4.
Heymans C., Bouckaert J. J. and Regniers P. (1933) *Le Sinus Carotidien et la Zone Homologue Cardioaortique.* Dion, Paris.
Heymans C. and Rijlant P. (1933) *C. R. Soc. Biol., Paris* **113,** 69.
Heymans J. F. and Heymans C. (1927) *C. R. Soc. Biol., Paris,* **96,** 716.
Hingston R. (1925) *Geogr. J.* **65,** 4.
Houston C. S. and Riley R. L. (1947) *Amer. J. Physiol.* **149,** 565.
Huey D. and Holmes J. (1950) *Fed. Proc.* **9,** 64.
Hurtado A. (1932) *Amer. J. Physiol. Antropol.* **17,** 137.
Hurtado A., Merino C. and Delgado E. (1945) *Arch. Intern. Med.* **75,** 284.
Keys A., Hall F. G. and Barròn Guzmànn E. S. (1936) *Amer. J. Physiol.* **115,** 292.
Kerwin A. (1944) *Amer. Heart J.* **28,** 69.
Kramer K. and Luft U. C. (1951) *Amer. J. Physiol.* **165,** 215.
Liljenthal J. L. Jr., Riley R. L. Proemmel D. D. and Franke R. E. (1946) *Amer. J. Physiol.* **147,** 199.
Lintzel W. (1928) *Z. Biol.* **87,** 1937.
Loeschke G. S. (1953) *Pflűg. Arch. ges. Physiol.* **257,** 349.
Loeschke H. H. and Schwartzer K. (1939) *Wschr. Kinderheilk.* **81,** 25.
Loewy A. (1890) *Pflűg. Arch. ges. Physiol.* **47,** 601.

Margaria R. (1928) *Arch. Scienze Biol.* II **425**, 453.
Margaria R. (1930) *Arbeitsphysiol.* **2**, 261.
Margaria R. (1941) *Riv. Sviz. di Med.* **2**.
Margaria R. (1943) Le condizioni di circolo degli aviatori. *VIII Rad. Soc. It. Cardiol. Roma.*
Margaria R. (1952) *Schw. Med. Woch.* **82**, 990.
Margaria R. (1955) Aggiorn. di fisiol. *Arch. Fisiol.* **3**.
Margaria R. and Green A. A. (1933) *J. Biol. Chem.* **102**, 611.
Margaria R. and Sapegno E. (1928) *R. Acc. Naz. Lincei* **8**, 712.
Merino C. (1950) *Blood* **5**, 1.
Merino C. and Reynafarje C. (1949) *J. Lab. Clin. Med.* **34**, 637.
Monge C. (1935) Fisiologia Andina. *Circulacion An. de la Facultad de Ciencias Medicas — Lima* **17**, 1.
Moore C. and Price D. (1948) *J. Exp. Biol.* **108**, 171.
Morgan D. E. and Chichester F. D. (1935) *J. Biol. Chem.* **110**, 285.
Mosso A. (1898) *"Fisiologia dell'uomo sulle Alpi" Treves—Milano*
Mosso A. and Marro G. (1904) *Giorn. R. Acc. Med. Torino* **10**, 65.
Nielsen M. (1936) *Skand. Arch. Physiol.* **74**, 87.
Otis A. B. and Bembower W. C. (1949) *J. Appl. Physiol.* **2**, 300.
Peyser E., Sass-Kortsàr A. and Verzàr F. (1950) *Amer. J. Physiol.* **163**, III.
Pflüger E. (1868) *Pflüg. Arch. Ges. Physiol.* **1**, 61.
Pugh L. G. C. E. (1950) *J. Physiol.* **141**, 233.
Rahn H. and Fenn W. O. (1955) *A Graphical Analysis of the Respiratory Gas Exchange.* The American Physiology Society, Washington.
Rahn H. and Hammond D. (1952) *J. Appl. Physiol.* **4**, 715.
Rahn H. and Otis B. (1949) Amer. *J. Physiol.* **157**, 445.
Rahn H., Otis A. B., Chadwick L. E. and Fenn W. O. (1946) *Amer. J. Physiol.* **146**, 161.
Reynafarje C. (1958) *Brookhaven Symposia in Biology,* Vol. 10.
Rotta A. (1943) *Rev. Arg. de Cardiol.* **10**, 186.
Rotta A. (1947) *Amer. Heart J.* **33**, 669.
Rotta A., Miranda A. and Chavez R. (1949) *Int. Symp. on High Alt. Lima.*
Rushmer R. F. (1959) *Physiol. Rev.*
Samaan A. and Stella G. (1935) *J. Physiol* **85**, 309.
Schilling J., Harvey R., Becker E., Velasquez T., Wells G. and Balke B. (1956) *J. Appl. Physiol.* **8**, 381.
Schneider E. (1916) *Amer J. Physiol.* **40**, 380.
Schneider E. (1921) *Physiol. Rev.* **1**, 631.
Schneider E. (1932) *Amer. J. Physiol.* **100**, 426.
Schumburg and Zuntz N. (1896) *Pflüg. Arch. Ges. Physiol.* **63**, 461.
Staines M., James M. and Rosenberg C. (1914) *Arch. Int. Met.* **14**, 376.
Stickney J. C. and Van Liere E. J. (1953) *Physiol. Rev.* **33**, 13.
Sundstroem E. (1919) *Univ. Calif. Pub. in Physiol.* **5**, 71, 87, 105, 113, 121, 133, 149, 159.
Talbott J. and Dill D. B. (1936) *Amer. J. Med. Soc.* **192**, 626.
Tenney S., Rahn H., Stroud R. and Mithoefer J. (1953) *J. Appl. Physiol.* **5**, 607.
Van Liere E. J. (1942) *Anoxia, its Effect on the Blood.* The University of Chicago Press.
Verzàr F. (1933) *Schweiz. Med. Wschr.* **63**, 17.
Verzàr F. (1945) Höhenklima. *Forschungen der Basler Physiol. Inst.* **1**, 81, 93. Benno Schwabe, Basel.
Viale G. (1919) *Giorn. R. Acc. Med. Torino* **25**, spp. IV., 350.
Viault F. (1892) *C. R. Soc. Biol., Paris,* **9**, 569.
Ward R. (1908) *J. Physiol.* **37**, 378.

WIESINGER K. and STEIMAN H. (1943) *Helv. Physiol. Acta* **1**, C 32.
WIESINGER K. and ABBÜHL K. (1944) *Helv. Physiol. Acta* Suppl. III, 131.
WINTERSTEIN H. (1911) *Pflüg. Arch. Ges. Physiol.* **138**, 167.
WYSS-DUNANT E. (1955) *Minerva Medica* **46**, 1. 21, 657.
ZUNUTZ H., LOEWY A., MULLER F. and CASPARI W. (1906) *Höhenklima und Bergwanderungen*. Berlin.

ZUR PATHOLOGIE UND PATHOGENESE DER HÖHENKRANKHEIT BEI HAUSTIEREN

R. SCHINDLER und H. H. SCHUMACHER
Bernhard-Nocht-Institut für Schiffs- und Tropenkrankheiten Hamburg.
(Direktor: Prof. Dr. h. c. E. G. Nauck)

Abstract — High mountain or brisket disease is a syndrome in cattle and sheep residing at high altitudes of the Western United States and the Andes. The causative factor is a chronic hypoxia. The disease manifests itself as congestive failure of the right side of the heart and all signs and lesions are attributed to this pathological phenomenon.

Résumé — La maladie de montagne ou «brisket disease» est un syndrome, quel est observé en bovins et moutons, entretien sur des pâturages élevé en la part d'ouest de U. S. A. et les Andes. La cause est une hypoxie chronique. La maladie est caractérisé par une décompensation de la part droite du coeur et tous les symptômes et lésions sont une conséquence de cette phénomène.

Auszug — Die Berg- oder Höhenkrankheit (Mal de Montaña, Brisket Disease) ist ein Syndrom, das bei Rindern und Schafen auf hochgelegenen Weiden im Westen der USA und den Anden auftritt. Die Ursache ist ein chronischer Sauerstoffmangel. Die Krankheit ist charakterisiert durch eine Dekompensation der rechten Seite des Herzens, und alle klinischen Symptome und pathologisch anatomischen Veränderungen sind darauf zurückzuführen.

In der Literatur gibt es zahlreiche Berichte und Untersuchungen über die akute Berg- oder Höhenkrankheit des Menschen (Übersichten bei Pichotka, 1954 und von Muralt, 1954). Die chronische Form der Erkrankung ist dagegen weniger bekannt. Es fehlen hier vor allem die für das Verständnis der Pathogenese wichtigen Sektionsbefunde (Monge, 1943; Hurtado, 1956). In der Veterinärmedizin ist die Situation gerade umgekehrt. Hier weiß man wenig über die akute Bergkrankheit, dagegen sind Klinik und Pathologie ihrer chronischen Verlaufsform relativ gut bekannt (Cuba Caparo, 1956). Wir glauben daher, daß wir mit einem Bericht über die chronische Bergkrankheit der Tiere einen auch für die Humanmedizin interessanten Beitrag zur Pathologie der Hypoxie leisten können.

Da die Bergkrankheit in verschiedenen Gebirgsgegenden ein wichtiges Problem für die Haustierhaltung ist (Phillips, 1956), werden wir auch auf ihre Bedeutung für die Tierzucht, ihre Bekämpfung und Behandlung eingehen.

Die chronische Höhenkrankheit ist nach Monge (1943) die Folge der Unfähigkeit eines Individuums, sich an das Leben in großer Höhe zu akklimatisieren oder

der Verlust der bereits eingetretenen Akklimatisation. Monge hat das dabei entstehende Krankheitsbild bei Menschen zum ersten Male 1925 beobachtet (zit. nach Cuba Caparo, 1956), es wird daher auch als die Monge'sche Krankheit oder Soroche bezeichnet. Bei Tieren nennt man die chronische Bergkrankheit "brisket disease" (brisket = Brust bei Tieren) oder Mal de Montaña. Sie wurde durch Glover und Newsom schon 1917 bei Rindern festgestellt und beschrieben, ist aber im Staate Colorado der U.S.A. bereits seit 1889 bekannt gewesen. Bei Schafen wurde die chronische Bergkrankheit bisher nur von Cuba Caparo (1949a, b, 1951) beschrieben. Verwertbare Berichte über das Vorkommen der Erkrankung bei anderen Tieren haben wir nicht finden können.

Glover und Newsom haben schon 1917 richtig erkannt, daß der Mangel an Sauerstoff in großer Höhe, die große Anstrengung, die mit der Futtersuche im Gebirge verbunden ist, und das rauhe Gebirgsklima bei der Entwicklung dieser Krankheit zusammenwirken. Sie tritt selten unterhalb von 2000 m/ü. M. auf und ist bisher nur in den Rocky Mountains der U.S.A. (Glover und Newsom, 1917; Puntriano, 1954; Jensen und Pierson, 1956; Ryff, 1957; Alexander und Jensen, 1959), den peruanischen (Cuba Caparo, 1949a, b, 1951, Caparo *et al.*, 1955; Watson zit. nach Pierson und Jensen, 1956; Schindler und Schumacher, 1958) und kolumbianischen (Velasquez, 1947; Arango, 1949) Anden und vielleicht auch in französisch Guyana (Hidivoglou und Prevost, 1958) aufgetreten.

In den Anden und Rocky Mountains können Pflanzen wegen des warmen Klimas noch in großer Höhe gedeihen. Die Weideflächen reichen daher über 4000 m hinauf, also bis zu Höhen, in denen in anderen Breiten wegen des Fehlens von Futterpflanzen eine Viehzucht nicht möglich ist. In diesen Höhen macht sich eine Abnahme des Sauerstoffpartialdruckes schon deutlich bemerkbar.

In Colorado fallen der Bergkrankheit jährlich 0,5—1,0% aller Rinder zum Opfer, die auf Höhen über 2000—2300 m/ü. M. gehalten werden. In manchen Herden betragen die Verluste sogar 5—10%. Besonders anfällig sind Tiere, die aus dem Flachland stammen; es erkranken aber auch Rnder, die in großen Höhen geboren wurden. Besonders häufig tritt die Krankheit bei Rindern der Hereford- und Aberdeen Angus-Rasse auf (Glover und Newsom, 1917; Pierson und Jensen, 1956; Ryff, 1957). Die Nachkommen der 1532 von Pizarro nach Peru eingeführten und seit Jahrhunderten in den Anden lebenden Rinder, das sogenannte Chusco-Vieh, scheinen an die Höhenhypoxie gut angepaßt zu sein, denn sie erkranken offenbar nicht an Bergkrankheit (Schindler und Schumacher, 1958). Hier ist vermutlich—in gleicher Weise wie vor Jahrtausenden bei Menschen (Monge, 1943) — bei der Spezies *Bos taurus* eine biologische Varietät entstanden, die an den niedrigen Sauerstoffpartialdruck besonders gut angepaßt ist.

Bei der Schilderung von Klinik und Pathologie der chronischen Bergkrankheit der Rinder, der sogenannten brisket disease, werden wir uns in erster Linie an die Angaben von Glover und Newsom (1917), Pierson und Jensen (1956), Cuba Caparo (1956) und eigene Beobachtungen halten. Die brisket disease tritt bei Rindern aller Altersstufen — vom Saugkalb bis zum erwachsenen Tier — auf. Besonders häufig scheint sie bei Tieren im Alter von 6—12 Monaten vorzukommen. Eine Geschlechtsdisposition besteht offenbar nicht. Trächtigkeit, Laktation, Futterknappheit, Kälte oder Hitze, starke Anstrengungen und Erkrankungen der Lunge (Lungenwürmer, Pneumonie) begünstigen ihr Auftreten. Ein Abstieg in tiefere Lagen — manchmal genügen 500 m — kann zur vollständigen Wiederherstellung führen.

Wenn sich die Krankheit langsam entwickelt, magern die Tiere ab, haben ein rauhes, struppiges Fell und einen jeder Behandlung trotzenden Durchfall. Die Temperatur ist dabei normal oder nur leicht (subfebril) erhöht. In rascher verlaufenden Fällen ist der Ernährungszustand anfangs noch gut. Es treten aber Schwäche, Atemnot und Husten auf. Später stehen die Symptome einer Herzinsuffizienz im Vordergrund: An der Unterbrust bilden sich ausgedehnte Ödeme, die sich cranial bis zum Kehlgang und caudal bis zum Bauch ausdehnen. Die Schleimhäute sind cyanotisch, der Herzschlag ist gallopierend (100—120 Schläge pro Minute mit Akzentuierung des 2 Tons, normal 40—60), die Vena jugularis ist gestaut und pulsiert. Manche Tiere zeigen im Verlauf der Krankheit psychische Veränderungen: sie werden aggressiv. Der Appetit ist bis zum Schluß normal. Ohne Behandlung führt die Erkrankung bei Jungtieren in 1—12 Wochen zum Tode. Bei erwachsenen Tieren kann sie sich über Jahre hinziehen, wobei Zeiten der Besserung mit Zeiten der Verschlechterung abwechseln. Bei starker Anstrengung kann es im Verlauf der Bergkrankheit zu Kollaps und plötzlichen Todesfällen kommen.

Über Blutuntersuchungen haben bisher Puntriano (1954), Cuba Caparo (1956) und Ryff (1957) berichtet und dabei einen Anstieg der Erythrozytenzahl von 8 Millionen (gesunde Rinder auf 2—400 m/ü. M.) auf 10—21 Millionen (bergkranke Tiere) beobachtet. Puntriano hat darüberhinaus festgestellt, daß der Hämatokrit- und Hämoglobinwert sowie die Viskosität des Blutes bei bergkranken Tieren ansteigen. Bei der Untersuchung des weißen Blutbildes fand er Lymphozytose und Eosinophilie. Watson (zit. nach Pierson und Jensen, 1956) bemerkte in seinen Fällen keine Veränderung im Blutbild.

Bei der Sektion bergkranker Tiere findet man folgende Veränderungen: Chronisch alveoläres Emphysem der Lunge, gelegentlich Tracheobronchitis und Bronchiolitis, häufig Atelektasen, Pleurafibrosen und Pneumonien. (Bei Tieren bis zum Alter von einem Jahr werden gelegentlich Thromben in den Lungenarterien gefunden.) Dilatation und Hypertrophie der rechten Herzkammer. (Infolge der starken Vergrößerung der rechten Kammer kommt es zu einer Abrundung und Rechtsverlagerung der Herzspitze. Glover und Newsom (1918) (zit. nach Alexander und Jensen, 1959) fanden, daß das Herz eines bergkranken Rindes 3,25 lb schwer war, während das Herz eines gleichalterigen und gleich schweren Normaltieres nur 1,25 lb wog. Alexander und Jensen (1959) konnten durch exakte Wägungen verschiedener Teile des Herzens von Rindern und einer genauen statistischen Analyse nachweisen, daß der Anstieg des Herzgewichtes bergkranker Tiere auf einer ausgeprägten Hypertrophie des rechten Ventrikels und einer geringgradigen Hypertrophie des Septums beruht, während das Gewicht der übrigen Teile des Herzens normal ist.) Ödem des Myocards und der Atrioventricularklappen. Erweiterung der Arteria pulmonalis

(Verhältnis Durchmesser A. pulmonalis zu Durchmesser Aorta wie 3 : 2). In manchen Fällen arteriosklerotische Veränderungen an den Lungenarterienästen. Stauung der Vena cava und infolgedessen: Hydrothorax, Hydropericard, Ascites, Ödeme der Unterhaut und der Wand des Magendarmkanals; Induration der Nebenniere oder Icterus und Schwellung der Nebennierenrinde; Anzeichen einer chronisch passiven Stauung in der Leber, beginnend mit der sogenannten Muskatnußleber im Frühstadium bis zur cardialen Zirrhose.

Histologisch wurden folgende Veränderungen festgestellt: Vesiculäres Lungenemphysem mit relativ gleichmäßiger Überdehnung der Lungenalveolen. Starke Verbreiterung der Media in der Wand der Lungenarterienäste, z. T. mit intramuralen Blutungen. (Eigene Beobachtungen und Pierson und Jensen, 1956). Kalkablagerungen in der Intima (Pierson und Jensen, 1956). Hypertrophie der Muskelfasern der rechten Herzkammer (Sera und Jensen zit. nach Alexander und Jensen, 1959). Nekrotische Herde, basophile Degeneration und Kalkablagerung im Myocard (Cuba Caparo, 1956). Stauungshyperämie, bindegewebiger Umbau und Verfettung in der Leber. Stauungshyperämie und Stauungsenteritis in der Schleimhaut des Dünndarms (eigene Beobachtungen). Herdförmige Nekrosen, Hämorrhagien und ausgedehnte Zerstörungen in der Nebennierenrinde (Cuba Caparo, 1956).

Schafe sind anscheinend gegen Sauerstoffmangel resistenter als Rinder. Das ist verständlich, denn nach Pichotka (1954) nimmt innerhalb der Gruppe der Warmblüter die Höhenfestigkeit mit fallender Körpergröße zu. Die Bergkrankheit wird jedenfalls nur bei Lämmern beobachtet (auch bei Rindern sind junge Tiere anfälliger), bei denen sie sich schnell entwickelt und ohne subkutane Ödeme verläuft. Bei erwachsenen Schafen tritt in großen Höhen lediglich eine meist reversible Störung der Fruchtbarkeit auf (Monge und San Martin, 1942; Velasquez, 1947; Phillips, 1956).

Klinik und Pathologie der Bergkrankheit der Schafe wurden von Cuba Caparo (1949a, b, 1951) ausführlich beschrieben. Er fand eine starke Steigerung der Atemfrequenz auf 48 Atemzüge pro Minute (normal 15—18), aber nur eine geringe Zunahme der Herzfrequenz (140 statt 115 Schläge pro Minute). Der Puls war klein, die Erythrozytenzahl stark angestiegen (bis auf 19,6 Millionen statt 8—13 Millionen normalerweise).

Bei der Sektion stellte er fest: Bronchopneumonien, Stauungen und Atelektasen in der Lunge. Vergrößerung des Herzens (Gewicht 120—140 g statt normal 70 g) mit Hypertrophie und Dilatation der rechten Kammer. Vergrößerung der Leber (Gewicht 400—500 g statt normal 200 g) mit Zunahme der Konsistenz und Muskatnußzeichnung der Schnittfläche. Ödeme der Lymphknoten und Stauungen in Milz und Nieren. Nebennieren und Thymus waren ebenfalls gestaut, z. T. fanden sich dort kleine Blutungen.

Die mikroskopische Untersuchung ergab folgenden Befund: Bronchopneumonie, Ödeme und herdförmige Atelektasen in der Lunge; Ödeme und Blutungen im Interstitium des Myocards; mittel- bis grobtropfige Verfettung, hochgradige Stauung und Hämorrhagien in den Zentren der Leberläppchen, z. T. mit Nekrosen und Dilatation der Sinusoide; Ödem und Dilatation der Sinus in den Lymphknoten z. T. mit Atrophie des Lymphgewebes; Stauungen in den Nebennieren, besonders an der Markgrenze, z. T. mit Nekrosen und Entfettung der Rinde. Der bei Schafen erhobene Befund stimmt also fast vollständig mit dem Bild der Bergkrankheit bei Rindern überein.

Wir wollen nun den Versuch machen, auf Grund der bei Tieren gefundenen klinischen pathologisch-anatomischen Veränderungen eine Vorstellung über die Pathogenese der Bergkrankheit zu entwickeln: Nach unserer Ansicht führt die als Folge der Höhenhypoxie auftretende Dyspnoe zu einer zunächst nur funktionellen Überdehnung der Lungenalveolen. Dadurch werden die Alveolarwandkapillaren gestreckt und komprimiert. Der Druck in der Arteria pulmonalis steigt also an. Die gleichzeitig auftretende Polycytämie bewirkt einen Anstieg der Viskosität des Blutes, wodurch die Blutzirkulation zusätzlich erschwert wird. Zur Überwindung des auf zweifache Weise verstärkten Widerstandes gegen den Blutumlauf in der Lunge muß die rechte Herzkammer mehr arbeiten. Es entwickelt sich infolgedessen eine Dilatation und Hypertrophie. Dazu kommt, daß einerseits Sauerstoffmangel an sich einen Reiz zur Kontraktion auf die Lungengefäße ausübt (Lit. bei Hurtado, 1956), andererseits der Herzmuskel gegen eine Hypoxie besonders empfindlich ist (Büchner, 1957). Die Gefahr einer Herzinsuffizienz ist also groß. Im Falle einer Abnahme der Herzleistung wird ein Circulus vitiosus in Gang gesetzt, bei dem die Herzinsuffizienz die Hypoxämie verstärkt, der O_2-Mangel andererseits die Polycythämie steigert, wodurch die Viskosität des Blutes ansteigt und die Herzarbeit weiter erschwert wird. Hält dieser Zustand länger an, dann kommt es einerseits zu Veränderungen in der Wand des Stammes und der Äste der Arteria pulmonalis und damit zur organischen Fixierung der Druckerhöhung in diesem Gefäßgebiet. Andererseits entwickelt sich eine chronische Stauung im venösen Schenkel des großen Kreislaufs mit allen ihren Folgezuständen (subcutane Ödeme, Diarrhoe infolge Stauungskatarrh der Darmwand, Höhlenhydrops und Leberzirrhose), die ja in der Tat das Bild der brisket disease beherrschen. Schließlich wird auch durch die Stauung vor dem rechten Herzen das Blutangebot für das linke Herz vermindert. Damit tritt eine Oligämie im großen Kreislauf und damit eine weitere Verschlechterung der O_2 Versorgung der Gewebe ein.

Pierson und Jensen (1956) haben aus ihren Befunden ähnliche Schlußfolgerungen gezogen und Alexander und Jensen (1959) schreiben am Schluß ihrer Arbeit: "An additional possibility exists (bei der Entstehung der Hypertrophie des rechten Herzens) where in the effects of pulmonary hypertension, increased blood viscosity, and increased blood volume combine to increase the work load of the right side of the heart". Büchner (1957) weist ausdrücklich darauf hin, daß es Endstadien der schweren Hypoxydose gibt, in denen die Kreislaufstörungen entscheidender die Form der morphologischen Veränderungen bestimmen als die Hypoxydose. Insofern ist die Bergkrankheit kein Sonderfall. Sie unterscheidet sich aber von Hypoxydosen anderer Genese u. a. dadurch, daß Druckanstieg im Lungenkreislauf und starke Zunahme der Viskosität des Blutes gleichzeitig auftreten.

Auch im Experiment konnte bei verschiedenen Versuchstieren durch Verminderung des O_2-Partialdruckes eine Herzhypertrophie erzeugt werden (Lit. bei Alexander und Jensen, 1959). Wir selbst haben bei Mäusen, die bis zu 9 Wochen bei einem Unterdruck von 400 mm Hg gehalten wurden, eine Dilatation und Hypertrophie der rechten Herzkammer beobachtet. Gleichzeitig bestand eine ausgeprägte Polyglobulie und ein geringgradiges akutes Emphysem (Dennig, 1959). Schwere anatomische Veränderungen in der Lunge sind also nicht die Voraussetzung für das Auftreten der Herzhypertrophie, funktionelle Überdehnung der Alveolen zusammen mit erhöhter Viskosität des Blutes scheinen dafür auszureichen. Daher wird eine Hypertrophie der rechten Seite des Herzens auch bei klinisch gesunden, längere Zeit in großer Höhe lebenden Tieren (Alexander und Jensen, 1959) und Menschen (Rotta, 1947) beobachtet.

Vergleicht man nun die Veränderungen der chronischen Bergkrankheit der Tiere mit denen der Monge'schen Krankheit des Menschen, so ergibt sich eine große Übereinstimmung. Auch bei Menschen gibt es Anzeichen für eine Sklerose der Lungengefäße und eine Hypertrophie des rechten Herzens (Hurtado, 1956).

Der Mensch kann bei ernsten Gesundheitsstörungen in tiefere Lagen ausweichen Daher finden sich bei ihm selten so schwere Veränderungen wie bei Tieren. Daß aber die Pathogenese der Bergkrankheit bei Mensch und Tier inden wichtigsten Punkten. übereinstimmt, scheint uns auf Grund der vorliegenden Befunde sehr wahrscheinlich zu sein.

Zum Schluß wollen wir noch kurz darauf eingehen, wie man die Verluste durch Bergkrankheit bei Haustieren senken kann:

Bei der Behandlung bereits erkrankter Tiere kommt es darauf an, das Herz zu entlasten und die Stauungsödeme zu beseitigen. Das geschieht am besten durch einen Abstieg in tiefere Lagen sowie O_2- und Digitalisbehandlung. Wichtiger als die Therapie ist die Prophylaxe: Sehr hochgelegene Weiden sollten nur mit den gegen O_2-Mangel resistenteren Schafen beschickt werden. Hierbei ist allerdings der Einfluß der Hypoxie auf die Fruchtbarkeit zu berücksichtigen. Da aber die Trächtigkeit die Widerstandsfähigkeit gegen den O_2-Mangel vermindert, wird man Zuchttiere ohnehin auf den niedriger gelegenen Weiden halten.

Weiterhin könnten Verluste vermutlich verringert werden, wenn die Tiere in futterarmen Zeiten eine Zufütterung erhalten. Auf jeden Fall sollte eine Überbesetzung der Weiden und damit eine Verschärfung der Futterknappheit vermieden werden. Da es primitive Rinder — wie das peruanische Chusco-Vieh — gibt die an den niedrigen O_2 Partialdruck gut angepaßt sind, müßte es möglich sein, durch Zuchtwahl auch bei anderen Rassen die Toleranz gegen O_2-Mangel zu steigern. Die Entwicklung von leistungsfähigen, an die besonderen Bedingungen großer Höhen angepaßte Haustierrassen, dürfte zusammen mit einer Verbesserung der Futtergrundlage die beste Lösung des Problems sein.

Zum Schluß möchte ich noch darauf hinweisen, daß der Aufenthalt in mittleren Höhenlagen einen durchaus günstigen Einfluß auf die Tierhaltung haben kann, was sich besonders in einer Steigerung der Gesundheit, Fruchtbarkeit und Lebensdauer äußert (Ecemis, 1957). Doch werden auch hier ungünstige Wirkungen beobachtet, worauf Karg (1959) hingewiesen hat.

LITERATUR

ALEXANDER A. F. und JENSEN R. (1959) Gross cardiac changes in cattle with high mountain (brisket) disease and in experimental cattle maintained at high altitude. *Amer. J. Vet. Res.* **20**, 680.

ARANGO J. E. (1949) Alvededor de la llamada enfermedad de las alturas. *Rev. Fac. Med. vet. (Bogota)* **18**, 141.

BÜCHNER F. (1957) Die Pathologie der cellulären und geweblichen Oxydation. *Handb. Allgem. Pathologie* **4**, II, 569.

CUBA CAPARO A. (1956) Estudio comparativo del mal de montaña. *An. Fac. Med. (Lima)* **2**, 1104.

CAPARO A. C., COPAIRA M. und DE LA VEGA E. (1953) Mal de montaña crónico en vacunos. *An. Fac. Med. (Lima)* **38**, 222.

CUBA CAPARO A. (1951) Policitemia y mal de montaña en corderos. *Rev. Fac. Med. vet. Lima* **6**, 5.

CUBA CAPARO (1949a) Policitemia de la altura en corderos. *Rev. Fac. Med. vet. (Lima)* **4**, 1.

CUBA CAPARO (1949b) Policitemia de la altura en corderos. *Rev. Fac. Med. vet. (Lima)* **4**, 5.

DENNIG H. K. (1959) Experimentelle Untersuchungen zur Höhenkrankheit. 16. *Intern. Tierärztekongreß Madrid.*

ECEMIS M. (1957) Untersuchungen über die Fruchtbarkeitsverhältnisse beim schweizerischen Braunvieh in Berg- und Talgenossenschaften. *Z. Tierzücht. Züchtungsbiol.* **69**, 351.

GLOVER G. H. and NEWSOM I. E. (1917) *Brisket Disease.* Colorado Agricultural College Bulletin 229, revised (1931).

HIDIVOGLOU M. und PREVOST R. (1958) L'oedème des bovins en Guyane français. *Rec. Med. vet. exot.* **134**, 221.

HURTADO A. (1956) Aspectos patologicos de la vida en las grandes alturas. *An. Fac. Med. (Lima)* **2**, 957.

KARG H. (1959) Höhenphysiologische Beobachtungen in der Tierzucht. *Berl. Münch. Tierärztl. Wschr.* **72**, 275.

MONGE C. (1943) Chronic mountain sickness. *Phys Rev.* **23**, 166.

MONGE C. und SAN MARTIN M. (1942) Note on azoospermia in rams recently arrived at high altitude. *An. Fac. Cienc. med. Lima* **25**, 58; ref. *Veterin. Bull.* (1947).

VON MURALT A. (1954) Krankheiten durch verminderten Luftdruck und Sauerstoffmangel. *Handb. Inn. Med.*, Bd. 6 II, S. 293. Springer, Berlin, Göttingen, Heidelberg.

PHILLIPS R. W. (1956) *Recent developments affecting livestock production in the Americas.* FAO Development Paper, p. 13 Rome.

PICHOTKA J. (1957) Der Gesamtorganismus im Sauerstoffmangel. *Handb. Allgem. Pathologie,* Bd. 4 II, S. 497. Springer, Berlin, Göttingen, Heidelberg.

PIERSON, R. E. und JENSEN R. (1956) Brisket Disease. In *Disease of Cattle,* p. 117. Amer. Vet. Publ. Inc., Evanston, Illinois.

PUNTRIANO G. O. (1954) Physiological basis of "brisket disease" in cattle. *J. Amer. Vet.Med. Ass.* **125**, 327.

RYFF J. F. (1957) Brisket disease syndrome. *J. Amer. Vet. Med. Ass.* **131**, 425.

SCHINDLER R. und SCHUMACHER H. H. (1958) Rinderkrankheiten in Nord-Peru. *Die Blauen Hefte für den Tierarzt* **1**, 12.

VELASQUEZ Q. J. (1947) Enfermedad de las alturas — 4. *Rev. Med. vet. (Bogotá)* **16**, 53.

HIGH ALTITUDE AS A STIMULUS TO THE HUMAN BODY

A. von MURALT and W. H. WEIHE
High Altitude Research Station, Jungfraujoch

Abstract—The effect of a stay at an altitude between 2000—4000 m (6000—12,000 ft) on the nervous system and the endocrine system is surveyed. The threshold of excitability is lowered in this altitude range, reaching its lowest point at an altitude of about 3500 m (11,500 ft) or 500 mm Hg. This is illustrated by several examples. Among the effects of the stay at this altitude on the endocrine system an increased activity of the pituitary adrenal cortex system has been observed during the phase of adaptation.

Résumé—On a examiné l'effet d'un séjour à des altitudes comprises entre deux mille et quatre mille mètres sur le système nerveux et le système endocrinien. Le seuil d'excitation du système nerveux est abaissé pour toutes les fonctions examinées; ceci est le plus marqué pour une altitude de 3500 m (500 mm Hg). Quelques exemples illustrent ce phénomène. Parmi les effets d'un séjour à l'altitude sur les glandes à sécrétion interne, on a observé une activité plus grande du système hypophyse-corticosurrénales pendant la phase d'adaptation.

Auszug—Dies ist eine Übersicht über die Wirkung des Aufenthaltes in Höhen zwischen 2000—4000 m auf das Nervensystem und das endokrine System. Die Reizschwelle des Nervensystems ist für alle bisher untersuchten Funktionen herabgesetzt, am stärksten in Höhen um 3500 m (500 mm Hg). Dafür werden Beispiele angeführt. Unter den Wirkungen des Höhenaufenthaltes auf die Drüsen mit innerer Sekretion ist in der Phase der Adaptation eine verstärkte Aktivität im Hypophysen-Nebennierenrinden-System beobachtet worden.

SINCE life existed on this earth, it has been subjected to the constant pressure of dangers: oxygen lack, cold, heat, lack of water and food, and enemies. In every living organism defence mechanisms against these hardships have been developed. Cannon (1) was the first to recognize the importance of the sympathico-adrenal system in what he called the emergency reaction, a reaction which produces hidden powers of the body, enabling it to meet the challenging or dangerous stimuli. Hess (2) considering the autonomous nervous system, called this "the ergotropic reaction" and Selye (3) considering the endocrine system, introduced the term "stress", for the way in which the body reacts to a challenge with an increased resistance.

High altitude is marked by a decrease of the partial pressure of oxygen, by an increase in the intensity of the sun's radiation, with a shift towards the ultra-violet, by dryness or high humidity of the air, by rapid shifts between cold (at night) and heat (on a sunny day) and by a change of the ion-content of the air. (The Langevin and Aitken types of ions which are abundant in our industrial areas disappear completely at high altitude and the number of large ions per cm³ drop from 10,000 at low altitude to 100 in the Alps. The small ions, however, increase in number, due to the action of cosmic radiation (4). With respect to oxygen lack and ultra-violet radiation, high altitude is unfavourable to life. Plant growth stops in the Alps at about 3000 m (9843 ft,) above sea level and only a few migrating animals such as rodents and ruminants are found above this level.

The conquest of the air and the problems connected with flight at high altitudes created a scientific endeavour with the aim of overcoming the dangers by technical development. In low-pressure chambers the effect of a decrease of barometric pressure was studied, and it was seen that at a pressure of less than 400 mm Hg serious changes occur; for example loss of co-ordination, a gradual decline of mental functions ending in unconsciousness. These effects impressed those who made these studies to such an extent that they were not aware of a previous reaction which occurs at higher pressure ranges, somewhere between 550 and 450 mm Hg, and which is opposite to the failures which are observed at pressures below 450 mm Hg. From the technical point of view, knowledge of the breakdown of functions at very high altitudes is important in order that we may develop protective measures of a technical nature. From the physiological point of view the study of the body in the "physiological range" of pressure between 550—450 mm Hg is much more informative about the efficiency of the emergency reaction against hypoxia. This reaction is one of the main objects of the research at the Jungfraujoch Station at an altitude of 3454 m (11,333 ft,), where the average pressure is 500 mm Hg and where these effects can be studied at their best.

Let us review the essential findings of the previous experimental work at Jungfraujoch. Most of the work done was concentrated on the central and autonomic nervous system.

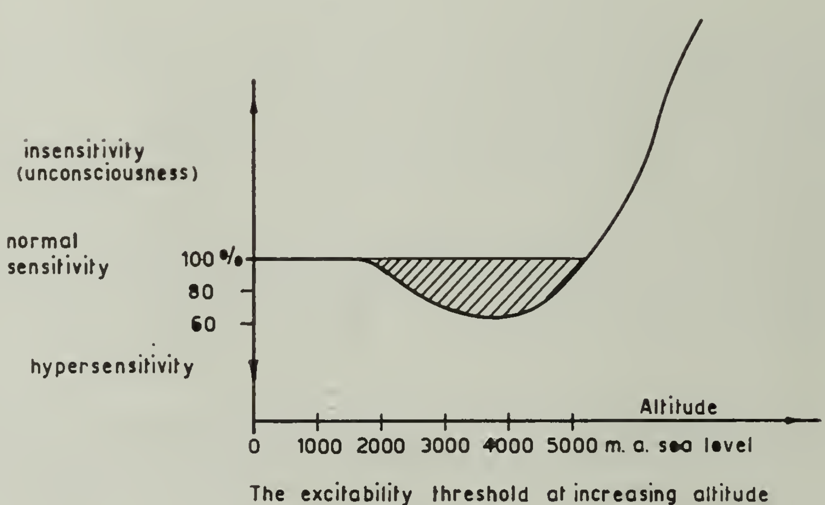


Fig. 1

Fig. 1 is a diagram of the general course of events if a human body is studied at various heights. The ordinate represents the (normal) threshold of excitability for all nervous functions, assuming that 100 per cent sensitivity represents the result of any test at sea level. Starting at 2000 m (6562 ft,) there is a marked decrease of the threshold which produces an increase of sensitivity and response to environmental stimuli. The curve reaches the lowest point at about 3500 m (11,483 ft) and then rises steeply into a range of increased threshold of excitability (decreased sensitivity) leading to unconsciousness. This ascending part of the curve is the range studied by those interested in aviation medicine, the dotted part of the curve is the one studied by us at Jungfraujoch.

This significant lowering of the threshold in the altitude range from 2000 to 4000 m above sea level can be illustrated by quoting some of the experimental work, first of the nervous system and later of the endocrine system.

PUPILLARY REACTION

One of the striking effects of light is the closing of the pupil. If the pupillary diameter is measured under well-controlled constant illumination, it is found that the average diameter is very constant and that there are oscillations of the pupil:

(a) of short duration; (b) with a diurnal rhythm.

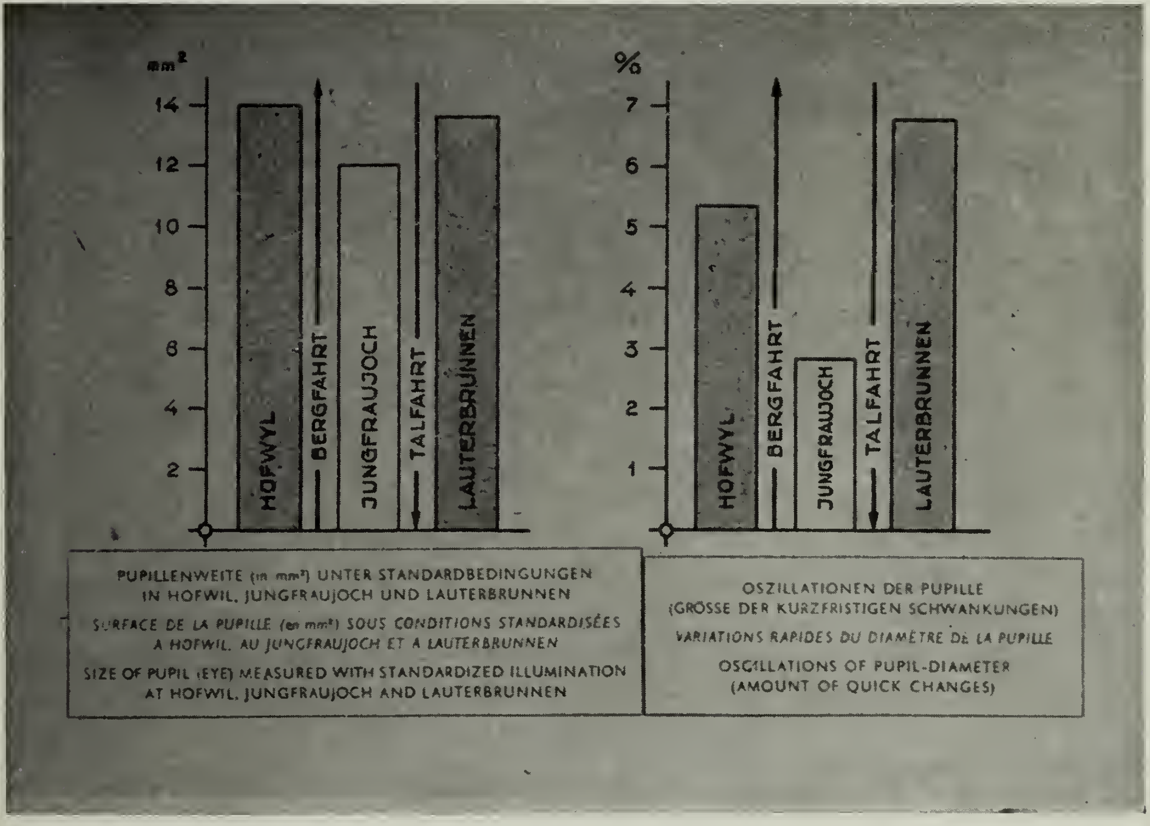


Fig. 2

If the same investigation is carried out first at sea level and then at Jungfraujoch on the same subjects, striking differences are observed. At Jungfraujoch the average diameter of the pupil is 12 mm² compared with 14 mm² at sea level (Fig. 2) and the pupil becomes more rigid with respect to oscillations. (Short period-oscillations decrease from 6 to 5 per cent and the diurnal rhythm from 5 to 3 per cent. What is the significance of these observations?

Considering the increase of the sympathetic tone alone, one would expect a dilatation of the pupil at high altitude (mydriasis). The increase in sensitivity to the light stimulus in the retina is so strong, however, that a resultant constriction of the pupil is observed (miosis). The oscillations are due to a slow phasic change of tone of the antagonists—parasympathetic constriction and orthosympathetic dilatation. At high altitude the pupil becomes more rigid, due to an increase of the autonomic tone on both sides. This was called the *amphotonic reaction* by Fleisch and von Muralt (5).

PATELLAR REFLEX

The same observation can be made in studying the threshold of the patellar reflex. At high altitude the mean thresholds are lowered to about 75 per cent of normal, as a result of the increase of the sympathico-adrenal tones (Fig. 3).

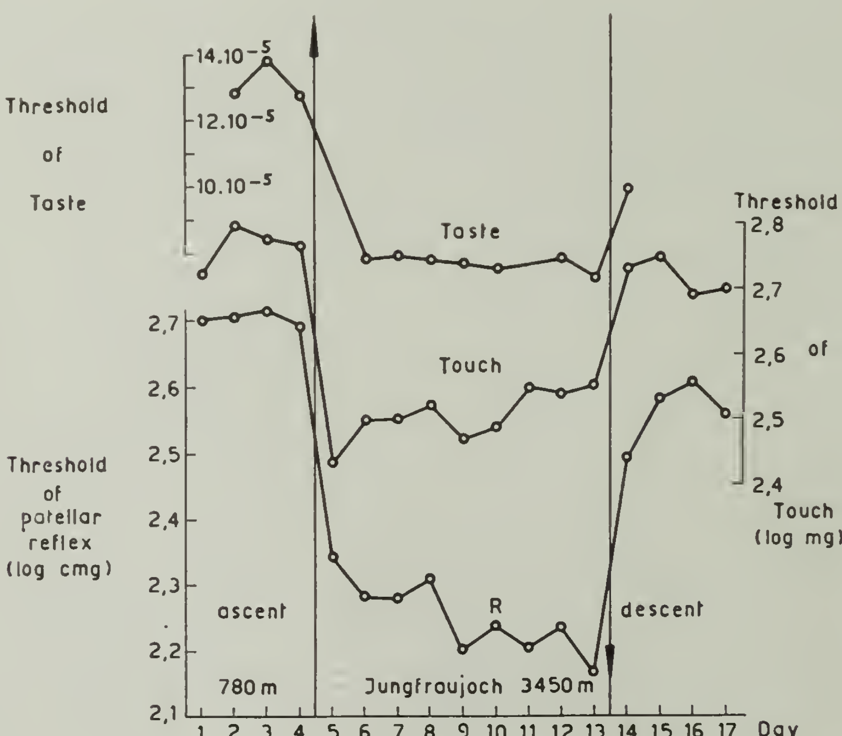


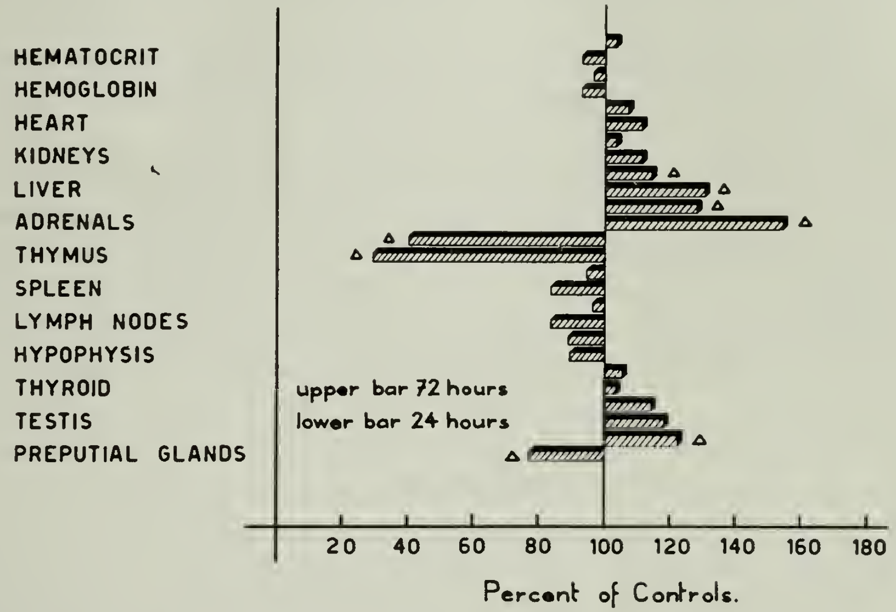
FIG. 3. The change in the thresholds of taste, touch and patellar reflex at high altitude

THRESHOLD FOR TASTE

The thresholds for taste were studied by Fleisch and Grandjean (6), (Fig. 3). They found that the thresholds for all four sensations (bitter, sour, salty and sweet) were lowered to about 60 per cent. This is an effect strong enough to carry out a very striking experiment. For ten subjects a quinine solution was made up, the concentration of which was just sub-threshold at "sea level", so that this solution was tasteless. The same solution tasted bitter for all ten subjects at Jungfraujoch !

THRESHOLD FOR TOUCH

The same authors found that the thresholds for touch were also lowered (Fig. 3). This demonstrates that the observed effect is a general phenomenon, which can be



Effect of acute exposure to 12470 ft. on organ weights of rats born at sea level and transferred to altitude at 35 days of age.
Δ = statistically significant ($P < 0.05$)
(from Timiras, P.S., A.A. Krum and N. Pace, Amer. J. Physiol. 191, 598 (1957))

Fig. 4

observed throughout the whole nervous system. The orthostatic responses, the threshold for pain, the threshold of the circulatory reflexes, of the respiratory centre, dark adaptation and the regulation of blood sugar are all lowered as a proof of the increase in the reactivity of the body.

Investigations on the effect of high altitude upon the endocrine system are rare. From the wealth of knowledge about the importance of the pituitary and the adrenal cortex in the response of the body to stressors, a reaction of these glands could be expected. Fig. 4 shows the change of organ weights in 35-day-old male rats which were killed in the White Mountain Station, California, at 12,470 ft, 24 hr, and 72 hr after arrival (7). The most striking changes were the increase in weight of the adrenals and the loss in weight of the thymus. Verzàr (8) found after a prolonged stay of 4 weeks at high altitude (3454 m, 11,333 ft,) slightly smaller adrenals on rats and a normal thymus weight compared with his control animals in Basle, but Timiras, *et al.* (7) found the adrenals still enlarged and the thymus reduced after 3 months at high altitude. Increased adrenal weight and loss of thymus are the classical signs of stress described by Selye. In accordance with the original concept of stress one should expect an increased discharge of adrenal-cortical hormones. At Jungfraujoch, Koller *et al.* (9) have found an increase of 17-ketosteroids in the urine of healthy men, an increase of thrombocytes and total leucocytes and a decrease of eosinophils and of antithrombin, all expressions of stress. Similar observations were made by Iwase *et al.* (10).

Indirect signs of increased corticosteroid action are inferred from the retarded wound healing, the increased tolerance to diphtheria toxin (11), and the increased glycogen content in the liver of fasted rats (12).

Little is known about the function of other endocrine glands at high altitude. Adrenaline is immediately released as a result of the lowering of oxygen tension (13). The thyroid function is not yet investigated. Greater changes are unlikely since there is nothing known about altered basic metabolic rate at high altitude. At an altitude of 1700 m above sea level (5577 ft,) no changes in the basic metabolic rate (14) were seen, and at about 450 mm Hg (13) it is only slightly increased. Sundstroem and Michaelis (15) have concluded from their experiments with rats in the range of 460, 360 and 300 mm Hg "that the basal metabolic rate tends to occupy relatively high levels at the time when the adaptive faculties are in operation" which is during the first week of exposure to such low pressure.

The organs of reproduction have attracted great attention since it was known that in the high Andes the fertility rate of animals is low. Testis development, opening of the vagina, course and frequency of the cycle in rats is normal when compared with the observations at sea level. The size of litter and the frequency of pregnancy are the same as at sea level, though the nursing of the ratlings is impaired in the first generation born at a high altitude. It has been seen by Pace (16) and his co-workers in rats that the amount of milk of the does is strikingly reduced possibly due to insufficient stimulation of the glands by lactotropic hormone. This has not been seen in mice at Jungfraujoch.

Irregularities of menstruation in women living at Jungfraujoch have been described by Müller (17), however, we do not know yet to what extent hormonal disorders are primarily involved.

No metabolic abnormalities at high altitude have been observed. Various single observations need augmentation and correlation before they can be fully understood. Weight curves of rats at high altitude compared with those at sea level run almost parallel. The bodyweight reaches the final level earlier at high altitude than at sea evel (7, 18), but there is no difference in the rate of growth.

To sum up, it becomes apparent that animal and human life at high altitude differ in one important respect from life at sea level: the organism is in a state of stress with increased excitability. Applying this to Selye's more recent concept of the general adaptation syndrome (19), this means that the body is conditioned, being more susceptible to corticosteroids and showing a higher susceptibility to various environmental stimuli. Hale and Meffered (20) concluded from their experiments with rats at 380 mm Hg: "In many respects the results at altitude were closer to the ideal than those at ground level, which suggests that the chronic hypoxia acts to accelerate adaptive changes to temperature".

CONCLUSIONS

High altitude between 550—450 mm Hg acts as a stimulus evoking an "emergency reaction": this action is mainly due to the decrease in oxygen tension. Radiation, cold, low or high humidity, and ionic shift in the air may also play a role. As a result of this stimulus, the reactivity of the body is increased, all the regulating powers of the internal environment are enhanced, and adaptation to the new environment occurs. At extreme heights, where the barometric pressure is below 450 mm Hg, the rate of adaptation is not in step with the decrease of oxygen tension if the ascent is rapid, and therefore leads to a breakdown. If a slow acclimatization is allowed, as in mountain excursions, greater heights can be gained without danger, as was the case in the ascent of the high peaks of the Himalayas. With slow and gradual acclimatization a surprising degree of adaptation takes place, even to very low oxygen tensions.

REFERENCES

1. W. B. Cannon, *The Wisdom of the Body*. London (1932).
2. W. R. Hess, *Die Regulierung des Blutkreislaufes*. Thieme, Leipzig (1930).
3. H. Selye, *Stress*. Montreal (1950).
4. A. von Muralt, *Das Höhenklima und seine Wirkung auf den Menschen. Wander-Gedenkvorlesung*. Bern (1958).
5. A. Fleisch and A. von Muralt, Das Programm und die Ergebnisse der klimaphysiologischen Untersuchungen in der Schweiz. *Klimaphysiologische Untersuchungen in der Schweiz*, 2 Teil V—XIX. Basel (1948).
6. A. Fleisch and E. Grandjean, Die Reizschwellen des Druck- und Geschmacksinnes im Hochgebirge. *Helv. Physiol. Acta* suppl. III, 35—45 (1944).
7. P. S. Timiras, A. A. Krum and N. Pace, Body and organ weights of rats during acclimatization to an altitude of 12,470 feet. *Amer. J. Physiol.* **191**, 598—604 (1957).
8. F. Verzàr, Bemerkungen über die Grösse innersekretorischer Organe in grossen Höhen. *Höhenklima-Forschungen des Basler Physiologischen Instituts II*. 39—40, Benno Schwabe, Basel (1948).
9. F. Koller, E. Schwarz and M. Marti, Ueber die Reaktion der Nebennierenrinde beim Aufstieg ins Hochgebirge. *Acta Endocrin.* **16**, 118—140 (1954).
10. K. Iwase, T. Mukai and K. Asai, Studies on the function of the pituitary-adrenocortical system in altitudes. *Japan. J. Balneo-Climatology* **18**, 137—48, 269—82 (1954).
11. R. Regamey and G. Klinkhart, Ueber den Einfluss der Höhenlage auf die Immunisierbarkeit kleiner Versuchstiere gegen Diphtherintoxin. *Z. f. Immun. Forsch.* **99**, 5 (1940).

12. P. S. Timiras, R. Hill, A. A. Krum and A. W. Lis, Carbohydrate metabolism in fed and fasted rats exposed to an altitude of 12,470 feet. *Amer. J. Physiol.* **193**, 415—24 (1958).
13. B. A. Houssay, *Human Physiology*. McGraw-Hill, New York (1955).
14. R. Doetsch and W. Voegtli, Der Grundumsatz in mittleren Höhen (1700 m. ü. M.) *Höhenklima-Forschungen des Basler Physiologischen Instituts I.* 101—15, Benno Schwabe, Basel (1945).
15. E. S. Sundstroem and G. Michaelis, The adrenal cortex in adaptation to altitude climate and cancer. *Memoirs of the University of California*, vol. 12. University of California Press, Berkeley (1942).
16. N. Pace, Personal communication, Department of Physiology, University of California, Berkeley.
17. C. Müller, Ueber Uterusblutungen und Zyklusstörungen im Hochgebirgsklima. *Schweiz. Med. Wschr.* **16**, 397 (1938).
18. W. H. Weihe, Unpublished observations.
19. P. J. Rosch, *Growth and Development of the Stress Concept and its Significance in Clinical Medicine*, pp. 278—98. Butterworths. London (1958).
20. H. B. Hale and R. B. Meffered, Factorial study of environmentally-induced metabolic changes in rats. *Amer. J. Physiol.* **194**, 469—75. (1958).

DISCUSSIONS

W. Bianca (zum Vortrag von Dr. R. Schindler): 1. Eine respiratorische Alkalose kann entstehen nicht nur in grosser Höhe sondern auch unter dem Einfluss von Wärme. Der Hund und das Rind, d. h. Tiere die nicht oder nur mässig schwitzen, erhöhen unter Wärmebelastung ihre Ventilation. Dies führt zu einer Auswaschung von CO_2 und einem Anstieg des pH des Blutes. Bei einer gleichzeitigen Belastung durch Höhe und Wärme könnte ein Summationseffect entstehen.

Frage: Besteht die Möglichkeit, dass die Tiere in der Höhe trotz einer niederen Lufttemperatur durch die intensive Sonnenstrahlung zusätzlich belastet werden?

2. Es wurde gesagt, dass das einheimische Chusco-Vieh der Höhenkrankheit weniger unterworfen ist als ausländische Rassen.

Frage: Bestehen physiologische Untersuchungen an diesen Tieren, welche diese Überlegenheit erklären?

3. Im Hinblick auf die Vermutung dass nicht-heimatische Faktoren wie z. B. dic Ernährung bei der Entstehung der chronischen Höhenkrankheit des Rindes mit eine Rolle spielen, würde es vielleicht zweckmässig sein, das Problem vom Berg in das Laboratorium zu tragen und die einzelnen Faktoren getrennt zu untersuchen.

H. Cauer (zum Vortrag von Dr. W. H. Weihe): Priv. Doz. Dr. Kanz (München) hat auch eine Veränderung der Geschmacksempfindung gegenüber sehr verdünnten Kochsalzlösungen gefunden. Bei Wetteränderungen, Eintritt von echtem Föhn sind Empfindungen von salzig, süss und mitunter bitter bei der gleichen Konzentration festgestellt worden.

H. Jungmann (zum Vortrag von Prof. R. Margaria): Die Vitalkapazität ist bereits in 2000 m Höhe verkleinert. Untersuchungen an 40 gesunden Personen zeigten in Obergurgl eine statistisch gesicherte Abnahme, die erst nach 3 Wochen Höhenaufenthalt verschwand.

H. Jungmann (zum Vortrag von W. H. Weihe): Die Untersuchungen von Prof. v. Muralt und seinem Mitarbeiter sind wohl inzwischen in der ganzen Welt bekannt geworden und bilden eine wichtige Grundlage für alle späteren Höhenuntersuchungen im Gebirge.

(zu Warm): Die statistischen Berechnungen wurden nach den Anweisungen von Grandjean und Linder durchgeführt und berücksichtigen auch konstitutionelle Unterschiede.

(zu Weihe): Es erscheint wichtig, noch auf einen Faktor aufmerksam zu machen, der bisher nicht erwähnt wurde: die Zeit. Die Reaktion auf die Höhe ist nicht nur von der Höhe selbst bzw. vom Höhenunterschied abhängig, sondern auch von der Dauer des Höhenaufenthalts. Am Beispiel der Ausscheidung von sog. Porter—Silve—Chronogenen im Harn (zusammen mit F. Gabl, Innsbruck) lässt sich nachweisen, dass die von Weihe zitierte Vermehrung dieser Substanzen in 2000 m bis zu 1 Woche anhält, dann abnimmt und in der 3. Woche wiederum vorübergehend ansteigt. Ähnliche phasische Veränderungen zeigten die Reaktionszeit, der Kreislauf sowohl in Ruhe als auch im Belastungstest und das Körpergewicht (Untersuchungen zusammen mit F. Gabl, M. J. Halhuber und G. Hildebrandt in Obergurgl). Vermutlich sind auch manche Differenzen in früheren Messergebnissen darauf zurückzuführen, dass die Messungen in verschiedenen Phasen der Höhenanpassung ausgeführt wurden.

H. Jungmann (zum Vortrag von W. Undt): Paralleluntersuchungen mit verschiedenen Methoden an immer den gleichen Personen über längere Zeit am Heimatort gibt es wohl wenig. Wir haben bei unseren Höhenuntersuchungen stets mehrere Methoden gleichzeitig verwandt und in gleicher Weise die Voruntersuchungen am Heimatort durchgeführt. Messungen über Monate oder gar Jahre wurden nur jeweils mit 1 Methode durchgeführt um Normalwerte und Streuung zu ermitteln.

B. Primault: Le fait que le «mal de montagne» est inconnu en Suisse est il dû à la technique de l'alpage. Il y a une adaptation graduelle à l'altitude car les troupeaux montent de quelques 500 m avec un sejours de 3 semaines à chaque étage. Le même phénomène se produit lors de la descente en automne.

W. Undt: Von Wichtigkeit erscheint, die verschiedenen Teste parallel durchzuführen z. B. Blutbestandteile, C_{17}-Ketosteroide, Blutzucker, ph-Werte, Kapillarresistenz, Pupillenweite, Geschmacksempfindung u. a. und zu sehen, wie weit diese gleichlaufen und an welchen Tagen diese widersprechen und ob diese Tage bestimmte Wetterstörungen aufweisen. Dabei wäre noch die Konstitution zu berücksichtigen bzw. bei den einzelnen Personen das persönliche Niveau, um das die Werte streuen, zu bestimmen.

2nd Session

TROPICAL BIOCLIMATOLOGY

Chairman: Dr. E. M. Glaser

CUTANEOUS VASCULAR AND CARDIAC RESPONSES TO HEAT*

ALRICK B. HERTZMAN and L. CHARLES SENAY, Jr.
Department of Physiology, St. Louis University School of Medicine, St. Louis, Mo.

Abstract—During exposures of the nude resting subject to various levels and increases in ambient temperature (climatic chamber) cutaneous arterial vasodilatation (as recorded by photoelectric plethysmographs) may differ in onset and amount in the digits forearm, calf, cheek and ear. Similar regional differences in sweating have been reported previously. There was no systematic relation of the cutaneous vasodilatation in a given region to sweating in the same area. Local skin temperature seems to be closely related to the local vascular events. Increases in the stroke volume and rate of the heart accompanied the cutaneous vasodilatation but the possibility that the latter entirely accounted for the increased cardiac load was considered unproven.

Résumé—Si l'on expose un sujet nu, au repos, à des températures variés ou à des changements variés de temperature (chambre climatique), la vasodilatation artérielle de la peau (enregistrée au plethysmographe photoélectrique) peut être differente suivant qu'elle est mesureé au doigt, à l'avant-bras, au mollet, à la joue ou à l'oreille. De semblables différentes régionales de transpiration ont été rapportées ailleurs. Il n'y a aucune relation systematique entre la vasodilatation cutanée et la transpiration d'une même region. La température cutanée locale semble être etroitement liée à l'état vasculaire. Une augmentation du débit et du rythme cardiaques accompagnent la vasodilatation mais on n'a pas pu démontrer s'il est possible que cette dernière explique entièrement la modification des fonctions cardiaques.

Auszug—Unbekleidete Personen im Ruhezustand wurden in der Klimakammer verschiedenen Temperaturen und verschiedenen Temperatur-Erhöhungen ausgesetzt. Die Erweiterung der Hautgefässe (gemessen mit einem photoelektrischen Plethysmograph) ist unterschiedlich in Beginn und Aussmass in Finger, Unterarm, Wade, Wange und Ohr. Ähnliche regionale Unterschiede in der Schweissproduktion wurden früher berichtet. Eine systematische Korrelation zwischen Gefässerweiterung und Schweissproduktion im gleichen Hautbezirk wurde nicht gefunden. Die örtliche Hauttemperatur scheint mit örtlichen Gefässreaktionen gut zu korrelieren. Zunahmen des Schlagvolumens und der Pulsfrequenz begleiteten die cutane Gefässerweiterung, aber die Möglichkeit, dass dieselbe voll und ganz verantwortlich ist für die erhöhte Herzbelastung wurde als unbewiesen betrachtet.

We are indeed grateful for having the opportunity of addressing to this distinguished audience a partial reply to a famous statement attributed to Mark Twain that "everybody talks about the weather but no one does anything about it." Certainly

* Aided by grants from the United States Air Force and Public Health Service.

when one is exposed to heat, the circulatory system, the nervous system and the sweat glands do a great deal about it.

The air conditioning people have used for many years the comfort vote as an index of the avoidance of heat stress and recently our weather bureau has been reporting our hot days in terms of a distress or discomfort index. This procedure is undoubtedly useful for certain practical applications but it helps little in understanding what actually happens in the body during exposure to heat and why the physiological responses occur.

Various numerical indices of the physiological costs of heat exposures have included the parameters of sweating, body temperatures and heart rates. The measurement of sweating is justified because evaporative cooling not only provides the sole route of the transfer of the body's heat to a hotter environment but also protects against a transfer in the reverse direction. The changes in the body temperatures show how successful the sweating mechanism has been in preventing their rise. The increase in heart rate is related to the circulatory responses.

When the resting subject is exposed to a climate as warm or warmer than his, his surface temperatures rise and transverse gradients in his body temperatures decrease as also do longitudinal gradients along his extremities. In other words, the body approaches thermal homeogeneity. As this occurs, heat transfer from the interior of the body is effected increasingly by vascular convection and less and less by physical conduction. Hence, circulatory responses have a special significance and interest in the physiology of heat.

The vascular convection of heat is expressed numerically in the equation

$$H = F \cdot k(T_1 - T_2)$$

in which H, F, k are the heat transfer, blood flow and specific heat of blood and T_1 and T_2 the temperatures of the blood before and after heat loss. From this equation, one may construct a family of curves (Fig. 1) which show the relations which must hold between the skin blood flow and the skin temperature at a particular level of heat transfer and for various levels of core temperature. Actual experimental points do not follow a particular curve but shift across the chart. As the body shows increasingly uniform temperatures, skin blood flow must increase. But evaporative cooling can increase the temperature differential between the core and the surface and so allow a smaller cutaneous blood flow to transfer the required amount of heat. It is not surprising therefore that the sweating and circulatory responses to heat exposures are somehow related to the body temperatures. This paper is directed primarily to a discussion of the circulatory reactions.

It is useful to mention certain deficits in our current knowledge concerning the circulatory responses to heat. First, although measurements have been made of the cutaneous blood flows during heat exposures (1—5), these studies have not recorded adequately the cutaneous blood flows in the several regions — the hand, arm, face, trunk, leg and foot — nor have they clearly identified the relative importance of several possibly available regulatory mechanisms in the control of the cutaneous blood flow. This information is needed because the final convective pathway for the transfer of the body's heat to the environment is the cutaneous vascular system.

Second, despite the frequency with which the heart rate is counted in subjects exposed to heat, little is known concerning the changes in heart action. Some data are available on the output of blood by this pump but the generally held opinion

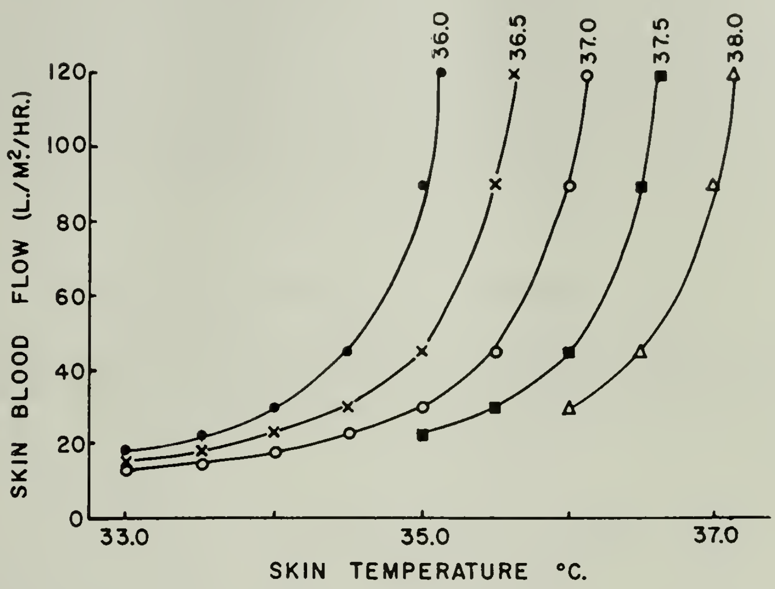


Fig. 1. Cutaneous blood flows calculated from the equation for convective heat transfer at various levels of skin and core temperatures. (Published with permission of the Editor of the *Journal of Applied Physiology.)*

that an increase in cardiac output is elicited by the increased blood flow in the skin and that the two increases are essentially equal has not been demonstrated by experiments which were designed to test the point in a specific instance. Any increases in cardiac output beyond those which were required to supply the increase in cutaneous blood flow would not be useful, yet such increases have been reported (6). Cardiologists have long recognized the relatively low acceptance of heat exposures by cardiac patients.

Recent experimental work in our St. Louis laboratories has been directed to the description and explanation of the changes in the cutaneous circulation and in heart action in normal resting subjects exposed to a hot environment. Our concern with the cardiac events has focused on their temporal relations with those in the cutaneous circulation in preparation of an answer to the question, "does the cutaneous vasodilatation directly elicit an increase in heart action because of the greater cutaneous venous return to the heart or do the two circulatory events develop coincidentally but independently?"

We have employed several standard heat stresses which were supplied by a precisely controlled climate chamber. During the exposures of the subject to a constantly hot chamber or to a slowly or rapidly rising ambient temperature, simultaneous, and in many instances, continuous measurements were made of sweating in several areas of the body; of cutaneous blood flows in the finger, toe, calf, thigh, forearm, cheek, ear and forehead; of cardiac outputs and of skin, oral and rectal temperatures. Sweating was measured by means of a desiccating capsule which covered an area of 10 cm². The cutaneous blood flow in any area was measured by recording the cutaneous volume pulsations with a specially designed photoelectric plethysmograph. The photometric arrangement detects the pulsatile changes in skin opacity resulting from each volume pulsation. The relation to flow is such that a pulsation amplitude of 1 per cent in the photoelectric current is equivalent to a blood flow of 0.1 cm³/cm² of skin area per min. An adaptation of the ballistocardiograph was used for following the changes in heart action.

THE CUTANEOUS VASCULAR RESPONSES TO HEAT

Two illustrations serve to demonstrate that these vascular responses often are dissimilar when recorded simultaneously in several regions.

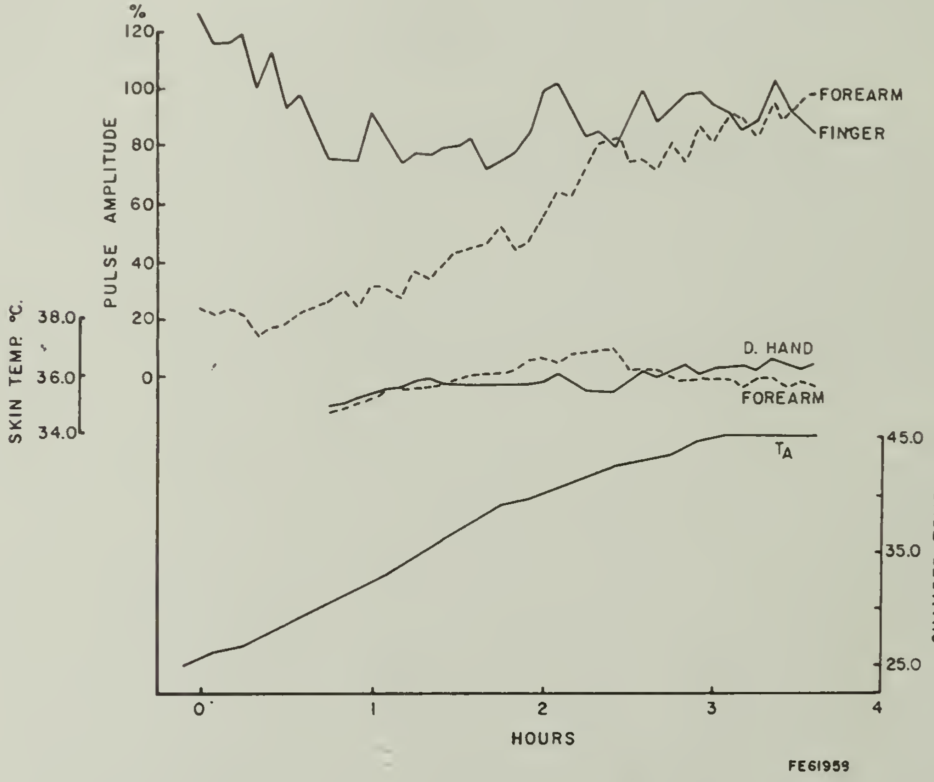


Fig. 2. Amplitudes of skin pulses in finger pad and forearm, and skin temperatures during rising chamber temperature (T_A). Pulse amplitudes in per cent of maximum (forearm, 1.5 per cent, finger pad, 7.8 per cent of photoelectric current) attained

1. *Finger and Forearm*

Fig. 2 shows the skin pulse amplitudes in the finger and forearm and the changes in skin temperature of the hand and forearm while chamber temperature was increased slowly from 25° to 45° C. The amplitudes of the skin pulses were entered as per cent of the maximum value attained in order to facilitate comparisons. Note that the vasodilatation in the forearm skin was not exhibited in the finger. The latter's vessels were already dilated at the beginning of the experiment. This difference was noted quite regularly in the experiments done during the summer months but not during the winter months. In the latter experiments, digital and forearm cutaneous vasodilatations often developed together.

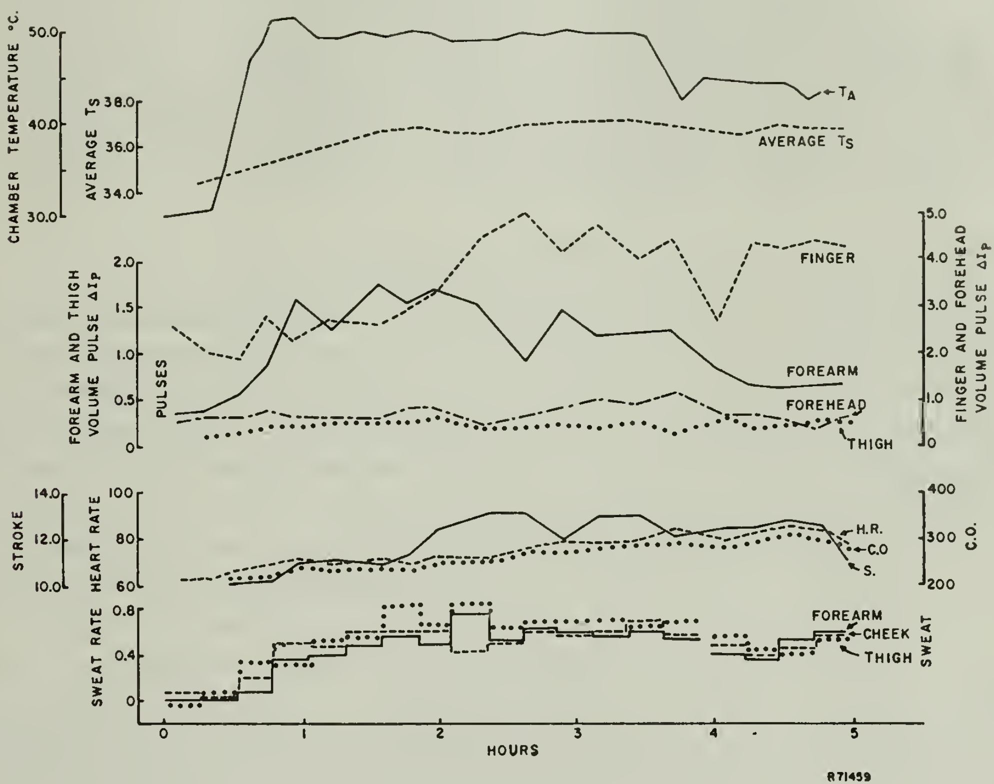


Fig. 3. Cutaneous volume pulses in finger, forearm, forehead and thigh during rise in chamber temperature (T_A). Amplitudes of skin pulses in per cent of photoelectric current, ΔI_p. Note different scales for finger—forehead and forearm—thigh required by greater vasculature in finger and forehead. Sweat rates in mg/cm² per min. Ballistocardiographic data: S, stroke (amplitude of $I-J$ wave) $H. R.$ heart rate; $C. O.$ product of S and $H. R.$ Recordings of skin pulses and temperatures were continuous, of ballistocardiograms for 15 sec every 5 min., of sweating by capsules in place for 15 min. and followed immediately by the replacing capsule. A single summer experiment on subject R.

2. *Forearm, Finger, Thigh and Forehead*

Some relations between skin pulses, regional sweating, and skin temperature during exposure to a hot environment are shown in Fig. 3. This particular experiment was selected to illustrate that cutaneous vasodilatation may be negligible on the lower extremity when quite great on the upper extremity and when sweating is general over the body. In some other experiments, cutaneous vasodilatation appeared at the same time on both upper and lower extremities but progressed less in the latter. The difference in the amount of vasodilatation was not due to a lesser cutaneous vasculature in the leg; earlier experiments demonstrated that about equal cutaneous blood flows resulted in the calf and forearm during the action of vasodilator drugs (7). In only one subject have we observed a more rapid cutaneous vasodilatation in the calf than in the forearm during heat exposure. This subject was a "poor" sweater and the skin temperature of the leg rose rapidly and to higher levels than in other subjects exposed to the same hot environment.

Several possible influences required study in an effort to explain the observed regional differences in the cutaneous vascular responses to body heating: the local skin temperature, local sweating and regional differences in the actions of the vasomotor innervation of the cutaneous blood vessels.

Local Skin Temperature and Local Cutaneous Blood Flow

When the data were treated by charting the cutaneous blood flows in the calf and forearm against the corresponding local temperatures, the experimental points usually fell on the same curve, that is, at the same level of local skin temperature the cutaneous blood flow in the calf was the same as that in the forearm. This fact strongly suggested that the failure of the skin vessels of the calf to dilate as much as those of the forearm was due to the smaller increase in calf skin temperature which did not quite attain the critical level at which the vessels dilate greatly. Hence, it should be possible to prevent the cutaneous vasodilatation simply by keeping the skin cool in a small local area by means of a specially designed thermode while chamber temperature increases. The design of the thermode permitted continuous recording of the skin pulses and the measurement of sweating in the cooled area under the thermode. The local sweating response in this area to the rising chamber temperature was unaffected but the cutaneous vasodilatation was inhibited greatly by keeping the skin cool. When the thermode temperature was allowed to rise above 36—37° C, the skin pulses in this covered area rapidly increased in amplitude (8).

Another illustration of the correlation between low calf skin temperature and absence of cutaneous vasodilatation in the leg is provided in an experiment which was described in an earlier technical report (9). The subject was covered by an electric blanket and a small area of calf skin was left exposed so that skin temperatures, sweating and skin pulses in this area could be recorded. The room temperature was rather low (22.1—23° C) as were also the skin temperatures of the exposed area (29.5—31.1° C). On heating the subject with the blanket, profuse sweating appeared in all regions, including the exposed calf skin. However, there was no evidence of cutaneous vasodilatation in this area, either in the amplitudes of the skin pulses which were quite small (0.24 per cent of photoelectric current) or in the calculated local conductances. The surface temperature of the exposed area decreased nearly 2° C, as the result of the evaporative cooling.

Sweating and Cutaneous Blood Flow

The demonstration by Fox and Hilton (10) of the liberation of the vasodilator substance, bradykinin, in forearm skin with the onset of sweating suggested that the activity of the sweat gland might greatly influence the cutaneous circulation. However, the experiments presented above demonstrate that thermoregulatory sweating can occur without detectable cutaneous vasodilatation. The converse question "does cutaneous vasodilatation occur without sweating in the normally innervated skin?" is much more difficult to answer, but several attempts on our part to obtain decisive evidence indicate an affirmative conclusion. First, when the temporal sequences in cutaneous vasodilatation and sweating on the forearm were examined closely there was no apparent influence of the onset of sweating on the skin pulses (8). Often, the rate of increase in the latter diminished as evaporative cooling increased. In a more recent unpublished experiment, the sensitivity of the method of detecting the onset of sweating by the change in skin resistance was greatly increased so that it exceeded that of the sweat print technique. We still failed to obtain any indication that the onset of sweat gland activity influenced the cutaneous vasodilatation. In this experiment, the photoelectric plethysmograph and the resistance sensor were combined so that each unit "saw" essentially the *same* skin area. Again, in charts of sweating and cutaneous blood flows in the forearm, an upsurge in cutaneous blood flow did not appear when sweating occurred (8). On the contrary, the cutaneous vasodilatation tended to flatten out as sweating and resultant evaporative cooling increased.

Vasomotor Influences on the Cutaneous Circulation

A recent review from this laboratory summarized some of the information pertinent to the role of the vasomotor innervation in the cutaneous vascular responses to heat (11). Benzinger's calorimetric experiments (1) indicated the onset of cutaneous vasodilatation at a slightly but definitely lower intracranial temperature than that of the onset of sweating. He concluded that this represented a vasomotor effect but did not distinguish the actions of vasodilator or of vasoconstrictor pathways in accounting for the observed result. Two quite different experiences may be cited to emphasize the possible role of the vasomotor system in accounting for the presence or absence of cutaneous vasodilatation during body heating and for regional differences in its onset and intensity.

First, it is well known that heat acclimatization lowers the sweating threshold, i.e. sweat rates at any given level of body temperature are greater after than before this process is completed. The peripheral blood flows and cardiac outputs at the *same* levels of sweating are greater before than after acclimatization (12). This result would follow if the level of body temperatures determined how much peripheral vasodilatation occurred (1). Regional differences in the cutaneous vascular results present no greater problem than do those in the regional distribution of the sweating response over the body (13).

Second, during the progressive dehydration elicited by sweating during continuous exposure of the resting nude subject to 43.3° C, sweating remained almost unchanged despite a steady rise in body temperatures but peripheral conductance tended to decrease (14). The sweating threshold appeared to rise at the same rate as the body temperature. The increase in the latter did not elicit further cutaneous vasodilatation as would have occurred in the normally hydrated subject experiencing the same rise in body temperatures. Several choices may be considered in attempting an explanation of these observations; a rising body temperature does not iyfluence equally the cutaneous vasomotor and sudomotor systems. This would permit considerable separation of the cutaneous vascular and sweating responses in heat acclimatization, exercise and dehydration and also in the regional topography of the responses. Local skin temperatures greatly influence the local cutaneous vascular responses to body heating, probably through spinal reflexes facilitated by the descending hypothalamic pathways. But the cutaneous circulation tends to decrease in dehydration despite the increase in skin temperature. Hence, it seems probable that vasoconstrictor influences elicited by the dehydration offset other vasodilator effects of heat.

CARDIAC RESPONSES

The ballistocardiograms demonstrated increased force of the cardiae contractions synchronously with the cutaneous vasodilatation, particularly with that in the forearm. In some subjects, the correlation was quite good; in others the stroke in the ballistic record increased relatively less than the vasodilatation in the forearm. Fig. 3 shows the results in an experiment on a particular subject.

Although the semi-reclining position of the subject in these experiments did not permit estimation of the actual cardiac output from the ballistic records, repeat experiments on the same subject yielded the same numerical data. If one assigned a standard normal stroke volume to the ballistic record of the resting comfortable subject, the calculated increases in cardiac output exceeded in some experiments the increases in the cutaneous blood flow as estimated from recordings of the skin pulses in several representative regions. But most if not all of the increase in the cardiac output appeared to be accounted for by the cutaneous vasodilatation. In repeat experiments on the same subject, the greater cutaneous blood flows correlated with the greater ballistic effects.

These experiments have not been carried far enough to answer decisively the question, does the increase in cutaneous blood flow lead to an equal increase in cardiac output? But it is clear that the load on the heart is related closely to the progress of the cutaneous vasodilatation. Since the latter is related, directly or indirectly, to the level of the skin temperature, one may expect the requirement for cardiac output also to rise with the skin temperature. The relation is not a simple linear one. Cutaneous blood flow increases precipitously at skin temperatures above 36° C.The relation seems to be logarithmic. Hence, one may predict excessive cardiac loads to develop as the skin temperature rises above this critical level.

Experience with the work capacity of normal subjects in a hot environment agrees directionally with the last statement (11). Some measurements in heart patients exposed to a hot environment indicate excessively large increases in their cardiac outputs (6). Whether or not their skin temperatures were also higher is not clear in the reported data.

An interesting feature of the cardiac responses to heat was the consistent evidence of an increased stroke volume. The greater ballistic impact and the small changes in arterial blood pressure indicated that cardiac output compensated almost precisely for the decrease in peripheral resistance. The increase in stroke volume during exposure of the resting subject to heat contrasts with the absence of change in stroke volume of sedentary subjects taking moderate exercises (14). The regulatory mechanisms acting on the heart appear to operate differently in the two stresses. The heat experiment seems to invoke Starling's law of the heart.

CONCLUSION

The responses of the circulatory system to heat stress are sufficiently large to warrant inclusion in the development of indices of the physiological strain resulting from a heat load. In the resting nude subject the cardiac and cutaneous vascular responses are closely related. It is not yet clear whether or not the cutaneous vascular dilatation determines the level of the heart action but both appear to be related closely to the level of the body temperatures. If this proves to be true in many circumstances, a practical application would be directed at improvement in evaporative cooling. The sweating response of the subject would be a principal determinant of the level of the circulatory strain elicited by heat. Since dehydration raises the thermal threshold of sweating, it may increase significantly the circulatory response elicited by heat before the loss of body fluids impair the circulation. We have noted this situation at levels of dehydration below 3—4 per cent of the body weight.

REFERENCES

1. T. H. Benzinger, On physical heat regulation and the sense of temperature in man. *Proc. Nat. Acad., Sci. Wash.* **45**, 645—59 (1959).
2. O. G. Edholm, R. H. Fox and R. K. Macpherson, The effect of body heating on the circulation in skin and muscle. *J. Physiol.* **134**, 612—19 (1956).
3. I. C. Roddie, J. T. Shepherd and R. F. Whelan, The contribution of constrictor and dilator nerves to the skin vasodilatation during body heating. *J. Physiol.* **136**, 489—97 (1957).
4. R. H. Fox, R. Goldsmith and D. J. Kidd, Cutaneous vasomotor nerves in the human ear and forehead. *J. Physiol.* **150**, 12 (1960).

5. A. B. Hertzman, Some relations between skin temperature and blood flow. *Amer. J. Phys. Med.* **32**, 233—51 (1953).
6. G. E. Burch and A. Hyman, Influence of a hot and humid environment upon cardiac output and work in normal man and in patients with chronic congestive failure at rest. *Amer. Heart J.* **53**, 665—79 (1957).
7. A. B. Hertzman and W. C. Randall, Regional differences in the basal and maximal rates of blood flow in the skin. *J. Appl. Physiol.* **1**, 234—41 (1948).
8. L. C. Senay, Jr., M. Christensen and A. B. Hertzman. Cutaneous vascular responses in finger and forearm during rising ambient temperatures. *J. Appl. Physiol.* **15**, 611—18 (1960).
9. A. B. Hertzman, W. C. Randall, H. E. Ederstrom and C. N. Peiss, *The Cutaneous Vascular Responses to Rising Environmental Temperature.* AF Technical Report No. 6680, Part 6, December (1951), Wright Air Development Division, Wright-Patterson Air Force Base, Ohio.
10. R. H. Fox and S. M. Hilton, Bradykinin formation in human skin as a factor in heat vasodilatation. *J. Physiol.* **142**, 219—32 (1958).
11. A. B. Hertzman, Vasomotor regulation of cutaneous circulation. *Physiol. Rev.* **39**, 280—306 (1959).
12. C. H. Wyndham, Effect of acclimatization on circulatory responses to high environmental temperatures. *J. Appl. Physiol.* **4**, 383—95 (1951).
13. A. B. Hertzman, Individual differences in regional sweating. *J. Appl. Physiol.* **10**, 242—8 (1957).
14. R. Rushmer and O. A. Smith, Jr., Cardiac control. *Physiol. Rev.* **39**, 41—68 (1959).

ADAPTATION OF DOMESTIC ANIMALS TO THE TROPICS

J. C. D. HUTCHINSON
Division of Animal Physiology, CSIRO, Ian Clunies Ross Animal Research Laboratory, Prospect, New South Wales, Australia

Abstract—The role of coat character in the adaptation of beef cattle will be discussed. Bonsma's early work has been extended in recent investigations. Yeates has emphasized the importance of photoperiodic stimulation in controlling seasonal variations of the coat. Turner has defined more closely the characteristics of the coat and their relation to thrift in a tropical environment. In addition, the cycles of growth and shedding have been studied. Genetical and physiological problems which arise out of this work will be examined.

In sheep, adaptation to the arid tropics does not seem to be related to coat character. In Merinos a long fleece aids heat dissipation by protecting against solar radiation; but in Africa there are short-coated sheep which live in a similar climate. The Merino has been found to sweat very little, so that the fleece is not likely to interfere much with evaporative cooling. Possibly the short-coated African breeds sweat more and pant less than the Merino. Maintenance of reproductive efficiency seems to be the main difficulty in adapting Merinos to the arid tropics.

Although recent interest has been focused on the pelage, yet Allen's rule appears to hold for domestic animals, as if conformation were also important in adaptation to the tropics. Recent experiments on mice have confirmed that temperature of rearing has an influence on conformation. The role in tropical adaptation still needs to be assessed.

In the arid tropics and subtropics of Australia the pastures are of very large extent and it seems that animals must walk a considerable distance to get feed and maintain contact with their supplies of water. The influence of climate on the utilization of such pastures, and the physiological and psychological characteristics that improve it, are likely to be important subjects for future study.

Résumé—Le rôle du type de pelage dans l'adaptation des bovinés sera discuté. Les travaux tout d'abord faits par Bonsma ont été développés dans des recherches récentes. Yeates a mis en relief l'importance de la stimulation photopériodique en vérifiant les variations saisonnières du pelage. Turner a défini d'une façon plus précise les caractéristiques du pelage et leur relation avec le statice dans un milieu tropical. De plus les périodes de croissance et de mue ont été étudiées. Des problèmes génétiques et physiologiques, posés en dehors de cette étude, sont examinés.

Chez les moutons l'adaptation aux tropiques arides ne semble pas être en relation avec le type de pelage. Chez les mérinos une longue toison favorise la dissipation de la chaleur contre le rayonnement solaire, toutefois en Afrique il y a des moutons à toison courte qui vivent dans un climat semblable. On a constaté que les mérinos transpirent peu, de sorte que la toison ne gêne probablement guère le refroidissement par évaporation. Il se peut que les races africaines à toison courte transpirent davantage et pantellent moins que les mérinos. Le maintien de l'efficience de la reproduction semble être la principale difficulté de l'adaptation des mérinos aux tropiques arides.

Bien que l'intérêt de ces derniers temps se soit concentré sur le pelage, la règle d'Allen semble rester valable pour les animaux domestiques, comme s'il fallait tout de même admettre que la conformation joue également un rôle important dans l'adaptation aux tropiques. Des essais récents sur des souris ont confirmé que la température d'élevage influence la conformation. Son rôle dans l'adaptation aux tropiques reste à établir.

Dans les régions tropicales arides et subtropicales d'Australie les pâturages sont de très grande étendue, et il semble que les animaux soient obligés à faire de très longues étapes pour se procurer de la nourriture et maintenir le contact avec l'approvisionnement en eau. L'influence du climat sur l'utilisation de tels pâturages et les caractéristiques physiologiques et psychologiques susceptibles de les améliorer seront probablement étudiées à fond dans les futures recherches.

Auszug — Es wird die Rolle, welche die Eigenschaften des Felles bei der Anpassung von Fleischvieh spielt, besprochen. Die frühe Arbeit von Bonsma ist durch neue Forschungen erweitert worden. Yeates hat die Bedeutung photoperiodischer Stimulierung für die Kontrolle der jahreszeitlich bedingten Veränderungen des Felles nachdrücklich betont. Turner hat die Charakteristika des Felles und deren Beziehungen zu einem Gedeihen in tropischer Umgebung genauer definiert. Außerdem sind die Zyklen des Wachsens und des Abwerfens des Felles studiert worden. Die sich aus dieser Arbeit ergebenden genetischen und physiologischen Probleme werden studiert werden.

Bei den Schafen scheint die Anpassungsfähigkeit an die trockenen tropischen Gebiete nicht mit dem Charakter des Felles in Verbindung zu stehen. Bei den Merino-Schafen unterstützt das langhaarige Fell die Hitzeverteilung, indem es die Tiere gegen die Sonnenstrahlung schützt. In Afrika gibt es jedoch auch Schafe mit kurzhaarigen Fellen, die in ähnlichen Klimaten leben. Es ist festgestellt worden, daß das Merinoschaf nur sehr wenig schwitzt, so daß es nicht wahrscheinlich ist, daß das Fell die Verdunstungs-Kühlung stark behindert. Möglicherweise schwitzen die kurzhaarigen afrikanischen Rassen mehr als das Merinoschaf, und schnappen weniger nach Luft als dieses. Die Erhaltung der Fortpflanzungs-Leistungsfähigkeit ist anscheinend die Hauptschwierigkeit bei der Anpassung von Merinoschafen an trockene tropische Gebiete.

Obwohl sich kürzlich das Interesse auf das Fell konzentriert hat, so scheint Allen's Regel für Haustiere doch gültig zu sein, nämlich, daß bei der Anpassung an die Tropen die Struktur des Felles auch von Bedeutung wäre. Experimente, die kürzlich mit Mäusen durchgeführt wurden, haben bestätigt, daß die Zucht-Temperatur einen Einfluß auf die Struktur hat. Ihre Aufgabe bei der Anpassung an tropische Klimate muß jedoch noch festgestellt werden.

In den trockenen tropischen und subtropischen Gebieten von Australien nehmen die Weideflächen große Gebiete ein, und die Tiere müssen beim Grasen sowie zu den Tränken beträchtliche Entfernungen zurücklegen. Der Einfluß des Klimas auf die Nutzbarmachung derartiger Weideflächen, sowie die physiologischen und psychologischen Charakteristika, die zu einer Verbesserung führen, stellen wahrscheinlich wichtige Gegenstände einer zukünftigen Untersuchung dar.

I am not going to try to review our knowledge of this subject, nor to describe any particular experimental study in detail, but rather to indicate certain problems and changes of viewpoint arising out of recent work, some of which I hope will be discussed by others during this Congress. I shall speak mainly of beef cattle and sheep.

COAT CHARACTER AND THRIFT OF BEEF CATTLE

Bonsma (3) found that there was a correlation between the felting properties of the hair and the heat tolerance and thrift of cattle in the semi-arid tropics. Well adapted animals had a smooth sleek coat, which did not felt easily. He thought that calves of European breeds did not shed their winter coat normally. Yeates (23) found that in Shorthorns this shedding was controlled by day-length. From this observation he suggested that European cattle might have difficulty in making the normal seasonal changes of coat in near equatorial latitudes because the change of day-length was small. It has been shown that when there is no change in day-length at all, the natural hair cycle of Shorthorns is disrupted (24), but work in near equatorial day-length has not been attempted.

During the last few years the relation between coat character and thrift has been reinvestigated at the National Cattle Breeding Station (CSIRO), at Rockhampton, Queensland, which is just within the tropics. The animals available are Herefords

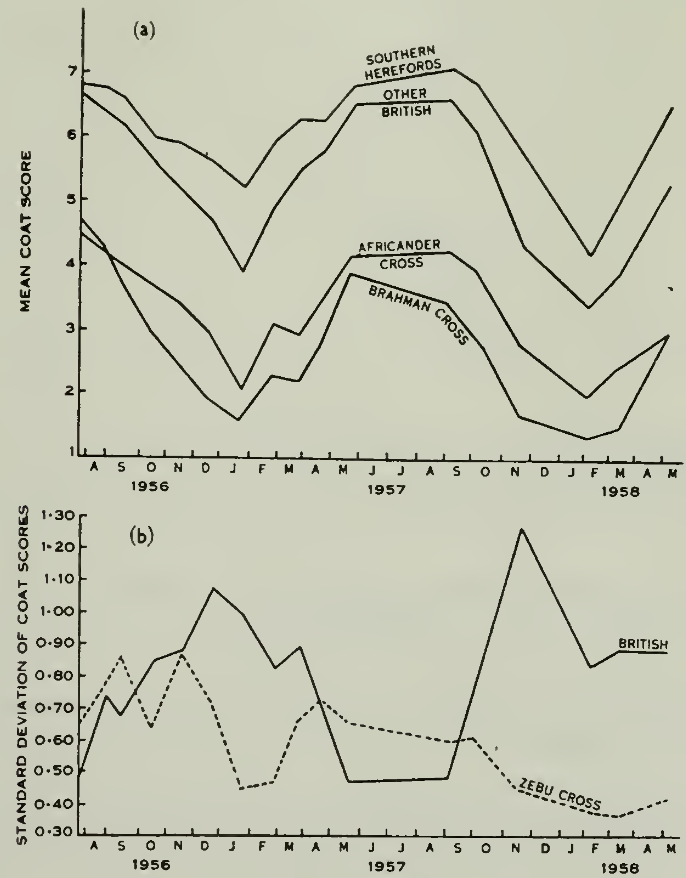


FIG. 1. Seasonal changes in coat score: data from weaning to 28 months of age for calves born in November 1955. (a) Mean scores for southern-bred Herefords, other British breed calves, Afrikander cross, and Brahman cross calves. (b) Standard deviations of scores within breed groups, shown separately for British and Zebu cross calves. (From Turner and Schleger (21).)

and Shorthorns and first crosses between these breeds and with Afrikander and Brahman bulls. A subjective scale of coat character has been devised, intended to discriminate between the coat types of breeds adapted to the tropics and the woolly coats found in animals originating from temperate climates (21). The scale

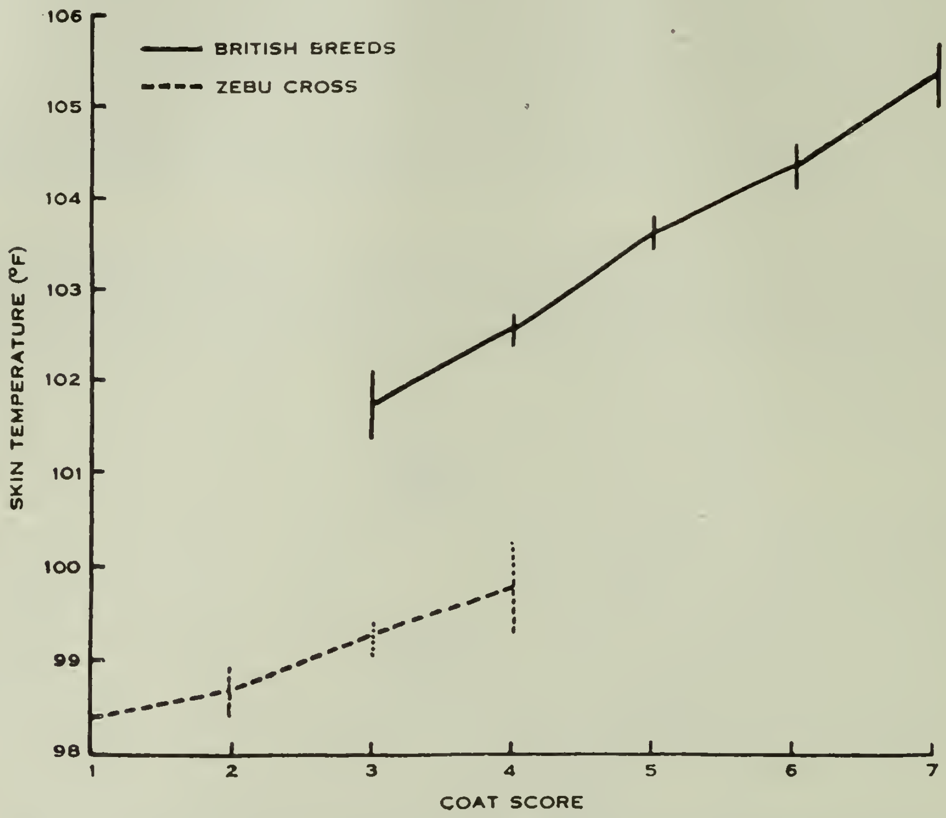


FIG. 2. Relation between skin temperature and coat score: coat score in March 1956 and temperature in April 1956 for 201 calves born in November 1954. Vertical lines indicate standard errors. (From Turner and Schleger (21).)

has been found to be significantly correlated with objective characters such as depth, medullation, felting, fibre diameter, follicle angle, fibre length and curvature (22).

Fig. 1 shows the seasonal variations of the coat score for various breed types over 22 months from weaning A low coat score indicates a coarse sleek Zebu type of coat, and a high score means a woolly coat. The coat scores of the main breed groups can be distinguished at any time of year despite the seasonal changes. A strain of Herefords imported from a temperate climate had a higher coat score than Herefords which had lived for a number of generations in Queensland. Coat score decreased with age. Steers had a higher score than cows, and cows a higher score than bulls.

Fig. 2 shows the relation between coat score and skin temperature, measured in hot weather in shaded positions on the trunk. There is a good relationship for the British breeds and for the Zebu crosses taken separately, but a discontinuity between these groups. The discontinuity could be due to a difference in sweating or in heat production. Coat score is also correlated with rectal temperature and respiratory rate.

Fig. 3 shows the relation between coat score and gain in weight of calves over the 10 months after weaning. In this case there is a continuous curve over the

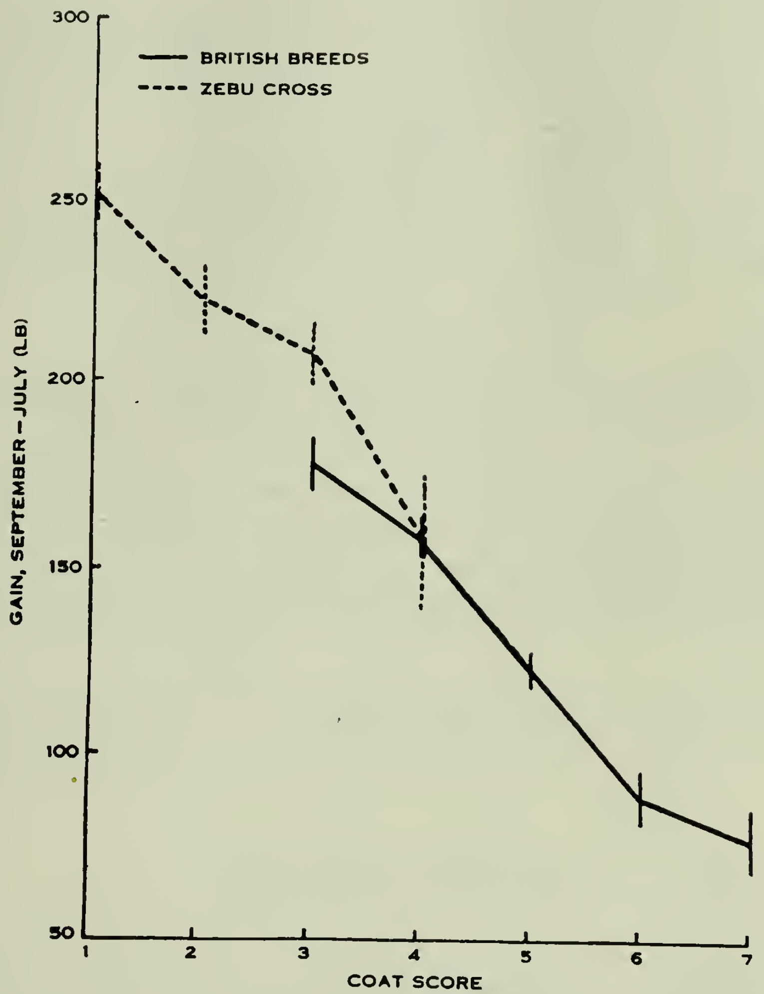


Fig. 3. Relation between coat score and growth rate: gain during 10 months after weaning. Data for 197 calves born in November 1954. Vertical lines indicate standard errors. (From Turner and Schleger (21).)

whole range of breed groups. However, closer examination of the data shows that there is a difference between the Zebu crosses and British breed. For the former there is no significant correlation within the breed groups. The slope of the curve is due to breed group differences. Within the British breed groups within sexes the correlation is significant ($r = -0.577$; $P < 0.01$). Figs. 4 and 5 show that the calving rate of Herefords and the birth weights of the resulting calves are also related to coat score (20).

Coat score has a heritability as high as 63 per cent for calves of British breeding and is likely to have a practical value in selection.

Up to this point the investigation was essentially an extension of Bonsma's work, confirming his conclusions on a larger scale. Turner and Schleger next examined

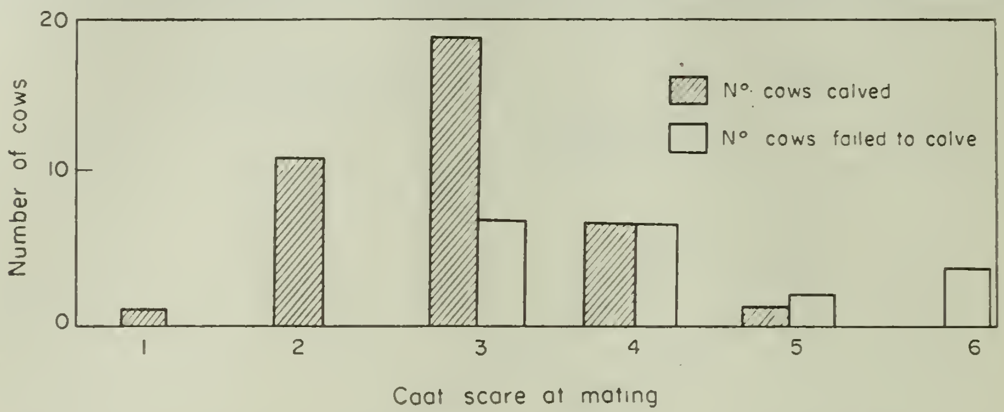


FIG. 4. Calving performance and coat score at mating of Shorthorns. (From Turner and Schleger (20).)

the growth rate, over the hotter months, of Hereford cattle whose coat score was reduced by repeated clipping. They considered that if the coat influenced growth by reason of its insulating properties, the clipped animals would grow much faster than the rest; the difference in their growth could be predicted by the regression

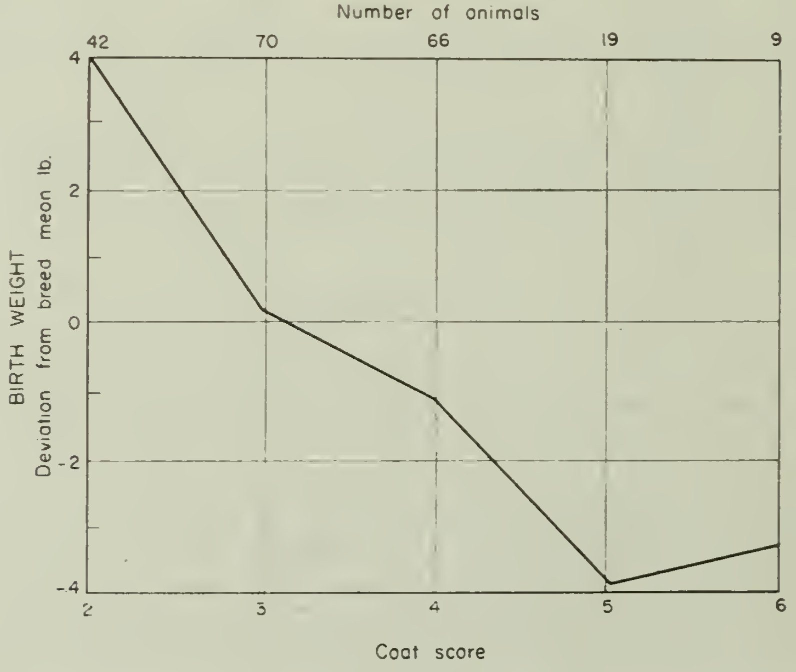


FIG. 5. Birth weight of calf related to coat score of dam. (From Turner and Schleger (20).)

of growth on coat score within the control group. Clipping increased growth rate by about 14 per cent, indicating the effect of the insulating and hydrodynamic properties of coat cover upon growth rate. However, the effect was much less (about one-quarter) than that expected from the regression of growth rate on coat score among unclipped animals. A large part of the difference in coat type seems to be unaccounted for by coat cover *per se*. Coat type is therefore correlated with, and possibly dependent on, other characteristics affecting growth. These correlated characters could be factors influencing thermoregulation, namely sweating rate (see Hayman and Nay (8), and Nay (17)), and rate of energy metabolism. However, it seems likely from the data so far accumulated, that coat type is associated with other metabolic characteristics, independent of heat tolerance, which influence the capacity of animals to thrive in a difficult environment. Thus, to some extent, correlation between measures of heat tolerance and growth rate may give an exaggerated impression of the importance of heat tolerance *per se*.

Because this significance is attached to coat type, it is important to identify the physiological factors responsible for different animals growing different types of coat. For this reason, detailed studies are being made at Rockhampton of hair characters, follicular cycles of hair growth and replacement, skin structure and composition, and effects of hormones on hair growth. Also, as a direct attack on metabolic attributes which may or may not be related to heat tolerance, efficiency of feed utilization by Zebu and British breeds is being studied. Early results (Ashton, unpublished data) give indications of differences in apparent digestibility of nitrogen and in metabolism of nitrogen.

Besides the relation between inherited coat character and thrift there is also an influence of nutritional state upon coat character. For it has been shown that poor nutritional condition delays the spring shedding so that the winter coat is retained into the summer (25).

ADAPTATION OF SHEEP

In contrast to beef cattle the adaptation of sheep to the tropics and sub-tropics does not seem to be associated with coat character. The woolly Australian Merino extends well into the tropics of Queensland and Western Australia, while in Africa short-coated Hair sheep may be found in similar climates. Indeed, in Africa Merinos and Hair sheep sometimes live in the same habitat. The long fleece of the Merino protects it against solar radiation increasing, not decreasing, its heat tolerance. Thus, Macfarlane (13) found that in tropical Queensland the wool tips attained a temperature as high as 87° C in the sun. The fleece maintained a gradient of over 40° C between the tips and the skin. In this climate shorn sheep panted twice as fast as animals with 5 cm of fleece. This effect of the coat on heat tolerance is the opposite of what has been found with cattle.

One might suppose that the difference between the two species might lie in a greater sweating power in cattle. If sheep do not sweat much, a heavy coat may not interfere with evaporative cooling. Recently Brook and Short (4) have measured the sweat production of sheep with desiccating capsules. They compared, in a hot humid environment, the moisture uptake trom normal sheep of a number of breeds with that from Merino mutants which had no sweat glands. The difference between the two groups in moisture uptake was only 32 g/m^2 per hr (Table 1). In cows

*Table 1. Weight Gains of Desiccating Capsules applied to Normal and Sweat-Glandless Sheep in Ante-room (20° C, Vapour Pressure 12.5 mm Hg) and Hot Room (40.5° C, Vapour Pressure 29.5 mm Hg)**

Type of sheep	Hot Room mean (g/m^2 per hr)	Hot Room s. e. of mean	Ante-Room mean (g/m^2 per hr)	Ante-Room s. e. of mean	Difference
Normal	63.1	3.6	22.6	1.7	40.5
Sweat-glandless	31.0	3.5	12.4	0.8	18.6
Difference	32.1		10.2		21.9

* From Brook and Short (4).

McDowell and his colleagues (11, 12) found rates of evaporation up to 660 g/m^2 per hr, 80—90 per cent of which appeared to be true sweat, so it seems that there is, in fact, a considerable difference in sweating between cows and sheep.

An impermeable plastic coat decreases markedly the heat tolerance of cattle, demonstrating the importance of sweating in their heat regulation (5). On shorn and unshorn sheep such a cover had little effect on heat tolerance in a hot humid laboratory climate (Fig. 6). If the humidity was raised high enough to block evaporation from both the skin and respiratory tract, rectal temperature rose very rapidly (Bennett, Brook, Hutchinson and Wodzicka, unpublished data). These experiments suggest that panting is more important than sweating in the heat regulation of sheep. Alexander and Brook (1) reached a similar conclusion in calorimetric experiments with young lambs.

In Australia the main physiological limit to the range of Merinos in the tropics appears to be failure of reproduction. Field surveys by a number of workers (14—16, 19) show that in tropical Western Australia and Queensland the rate of reproduction is low; some flocks in Western Australia cannot even maintain themselves. Probably reduced efficiency at all the stages of reproduction contributes to this state of affairs. This situation has led to renewed interest in the heat regulation of the testicles. Recently Waites (unpublished data) has found that warming the scrotum of a ram, kept in a cool room, will initiate sweating from the scrotum and also panting. Apart from its importance in the heat regulation of the testicles, this observation has a bearing on the problem of the role of peripheral and central sensory receptors in heat regulation.

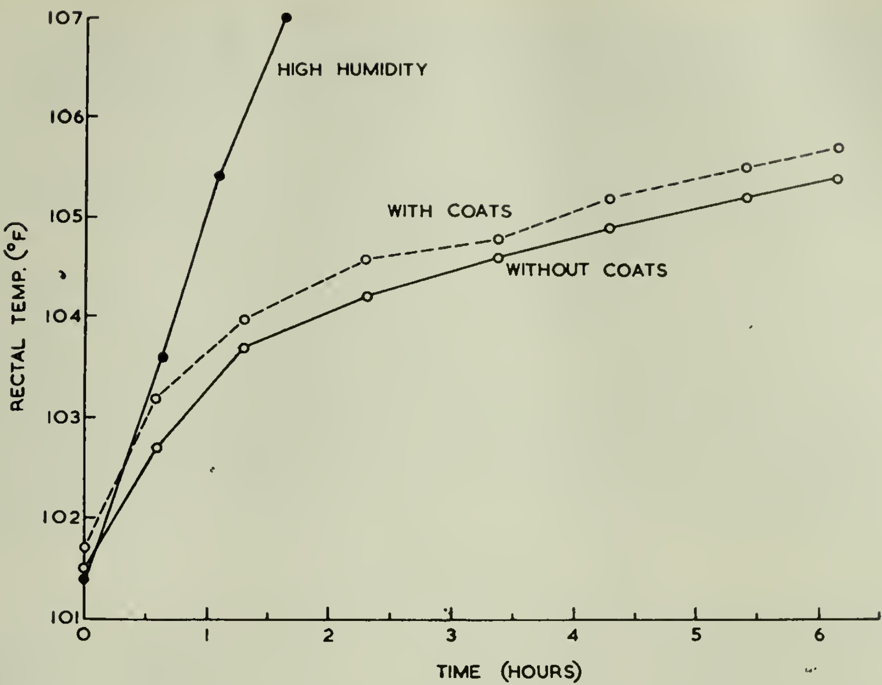


Fig. 6. Mean rectal temperature of twelve sheep over 6 hr in a climate room, with and without an impermeable coat. Air temperature 40.2° C, humidity 30 mm Hg vapour pressure except for the experiment at a high humidity for which the vapour pressure was 49.4 mm Hg. Relative humidity in the ante-room was the same as in the climate room, to prevent moisture interchange between the wool and the atmosphere when the sheep entered the climate room. Breeds represented were: Merino, Corriedale, Dorset Horn and Southdown. Four animals were unshorn; the rest were closely clipped

CONFORMATION

All investigators who have reared rats or mice in two widely different temperatures have found that the environmental temperature, in part, determines the tail length; the higher the temperature the longer the tail. This conclusion has recently been confirmed by Harrison *et al.* (7) in a comparison of the effect of a tropical and cool environment. Mice reared in the heat survived longer than the controls in a lethal hot humid environment (6). When the tails were cut off 5 weeks before exposure, the survival time was reduced. Thus, it seems that the longer tails of the heat-reared animals contributed to their longer survival time.

The influence of climate on the morphological development of mice accords with Allen's climatic rule, and it is obviously a question of importance whether the working of this rule contributes to the adaptation of the larger domestic animals to the tropics. It is supposed to work in a general way for the appendages and limbs of cattle. To see if I could get any quantitative information on the relative length of limbs, I have compared the height at withers with body weight of a large number of breeds of cows from various European countries and also from the Indian subcontinent. I have used these particular measurements, because they were the only ones available for a large number of breeds.

From Table 2 it is apparent that the ratio of height cubed to weight increases from the North to South of Europe, suggesting that the higher the mean temperature,

*Table 2. Comparison of the Heights at Withers and Weights of Breeds of Cows From Different Countries**
(Single purpose meat breeds excluded)

Country of origin	No. of breeds	Mean live wt. (kg)	Ht.^{3}/wt. (cm^3/kg)	Approx. latitude of habitat (°N)
Norway, Finland	8	394	4160	58—68
Britain, Belgium, Germany, Holland	18	550	4239	47—55
France, Switzerland	18	558	4344	43—51
Italy	17	607	4575	37—47
India, Pakistan (Zebus)	7	297	7004	22—28
India, Pakistan (Zebus)	5	345	5559	19—30
India Pakistan (Zebus)	7	400	5015	10—34

* Data from Bonadonna (2), Johansson (9), Joshi and Phillips (10) and Schmidt (18).

the more "leggy" are the breeds of cattle. Single purpose meat breeds are excluded because they are found only in the North of Europe; they have a very low ratio. The indian Zebu breeds have a higher ratio than the European animals, again suggesting a relation between mean temperature and relative length of limbs. It is uncertain how far this is an adaptive character for heat regulation, and how far it reflects differences in nutrition. Nutritional differences could be a response to climate as well as reflecting variations in the availability of feed.

I should mention that the European breeds increase in body weight from North to South, which is not in accordance with Bergmann's climatic rule. I have divided the Zebus into three weight groups because it became apparent that the ratio of height cubed to body weight varied with body weight, being larger in the lighter breeds.

Whether or not conformation has any important adaptive significance in the tropics is not at all clear. In the semi-arid tropics and sub-tropics of Australia the pastures are of very large extent. Adaptation of sheep and cattle must comprise ability to make use of extensive but sparse pastures, and to resist drought as well as survive high temperatures without undue physiological stress. In dry conditions cattle and sheep must range as far as possible and yet maintain contact with their supplies of water.

It has already been shown that Merino sheep approach the camel in their resistance to dehydration (13), and this characteristic must be as important as heat tolerance in their survival. It is possible that conformation and body size are important in their relation to efficiency of locomotion and, therefore, to efficiency of grazing rather than in any influence they may have on heat tolerance. Unfortunately, there is as yet no systematic energy physiology of the wide open spaces; it is not even known how far cattle and sheep walk in pastures of different size and nature. One can only speculate what determines efficient pasture utilization, but I think that this subject is likely to prove a rewarding field of future investigation.

ACKNOWLEDGEMENT

I am most grateful to Drs. Turner and Ashton of the Division of Animal Genetics (CSIRO) for help in preparing that part of this paper which deals with work at the National Cattle Breeding Station and Cattle Research Laboratory, Rockhampton, Queensland.

REFERENCES

1. Alexander G. and A. H. Brook, Loss of heat by evaporation in young lambs. *Nature, Lond.* **185,** 770—1 (1960).
2. Bonadonna T., *Zootecnica Speciale,* vol. 2., *Bovini-Equini.* Cisalpino, Milan (1950).
3. Bonsma J. C., Breeding cattle for increased adaptability to tropical and sub-tropical environments. *J. Agric. Sci.* **39,** 204—21 (1949).
4. Brook A. H. and B. F. Short, Sweating in sheep. *Aust. J. Agric. Res.,* **11,** 557—69 (1960).
5. Dowling D. F., The significance of sweating in heat tolerance of cattle. *Aust. J. Agric. Res.* **9,** 579—86 (1958).
6. Harrison, G. A., The adaptability of mice to high environmental temperatures. *J. Exp. Biol.* **35,** 892—901 (1958).
7. Harrison G. A., R. J. Morton and J. S. Weiner, The growth in weight and tail length of inbred and hybrid mice reared at two different temperatures. *Philos. Trans.* B **242,** 479—516 (1959).
8. Hayman R. H. and T. Nay, Sweat glands in Zebu *(Bos indicus L.)* and European *(Bos taurus* L.) cattle. *Aust. J. Agric. Res.* **9,** 385—90 (1958).
9. Johansson I., *Husdjursrasena.* L. T. 's Forlag, Stockholm (1953).
10. Joshi N. R. and R. W. Phillips, *Zebu Cattle of India and Pakistan.* Agric. Studies No. 19, Rome: F. A. O., (1953).
11. McDowell, R. E., D. H. K. Lee and M. H. Fohrman, The measurement of water evaporation from limited areas of a normal body surface. *J. Anim. Sci.* **13,** 405—16 (1954).
12. Mcdowell R. E., M. F. McMullan, Manika Wodzicka, D. H. K. Lee and M. H. Fohrman, Rate of water evaporation from various areas of normal body surface and with sweat glands inactivated under hot conditions. *J. Anim. Sci.* **14,** 1250 (1955).
13. Macfarlane W. V., Experimental approaches to the functions of tropical livestock. *Symposium on Arid Zone Climatology, Canberra.* UNESCO, Papers from Aust. and N. Z., No. 27, 1956.
14. Miller S. J. and G. R. Moule, Clinical observations on the reproductive organs of Merino rams in pastoral Queensland. *Aust. Vet. J.* **30,** 354—63 (1954).
15. Moule G. R., *Vital Statistics in the Queensland Sheep Industry.* Queensland Dept. Agric. Div. Anim. Industr. Pamphlet No. 15 (1952).
16. Moule G. R., Some problems of sheep husbandry in tropical Australia. *Aust. Vet. J.* **32,** 289—98 (1956).

17. Nay T., Sweat glands in cattle: histology, morphology and evolutionary trends. *Aust. J. Agric. Res.* **10**, 121—8 (1959).
18. Schmidt J. (Ed.), *Handbuch der Landwirtschaft*, vol. 4. *Besondere Tierzuchtlehre,* 2nd ed. Paul Parey, Berlin (1953).
19. Stewart A. H. and R. J. Moir, Fertility in Merino sheep in North Western Australia. *Aust. Vet. J.* **19**, 152—64 (1943).
20. Turner H. G. and A. V. Schleger, Field observations on associations between coat type and performance in cattle. *Proc. Aust. Soc. Anim. Prod.* **2**, 112—14 (1958).
21. Turner H. G. and A. V. Schleger, The significance of coat type in cattle. *Aust. J. Agric. Res.* **11**, 645—63 (1960).
22. Turner H. G. and A. V. Schleger, Analysis of coat characters of cattle *Aust. J. Agric. Res.* In press.
23. Yeates N. T. M., Photoperiodicity in cattle — I. Seasonal changes in coat character and their importance in heat regulation. *Aust. J. Agric. Res.* **6**, 891—902 (1955).
24. Yeates N. T. M., Photoperiodicity in cattle — II. The equatorial light environment and its effect on the coat of European cattle. *Aust. J. Agric. Res.* **8**, 733—9 (1957).
25. Yeates N. T. M., Observations on the role of nutrition in coat shedding in cattle. *J. Agric. Sci.* **50**, 110—12 (1958).

PLANT LIFE AND TROPICAL CLIMATE

P. W. RICHARDS

Professor of Botany. University College of North Wales, Bangor, Wales, Great Britain

Abstract—The absence of a cold season results in plant activities in the tropics being limited by lack of water rather than by low temperatures. The distribution of natural vegetation types in the tropics is thus mainly determined by the seasonal distribution of rainfall. The effects on plants of the excessively high temperatures found in some tropical habitats has been little studied, but the survival of some plant species in these seems to be dependent on the cooling due to transpiration.

Information on the growth rates of tropical plants, apart from a few cultivated species, is surprisingly incomplete, but the available data indicate that the very high rates found in some species depend on the rapid development of new leaf area rather than on net assimilation rates higher than those of temperate plants. The scanty evidence suggests that the rate of organic production by tropical forests is not much higher than in temperate hardwood forests.

In tropical countries with little seasonal change plants often show regular rhythms of flowering, leaf change, etc., but these may be out of phase with the climate. Even where there are marked wet and dry seasons, plants do not always behave in the way expected, e.g. some trees lose their leaves in the wet season and not in the dry. Seasonal rhythms in plants seem to be partly dependent on internal physiological rhythms and not entirely on the external environment.

Even in latitudes where differences in day-length are very small, day-length may be an important factor in controlling flowering and other seasonal phenomena in plants.

Résumé—L'absence de saison froide a pour conséquence que les activités des plantes sous les tropiques sont limitées par le manque d'eau plutôt que par les basses températures. Par conséquent la distribution de types de végétation naturelle sous les tropiques est surtout déterminée par la distribution saisonnière des chutes de pluie. Les effets sur les plantes des températures excessivement hautes trouvées dans quelques habitats tropicaux ont été peu étudiés, mais la survivance de quelques espèces végétales dans ceux-ci semble dépendre d'un refroidissement dû à la transpiration.

Les renseignements sur les taux de développement des plantes tropicales, à l'exception de quelques espèces cultivées, sont étrangement incomplets, mais les données dont on dispose indiquent que les taux très élevés trouvés chez certaines espèces dépendent du développement rapide d'une nouvelle aire foliaire plutôt que des taux d'assimilation nette, plus élevés que ceux des plantes tempérées. Les quelques renseignements que nous avons laissent supposer que le taux de production organique des forêts tropicales n'est pas beaucoup plus élevé que dans les forêts tempérées d'essences à bois dur.

Dans les pays tropicaux à légers changements saisonniers les plantes montrent souvent des rythmes réguliers de floraison, de changement de feuilles etc., mais ces rythmes peuvent bien être sans relation avec le climat. En effet, là où il y a des saisons humides et sèches nettement marquées, les plantes ne se comportent pas toujours dans le sens attendu, par ex. perdent leurs feuilles dans la saison humide et non pas dans la saison sèche. Les rythmes saisonniers chez les plantes semblent dépendre en partie de rythmes physiologiques internes et non pas entièrement du milieu.

Même dans les latitudes où les différences entre la longueur des jours sont très légères, la longueur du jour peut être un facteur important pour contrôler la floraison et les autres phénomènes saisonniers chez les plantes.

Auszug—Durch das Fehlen einer kalten Jahreszeit wird die Tätigheit der Pflanzen in den Tropen mehr durch Wassermangel als durch niedrige Temperaturen beschränkt. Die Verbreitung der natürlichen Vegetationstypen in den Tropen ist daher hauptsächlich von den Regenzeiten abhängig. Der Einfluss der besonders hohen Temperaturen auf die Pflanzen einiger tropischen Standorte ist erst wenig erforscht worden, aber manche dieser Pflanzenarten verdanken scheinbar der kühlenden Wirkung der Transpiration ihre Existenz.

Die Wachstumsverhältnisse der Tropenpflanzen, mit Ausnahme einiger Kulturpflanzen, sind überraschend wenig bekannt, aber die vorhandenen Ziffern zeigen dass das sehr schnelle Wachstum einiger Arten von der rapiden Entwicklung neuer Blattflächen abhängig ist eher von höherer Assimilation im Vergleich mit den Pflanzen der gemässigten Zonen. Die geringen Beweise deuten auf keine höhere organische Produktion in den Tropenwäldern, mit den Laubwäldern der gemässigten Zonen verglichen.

In tropischen Ländern mit wenig Unterschied zwischen den Jahreszeiten zeigen die Pflanzen oft einen regelmässigen Rhythmus der Blüte, des Blattwechsels, usw., der aber nicht dem des Klimas entspricht. Selbst dort wo es ausgesprochene Regen- und Trockenzeiten gibt, verhalten sich Pflanzen nicht immer erwartungsgemäss, z. B. verlieren manche Bäume ihre Blätter in der Regenzeit und nicht in der Trockenzeit. Der Jahreszeitrhythmus der Pflanzen scheint teilweise vom inneren physiologischen Rhythmus und nicht nur von der äusseren Umgebung bestimmt zu werden.

Selbst in Breiten wo der Tageslängenunterschied sehr gering ist, kann die Tageslänge ein entscheidender Punkt für die Blütezeit und andere zeitlichen Erscheinungen der Pflanzen sein.

As the sole protagonist for the plant kingdom in this symposium, I feel I have a formidable task. In twenty minutes I can hope to deal with only a very few facets of the complex relationships between plants and climate in the tropics. All I will attempt to do is to indicate in a general way one or two of the problems in this field which seem important to botanists at the present time. Most of these problems lead quickly into difficult and rather controversial fields of plant physiology about which not very much is yet known; as I am a field ecologist rather than a plant physiologist I must be excused if I deal with such questions generally rather than critically.

The title of my paper is "plant life and tropical climates" and I need not emphasize to this audience that even if we leave out mountains and plateau areas, tropical climates cover a very wide range. I do not want to discuss the various definitions of a tropical climate which have been proposed, but if we keep to the geographical definition of the tropics as the region between 23½° north and south latitude, we have at the one extreme desert climates with very large temperature ranges and very low and unreliable rainfall, and at the other climates such as that of Singapore and some of the Pacific islands which are constantly hot and humid and are more uniform throughout the year than any other environment on earth. This constancy of conditions reaches its limit in the microclimate of the undergrowth in the tropical rain forest. The American ecologist Allee (1926) wrote of the rain forest of Panama: "The animals of the lower forest. . . would need only to avoid the sun-flecks in order to keep under environmental conditions so constant that they must excite to envy of every experimental ecologist with experience in trying to control environmental factors for land animals in the laboratory."

With each tropical climate a particular type of natural vegetation is in equilibrium and there is as wide a difference in vegetation as in climate between the deserts and thorn scrubs of the arid tropics and the luxuriant evergreen forests of the equatorial regions.

Though lowland tropical climates differ widely their common features are that the mean temperature is relatively high and (possibly with a few rare exceptions) they are free from frost. From the plant's point of view this is of great importance as it means that plant activities are practically never checked by low temperatures; growth and other processes can proceed continuously, day and night, throughout the year. In fact they do not usually do so, but if they are checked by any factor in the external environment it is not as a rule by temperature but by some other factor, usually shortage of water. We can thus make a crude generalization and say that the earth consists of three regions, the tropics where plant activities may be limited by water, but hardly ever by temperature, the Arctic and Antarctic regions where temperature is a more important limiting factor than water, and the intermediate regions where conditions are complicated and both water and temperature may be limiting.

From the comparative unimportance of temperature as an ecological factor in the tropical lowlands it follows that the distribution of the major climatically determined vegetation types (such as evergreen rain forest, savanna woodland, etc.) depends mainly on the water supply at different times of the year, i.e. on the annual incidence of drought. The total annual rainfall is relatively unimportant compared with the seasonal distribution of the rainfall, together with certain modifying factors such as the water-retaining properties of the soil and desiccating winds (e.g. the West African Harmattan). Thus we sometimes find a less hygrophilous (or moisture-demanding) type of vegetation in localities with a high but unevenly distributed rainfall than in those with a lower rainfall which is spread throughout the year.

There is of course no simple definition of a dry season from the plant ecological point of view and there have been many attempts to classify tropical climates for biogeographical purposes so as to define quantitatively the climatic limits of the various types of natural vegetation. One of the most successful of these seems to be that of Lauer (1952) who defines a "dry month" as one in which the de Martonne index of aridity $12n/(t + 10)$, where n = precipitation in millimetres and t the temperature in °C) is less than 20. From the study of data from about 4,000 stations in tropical Africa and America, Lauer has shown that there is a very good correlation between the type of natural vegetation and the number of dry months calculated in this way.

Though water rather than temperature is the dominant ecological factor for plant life in the tropics, we must not of course neglect temperature entirely. It should be noted that in the tropics the daily variation of temperature is commonly greater than the seasonal variation of the means; thus, to use Carl Troll's terms, tropical climates are *Tageszeitenklimate* rather than *Jahreszeitenklimate*. This is of some importance in particular in relation to seasonal phenomena in tropical plants, a subject I shall refer to presently.

So far only the effects of low temperature on plants have been mentioned, but before leaving the subject of temperature reference should be made to heat resistance in plants. Plants are not homoiothermous organisms and plant physiologists, unlike human and animal physiologists, have not been much concerned with the effects of excessive heat, though of course plant cells, like animal cells, are readily killed or inactivated by high temperatures. As far as I am aware there is little definite information on the cooling effect of transpiration on leaves. It is of considerable interest however that Lange (1959) in a recent study of the heat resistance of the leaves of desert and savanna plants in Mauritania showed that different species differed widely in heat resistance and also in the temperature ordinarily reached by the leaves during the hottest parts of the day. In some the leaves often became up to 13° hotter than the surrounding air, while in others, apparently owing to the cooling effect of transpiration, the leaves are normally at a lower temperature, sometimes as much as 15° lower, than their surroundings. The species in which transpiration keeps the leaves well below air temperature have in general a low resistance to heat, temperatures only a few degrees above those normally reached being lethal. It seems probable that desert plants of this physiological type depend for their survival on the cooling produced by transpiration. The difference in heat resistance between different species appear to depend on differences in the properties of their protoplasm.

The first of the botanical problems I wish to deal with is that of growth and growth rates in tropical plants. The newcomer to the tropics invariably remarks on the luxuriance of the vegetation and if he stays long enough to notice it, on the rapid growth of tropical plants. Small clearings in the tropical forest if left to themselves become covered with a dense mass of vegetation in a few weeks; after a year or so the vegetation may be so dense that it is easier to walk round the former clearing than across it. Abandoned roads and railways soon disappear beneath second-growth vegetation. This luxuriance of tropical vegetation is of course mainly a feature of humid tropical areas like Borneo, southern Malaya and the central basin of the Congo where there is no well marked dry season to check plant growth, but it is also a feature of the seasonal tropics during the wet season; one cannot fail to be impressed by the sudden transformation of a dry and dusty savanna into a mass of lush vegetation with the coming of the rains.

Is rapid growth universal among tropical plants and how do their growth rates compare with those of temperate plants under comparable conditions, e.g. during moist summer weather when temperatures in temperate latitudes may be of the same order as in the humid tropics? Somewhat surprisingly it is possible to offer only tentative answers to these questions, because remarkably little is known about the growth rates of tropical plants, especially of wild plants in their natural habitats.

It is certain that some tropical plants grow extremely fast, but their growth rates vary very widely. One of the most famous examples of a rapid grower is the giant bamboo *Dendrocalamus giganteus*. According to Kraus (1895) under favourable conditions the stem may grow 22.9 cm in length per day over a period of 2 months; one specimen that he observed grew as much as 57 cm per day. The tree *Albizzia falcata* in Java is said to reach a height of 25 m in 6 years and 35 in 10 (Haberlandt, 1926, p. 111). The "Parasolier", *Musanga cecropoides*, which is so conspicuous on roadsides and old farmland in the moister parts of tropical Africa, can become a substantial tree 16 m or so in height in 14 years. It is interesting and perhaps significant that many of these rapidly growing trees are shortlived: *Musanga* usually dies before it is 20 years old.

All the examples just quoted are species of the secondary jungle, plants which spring up on old clearings and abandoned cultivated land and along railways and roads. The secondary forest species in fact occupy the habitats they do partly because of good means of seed and fruit dispersal (often by wind or birds) and partly because of their rapid growth. Since under modern conditions the average visitor to the tropics sees much more of these secondary forest species than of the slower-growing primary forest species he may get an exaggerated impression of the rapidity of growth of tropical plants in general.

As the examples given show, however, some tropical plants are indeed very fast-growing. It is interesting to compare these with rapidly growing temperate plants such as the sunflower *(Helianthus annuus)* under similar conditions. What is the exact physiological basis for their fast growth? There seem to be three possibilities:

(1) The average net assimilation rate (N. A. R. or unit leaf rate), i.e. the increase in dry weight of the whole plant per unit leaf area per day may be higher than in temperate plants.

(2) A larger proportion of the total net assimilation may be expended in increasing the leaf area than in temperate plants, leading to a more rapid increase in size of the plant as a whole.

(3) The rapid growth of tropical plants may depend simply on a long unbroken period of active growth, not interrupted by resting periods.

To have a firm basis for a comparison of tropical and temperate plants a large variety of tropical plants, under a range of conditions and at various stages in their life-cycle, will have to be studied: at present adequate data are not available, except for a few cultivated species which may not be typical. It is interesting to note the results obtained in two recent investigations designed to test the three possibilities mentioned above. Professor E. Njoku (1959) working at Ibadan in Nigeria studied a number of herbaceous plants commonly cultivated in West Africa, including maize, tomato and *Ipomoea purpurea (Pharbitis purpurea)* in two successive seasons.

Dr. D. E. Coombe (1960) studied young plants of *Trema guineensis*, one of the very fast-growing secondary forest trees which often colonizes clearings in the forest region of tropical Africa in the same way as the *Musanga* mentioned above. The plants were grown in experimental greenhouses at Cambridge and in order that the conditions should be similar as possible to those in the tropics the experiment was carried out at the equinox, with approximately 12-hr days. For comparison sunflowers were grown under the same conditions.

Neither Njoku nor Coombe found evidence in support of the first of the three possibilities mentioned above, i.e. their results are against the view that the rapid growth of tropical plants is due to a rate of carbon assimilation higher than in temperate plants. For his herbaceous species Njoku found values of the net assimilation rate somewhat higher than those usually found in the majority of temperate plants, but they were of the same order of magnitude and only a few were higher than values obtained for fast-growing temperate herbaceous plants such as the sunflower. In Coombe's young *Trema* the N. A. R. was of the same order as in temperate woody species, but about half that of the sunflowers grown in the same environment. The evidence from both these investigations, as far as it goes, favours the view that rapid growth in tropical plants is mainly a result of rapid and efficient development of new leaf area; this does not of course rule out a contribution by the third of the three possibilities, uninterrupted activity. Other factors besides temperature, especially light, must be taken into account in discussing results such as those of Njoku and Coombe, but to do this would take us too far.

It would be very interesting to be able to discuss production rates, i.e. the amount of organic matter per unit of land surface, annually produced by rain forests and other tropical plant communities, but data are even less adequate than for the study of growth rates. It is of interest, however, to mention the provisional figures of D'Hoore (1959) for an area of old secondary rain forest at Yangambi in the Congo. He estimates that the standing forest (trunks, twigs, leaves, roots, etc.) represents 150—250 metric tons of dry matter per hectare. From this about 15 tons/hectare per year are returned to the soil in fallen wood, leaves, etc., and the amount of organic matter synthesized annually at about 20 tons/hectare. It would be rash to generalize from these figures, but it may be noted that the figure for the annual production appears to be of the same order as figures which have been published for hardwood plantations in temperate countries, but considerably lower than figures for conifer plantations.

Lastly I should like to deal briefly with what is to me one of the most fascinating subjects in tropical botany, viz. the periodic or seasonal behaviour of tropical plants. In temperate countries such as England we take the seasonal flowering, leaf production, leaf fall and growth of our plants very much for granted and tend to regard these phenomena, without further reflection, as depending on the seasonal changes of temperature and light. In the tropics many plants also show periodic rhythms, though some appear to be continuously active and others behave irregularly. Regular periodic behaviour is not unexpected in plants of tropical regions with strongly contrasted wet and dry seasons, but is more surprising in tropical climates which have rain at all seasons and only a very small seasonal variation of temperature. In such areas in fact the native inhabitants may be scarcely conscious of seasonal changes and depend on the seasonal behaviour of wild plants to provide them with a time-table for their agricultural operations. Thus in southern Malaya the flowering of the tree *Sandoricum koetjape* was formerly the signal for planting rice and various other trees are used similarly in planting crops in the New Hebrides.

Thanks chiefly to the patient work of Professor R. E. Holttum (1953, and further references given there) a most interesting body of data extending over a considerable number of years has been assembled on the date of leaf change and flowering for various species of trees at Singapore, which has one of the least seasonal climates in the world. Among the species which showed regular periodic behaviour with only a small standard deviation were some in which individuals renewed their leaves every 12 months, others every 6 months and some at other intervals such as every 9 months. One species changed its leaves at three successive intervals of 2 years and 8 months.

The occurrence of regular periodic rhythms of leafing and flowering in plants growing in an almost unvarying climate raises the question how far the plant's behaviour is dependent on the environment and how far on some kind of internal physiological "clock" which may be "regulated" by the external environment, but is not directly dependent on it. Even in tropical climates with well marked wet and dry seasons, the correspondence between the behaviour of the plant and the changes of climate is far from exact. A striking instance of this is the perverse plant *Acacia albida* which is widespread in the savanna regions of Africa; it is leafless during the rainy season and produces new leaves in the dry season when many of its associates are dropping theirs. The "pre-rain flora" of the African savannas is another example; it has often been noted that many savanna plants come into flower near the end of the dry season, not after the first falls of rain but some weeks or days before. The regrowth of the savanna grasses after the annual burning, at least in my own experience in the Guinea savannas of Nigeria, begins long before the rains when the dry season is still at its height.

Periodic phenomena such as flowering and leafing in tropical plants are often much less synchronized than in temperate plants, different species and different individuals of the same species flowering or shedding their leaves at different times of year. In some cases even different parts of the same individual plant may be at different stages at the same moment. This is common in the Silk Cotton or Kapok tree, *Ceiba pentandra*, in which it is quite usual to see trees with some branches in leaf, some bare, some in fruit and some beginning to flower. The mango and other trees behave similarly, though not so markedly.

At the other extreme to plants in which even different branches are not synchronized are those which show "gregarious flowering". In these cases large numbers of individuals, sometimes distributed over a large area, open their flowers at precisely the same time, often after a long period in which there have been no open flowers.

This type of behaviour is seen in several species of *Coffea* and in various orchids, of which the Malayan Pigeon Orchid, *Dendrobium crumenatum*, has been the most studied. In these orchids, and presumably in other instances of gregarious flowering, though there may be no obvious relationship to a change of weather, some external stimulus must trigger off the opening of the flowers. In *Dendrobium crumenatum* the stimulus has been shown to be a fall of temperature, such as may be caused by a heavy thunder shower.

A somewhat different phenomenon is the gregarious flowering of many bamboos and of species of *Strobilanthes*, all plants of tropical regions with a fairly well marked dry season. In these an individual plant flowers only once and then dies. In *Strobilanthes sexennis* and other species of the genus *Strobilanthes* in Ceylon flowering occurs every 12 years, though in different districts flowering may occur in different years. All the plants over a considerable area flower together and after flowering the ground is covered with the bare dead stems and a dense mass of young seedlings.

In species where different individuals or different parts of the same plant are not synchronous in behaviour, periodicity must presumably be due to some sort of internal physiological rhythm which is little if at all affected by external conditions. Such plants can exist only in a climate which is favourable to their activities at all times of year. The behaviour of plants which are synchronous, including gregariously flowering species, must be dependent on some change in external conditions; their periodicity may be basically dependent on an internal rhythm, but it must be "regulated" by the external environment.

In temperate climates, as is well known, day-length is one of the most important environmental factors determining flowering, leafing and other seasonal behaviour in plants, but until fairly recently it was generally supposed that the seasonal differences in day-length in the tropics were too small to be an important factor in controlling plant behaviour. Some years ago, however, Bünning (1948, 1953) argued that tropical plants might be more sensitive than temperate plants to small differences in day-length and that except close to the equator (where of course there are no differences of day-length) photoperiodic responses may be important in tropical plants. Since then evidence in support of this view has come forward. For instance it has been found that a Malayan variety of rice was sensitive to small differences of photoperiod (Dore, 1959). Njoku (1958) working at Ibadan in Southern Nigeria (7° 26′ N), where the day-length varies from 11 hr 40 min in December to 12 hr 33 min in June, experimented with a number of native and cultivated plants. In about half of these, flowering was dependent on day-length, and for some of them a difference of only 15 min may determine whether a plant flowers or not. Some species have a critical day-length of 12¼ hr or less, others 12½ hr or more. The results of the experiments fitted well with experience in the field; thus it is known that cowpeas in Nigeria should not be planted before July, otherwise they will not flower or seed freely, and in the experiments this plant proved to flower earlier and fruit better in day-lengths of 12 hr or less, though its critical day-length was outside the natural range of photoperiods at Ibadan.

This brief account will have made clear, I hope, that in plant physiology, as in animal physiology, tropical climates present very interesting special problems. The study of plant physiology in the tropics is still in its early stages; there is a great need for more research, especially on native plants in their natural habitats.

REFERENCES

ALLEE W. C. (1926) Measurement of environmental factors in the tropical rain-forest of Panama. *Ecology* **7**, 445—68.

BÜNNING E. (1948), Studien über Photoperiodizität in den Tropen. In *Vernalization. and Photoperiodism* (edited by MURNEE A. E. and WHYTE R. O.). Waltham, Mass.

BÜNNING E. (1953), Entwicklungs- und Bewegungsphysiologie der Pflanze. *Lehrbuch der Pflanzenphysiologie,* 3 Ed. Berlin.

COOMBE D. E. (1960), An analysis of the growth of *Trema guineensis*. *J. Ecol.* **48**, 219—31.

D'HOORE J. (1959), Paper communicated to *Colloque COTA/UNESCO sur les relations entre la végétation et les sols* (Abidjan).

DORE J. (1959), Response of rice to small differences in length of day. *Nature, Lond.* **183**, 413—14.

HABERLANDT G. (1926), *Eine botanische Tropenreise,* 3 Ed. Leipzig.

HOLTTUM R. E. (1953), Evolutionary trends in a tropical climate. *Symposia of the Society of Experimental Biology,* 7 *(Evolution*), pp. 159—73.

LANGE O. L. (1959), Untersuchungen über Wärmehaushalt und Hitzeresistenz mauretanischer Wüsten- und Savannenpflanzen. *Flora* **147**, 595—651.

LAUER W. (1952), Humide und aride Jahreszeiten in Afrika und Südamerika und ihre Beziehung zu Vegetationsgürteln. In *Studien zur Klima- und Vegetationskunde der Tropen*. Bonner Geogr. *Abhandl.* Heft 9.

NJOKU E. (1958), The photoperiodic response of some Nigerian plants. *J. West. Afr. Sci. Ass.* **4**, 99—111.

NJOKU E. (1959), An analysis of plant growth in some West African species — I. Growth in full daylight. *J. West. Afr. Sci. Ass.* **5**, 37—56.

In addition to the above, reference may be made to the author's *The Tropical Rain Forest* (1952, repr. 1957) in which many aspects of tropical vegetation in relation to climate are discussed.

PHYSIOLOGY AND BIOCLIMATOLOGICAL STUDIES IN EAST AFRICA

C. P. LUCK
Professor of Physiology, Department of Physiology, Makerere College Medical School, Kampala, Uganda

Abstract—The African Continent possesses a great variety of climatic and vegetational regions within which have developed a wide variety of animal species, showing a striking assortment of ways in responding to the climatic stresses imposed upon them. In East Africa there are examples of most of the major climatic and vegetational types to be found in the continent, with, consequently, the opportunities to study within a relatively small area a great number of animal adaptations. From the point of view of comparative physiology these studies should be intensified before the rapid transformations in the human sociological and political fields have so disturbed the present ecological phenomena that the animals concerned become extinct. The Departments of Veterinary and Medical Physiology at Makerere College, the University College of East Africa, have over recent years specialized in the techniques of animal capture and of performing laboratory investigations in the field. A wide range of animals can now be studied under their natural conditions with advanced laboratory equipment. It is to be hoped that many workers will avail themselves of the opportunities that now exist at this institution.

Résumé—Le Continent Africain possède une grande variété de régions climatiques et de types de végétation, à l'intérieur desquelles s'est développée une variété considérable d'espèces animales présentant un ensemble frappant dans la manière de réagir aux "stresses" climatiques qui leur sont imposés. En Afrique Orientale on rencontre des exemples de la plupart des principaux types de climat et de végétation qui existent sur le Continent, d'où l'occasion favorable d'étudier à l'intérieur d'une zone relativement restreinte un grand nombre d'adaptations parmi les animaux. Du point de vue de la physiologie comparée ces études devraient être intensifiées avant que la transformation rapide dans le domaine humain, sociologique et politique ait perturbé le phénomène écologique actuel au point que les animaux en question commenceraient à disparaître. Au cours des dernières années les Sections de Physiologie Vétérinaire et Médicale au "Makerere College", le "Collège" d'Université de l'Afrique Orientale se sont spécialisées dans la technique de la capture des animaux et de l'amélioration des recherches de laboratoire à ce sujet. A présent une grande série d'animaux peut être étudiée dans des conditions naturelles avec un équipement de laboratoire perfectionné. Il faut espérer que de nombreux chercheurs profiteront des circonstances favorables créées dans cette institution.

Auszug—Der Erdteil Afrika besitzt zahlreiche Gebiete mit stark unterschiedlichen Klima- und Wachstumsverhältnissen, in denen sich die verschiedenartigsten Tiergattungen entwickelt haben, die in verblüffender Vielfalt auf die ihnen auferlegten Klima-Beanspruchungen reagieren. In Ostafrika sind Beispiele für die meisten hauptsächlichen Klima- und Wachstumstypen des Kontinents zu finden. Dadurch ist Gelegenheit gegeben, die tierische Anpassungsfähigkeit in grosser Vielfältigkeit auf verhältnismässig kleinem

Raum zu studieren. Nach dem Gesichtspunkt der vergleichenden Physiologie müssten derartige Untersuchungen verstärkt werden, bevor die schnelle Wandlung auf dem Gebiet der menschlichen Soziologie und Politik die gegenwärtigen Umwälzerscheinungen so weit beeinflusst hat, dass die betreffenden Tiere aussterben. Die Abteilung für Medizinische und Veterinärmedizinische Physiologie der zur Universität von Ostafrika gehörenden Hochschule von Makerere hat sich in den letzten Jahren auf die Technik des Tierfangs und die Durchführung laboratorischer Untersuchungen auf diesem Gebiet spezialisiert. Eine grosse Zahl von Tieren kann heute in natürlicher Umgebung und unter Verwendung modernster Laboratoriumseinrichtungen studiert werden. Es ist zu hoffen, dass viele Wissenschaftler sich der Möglichkeiten bedienen, die heute in diesem Institut gegeben sind.

THE opportunities for studies in comparative physiology in East Africa are outstanding. The altitude ranges from sea level to nearly 20,000 ft; we have areas in which the rainfall is as low as 5 in./year and others in which figures reach 90 in./year. Desert and tropical rain forest, vast areas of swamp and open water, steppe and savannah, with every subtle modification and transition, can be found, with an equivalent variety of plant and animal life. Small, isolated ecological areas, islands of life in the desert exist. There is the slow creep of the desert, the desiccation of watered areas, the influence of catastrophic drought, the rapid inroads of man and its repercussions on animal, plant and climate. All remain to be studied in a land where ecological changes can be as rapid and as drastic as the political ones, of which they are at times the cause, at others the effect.

The changes come so fast that one fears that the full natural history of this extraordinary area will never be known or written before the final page is irrevocably turned, and that we shall perhaps, like Tarquinius with the sibylline books, belatedly be eager to pay all our fortune for pitiful remnants of what was once the greatest treasure house of biological knowledge that we shall ever have had the chance to explore.

Living where we do, I think we still have these opportunities. But immediately to the west the door has been closed — who knows if it will open again.

I shall not discuss in any detail what steps are being taken to know, preserve and record our forests, rivers, plains and all that moves in them. Our main hope is to make this extraordinary country a source of national pride, the strongest force in the countries at the moment, hoping that it may balance reckless greed when the time comes. Secondly, every effort is being made to emphasize whatever economic advantages may spring from a thoughtful conservation and an even more thoughtful exploitation of these resources.

Thirdly, and this is where we chiefly try to play our part, to discover and record while we may.

For this purpose we have the following general strategy.

We take every opportunity to investigate animals in the field. Principally it is physiological knowledge we seek, but we try not to wrest it from its true setting, as it is in the setting that the biological mechanism and purpose of physiological phenomena are to be found. At this level we make no claim to profound study, although we make it as thorough as circumstances will permit — the first task in mining is to reveal the ore and not to refine it. Facts of interest are noted and certain are singled out for close study, either because they particularly appeal to us or because they seem essential links in a chain. This second side of our work is now beginning to get under way, for which we have principally the Wellcome Trust to thank.

Our methods are, therefore, to take into the field the most practical and comprehensive laboratory possible, to allow us to exploit fully our fortune in the field, and to bring back what material we can for deeper investigation.

Then we move on to the next stage: to bring the animal of a particular study back to the base laboratory. We have therefore a small, compact animal house within our laboratory grounds in which, with care we can hope to house most animals, e.g. hippo, giraffe, antelope, certain carnivores and primates.

The next phase is to bring experts, workers who may, so to speak wish to refine the ore or start their own mining operations. This too is now largely possible, and we hope within the next few months, to see people working with us and doing what we would have neither the time, the skill or the intellect to do. We are extremely keen, however, that the work should be done on the spot; this for many reasons. It is so much more satisfactory to have at hand the opportunity to refer back to the entire animal, which includes its setting; not to be hagridden and cramped in one's work by the fear of losing an irreplaceable specimen. And we feel we owe it to the country and its institutions that they shall acquire a higher scientific reputation than one associates merely with a purveyor of animals to a zoo.

What has this to do with bioclimatology? Simply this. Our formal discipline is physiology. We know far too little of meteorology and climatology but we know enough to see how vital it is in grasping the wholeness of living things. I have no business to stand before you unless it be to show you opportunities that we can never use, but that might be of interest or use to you. If, however, I succeed in interesting you and even conceivably persuading you to lend us your advice, skill, and perhaps your personal presence, I have not come here in vain.

SOME ASPECTS OF THE TEMPERATURE RELATIONS OF FIDDLER CRABS (*UCA* SPP.)

E. B. EDNEY
Professor of Zoology, University College, Salisbury, S. Rhodesia

Abstract—Work in progress on *Uca* spp. at Inhaca is concerned with the evolution of terrestrial fauna and with physiological factors involved in local distribution.

Upper lethal temperatures are sharp, specifically distinct, and show acclimatization. Lower lethals are less sharp and not specifically distinct. Sharpness of the upper lethals may be the result of selection, since crabs are in nature exposed to near lethal temperatures. Acclimatization in respect of O_2 uptake is of selective advantage, and acclimatization in respect of upper lethal temperatures may be a neccessary result, rather than advantageous in itself.

Résumé—Les recherches en cours sur *Uca* spp. à Inhaca se concentrent sur l'évolution de la faune terrestre et sur les facteurs physiologiques liés à la distribution locale.

Les températures supérieures amenant la mort sont précises et spécifiquement distinctes; elles démontrent l'accoutumance. Les températures inférieures amenant la mort sont moins précises et ne sont pas spécifiquement distinctes. La précision des températures supérieures mortelles peut résulter de la sélection, puisque les crabes sont exposés dans la nature à des températures qui ne sont pas loin d'être mortelles. En ce qui concerne l'absorption de O_2, l'accoutumance est avantageuse dans la sélection naturelle. L'accoutumance à des températures supérieures mortelles peut résulter de la nécessité plutôt qu'être un avantage en soi.

Auszug—Die im Gange befindlichen Forschungen in Inhaca über *Uca* spp. befassen sich mit der Entwicklung der Landfauna sowie mit physiologischen Faktoren, die mit der örtlichen Verbreitung verknüpft sind.

Die tödlichen höheren Temperaturen sind genau bestimmt, spezifisch verschieden und zeugen von Angewöhnung. Niedere tödliche Temperaturen sind weniger genau bestimmt und nicht spezifisch verschieden. Die Genauigkeit der höheren tödlichen Temperaturen könnte das Resultat der natürlichen Zuchtwahl sein, denn in der Natur sind Krabben nahezu tödlichen Temperaturen ausgesetzt. Betreffs der Absorption von O_2 ist die Angewöhnung vorteilhaft in der Zuchtwahl. Betreffs der höheren tödlichen Temperaturen kann die Angewöhnung ein notwendiges Resultat sein, eher als ein Vorteil an und für sich.

INTRODUCTION

This paper describes some of the work which is being done on the factors determining the distribution of five species of *Uca* in Inhaca Island, near Lourenco Marques (lat. 26° S.). These crabs are semi-terrestrial, and the physiological problems they meet are similar to those which confront any population of animals as it evolves from marine to land life.

The crabs live in holes in the sand and/or mud of estuaries or mangrove swamps. The habitat is exposed for longer or shorter periods at low tide. During such exposure the crabs emerge from their holes to feed on organic detritus, and then they experience the rigours of terrestrial conditions, including high and rapidly fluctuating temperatures and dry air.

Observation suggests that the five species which occur at Inhaca differ in habitat preference, and that some species are more "landworthy" than others. Thus *U. inversa* lives in open sandy flats, and is exposed to direct insolation for long periods, while *U. urvillei* is restricted to channels in the mangrove swamps, a less terrestrial habitat. We shall be concerned here with some of the effects of temperature in the lives of these animals.

UPPER AND LOWER LETHAL TEMPERATURES

The upper lethal temperature (for 15 min exposures) may be determined to within 0.5°C, and it varies between species from about 43.3°C for *U. inversa* to about 40.0°C for *U. urvillei* (Fig. 1). The higher lethal temperatures are shown by the more

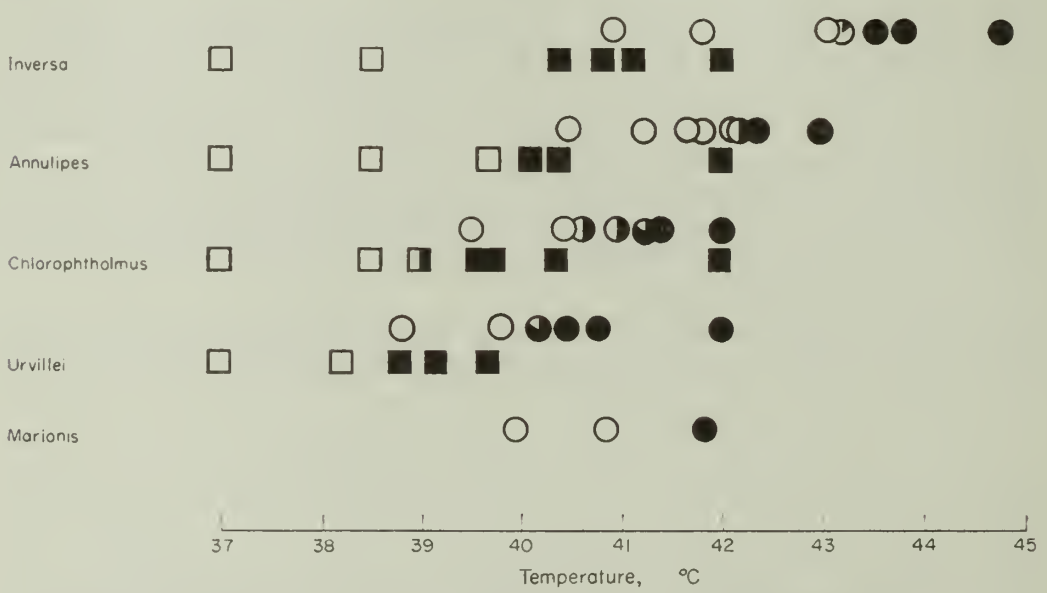


FIG. 1. High lethal temperatures of five species of *Uca*. Each symbol represents the results for six crabs and the number of dead crabs is shown by shading the symbol proportionately. Circles refer to observations in January 1959; squares to those in September 1957. The species differ in respect of their high lethal temperatures, and these are in each case about 2°C higher in January than in September

terrestrial species. The low lethal temperatures, however, are less precisely defineable, because there is greater variability between individuals (see Fig. 2). In addition, the results show no difference between the species as regards their low lethal temperatures: thus (for 15 min exposures again) all the crabs of all species studied lived at 8.5°C or above, while below 7.0°C they all died.

Acclimatization as regards high lethal temperature has also been found. The results reported above were obtained in January 1959 (high summer), but results

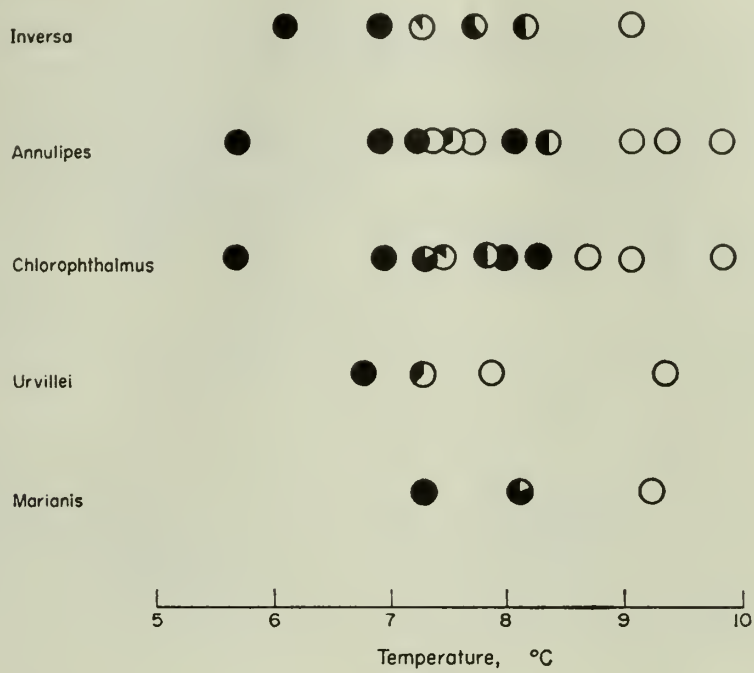


FIG. 2. Low lethal temperatures. Symbols as in Fig. 1. The species do not differ in respect of their low lethal temperatures, and these are less well defined than are the upper limits

obtained in September 1957 (when the ambient temperature was lower by some 2—3°C) showed that although the lethal temperatures again varied between species, they were nearly 2.0°C lower for each species. (There are no figures for *marionis* at this time.) Up to the present there are no figures for low lethal temperatures at any time other than January, so that we cannot say whether acclimatization occurs in this respect.

TEMPERATURES IN THE FIELD

Work being published elsewhere (Edney, in press) showed that the body temperature of a fiddler crab is lower than that of the environment, as a result of evaporation of water. In nature, of course, the body temperature of a crab is the resultant of a number of interacting factors, of which radiation from the sun and sky and from neighbouring bodies, conduction to and from the ground, convection by air movement and heat loss by transpiration, are important.

It is interesting, therefore, to measure the body temperature of crabs in the field and to consider this in relation to: (i) the known lethal temperatures, and (ii) temperature in the various habitats. What little information has already been obtained will now be described.

Temperatures of the crabs were measured by fine thermo-needles, which could be relied upon to the nearest 0.1°C. Fig. 3 shows a series of readings made on one

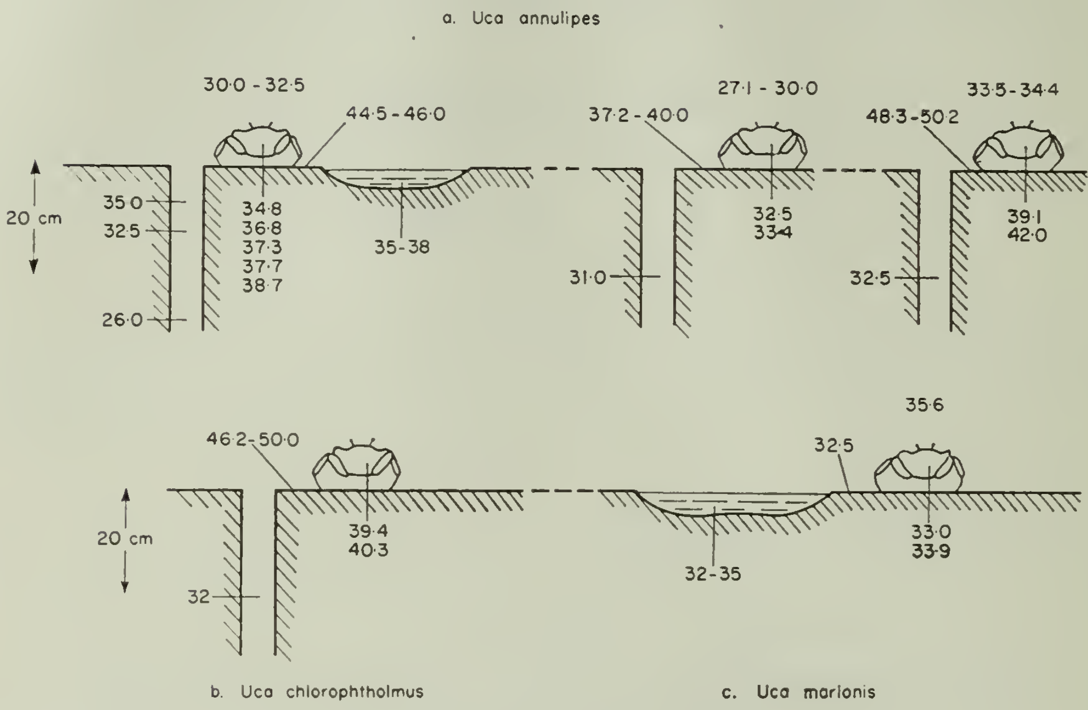


Fig. 3. A diagrammatic representation of temperatures measured in the natural habitat of three species of *Uca*. The crab's temperatures are usually below those of the ground, but even so they may be near the lethal level. Holes and pools form retreats for the crabs if their temperatures are too high or if they lose too much water. The scale refers to the holes only. Other numbers are temperatures in °C

afternoon, at low tide, when the habitat was exposed. Fig. 3(a) shows measurements at three points on a transect in the habitat of *U. annulipes* from a point near *Avicennia* mangrove forest (left of diagram) across an open sandy flat. It emerges from these readings that although the temperature of the sand surface was often well above the crabs' lethal temperature (up to 50.2°C) the crabs' temperatures were always lower (because of convection of heat to the cooler air and because of transpiration); though in one case a crab's temperature was as high as 42.0°C, which is close to its lethal limit for a 15 min exposure. However, there were numerous holes to which the crabs could retreat, where (as the diagram shows) temperatures were lower. There was no danger of desiccation, for all the holes went down as far as the water table.

Figs. 3(b) and (c) show comparable measurements made in the habitats of *U. chlorophthalmus* and *U. marionis*, respectively. These were near a stream in *Rhizophora* mangrove forest, and where this stream debouched upon a wider open channel. Here again, however, the temperature of *U. chlorophthalmus* was often near its lethal level, but well below that of the substrate.

Much more systematic information than is now available is necessary before we can assess the significance, if any, of environmental temperature in limiting the distribution of each species; but it can be said that, because it is necessary for the animals to emerge from their holes to feed, they are sometimes exposed to dangerously high environmental temperatures.

DISCUSSION

That the high lethal temperature varies between species is perhaps to be expected, and so far as the limited evidence goes, the more "terrestrial" species (living in drier, hotter and more exposed areas) show higher lethal temperatures; but more information about environmental temperature is necessary.

In any species, the upper lethal temperature is fairly sharp, and if, as the present evidence suggests, the crabs are commonly exposed to near lethal temperatures, such a sharpness and consistency between individuals might be expected, as a result of strong selection pressure leading to a more homogeneous population. There is, however, no evidence of any strong selection pressure affecting the low lethal levels, since temperatures as low as 7—8°C are seldom if ever met with at sea level in the latitude of Inhaca. A more heterogeneous population within a species may therefore be expected, because each species is not physiologically extended as it were, and the low lethal temperature may be determined by other factors which are the same for each species.

Verwey (1930), Orr (1955) and Teal (1958) have also established high lethal temperatures for various other species of *Uca*, and these are consonant with the present results if allowance is made for the rather different methods used. Teal, however, did not find any difference between the high lethals of three species of *Uca* from different habitats in salt marshes in America.

Acclimatization has been demonstrated in several species of *Uca* in respect of the relation between temperature and oxygen consumption (Roberts, 1957; Tashian, 1956; Vernberg, 1956, 1960; Demeusy, 1957), and Vernberg and Tashian (1959) have recently shown acclimatization by *Uca* in respect of lethal temperatures.

The ability to acclimatize in respect of metabolic rate is probably of greater general importance, since it affects processes going on at all times and permits animals to live economically yet actively at different latitudes and at different seasons. This is particularly valuable to a terrestrial organism, whose environment varies widely and rapidly in respect of temperature.

But acclimatization in respect of the high lethal temperature would not seem to confer any advantage upon even a terrestrial animal — for if it *can* survive a high temperature after certain pre-conditioning, what advantage is there in lowering this limit at another time? Unless, of course, toleration of extreme temperatures necessarily involves an animal in some other disadvantage, such as extra energy output, or other metabolic stress.

It is possible, however, that the two forms of acclimatization are linked. If we assume that a very high metabolic rate is lethal, then a change in the relation between rate of O_2 uptake and temperature ($R:T$) (either by a horizontal shift in position of the $R : T$ curve, or by a change in its shape (change of Q_{10}), or both), would result in a change in high and low lethal levels. On this view, acclimatization in respect of high and low lethal temperatures would depend upon alteration of the $R : T$ relation. Thus a rise in high lethal temperature would imply a lower metabolic rate at *any* temperature, and since this could lead to inefficiency when the environmental temperature falls, the $R : T$ relation must revert and hence the high lethal temperature must again fall.

CONCLUSIONS

The five species of *Uca* at Inhaca show different high lethal temperatures, and each is fairly sharp, perhaps as a result of strong selection pressure. In the field the crabs are exposed to a complex of factors which sometimes together produce a body temperature close to lethal. Acclimatization in respect of high lethal temperatures has been found, and it is suggested that this process may be necessarily linked with acclimatization in respect of metabolic rate; such acclimatization having been demonstrated by other workers with other species.

Much more information is necessary about conditions in the habitats preferred by each species, and about the length of time spent by any one individual in the open, before anything more can be said as to the effect of temperature in limiting local distribution.

ACKNOWLEDGEMENTS

I am indebted to the Portuguese authorities for facilities at Inhaca Island and to the Wellcome Trust for a grant in aid of my travel to London to attend the Society's Congress.

REFERENCES

DEMEUSY N. (1957), Respiratory metabolism of the fiddler crab, *Uca pugilator,* from two different latitudinal populations. *Biol. Bull. Wood's Hole* **113,** 245—53.

EDNEY E. B. (in press) The water and heat relationship of fiddler crabs *(Uca* spp.). *Trans. Roy. Soc. S. Afr.*

ORR P. R. (1955) Heat death — I. Time temperature relationship in marine animals. *Physiol. Zool.* **28,** 290—3.

ROBERTS J. L. (1957) Thermal acclimatization of metabolism in the crab *Pachygraprus crassipes* Randal — I. The influence of body size, starvation and moulting — II. Mechanisms and the influence of seasons and latitude. *Physiol. Zool.* **30,** 232—55.

Tashian R. E. (1956) Geographic variation in the respiratory metabolism and temperature coefficient in tropical and temperate forms of the fiddler crab, *Uca pugnax*. *Zoologica* **41**, 39—47.

Teal J. M. (1958) Distribution of fiddler crabs in Georgia salt marshes. *Ecology* **39**, 185—93.

Vernberg F. J. (1956) Study of the oxygen consumption of excised tissue of certain marine *decapod crustacea* in relation to habitat. *Physiol. Zool.* **29**, 227—34.

Vernberg F. J. (1960) Studies on the physiological variation between tropical and temperate zone fiddler crabs of the genus *Uca* — III. The influence of temperature acclimatization on oxygen consumption of the whole organism. *Biol. Bull. Wood's Hole* **117**, 582—93.

Vernberg F. J. and Tashian R. E. (1959) Studies on the physiological variation between tropical and temperate zone fiddler crabs of the genus *Uca* — I. Thermal death limits. *Ecology* **12**, 589—93.

MECANISME DE L'OLIGURIE TROPICALE

R. R. LEMAIRE et J. ALLEGRINI
Professeur de physiologie, Lab. de physiologie de la Faculté de Médecine de l'Univ. De Dakar, Senegal

Abstract—Oliguria observed in man in tropical climate is due to an increase of secretion of the antidiuretic hormone. This hypersecretion is produced by an increase of osmotic pressure of the plasma.

Résumé—L'oligurie constatée chez l'homme en milieu tropical est due à une augmentation de la sécrétion d'hormone anti-diurétique. Cette hyper sécrétion hormonale est consécutive à une hypertonie du milieu plasmatique.

Auszug—Die bei Menschen in tropischen Klimaten beobachtete Oligurie ist auf eine erhöhte Sekretion des anti-diuretischen Hormons zurückzuführen. Diese Hypersekretion wird hervorgerufen durch eine Erhöhung des osmotischen Druckes der plasmatischen Abteilung.

Dans les pays tropicaux, au cours de bilans hydriques, on constate que l'évaporation est considérablement augmentée, tandis que la diurèse est très diminuée; et en toute grossière approximation, on peut admettre que dans ces pays, le volume urinaire est inférieur à 1000 cm³/24 hr. Cette oligurie a été signalée par de nombreux auteurs: Adolph (1), Ladell 2). Son mécanisme est certainement complexe; on a pensé que l'oligurie tropicale pouvait être sous la dépendance d'un facteur endocrinien, l'hormone en cause étant peut-être alors l'hormone antidiurétique.

TECHNIQUE

Nous avons tout d'abord constaté que cette oligurie est en relation avec la rigueur des conditions ambiantes. A Dakar, en saison chaude, pour une température au thermomètre sec supérieure à 26°C, la diurèse moyenne est de 900 cm³/24 hr, tandis que sous des climats plus sévères, l'oligurie peut s'abaisser jusqu'à 600 cm³/24 hr (Gao, Bamako).

Nous avons évalué la teneur en HAD dans des urines recueillies dans ces différents pays. Après avoir stabilisé l'activité antidiurétique par action du froid et des acides, nous avons évalué l'HAD par une méthode biologique basée sur la réponse diurétique de rats préalablement hydratés, auxquels on a injecté dans le péritoine 1 cm³ du liquide contenant la quantité d'hormone à doser; la diurèse des animaux subit alors une diminution proportionnelle à la quantité injectée (3).

RESULTATS

Les valeurs d'HAD trouvées dans les échantillons urinaires, apparaissent dans le tableau ci-joint.

Si l'on admet que des sujets vivant à Dakar peuvent être considérés comme des témoins, on note que le jour la teneur en HAD des urines est faible tandis que

Tableau 1. Teneur en HAD des Urines des Sujets Vivant dans les Pays Tropicaux

Lieu du prélèvement date de l'expérience	HAD/jour (mU/cm^3)	HAD/nuit (mU/cm^3)	Diurese/24 hr
Atar—juin		0,60	700
		0,55	700
		0,70	700
		0,65	700
Atar — juillet	0,25		700
	0,25		700
	0,25		700
Dakar — mars	$\neq$ 0,20		1200
	$\neq$ 0,20		1100
	$\neq$ 0,20		900
	$\neq$ 0,20		1100
Dakar — avril		0,40	1050
		0,45	1100
		0,40	900

celle de la nuit est notablement plus élevée. Les unes et les autres restent toutefois nettement inférieures à 0,50 mU/cm^3. Pour des sujets vivant au Sahara Occidental, pendant la saison chaude, on constate que la teneur en HAD des urines du jour est légèrement augmentée, celle de la nuit est au contraire très élevée. Il existe donc pour les climats presque tempérés comme pour des ambiances très agressives, les mêmes variations nycthémérales des diurèses, mais en milieu désertique la quantité d'hormone éliminée par les urines est plus importante.

DISCUSSION

Dans l'interprétation de ces différences, deux mécanismes peuvent être invoqués.

L'augmentation d'HAD constatée en milieu tropical agressif est due, soit à une action directe de la chaleur sur les centres diencéphaliques par l'intermédiaire du système nerveux, soit être le résultat d'une action physico-chimique de la concentration électrolytique du plasma agissant par l'intermédiaire des «osmorécepteurs de Verney». Pour nous en rendre compte, nous avons inversé les données et enregistré les valeurs en HAD d'urines vespérales de sujets privés de boisson durant la journée, de même que les urines du matin d'un sujet ayant absorbé de l'eau plusieurs fois au cours de la nuit. Nous avons constaté une inversion des résultats: les urines du sujet privé d'eau le jour peuvent atteindre la valeur maxima de 1 mU/cm³ d'HAD, tandis que les urines du sujet buvant plusieurs fois par nuit, ne contiennent plus que 0,25 mU/cm³ d'HAD.

Afin de préciser l'influence que le système nerveux pourrait avoir sur cette oligurie tropicale, nous avons administré à des sujets en état d'oligurie au Soudan, de la «génésérine». Ce déséquilibre neuro-végétatif expérimental n'a pas modifié l'oligurie constatée.

CONCLUSION

L'oligurie tropicale est bien due à une augmentation de la sécrétion d'hormone antidiurétique qui est la conséquence d'une variation physico-chimique. Cette oligurie paraît en relation avec la quantité d'eau absorbée.

L'oligurie serait en quelque sorte une réaction de défense qui permet l'économie de l'eau dont une plus grande quantité devient ainsi disponible pour la thermolyse. Nous ne pouvons complètement éliminer la possibilité de l'intervention d'un mécanisme nerveux. Cependant, les constatations rapportées sont en faveur de la prédominance d'un mécanisme physico-chimique.

BIBLIOGRAPHIE

1. E. F. Adolph, *Physiology of Man in the Desert.* Interscience, New York (1947).
2. W. S. S. Ladell, *The Influence of Environment in Arid Region.* Rap. U.N.E.S.C. №. 214 (1955).
3. R. Lemaire et J. Allegrini, Oligurie tropicale. *Bull. & Mém. Ecole de Méd. Dakar* (1959).

CUTANEOUS VASCULAR RESPONSES TO COLD

J. GRAYSON

Professor of Physiology, Dept. of Physiology, Univ. College of Ibadan, Nigeria

Abstract — Exposure of any part of the body to cold produces vasoconstriction, particularly in the skin of the extremities. It has been established that stimulation of cold receptors, wherever they may be, produces a generalized increase in sympathetic discharge through some incompletely understood central mechanism. This is the origin of a great deal of normal vasoconstrictor tone.

The sensitivity of this reflex, however, has been shown to be highly dependent on "core" temperature. It can be abolished by artificially raising the rectal temperature. Conversely, the sensitivity of these cold constrictor responses can be enhanced by cooling the body.

Apart from the effects of artificially altering temperature there is considerable individual variation in the sensitivity of these cold constrictor responses which may be linked to the level of the resting rectal temperature.

Résumé — L'exposition de quelquonque part du corps au froid produit une vasoconstriction, particulièrement dans la peau des extremités. C'est bien etabli que la stimulation des recepteurs due froid où est-ce qui ils se trouvent, produit une augmentation generalisée des stimulus sympathétique par un méchanisme central pas bien compris.

Le sensitivité de ce reflexe, dépend sur le température du corps. Elle peut être aboli en soulevent la température rectale ou augmentée parmi de refroidir le corps. Outre ces moyens de changer artificiellement la température du corps, il y a des variations individuelles considérables dans la sensitivité de ces reflexes constrictifs du froid, qui sont peut être controllée par le taux de la température rectale au repos.

Auszug — Wird ein beliebiger Körperteil der Kälte ausgesetzt, so ruft dies Gefässverengung hervor, inbesondere in der Haut der Extremitäten. Erwiesenermassen ruft die Reizung von Kälterezeptoren, wo immer sich diese befinden mögen, einen allgemeinen Zuwachs an sympathischer Tätigkeit hervor. Daher stammt ein Grossteil des normalen Gefässzusammenziehungstonus.

Die Empfindlichkeit dieses Reflexes ist jedoch erwiesenermassen im höchsten Grade von der Körpertemperatur abhängig. Sie kann die Empfindlichkeit dieser Kälteverengungsreaktionen vergrössert werden, indem man den Körper abkühlt.

Es bestehen beträchtliche individuelle Schwankungen in der Empfindlichkeit dieser Kälteverengungsreaktionen. Diese können mit der Höhe der Rektaltemperatur im Ruhezustand zusammenhängen.

THESE remarks are prompted by Dr. Hertzmann's excellent paper. There can be no doubt that the "setting", so to speak, of the cutaneous circulation is a most complex thing depending on many factors. One of them is local temperature. Another is the total amount of "cold stimulus" to which the body as a whole is exposed.

Yet another is "core" temperature. There are many others including psychic factors and factors linked to the function of blood pressure regulation. I would like to deal briefly with two of these factors, namely general cold stimulus and "core" temperature. Now exposure of any part of the body to cold is a vasoconstrictor stimulus, particularly to the skin of the extremities, and even more particularly to the skin of the distal parts of the extremities. Experiments with heated chambers have established that, under "normal" conditions of core temperature, there is a reflex activation of the vasomotor mechanisms, stimulation of cold receptors wherever they may be bringing about a generalized increase in sympathetic discharge through some incompletely understood central mechanism. This is the origin of a great deal of normal vasomotor tone in temperate climates.

The sensitivity of this reflex, however, has been shown to be highly dependent on "core" temperature. It can be abolished by artificially raising the rectal temperature. Thus in a subject whose rectal temperature has been raised (by immersing the legs in hot water and covering with blankets) such reflexes can be totally abolished and it is possible to place the legs of such an artificially hyperthermic subject in ice cold water without invoking even a trace of cutaneous vasoconstriction. Conversely, cooling the subject has been shown to increase the sensitivity of such cutaneous vascular responses.

The importance of these linked phenomena in temperature regulation, particularly in temperate or cold climates, is self evident.

One final point should be added, which may have some relevance to the question of individual variations in adaptation to cold, is that there appears to be a percentage of apparently healthy men whose cold vasoconstrictor responses are exaggerated under normal resting conditions. In one group of such "abnormal reactors" it was found that the resting rectal temperature of the group was significantly lower than that of normal subjects.

REFERENCE

GRAYSON J. (1951) Cold and warmth vasoconstrictor responses in the skin of man. *Brit. Heart J.* **13**, 167–176.

TROPICAL CLOTHING
A PHYSIOLOGICAL APPRECIATION

E. T. RENBOURN

Director Clothing and Equipment Physiol. Research Establishment, Directorate of Physiol. and Biol. Research, War Office, Farnborough, Hants., Great Britain

Abstract—Although some thought has been given to clothing hygiene over the last two centuries, specific garments for the tropics are a matter of the last fifty years. "Flannel next the skin" was worn until almost recent times because it was believed that wool, by combating the "cold dews of the dawn" and the chills arising from sweating, prevented diarrhoea and dysentry. Hence the origin of the flannel or "cholera" belt. Fear of the sun's rays penetrating bone and entering the central nervous system led to the use of the sun helmet and the now forgotten spine pad. Sun glasses have been used on and off for a century to prevent ophthalmia and even sunstroke.

The warmth of a textile material is independent of its chemical nature and due mainly to the air clinging to the surface of the fibres and yarns and to that in the interstices. In the case of natural fibres (wool, cotton, linen and silk), vapour and liquid water pass not only through the air interstices but will be rapidly absorbed into the fibre substance. Hence these materials, even in tight weaves, do not feel particularly damp to the skin in the presence of sweating. On the other hand, continuous-filament synthetic materials (nylon, Terylene, etc.) take up very little water into the fibre substance, and in tight weaves do not absorb moisture easily. Thus, in the presence of continuous sweating, prickly heat and fungus skin infection may be aggravated. Special manufacturing techniques allow synthetic fibres to be woven into porous materials which transmit sweat efficiently by a wicking process. The good properties of synthetic fibres (hard wear, non-shrink, drip-dry), however, show themselves best in blends with wool, cotton or linen which make suitable light weight materials for socks, underwear and outer garments for the tropics.

In a hot climatic chamber, nudity is associated with less sweat production than when wearing clothing. However, in the damp tropics, clothing increases the efficiency of evaporation, and loose garments aid convection and ventilative cooling. When in the jungle, protection may be required from flora and fauna. For this, thin tight weaves (of natural fibres) are suitable and are as cool as are thicker but open materials.

Under desert conditions clothing acts as a tent, and keeps hot air, sand and flies, solar heat and ultra-violet radiation away from the skin. Light-coloured clothing reflects solar heat better than dark clothing but the effect may be less than generally believed. Good protective footwear is required for the hot sand of the desert. Any light-weight hat is suitable for the tropics, and sunglasses are of value in the presence of glare and blown sand.

Résumé—Bien qu'au cours des deux derniers siècles on ait déjà eu quelques notions d'hygiène du vêtement, le vêtement adéquat pour les tropiques est une question qui a surtout été traitée pendant les dernières cinquante années. Presque jusqu'à ces derniers temps on portait de la flanelle sur la peau parce qu'on croyait que la laine, protégeant contre la rosée froide de l'aube et les coups de froid, provoqués par la transpiration,

empêchait la diarrhée et la dysentrie. De là l'origine de la ceinture de flanelle. La crainte des rayons de soleil pénétrant dans l'os et entrant dans le système nerveux central a fait apparaître le casque et le protège-colonne vertébrale, complètement oublié aujourd'hui. Pendant un siècle, à différentes reprises, les lunettes contre le soleil ont été utilisées afin de préserver de l'ophtalmie et même des coups de soleil. La chaleur d'un tissu en textile est indépendante de sa nature chimique et due surtout à l'air adhérent à la surface des fibres et des fils et à celui emprisonné dans les interstices. Dans le cas de fibres naturelles (laine, coton, toile et soie) la vapeur et l'eau liquide passent non seulement par les interstices d'air, mais sont rapidement absorbées par la substance fibreuse. Aussi ces matières, même dans les tissages imperméables, ne provoquent pas spécialement une sensation d'humidité au niveau de la peau en cas de transpiration. D'autre part le filament continu des matières synthétiques (Nylon, Terylène etc.) enlève très peu d'eau par la substance fibreuse et dans les tissages imperméables elle n'absorbe pas facilement l'humidité. Ainsi en cas de transpiration continue la fièvre miliaire et l'infection de dermatomycose peuvent être aggravées Des techniques industrielles spéciales permettent de tisser des fibres synthétiques dans des matières perméables qui transmettent *efficacement* la sueur par un processus capillaire. Toutefois la bonne qualité (bon usage, pas de rétrécissement, séchage par égouttement) se trouve le mieux réalisé dans les mélanges avec de la laine, du coton ou de la toile qui donnent des matières convenables de poids léger pour chaussettes, linge de corps et vêtements sous les tropiques.

Dans une chambre climatique chaude un corps nu transpire moins qu'un corps habillé.

Cependant sous les tropiques humides le vêtement augmente l'efficience de l'évaporation et le vêtement ample favorise la réfrigération par convection et aération. Dans la jungle une protection est nécessaire contre la flore et la faune. Pour cela un tissage mince et serré (genre fibre naturelle) est approprié et est aussi frais qu'un tissu plus épais en genre filet. Sous les conditions désertiques le vêtement agit comme un abri et protège la peau contre l'air chaud, le sable et les mouches ainsi que contre la chaleur solaire et les radiations ultraviolettes. Les vêtements à couleurs claires réfléchissent mieux la chaleur solaire que les teintes foncées mais l'effet peut être moindre que l'on croit généralement. Il est nécessaire d'avoir de bonnes chaussures protectives pour le sable chaud du désert. N'importe quel genre de chapeau léger est approprié pour les tropiques et des lunettes de soleil sont précieuses en présence de l'éclat du soleil et des tempêtes de sable.

Auszug—Obwohl man der Frage der Bekleidungs-Hygiene während der letzten beiden Jahrhunderte eine gewisse Aufmerksamkeit geschenkt hat, so kennt man doch besonders für die Tropen geeignete Kleidungsstücke erst in den letzten fünfzig Jahren. Bis in die jüngste Vergangenheit trug man "Flanell unmittelbar auf der Haut", denn es wurde angenommen, daß die Wolle, indem sie gegen den kalten Tau der Morgendämmerung sowie gegen das durch das Schwitzen hervorgerufene Frösteln schützt, Diarrhöe und Dysenterie verhindern würde. Dies führte zur Schaffung der Flanell- oder 'Cholera'-Gürtels. Die Furcht davor, daß die Sonnenstrahlen die Knochen durchdringen und in das zentrale Nervensystem eindringen könnten brachte die Benutzung des Tropenhelmes und des nunmehr in Vergessenheit geratenen Rückgrat-Schutzes. Seit einem Jahrhundert werden immer wieder Sonnenbrillen benutzt zur Vorbeugung gegen Ophthalmie und sogar auch Sonnenstich.

Die Warmhaltefähigkeit eines Textilmaterials ist unabhängig von seiner chemischen Zusammensetzung; sie ist in der Hauptsache zurückzuführen auf die Luft, die sich an der Oberfläche der Fasern und des Garnes sowie in den Zwischenräumen aufhält. Im Falle von Naturfasern (wie: Wolle, Baumwolle, Leinen und Seide) gehen Dämpfe und Wasser nicht nur durch die Luft-Zwischenräume, sondern werden schnell von der Fasersubstanz

absorbiert. Daher kommt es, daß diese Materialien, auch die engen Gewebe, beim Schwitzen kein ausgeprägtes Feuchtigkeitsgefühl auf der Haut hervorrufen. Andererseits nehmen synthetische Materialien aus durchlaufenden Fasern (Nylon, Terylen usw.) wenig Wasser in ihre Faser-Substanzen auf, und von festen Geweben dieser Art wird Wasser nur schwer absorbiert. Bei andauerndem Schwitzen könnte unter diesen Umständen daher Hitzepickel sowie Fungus-Infektionen der Haut eine Verschlimmerung erfahren. Mittels besonderer Verarbeitungsmethoden können synthetische Fasern nunmehr zu porösen Materialien verarbeitet werden, die den Schweiß auf Grund eines aufsaugenden Vorganges wirksam eliminieren. Die guten Eigenschaften der synthetischen Fasern (große Widerstandsfähigkeit, nicht einlaufend, vollkommen trocken) zeigen sich jedoch am besten bei einer Mischung derselben mit Wolle, Baumwolle oder Leinen. Diese Mischungen ergeben Materialien leichten Gewichtes, die für die Herstellung von Socken, Unterwäsche und Oberbekleidung für die Tropen geeignet sind.

In einer Heißluftkammer tritt bei Nackheit eine geringere Schweißabsonderung auf, als wenn die infragekommende Person bekleidet ist. In den feuchten Tropen wird die Wirksamkeit der Verdunstung jedoch durch die Kleidung erhöht, und lose Kleidungsstücke unterstützen die Wärmeableitung und die Ventilations-Kühlung. In Dschungelgebieten kann ein Schutz gegen die örtliche Flora und Fauna erforderlich werden. Für diesen Zweck sind dünne, dichte Gewebe (aus Naturfasern) geeignet, und diese sind genau so kühl wie dickere, jedoch lose Gewebe.

Bei Wüstenklimaverhältnissen übernimmt die Bekleidung die Aufgaben eines Zeltes, indem sie dafür Sorge trägt, daß die Haut vor heißer Luft, Sand, Fliegen, Sonnenhitze und ultravioletter Strahlung geschützt wird. Hellfarbige Kleidung wirft die Sonnenhitze besser zurück als dunkelfarbige; die Auswirkungen mögen jedoch geringer sein als allgemein angenommen. Der heiße Wüstensand macht eine gutschützende Fußbekleidung erforderlich. Als Kopfschutz ist für die Tropen jener leichte Hut geeignet, und Sonnenbrillen sind nützlich bei blendendem Sonnenlicht und wehendem Sand.

HISTORICAL

In ancient Egypt linen garments were the vogue. The semitic people, Babylonians, Greeks and Romans, on the other hand, wore more substantial woollen clothing, but whether because of the climate, tradition, hygiene or availability is not clear.

The Greek and Roman physicians believed that insensible perspiration (*αδολος διαπνοη*, "perspiratio insensibilis") must be allowed free passage through the skin pores (10); for if these became narrowed or blocked by the action of cold, a damp air, or the chills arising after profuse sweating, the vapours retained in the body gave rise to fevers and most diseases of the flesh. In 1614, Sanctorius, by weighing the insensible perspiration, gave a stamp of authority to this ancient doctrine (10). As a consequence, it was widely believed, to almost recent times, that "flannel next the skin" must be worn in a hot as well as a cold climate; for not only did wool absorb sweat easily and maintain a uniform warmth of the skin, but its sponge-like interstices took up the miasms floating in the air (later known as "mal-aria") and hence prevented their passage through the skin (9). Linen and cotton garments easily became wet through with sweat, caused chilling and were hence unsafe for wear. The "flannel" rash (various fungus *disorders*, sudamina and miliaria) so common in Europe during the eighteenth and nineteenth centuries was undoubtedly related to a long overheated skin. In the past, the occurrence of rickets in overdressed but undernourished children may have been in part the consequence of vitamin D efficiency arising from covering the skin from the health giving rays of the sun. We may have a similar explanation of osteomalacia in women obeying the dictates of purdah and the impoverished health of Polynesians made to cover the sinful body by the righteous anger of the first colonizers. Even after thick woollen clothing (including waistcoats) were given up for use in the tropics, the flannel binder or "cholera belt" (9) was retained to prevent the so called "abdominal chills" of the tropical dawn and hence to ward off diarrhoea and dysentery.

About the middle of the eighteenth century, the reflecting power of a light colour for solar heat was realized, and Franklin and Rumford advocated white clothing for summer wear (7). During the Indian Mutiny (1857) the Havelock (white cap cover and neck curtain) was often seen (8), and khaki (Hindu, dust colour) was widely used as a dye when the scarlet of the soldier's heavy woollen tunic (with its tight constricting stock) was no longer available. By this time it was becoming clear that the central nervous system was concerned with body heat regulation, a concept which must have played a part in the introduction of the sun helmet (topi) before the Mutiny, and many years later the spine pad (8). Physicians were convinced that these clothing items, by preventing the solar rays from penetrating the bony cranium and vertebral column, protected from "ardent" tropical fever—insolation or sunstroke. The spine pad was still in use to about 20 years ago but is now unusual even as a museum piece. A topi is rarely worn nowadays by Europeans except on ceremonial occasions.

Over the turn of the present century confused thinking led British hygienists to put forward a theory, in vogue for about 25 years, that the essential cause of heat disorders (including prickly heat) was not the heat but the actinic or chemical rays of sunlight (8). Light-coloured outer garments were advocated to keep out the heat rays; but black, green, orange (and even metallized) linings for the topi, spine pad and outer garments, and similar coloured underclothes, were deemed essential to absorb the dangerous actinic rays. Even a century ago, shaded or tinted spectacles were worn in India because of the resulting sensation of "coolness" and also to keep glare, dust and flies away from the eyes. Later, sunglasses were used as a precaution against ophthalmia and even advised as a preventive of sunstroke.

These various ideas are now forgotten, but many were well known to those who served in the tropics during the First World War and later. They remain an object lesson in tropical hygiene.

MATERIALS

The thermal insulation of a textile, whether of natural or the modern synthetic materials, is pretty independent of the chemical nature of fibre, and due mainly to the still air clinging to the surface of the fibres and yarns and the less still air in the weave interstices. Generally speaking the thicker a clothing material the better it maintains the heat of the body and, like a thick wall, keeps out hot air and radiant heat. The scales on the wool fibre give a great surface area; and its crimp and elasticity explain why animal hairs do not lend themselves to be woven into very thin materials. Wool is unkindly to a sensitive skin, not very hard wearing or easy to wash and disinfect; it shrinks and may be more liable to harbour vermin and micro-organisms than other materials (11).

Cotton and linen materials are soft and fairly smooth, hard wearing and wash easily, and are, therefore, suitable for underclothing. These vegetable substances (and particularly wool) take up a considerable quantity of insensible and liquid perspiration into the fibre substance and, hence, do not rapidly feel damp to the skin, a virtue in undergarments when sweating. On the other hand, the fibre water dries out less quickly than that in the interstices. A wet garment is unpleasant to the skin and because it contains little air is a poor heat insulator.

Unlike wool, cotton and linen fibres which are of short or "staple" lengths, the synthetic fibres (nylon, Terylene, etc.) are produced as long transparent filaments. The latter are suitable for the manufacture of thin, fairly transparent tight weave materials which are hard wearing, crease-retaining, dry quickly, can be boiled and do not shrink. On the other hand they soil easily, produce static electricity and melt at relatively low temperatures. Very little water is taken into the fibre substance, and thin tight materials contain relatively little air interstices, so that even with slight perspiration undergarments may soon feel unpleasantly damp. This makes such materials unsuitable in the tropics, for sweat continuously retained at the skin level may predispose to prickly heat and to various skin infections. However, when cut into staple lengths, and together with other special techniques (Schappe, Taslan, etc.) they can be woven into thicker, airy materials which in "feel" and appearance resemble cotton, linen or even wool. In such materials, the synthetic fibres are able to show their good wicking properties, so that sweat not taken up into the fibres themselves can pass out fairly rapidly through the air interstices. Nevertheless, synthetic fibres when blended with wool, cotton or linen make more suitable lightweight materials for hot weather socks, undergarments and outer clothing, for they show the good properties of both systems and retain drip-dry qualities.

GARMENTS

The physiological performance of garments is sometimes assessed from the physical properties of its materials as measured in the textile laboratory. However, a garment is more than its constituent materials, for it has shape — drape and fit — and may contain several layers and have a lining. The insulating air layers between clothing may be as important as that within the interstices. In general, women depend for warmth on the air between thin garment layers, but men rely more on the air within their thicker clothing materials. Women, furthermore, appear to have a more efficient "thermostat" (3, 17). The fewer and thinner the clothing layers (and linings) used in the heat the easier can thermal balance be maintained, but suitable underclothing has a hygienic value and in most people adds to comfort.

Under hot conditions, convective heat loss through porous clothing is of much less importance than evaporative cooling dependent on the transmission of sweat through fibres or interstices. For this reason, thin tight weaves (except of synthetic fibres) are as physiologically acceptable as thicker open materials for shirts and outer garments and have, furthermore, the advantage of keeping out hot winds, fine sand and biting insects. Well fitting clothes are uncomfortable in the heat, and by encouraging frictional trauma aggravate tropical skin disorders (13).

As long as the ambient temperature is below that of the skin, ventilative cooling through large apertures is an important physiological property of clothing. Even under still air conditions warm moist currents pass by convection over the trunk to emerge at the neck (chimney ventilation) and are pumped through the clothing openings during breathing (bellows ventilation). During walking, and with a breeze, a billowing of air takes place around the tent like bottom of a skirt or loose jacket and at the openings of loose sleeves and trousers. Thus, unless one is in the hot desert, there is little sense in blocking up the open neck of a loose shirt by a handsome kerchief, having a jacket buttoned up or wearing a belt. A bush-jacket allows of better ventilation than a shirt worn inside the trousers and, if legs and thighs are to be cooled, shorts must be cut on very generous lines. A starched bush-jacket has a good appearance, and being fairly stiff encourages good ventilation which outweighs the decreased permeability of the material. It is conceivable, however, that unless a really hot iron is used the starch may act as a nidus for pathogenic microorganisms.

It has been said that the best garb for damp heat is that of nudity. With muscular work it is as well to have the chest bare, but this cannot be easily applied to both sexes. In any case, a good tan may decrease over-sweating as also the incidence of skin disorders. Although the presence of clothing may lead to a greater sweat production (14), it absorbs liquid which would otherwise drip of the body, gives a somewhat larger functional "skin" area for heat loss, and its ventilating properties may reinforce convective and evaporative cooling. It has been put forward (on incomplete evidence) that clothing increases the salt concentration of the sweat and hence plays a role in tropical "neurasthenia" (2). This impinges on the controversial problems of salt balance and the etiology of "tropical fatigue" (4, 12, 13). The dictates of decorum, hygiene and fashion may have to be followed in the town, and in the jungle the skin must be protected from flora and fauna in the shape of thorns, leeches, and disease-bearing pests, etc.

It may well be that in a climatic chamber under desert-like conditions, a man in the nude, or only in shorts, sweats less than when fully clothed in suitable clothing (14). However, short term exposure to the heat of a laboratory is not the same as living continuously in a real tropical environment (12). In the desert there is the added large solar heat load (1), and except for short periods of time it may be unwise to expose untanned skin to the high intensity ultra-violet light. Long loose clothing acts as a tent and keeps the hot air, wind and dust, annoying flies, and radiation from the sky and the hot ground away from the skin. Cooling of the body may be dependent entirely on evaporation of sweat, which because of the low air humidity takes place very rapidly. As a result, the skin and clothing are not constantly wet and prickly heat is uncommon (13). Although the desert Arabs may have learned the value of long shirts and robes, the wealthy inhabitant (and most women) wear outer garments which like the Bedouin tents are of a black colour. For those who because of convention cannot wear light-coloured clothes under the tropical sun, there is some consolation in the thought that (apart from a specific effect of the chemical nature of a dye) there may be somewhat less physiological difference between a white and black suit of the same material and design than is generally believed. This may be explained in terms of scattering and internal reflection of solar energy unabsorbed by the surface yarns. We have found no obvious physiological difference between uniforms of jungle green or light khaki when worn by soldiers marching in the desert.

The reflectivity of desert sand and stone for visible and ultra-violet light is not as high as that of snow, and glare may be greater from the white houses, roads and cars of the town (6). Apart from irritation from sand and dust, photophthalmia (comparable to snow "blindness") is not a great problem in the desert except perhaps when driving long distances. Some people find solace in neutral tinted sunglasses, but to wear them out of the sun adds nothing but an air of mystery. Although there are still lingering doubts as to the value of a topi (15, 16), any light-weight hat with a good dark lined peak is acceptable. Thick socks and an insulative sole protect the feet from hot ground, and the addition of a removeable porous insole makes for a cooler desert or jungle boot. Sandals should be worn whenever possible for they are useful prophylaxis against tinea pedis. Nights in the desert are cool or even cold. One is then pleased to have remembered the woollen shirt and blanket. When it is essential to wear completely impermeable clothing, heat stress may be minimized by either a wetted exterior or by artificial ventilation using cooled or dried ambient air.

For those who have listened with increasing apprehension to the above remarks, it is well to remember that an experienced observer once wisely observed that the best tropical clothing is a sunshade and sandals (5). Even in a hot climate, common sense together with one's thermal sensation may be as good a judge of what to wear as obstruse textile physics and controversial clothing physiology. And who is so brave as to offend (or amuse) one's hostess in her air conditioned house, by appearing with fly-swatter in hand, in a topi and sunglasses, bush-shirt (even starched), well-cut shorts and suede desert boots?

REFERENCES

1. Blum H., The solar heat load — its relative importance to the design of clothing. *J. Clin. Invest.* **24**, 714—21 (1945).
2. Castro J. de, *Geography of Hunger*, p. 82 London, (1952).
3. Hardy J. B. and E. F. Du Bois, Differences between men and women in response to heat and cold. *Proc. Nat. Acad. Sci. Wash.* **26**, 389—98 (1940).

4. Ladell W. S. S., Disorders due to Heat. *Trans. R. Soc. Trop. Med. Hyg.* **51,** 189—207 (1957).
5. Martin C. J., Thermal adjustments of man and animals to external conditions. *Lancet* **2,** 561—66, 617—20, 673—8 (1930).
6. Reid A. M., *A Comparative Trial of Goggles Multi-Purpose in the Middle East.* Unpublished Ministry of Supply Report (1955).
7. Renbourn E. T., The physiology of textiles and clothing. An historical note. *J. Roy. Army Med. Corps* **99,** 203—13 (1952).
8. Renbourn E. T., The spine pad. A discarded item of tropical clothing. *J. Roy. Army Med. Corps* **102,** 217—33 (1956).
9. Renbourn E· T., The history of the flannel binder and cholera belt. *Med. Hist.* **1,** 211—25 (1957).
10. Renbourn E. T., The natural history of insensible perspiration. A forgotten doctrine of health and disease. *Med. Hist.* **4,** 135—52 (1960).
11. Renbourn E. T., The science of clothing hygiene. Past and present. *J. Text. Inst.* In press.
12. Renbourn E. T, Physiological problems of the soldier in tropical warfare. *J. Roy. Army. Med. Corps,* **105,** 172—82 (1960).
13. Sargent F. and H. L. Slutsky, The natural history of the eccrine Miliarias, etc. *New Engl. J. Med.* **256,** 401—8, 451—9 (1957).
14. Shelley W. B. and S. M. Horvath, The effect of clothing on the ability of men to work in intense heat. *J. Clin. Invest.* **25,** 437—46 (1946).
15. Schweitzer, A. *On the Edge of the Primaeval Forest.* London (1949).
16. Winslow C. E. P. and L. P. Herrington, *Temperature and Human Life,* p. 156—60 New Jersey. (1949).
17. Yaglou C. P. and A. Messer, The importance of clothing in air conditioning. *J. Amer. Med. Ass.* **19,** 1261—7 (1941).

GENERAL READING

Adolph E. F. *et al., Physiology of Man in the Desert.* New York (1947).
Newburgh L. H. *et al. Physiology of Heat Regulation and the Science of Clothing.* London (1949).
Renbourn E. T., See Ref. (11) above.
Weiner J. S., Biological assessment of clothing for tropical use. *Med. Bull.* **5,** 1016, 1947—8.
Winslow C. E. P. and L. P. Herrington, See Ref. (16) above.

CLIMATIC FACTORS AND SOME RENAL AFFECTIONS IN SIAM

OUAY KETUSINH

Professor of Physiology, Dept. of Physiology, Faculty of Medicine and Siriraj Hospital, Bangkok, Siam

Abstract—Threc sets of graphs are presented in chronological relationship, which depict, respectively, monthly fluctuations in climatic elements (air temperature, rainfall, relative humidity), urinary secretion (total volume output, nitrogen excretion, total solids, specific gravity) and incidence of renal affections (urolithiasis, nephritis). Between the highest output of urine in the cool-and-dry season and the lowest in the hot-and-dry there is a difference in daily volume amounting to ½ l. and involving nearly 25 per cent of excreted nitrogen. In April the urine is almost one-third as concentrated again as in January; in April there is a big rise in the incidence of urolithiasis. The admission of cases of nephritis is as low in the cool-and-dry as in the hot-and-dry season. In the former there is an extra amount of water available to the kidney; in the latter the kidney is aided partly by the increased activity of the sweat glands.

Résumé—Trois groupements graphiques ont été présentés sous rapport chronologiques, qui dépiquent basculements mensuels des éléments climatiques (température de l'air atmosphérique, tombées de pluie, humidité relative), de l'excrétion urinaire (volume total, formule d'excrétion d'azote, formule des solides totales, densité) et d'incidence des affections rénales (lithiase urinaires et de néphrites). Entre la valeur maximum d'excrétion urinaire en saison fraîche et sêche et celle la plus basse de la saison chaude et sêche il y a une différence de volume d'excrétion quotidienne montant à un demi-litre affectant à l'environ de 25 pourcent de la valeur d'azote urinaire. En avril, l'urine a une tierce concentration plus de celle du mois de janvier et il y a, en avril une forte augmentation d'incidence d'urolithiase. Le nombre d'admission des cas néphrétiques est aussi bas en saison fraîche et sêche qu'en saison chaude et sêche. A la première saison il y a une quantité en extra d'eau disponible pour le rein tandis que ceci est soulagé par une augmentation d'activité des glandes sudoripares pendant l'autre saison.

Auszug—Es werden drei Gruppen von Kurven in chronologischem Verhältnis gezeigt, die darstellen: monatliche Schwankungen der Klima-Elemente (Lufttemperatur, Regenmenge, Luftfeuchtigkeit), der Harnausscheidung (Menge, Stickstoffgehalt, Menge der festen Bestandteile, spezifisches Gewicht) und der Einfall der Nierenerkrankungen (Urolithiasis, Nephritis). Zwischen der höchsten Urinausscheidung in der kühlen und trocknen Jahreszeit und der niedrigsten in der heissen und trocknen besteht ein Unterschied von einem Halbliter Harn und fünfundzwanzig Prozent des ausgestossenen Stickstoffs. Der Urin im April ist fast 130 Prozent so konzentriert wie der im Januar; im April steigt die Anzahl der Harnsteine deutlich an. Der Einfall von Nierenentzündungen bleibt niedrig in der kühlen und trocknen Jahreszeit sowie in der heissen und trocknen. In der ersteren steht der Nicre eine grössere Menge Wasser zur Verfügung; in der letzteren wird die Niere durch die erhöhte Schweissdrüsentätigkeit teilweise abgelöst.

LIVING in a tropical country as we do in Siam it is only natural that we should be concerned with heat and its effects upon the body. But our attitude probably differs somewhat from that of most workers in temperate climate in that we tend to think of heat more as an element of our environment rather than as a source of stress.

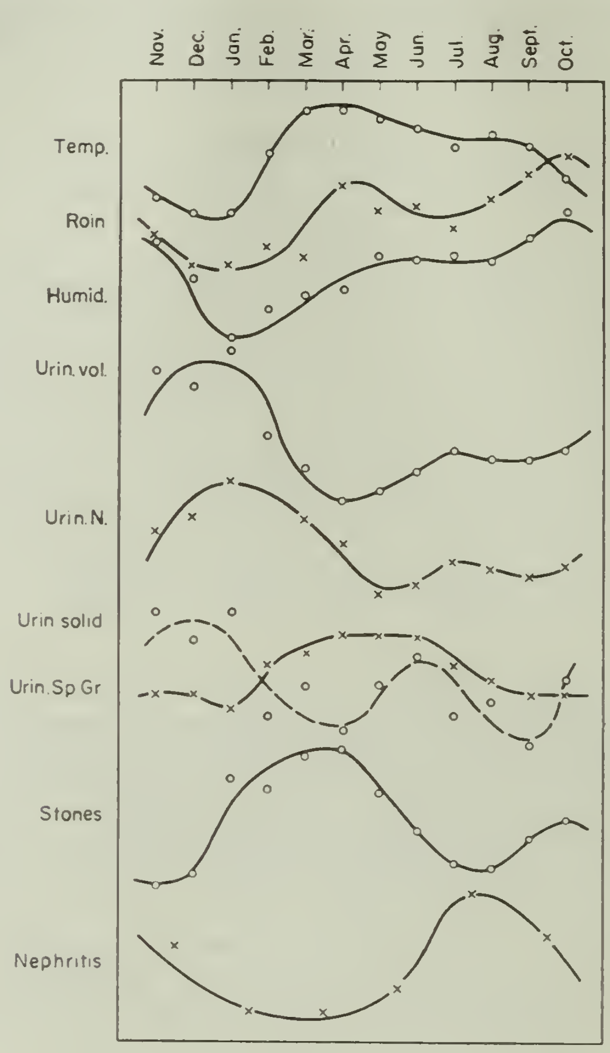


FIG. 1

Thus we are interested in the chronic as well as the acute effects of heat. We want to know how heat affects us from day to day under usual conditions of living and working. In particular we hope to be able to apply the knowledge gained by our studies to the improvement of our well being and the prevention of some of our endemic diseases. As illustration I may refer you to Fig. 1 upon which are summarized the results of some work performed by us in Siam.

On the diagram a number of graphs are reproduced. Since we are interested only in fluctuations — rises and falls or increases and decreases — numerical values have not been affixed. There are actually three sets of graphs. The first set of three curves refer to climatic elements: air temperature, rainfall and relative humidity, as measured by the Meteorological Department in Bangkok and recorded as mean daily values for the months November to October. We start with November because it is the beginning of the cool-and-dry season, which lasts till February. From March to May the weather is hot-and-dry, and from June to September hot-and-humid. October is the period of transition, during which the rainy season changes over to the cool-and-dry.

The next set of four curves refer to urinary secretion: total volume output, nitrogen excretion, total solids and urine specific gravity, recorded as mean daily value for the corresponding months. The data were obtained from analysis of the urine of twelve medical students who volunteered to collect a 24-hr sample once every week for fifty-two consecutive weeks. During this period the students went about their work and other activities as usual, so as to obtain a picture of the fluctuations as near natural as possible.

The last set of curves concerns disease. The last but one graph shows monthly fluctuations in the number of cases of urolithiasis admitted into four provincial hospitals in the so-called stone-belt, while the last curve depicts the rise and fall in the number of cases of acute and chronic nephritis admitted into the Siriraj Hospital in Bangkok.

Thus three different sets of data have been grouped together on the diagram: data relating to the climate, to the normal individual, and to the diseased. This bringing together is to provide an objective — though implied — evidence for the influence of climatic factors upon the human organism under natural conditions. The effects upon urinary secretion are obvious and readily explanable. I only wish to point out that from our findings, between the highest output in the cool-and-dry season and the lowest in the hot-and-dry, there is a mean difference amounting to ½ l. of urine per day and involving nearly 25 per cent of the total amount of nitrogen excretion. The cause of the difference is obviously additional loss via sweat. Thus it would not be much wrong to infer that in a normal individual with moderate physical activity, during the hot-and-dry season the sweat glands may take over as much as 25 per cent of the usual work of the kidney. Our data also show that in April the urine is almost 30 per cent as concentrated as it is in January. In a predisposed person this high concentration might switch on a train of events leading to some colloidal imbalance in the urine, resulting in precipitation and stone formation. This probably explains why there is a sharp rise in the number of cases of urolithiasis during the hot-and-dry months. A different picture is seen in the case of nephritis. The incidence remains low throughout the cool-and-dry as well as during the hot-and-dry seasons. Probably two factors are here exerting their influences. In the cool season the lowered activity of the sweat glands renders available to the kidney an extra amount of water — otherwise lost through the skin — which facilitates the work of excretion. On the other hand, during the hot season the active secretion of sweat helps to eliminate some of the waste products, relieving the kidney of part of its burden and thus lowering the danger of a breakdown. Here again, just as in the case of urinary stones, other factors certainly play their part; but the role of sweat glands in aiding the kidney should not be overlooked. In Siam the incidence of nephritis is comparatively low. Is it not because the kidney is being relieved of much of its work during several months of the year and thus spared of much wear and tear? From a theoretical standpoint the question may be answered in the affirmative, though more work will be required to conclude the matter. For the present it seems reasonable to believe that a proper assessment of the part played by sweating in favouring stone formation on the one hand, and preventing renal breakdown on the other hand, might yield some interesting concepts upon which a valuable method of prevention and treatment of these affections may be based.

REFERENCES

1. O. KETUSINH, C. KASHEMSANT D. VISESHKUL, S. SRISORASASTR, A. KETUSINH and D. BEJRBLAYA, Seasonal variations in the excretion of water and nitrogenous waste substances. *Ninth Pacific Science Congress, Bangkok* (1957).
2. S. UNAKUL, *Med. J.* 7 (1), 30—52 (1958).
3. A. J. BUTT, *J. Urol.* **67**, 450 (1952).
4. METEOROLOGICAL DEPT, *Climate of Thailand* (Bangkok, 1952).

GENERAL REMARKS TO THE MAIN SESSION ON TROPICAL BIOCLIMATOLOGY

H. BOYKO
The Negev Institute for Arid Zone Research, Beersheba, Israel

A DEFINITION of the concept of a "tropical climate" has to be critically discussed. This concept, like most of such general formulae, is much too vague for biological purposes. This is easily understandable because the meteorological network in most tropical countries is much too loose to allow an exact understanding on the basis of the analytical meteorological data at our disposal.

Ecologically we can find most of the main criteria of a tropical climate far beyond the tropics themselves, particularly north of the Tropic of Cancer. This can best be seen by the natural occurrence of typical tropical plants and animals far outside the geographical tropics. Examples are the Flamingos in the Hule-lake and the Papyrus swamps in Israel in latitude 33° north and in Southern Sicily even in latitude 37° north of the equator. The same applies to the tropical vegetation in the Dead Sea depression, in all places where we find fresh-water springs like in Ein Gedi in Israel and in Ghor es Safiah in the Kingdom of Jordan.

On the other hand we all know that even in equatorial areas all gradations of our earth's climate occur — at least as far as the temperature factor is concerned. In Africa, as well as in South America, we find frozen soils without vegetation and with a permanent cover of ice and snow, at high altitude.

The question is, do we have to use the concept tropical climate for all those climates occurring between the Tropics of Capricorn and Cancer or do we have to use other criteria and best of all biological ones? The natural border of the whole family of palm trees is suggested as such a criterion. This would also include the subtropics north and south of the tropics, and on the other hand the hot deserts between the tropics. For subdivision of tropical climates, vegetation units seem to be the best basis.

For the definition of borderlines, however, we have another possibility: Radiation in general and direct solar radiation in particular has a decisive biological effect on plant distribution in non-temperate zones, and in all measurements we have, therefore, to take into account the I. E.-factor (insolation—exposure factor) to a much higher degree than it has been done up to now.

Statistical plants—sociological records give us the means to compare numerically the topographical distribution of plantspecies according to the I. E.-factor, and thus to define exactly climatic borderlines. We made such records around a number of

"Tels"* north and south of Beersheba and by this method we could recognize that the influence of the summer Monsoon stretches through the Red Sea and Wadi Araba up to the Central Negev, that is, almost 30° of northern latitude. Quantitative data about this investigation will be published elsewhere.

* The remainders of ancient cities and settlements are frequently found as hills. Such a hill is called "Tel" in South West Asia. The "Tels" around Beersheba were inhabited cities, fortresses, or settlements from about 3,000 to 1,000 B. C.

GENERAL CLIMATOLOGICAL CONSIDERATIONS IN RELATION TO TROPICAL BIOCLIMATOLOGY

J. P. NICOLAS
Dept. de Géographie, Institut Français d'Afrique Noire, Dakar, Senegal, W. Africa

Geographers usually consider climatology as an approach to the knowledge of a natural region; some of them, with the exception of physical geographers who are concerned mainly with human problems, emphasize climatological aspects.

In describing a tropical country we are obliged to consider the equilibrium which arises between atmosphere and living organism. To understand the environment where geographical facts are developing, more is needed than the analysis of the different factors representing this environment. A synthetic view of the problem through an evolutionary process is required. At first sight, changing the climatic influence may be of great importance, but on close inspection cyclical evolution may explain a lot of facts, provided that the environment be clearly defined.

A great deal of confusion exists now in the concept of environmentalism. This is not peculiar to tropical zone studies. The analysis of climate in an ecological study usually includes many factors apart from the living thing under study. The efforts of ecologists are well known but that of biogeographers is not. This method is erroneous because there is no "climate" as such, but only reactions between a physical state of atmosphere and a physiological state of living. In other words, a system of energy balance takes place. The living being has characteristics which differ according to its type of constitution and its physiological functions, one of the most important being thermoregulation. Climatic analysis cannot be conducted in the same way if the object of study is a snail as though it is a monkey. Even in a group of mammals, the method will be different for a sweating man and a panting dog.

Another source of confusion is the different point of view of the workers who study the biological equilibrium in climatic changes. These investigations are of paramount importance in our changing world where speed of travel is increasing and where people suddenly have to work in new environmental conditions. They find a justification in mines, in the microclimates of submarines, in jet-plane pilots' physiology. But this, strictly speaking is not bioclimatology, but the study of working environments. Usually workers in these fields investigate extreme conditions, which constitute a stress. Of more concern to the geographer is the research concerned with people working in petroleum fields, desert, etc.

The geographical expression of climatic influence either on animals or on man includes the time factor, either a long-term influence covering several generations, or a short-term effect through years and centuries. We have begun to be convinced of this in temperate zones, but not in tropical ones, because all the studies of the effects of heat and cold have been made by white men for whom the climatic conditions approach the stress level in many cases. However, the extreme conditions that we are able to produce in climatic chambers are, in fact, very rare in nature, and if they occur in some places, it is difficult to say if these conditions are really extreme for adapted populations.

Thus, there are two main considerations to guide geographers in their bioclimatological investigations. First, climate is of no significance in itself, but only in combination with a living being, whose physiological functions have to be well known. Secondly, the duration of moderate conditions are more important than those of extreme ones, especially as populations are adapted to those extreme conditions, and because physiological investigations are not yet sufficiently advanced for us to be certain about racial differences.

Geographers must also take into account the sociological and psychological factors affecting the conditions dictated by the atmospheric complex. A typical effect of those factors is the spectacular change in the way in which white people live in the tropics as a result of improved housing and acclimatization.

All the experience acquired in the tropics leads me to express my wish that more observations be made on the environmental complex, and that through a knowledge of the different factors influencing a biological equilibrium, climate be considered with more attention to the living thing under study.

KREISLAUFVERÄNDERUNGEN IN MENSCHEN, DIE AUS DEM WINTER MITTELEUROPAS IN TROPISCHES KLIMA REISEN

H. JUNGMANN
Wrangelpark II, Hamburg/Othmarschen, Deutschland

Im Vergleich zu den vorgetragenen Reaktionen des Kreislaufs auf akute, kurzdauernde Hitzeeinwirkungen mag es von Interesse sein, die Kreislaufveränderungen zu prüfen, die sich an Menschen einstellen, die langsam, innerhalb von Tagen und Wochen aus dem Winter Mitteleuropas in tropisches Klima reisen.

Wir hatten Gelegenheit, an 22 Mitgliedern der Besatzung eines Frachtschiffes jeden zweiten Tag Herz und Kreislauf im Liegen während einer Reise von Hamburg in die feuchtheissen Gegenden Panamas, Boliviens und Ekuadors zu untersuchen. (Einzelheiten sind im *Arch. physik. Therapie* **12.** 225 (1960) veröffentlicht.) Die Aussentemperatur nahm im Tagesmittel von 0° C, auf etwa 28—30° C, zu, die relative Feuchte lag während der ganzen Reise bei 70 bis 90%, die Äquivalenttemperatur stieg von 10° bis auf über 80° innerhalb der 4 Wochen dauernden Fahrt.

Trotz dieser subjektiv eindrucksvollen Zunahme der Wärmebelastung blieb bei den 22 Seeleuten die Ruhepulsfrequenz vollständig unverändert. Systolischer und diastolischer Blutdruck zeigten ebenfalls keine messbaren Abweichungen. Das aus Blutdruck, Pulswellengeschwindigkeit, Systolendauer und Herzfrequenz berechnete Herzminutenvolumen stieg in den Tropen gering aber nicht signifikant an.

Die Ergebnisse zeigen, dass der langsame *Übergang* ins feuchtheisse Klima an der Herztätigkeit des liegenden Menschen keine messbaren Veränderungen auslöst. Der in unserem Fall nur 14 Tage dauernde *Aufenthalt* im feuchtheissen Klima ist offenbar zu kurz, um Kreislaufumstellungen hervorzurufen, die als Symptom einer Akklimatisation gedeutet werden könnten.

DISCUSSION OF THE SESSION TROPICAL BIOCLIMATOLOGY

Compiled by Dr. G. C. Whittow

A. B. Hertzman (in reply to questions raised by other speakers): It is dangerous to extrapolate results obtained from experiments in which the whole body was immersed in hot water to the behaviour of men exposed to warm air. It is equally important that deductions from measurements of blood flow through the finger, for instance, should not be applied to other cutaneous vascular beds such as the forearm, face, calf, etc. I would like to emphasize that the sequence of the vascular and sweating responses to heat depends upon the way in which the heat load is developed and also on previous climatic experience.

Questions for Dr. J. C. D. Hutchinson and replies

R. E. McDowell: Since coat score is a subjective observation and has a heritability only slightly better than rate of gain, would not the use of rate of gain be a better means of improving genetic character for overall tolerance?

J. C. D. Hutchinson: I think it is perhaps too early to make a comparison of coat score versus rate of gain as an index of selection. The rate of gain of an animal can be predicted better by coat score than by the previous rate of gain.

S. W. Tromp: Did Dr. Turner study the relationship between the differences in the seasonal curve from one year to another in connexion with coat score differences?

J. C. D. Hutchinson: Dr. Turner has not given me any information on this subject.

Th. Stegenga: Differences in live-weight between cattle in European countries depend not only on climatic differences but, for example, on breed differences, breeding policy and feeding conditions. The differences in fertility and birth weight in groups of animals with a heavy and light coat: do the differences include seasonal differences or did Dr. Turner compare fertility of animals with a light and heavy coat within the same month?

J. C. D. Hutchinson: I agree with your first statement. The coat score was made at the time of mating which was the same for all dams. Therefore seasonal differences are not included.

O. Wilson: My question deals not with heat acclimatization but with cold acclimatization. I noted that cattle breeds of the Northern Hemisphere had a higher coat score but closely followed the seasonal changes of the more tropical Southern Hemisphere breeds. I assume that these northern breeds were born in the southern region. What happens if northern cattle are brought directly to the southern hemisphere? Do they show a reversed seasonal coat change? If it is reversed how long a time will it take until they attain a coat change related to the right season? Or does perhaps a tendency towards a reverse reaction persist? Why I ask is because in the Antarctic we had considerable trouble with our Eskimo husky dogs. They lost their winter fur coat according to the calendar and not to the southern hemisphere climate. So that when the Antarctic winter came they had only the less protective summer fur coat and in the summer they had the extra heat of a new winter coat. This reversed seasonal change was also evident during the second year. The pups born in the Antarctic however showed the right seasonal fur change.

J. C. D. Hutchinson: Yes, the British breeds used in the Belmont work were born in the Southern Hemisphere. Yeates' work indicates that cattle transferred from the Northern to the Southern Hemisphere would within a year attain a coat change related to the right season and that in an equatorial day length the hair cycle is disrupted.

My colleagues and I find that the seasonal shedding of hair and wool from the legs of sheep is easily reversed by reversing the photoperiodic rhythm; but in their case a persistent rhythm remains on transfer to an equatorial day-length.

I have seen in the Danish press a report that horses transferred from South America to the Royal Danish Stables take several years to attain coat changes appropriate to the Northern hemisphere. Your Husky dogs appear to be similar to the horses. I do not know how long they would retain the persistent rhythm initiated in the Northern Hemisphere in the face of the reversed stimuli they met in the Southern Hemisphere. It seems that there are considerable differences between species in the persistence of the rhythm of coat change after it has been initiated.

Questions for Professor P. W. Richards and replies

P. C. Ekern: Water uptake in sugar cane and cotton is sharply curtailed at temperatures of 60°F. Root growth and leaf growth of pineapple are sharply curtailed at temperatures below 65°F. There should perhaps be sub-delineations within the tropics based on these rather than the frost point.

P. W. Richards: In an endeavour to present a clear picture in a few words I may perhaps have exaggerated the relative unimportance of temperature as an ecological factor in the tropics; in any case I was referring mainly to temperature as a factor governing the distribution of the major types of vegetation, rather than to its effects on individual species or particular physiological functions. For individual species low temperatures considerably above the freezing point may be limiting; according to Molisch some tropical plants are actually killed by exposure to temperatures some degrees higher than the freezing point. I do not think the ecological importance in the tropics of minimum temperatures above the freezing point has ever been carefully investigated. It is quite likely, as you suggest, that sub-zones determined by minimum temperatures above 0° could be recognized.

P. C. Ekern: Certain tropical plants have moisture use regimen drastically different from that of temperate thin-leaved plants. The pineapple and perhaps other Bromeliads have no acceleration of transpiration by day and are extremely conservative in their use of water. This suppression of day-time transpiration has concomitant alterations in the carbondioxide metabolism.

P. W. Richards: In their use of water the Bromeliads (or some of them) would appear to resemble certain types of temperate xerophytes, such as some succulents. Quite possibly the Cactaceae and other succulents which grow in the humid tropics as epiphytes on trees and on bare rocks, and other intermittently dry habitats may have similar water relations, but as far as I know they have not been investigated. There are probably so many different types of ''moisture use regimen'' among tropical plants that it would be useless to generalize. The Bromeliaceae are a peculiar and specialized group of plants and I would not like to draw from them any conclusions about tropical plants in general.

Dr. P. C. Ekern: The pineapple, despite the conservative water use and disturbed carbon dioxide metabolism still has rapid growth rates that exceed those for sugar cane, for example.

P. W. Richards: The rapid growth of the pineapple is interesting and it would be useful to know how its N. A. R. compares with that of other tropical and temperate plants.

P. E. Ekern: The interplay of photoperiod and thermoperiod are quite evident in the flowering of pineapple and the Tasseling of sugar cane.

P. W. Richards: I do not know enough about this subject to comment.

P. C. Ekern: Leaf and fruit temperatures of the pineapple are much elevated above air temperature. Temperatures shortly beneath the skin of the pineapple fruit may reach 150°F with air temperatures of 85°F.

P. W. Richards: I would suspect that many tropical plants are like the pineapple in that their tissues may reach temperatures much above the air temperature, but I would suspect that this is only of critical importance in extremely hot habitats like the deserts in Mauretania studied by Lange.

3rd Session

BIOCLIMATOLOGICAL CLASSIFICATION

Chairman: Prof. J. S. Weiner

OLD AND NEW PRINCIPLES OF PHYTOBIOLOGICAL CLIMATIC CLASSIFICATION

HUGO BOYKO

*The Negev Institute for Arid Zone Research, Beersheba, Israel

Abstract—The author gives a short historical review on the climatic concept from ancient times until the concept of the twentieth century based on meteorological data accumulated during the last decennia. The obvious disadvantages of this purely analytical concept for biological purposes lead to different formulae to include not only single climatic factors but also complicated factor complexes like moisture indices, data of extremes, seasonal fluctuations, and others. Some of such climatic classifications are discussed.

A further progress is mentioned by taking into consideration the "climatic soil coefficient" (C.S.C.) and the "Factor of erratics", which is difficult to grasp but particularly characteristic for the climatic pattern of deserts (examples are given).

From the biological point of view two basic bioclimatic rules can be formulated:

(1) The biological effect of the same climatic factor of a certain strength can be very different if other factors of the whole complex are changed.

(2) Even a considerable shift in the numerical values of one single climatic factor can result in the same biological effect, if an adequate changement of other factors takes place (see examples).

In order to overcome all these difficulties the new line of research, "ecological climatography", aims to base climatic classifications on biological yardsticks. In the natural vegetation we have the most exact climatic indicator, and many species can serve as quantitative climatic indicators. Several methods are given as examples and some details given in the figures.

For practical purposes, as for example for forestry, agriculture, land use and planning, etc., it is recommended that the conservative analytical principles of meteorology be combined with the new synthetic principles of ecological climatography.

Résumé—L'auteur donne un bref résumé historique sur le développement du concept de climat, commençant par l'antiquité jusqu'au 20me siècle; ce dernier basé sur les dates météorologiques accumulées pendant des dizaines d'années.

Cependant ce concept—purement analytique—est désavantageux en respect de buts biologiques et pour s'y en débarrasser on a tâché de trouver un nombre de formules différentes. Ces formules comprennent non seulement des facteurs isolés, mais même des complexes de facteurs divers, compliqués géophysicales—comme par exemple l'index de l'humidité, les dates d'extrêmes manifestations de turbulence, des variations de saisons etc. Un nombre de ces classifications sont discutées en détail.

L'auteur ensuite démontre deux phénomènes importants et très négligés jusqu'alors — le «coefficient climatique du sol» et le «Facteur d'Erratique», ce dernier très caractéristique pour le climat du désert.

Du point de vue biologique on peut formuler deux règles générales bioclimatologiques:

(1) l'Effet biologique du même facteur climatique d'une force donnée peut changer très décisivement tout au moment ou un ou plusieurs des autres facteurs du complex-total ont été changés.

(2) Mêmes des changements décisifs de valeurs numériques d'un facteur climatique peuvent résulter en même effect biologique, tout au moment qu'un changement adéquate se fait par des autres facteurs (voyez examples).

Pour trouver une solution qui fait compte de ces difficultés «l'Ecologie Climatographique» travaille en direction d'évaluer la classification dè climats à la base de mésures biologiques — c'est à dire à la base de la végétation naturelle; de même de spécies particuliers qui se prètent à une telle indication quantitative.

Un nombre de méthodes en cette direction sont montrées et expliquées au moyen de photos.

Il est suggéré pour buts pratiques comme par example pour la forestrie, l'agriculture, la planation générale etc. de combiner les principes conservatives analytiques de la météorologie avec les principes nouvelles synthétiques de la climatographie écologique.

Auszug — Der Autor gibt eine kurze historische Übersicht über die Entwicklung des Klima-Begriffes seit dem Altertum bis zu dem Klimabegriff des 20. Jahrhunderts, die die durch Jahrzehnte accumulierten meteorologischen Daten zur Grundlage nimmt. Dieser rein analytische Klimabegriff hat jedoch grosse Nachteile für viele biologische Zwecke und dies führte zur Aufstellung von verschiedenen Formeln, die nicht nur Einzelfaktoren in sich einschliessen, sondern auch sehr komplizierte geophysikalische Faktoren-komplexe wie zum Beispiel den Feuchtigkeits-Index, die Daten extremer Wettererscheinungen, saisonbedingte Schwankungen, und so weiter. Einige Klimaklassifikationen, die darauf beruhen, werden näher besprochen.

Der Autor lenkt dann die Aufmerksamkeit auf zwei wichtige geophysikalische Phenomena, die bisher zu sehr vernachlässigt worden sind, und zwar auf den «Klimatischen Boden-Koeffizienten» (C.S.C., climatic soil coefficient) und auf den schwer zu erfassenden «Faktor der Erratik», von denen der letztere ganz besonders das Wüstenklima charakterisiert.

Vom biologischen Standpunkt aus gesehen, lassen sich zwei bioklimatologische Grund-Regeln formulieren:

(1) Der biologische Effekt desselben klimatischen Faktors von einer bestimmten Stärke kann sehr verschieden sein, wenn andere Faktoren des Gesamtkomplexes sich ändern.

(2) Selbst starke Verschiebungen in den numerischen Werten eines einzelnen Klima-Faktors, können zum gleichen biologischen Effekt führen, wenn eine entsprechende Veränderung von anderen Faktoren stattfindet (Siehe Beispiele).

Um allen diesen Schwierigkeiten zu begegnen arbeitet die «Oekologische Klimatographie» daran, Klima-Klassifikationen auf Grund von biologischen Masstäben aufzustellen, indem sie hauptsächlich den exaktesten Klimaindikator zur Grundlage nimmt, nämlich die natürliche Vegetation und einzelne Arten, die sich für eine quantitative Indikation eignen. Einige Methoden dieses neuen Wissenschaftszweiges werden an Hand von Zeichnungen eingehender erklärt. Für praktische Zwecke, wie Forstwirtschaft, Landwirtschaft, allgemeine Planung, etc., wird vorgeschlagen, die conservativen, analytischen Prinzipien der Meteorologie mit den neuen, synthetischen Prinzipien der oekologischen Klimatographie zu verbinden.

As soon as man began to travel over greater distances he became conscious of climatic differences between various regions. Recognition of the cause, however, came much later. We can see for instance, that the ancient Greeks already understood in 600 B.C. the fact that shifts in latitude are connected with shifts in temperature. Hippocrates, Aristotle, and 500 years later Strabo — to name but a few — transmitted this knowledge to later generations. They knew that the climate grew hotter and hotter the more they travelled in a southern direction, particularly through the Nile Valley, and this discovery was used as a basis for scientific theories. It was a great and conscious contribution to their admirable theory of a global form of our earth, which theory is in strict contradiction to what we are lead to believe through our senses. This knowledge was lost again, as also was the knowledge of these basic climatic principles. This first climatic concept at least in the European history of science, was strictly a geophysical concept.

Later on, in the Middle Ages, the close co-operation of Jewish and Arab scholars led to one of the finest cultural and scientific periods and to the revival of the scientific approach on the basis of the knowledge of the ancient Greeks. Causal connexions between climate and geography were assumed but not yet fully recognized. The travels of the crusaders as well as the great voyages of the merchants of the Mediterranean republics helped in the accumulation of knowledge about other countries, and when the Spaniards and Portugese began their transoceanic explorations there was already quite a respectable fund of knowledge at hand. The collected facts were geophysical ones as well as biological ones.

I am restricting my remarks to the Mediterranean and to Europe as a centre, simply because of our unfortunate method of education by which we know so little about similar trends in other parts of the world; for instance, in South and East Asia or about the great voyages of the Maori in the Pacific region.

The concept of a climate, however, does not yet appear to be clearly defined. As far as nautical purposes were concerned the wind factor was intensively studied and served as a main principle of a certain climatic classification. The meagre data on wind direction, wind frequency and wind intensity were the main basis. The passate zone was soon recognized, the Monsoon region was an old concept passed down by the Arabs, and the misleading first experience on the Pacific Ocean of a calm expanse of sea led to its name. In respect to the continents and *terra firma* in general it was only slowly recognized that the biological consequences of the climate, and particularly the vegetation, must serve as the primary indicators in any description.

A scientific climatic classification on the basis of the great *vegetation units*, however, began only at the end of the eighteenth or at the beginning of the nineteenth century. Alexander von Humboldt was, it seems, the first to base his description on this principle.

In the second half of the nineteenth century this system was worked out in more detail. I need only recall the names of Grisebach (1872), De Candolle (1874), Drude (1890) in Europe or Sargent (1884) and Merriam (1894) in America. In the last decades of that century more and more of the accumulated *meteorological data* was used, and an attempt was made to recognize the climate of a certain region by consulting the various tables and collected data of precipitation and temperature. If available the data on wind, frost, cloudiness, humidity were added.

The global climatic classification was mainly constructed on this basis and slowly the climatic concept became a purely *analytical* one. The biologists, however, were never satisfied with this concept, particularly not with the stress on mean monthly or yearly figures. They also studied existing vegetation maps of the respective region to round off the picture of the climate more adapted to their own purposes.

In addition to the climatic maps and the vegetation maps, the biologists also used the orographic maps for complementary deductions, but the main average data for temperature and precipitation were still the most frequently used method of describing a climate in scientific and popular climatic classifications.

Among agronomists it is still usual to give the figure of average yearly rainfall as a standard climatic concept for general agricultural purposes. It would be a waste of time to explain here, that the same rainfall figures, with different distribution or in another latitude, etc., have very different meanings as far as agriculture is concerned. A two-months dry period in the tropics has a most selective effect on the natural vegetation, even in regions with very high rainfall figures. Moreover, the wilting processes in the tree tops of the most humid rain forests, when there is a lack of clouds at noon are well known.

It is much easier to criticize the disadvantages of a climatic classification based on analytical principles than to put a better one in its place. The drawbacks have always been recognized, otherwise there would not have been so many attempts to replace these principles. Yearly and monthly means were introduced, the means of the coldest and the hottest month and temperature and precipitation factors were connected into one formula. In these latter attempts Koeppen (17) laid more stress on the temperature factor, whereas almost all other classificators laid the main stress on precipitation. From the phytobiological point of view both factors are not disconnected from one another. We know, however, that at the fringe of polar and alpine vegetation, the temperature factor is more frequently the decisive one, whereas in lower latitudes, and particularly on the arid borders, the decisive factor precipitation, or the presence of water in general, is the decisive factor.

In the last 40 years formulae have been sought which more adequately expressed the biological, and particularly the phytobiological, requirements. In addition to the mean values of temperature and precipitation the mean values of maxima and minima were included, a big step forward.

The success of Koeppen's classification, published in 1918, was achieved mainly by the fact that the actual basis of his principle was constituted by the five general vegetation units of the great French botanist De Candolle (1874). Koeppen investigated the main differences among them with regard to temperature and moisture and this climatic classification, based on biological sources, was, of course, much more useful to the phytobiologists than those of his predecessors.

By such methods the way was opened for analogous climatic classifications and many others followed as a result. The widest application resulted from Thornthwaite's classification (22). By combining five rainfall types with six temperature types and subdividing the rainfall types further into four types according to the seasonal distribution, he arrived at his thirty-two to thirty-six types of climate. By introducing the evaporation factor and, particularly, by expressing all types by letters and figures, his classification became the easiest to apply and soon achieved a world-wide recognition. The combination of the three indices, namely, the general moisture index (as humidity or aridity index) with the seasonal variations as the second, and the thermal efficiency as the third, makes this method much more applicable than the previous classifications. The last index is based mainly on the extensive research work of Geslin (16). Potential evaporation as an index leads to a certain conformity with our general concept of the climate from the hot equatorial regions to the Arctic and Antarctic, respectively.

Like all others the classification of Thornthwaite, although applicable for many purposes, still has many gaps from the phytobiological standpoint. There are many factors which have never been considered as relevant to such formulas. The intensity and frequency of the factors included in them are of particular importance. These matters, however, are not expressed in his classification.

The main representatives dealing with these principles are Boyko, Emberger and Gaussen. Boyko devised the "Biological Rules of Climatic Extremes" (4). Emberger included the mean maxima and minima of the hottest and the coldest months in his formulae (13). Gaussen introduced the effectiveness of rainfall (15) and stressed that the duration of drought surpassed in its importance that of intensity. He presented his principles in climatograms. Such climatograms are very instructive. Walter elaborated them in more detail for easy comparison, and a global atlas of his climatograms has now been published (25).

With regard to the precipitation effectiveness, it should be considered that it depends not only on the amount and intensity of rainfall and on air humidity and temperature, but also on the respective soil structure. Here Boyko's C. S. C., the "climatic soil coefficient" has to be taken into account (7). This coefficient has been devised by him in 1949 for soil types of south-west Asia only. Since it is an empirical coefficient it must be determined for each soil type in each region separately.

In some cases this has been done. McGinnies (18) reported for instance, that *Larrea tridentata* occurred on sandy soils in south-west Arizona in a rainfall area of 25—50 mm only; the same shrub on poorer, heavier soil in southern New Mexico indicates an average rainfall of 200—250 mm. Here we have a climatic soil coefficient of 175—200 mm for this heavy soil in relation to the sands in these semi-desert and desert regions of the United States of America. Vernet (24) reported a difference of 250 mm between the rainfall indication of *Plantago albicans* on deep, sandy soil and on silt in Tunis. I always took light dune-sands as a basis for such comparative scales, and in the Negev used the gradation in column 1 below; the corresponding C. S. C. (climatic soil coefficients) are given in column 2:

for light sand (dunes)	of	+0	(taken as basis)
for hard limestone	of	plus	30 mm rainfall
for soft limestone	of	plus	50 mm rainfall

for loessy sand	of	plus	50 mm rainfall
for sandy loess	of	plus	100 mm rainfall
for heavy loess	of	plus	150—175 mm rainfall
for gypsy marl	of	plus	50 mm rainfall

(The records were taken of squares of the same size, mostly 10 to 10 m, with a similar number of individuals of the same species, or with a similar composition of the whole plant community.)

Asphodelus microcarpus in the Negev may serve as a practical example. A similar occurrence of this species on its arid distribution border indicates an average yearly precipitation of about 125 mm on light sand and 300 mm on heavy loess.

In all these cases the permeability of the soil or the percentage of clay particles in it may present the possibility of a numerical approach. It is a different question if such a numerical approach is really desirable from the biological point of view. We are here confronted with the same question in respect to the soil as we are in respect to the climate.

Quite generally it can be said that the disadvantage of all these climatic formulae and classifications is that they are based exclusively on the data supplied by meteorological measurements. We all are aware of the insufficiency of meteorological instruments. Konrad Buettner's well known experiments with rain gauges are a striking proof of this. They showed for instance, that after a stormy day only one-sixteenth of the actual rainfall could be measured in the rain gauge. The Negev in Southern Israel is classified as a hot desert. Nevertheless in the winter 1950—1951 my wife was marooned for 3 day near Kurnub, at an altitude of 600 m after a heavy snowfall, and we had to send bread and blankets by plane to save her and her colleagues. The snow cover, measured by her, was 60 cm deep and 3 days passed before their command car could move again, for at that time this area was roadless. On the tops of the mountains, however, at an altitude of 1,000 m, three cloudless *weeks* passed before an airborne observer could record that the snow cover had disappeared. This means that there was a snow cover of at least 150 cm, or expressed as precipitation about 180 mm. The rain gauges (totalizators had been erected there in 1949) showed only 70 mm for the whole rainy season, despite the fact that at least two more similar rainstorms occurred in the same winter. These are, of course, extreme examples but they show clearly the weakness of the existing formulae which are generally the basis of all present classifications.

In the temperate zones there are no such extreme discrepancies. Moreover, there is usually a dense network of meteorological stations with highly skilled critical observers. This is, however, not the case in the greater part of the world. Another weakness of all the current formulae and classifications is that many factors, although they have a strong influence on and often even decisive for plant life, are omitted and sometimes of necessity. Formulae can be misleading even if they are right, if climatic features are erratic, as is the case in most arid regions. Plant life there is often surprisingly well adapted to this "factor of erratics" and many species living there indicate this clearly to the ecologist at the first sight. *Poa sinaica* for instance' survives one or may be more dry years without difficulty in the form of a dry moss-like cushion of a few millimetres height only, but grows with flowering and fruiting stalks of 30 cm high and more in years of adequate rainfall. In dry years it probably lives mainly on the subterranean dew which condenses rather regularly in the cool early hours of the morning and moistens a narrow soil layer or the crevices in hard limestone where the species roots.

Many single factors are often completely lacking or substituted inadequately by others. Day-length, for instance, may be substituted for the amount of light to a certain degree and even more dubiously for the influence of the various parts of the spectrum and radiation in general. Furthermore the possibly decisive influence of electric fields on plant life as shown by Stetson (21) is almost unknown or insufficiently known to biologists themselves. The very important wind factor is much better known in its influence on plant life, but has not yet been taken into account in any formula. Many other factors can be added, as for example fog, air pollution, pH of rain water, etc., and each factor has complicated biological implications of its own. Barkmann (2) includes, for instance, the frequency of those days which are foggy at 2 p.m. stating quite rightly that fog at that time of day is of far greater influence on plant life than fog in the morning. Cauers' investigations on the pH of rain water in connexion with human ecology open new ways too in the direction of bioclimatological research with regard to plant life.

All these factors are rarely restricted to a limited space, let us say to the space of a microclimate of an environment only, but mostly influence, and influence decisively, more or less regularly large areas. As for the description of a microclimate we know of quite a number of additional factors, for instance the reflex radiation, dew above the surface and on the leaves, subterranean dew, etc.

In this connexion I should like to say a few words about the classification of climate according to the space of investigation. Quite generally we distinguish between macro-, eco, and micro-climate. I think that we must enlarge this scale of concepts by adding two or three additional subdivisions. First of all we might speak of the *geoclimate* in contrast, for instance, to the climate of any other planet. The next concept, *macroclimate*, already has too vague a meaning. It may serve for the climate of the large vegetation units from which the concept climate originally stems, e. g. tropical rain forest climate, steppe climate, desert climate, or for climatic concepts for large geographical areas such as the Mediterranean climate, etc.; but it has also been used for much smaller subdivisions down to the characterization of specific climatic conditions of a relatively small area, comparing it with a specific microclimate. I believe that we must decide upon more precise definitions.

I would propose the use of the term *general climate* for the climate of the original large vegetation units and such like, and leave the term *macroclimate* for the types similar to the thirty-two to thirty-six types of the Thornthwaite's classification. For the smaller units we are confronted with more difficulties resulting mainly from orographical influences; these have occasioned the criticisms and additions mentioned above. We have, for instance, to define more clearly the areas for which we habitually use the concept ecoclimate. I believe that a small working group could work out such and other precise definitions as a proposal for international use. This suggestion applies also for the following grades in the scale such as ecoclimate, topoclimate, microclimate and finally point-climate. The latter is of great importance for physiological investigations, although apart from the thermo-needle we have not yet developed suitable instruments for its measurement. A wide field is open in this direction for important future development. May I mention only the influence of the differing wind-climate around the stomata according to their morphological or anatomical position and its very important influence on evapo-transpiration.

If we speak of an *ecoclimate*, we mean the climate of a small geographical unit e. g. a valley or mountain or forest but the actual climatic data may be very different in various spots. The climate of the small valley Vallungo in the Dolomites of Northern Italy, to mention a practical example, "has very different climates on the northern and southern slopes, and these different climates are strikingly expressed by the very different plant associations on the two opposite slopes even at the same altitude, namely a *Piceetum ericetosum* on the southern slope and an *acidophilous Piceetum* with *Vaccinium* and *Rhododendron* on the northern slope. There are also differences of about 200 m for the respective altitudinal limits for the same species on southern and northern exposures. The big climatic differences in this valley resulting from different altitudes are of course also expressed by the vegetation cover reaching from the upper limit of *Pinus silvestris* over the whole *Picea* zone and that of *Pinus Cembra* to the Arctic—alpine zone of *Salix herbacea* and lichens as characteristic species. On the other hand, there exists in this area a number of *common* climatological factors, for instance day-length, seasonal distribution of rain and snow, warm winds coming up from Val Gardena, and so on.

The *topoclimate* may be defined as the ecoclimate in the same latitude and with the same exposure. Here the main factors are generally of the same order as, for instance, in the *Piceetum ericetosum*, which occurs only on the southern slopes of the lower parts in the same valley Vallungo, as mentioned before.

The next class could then be the microclimate of the actual habitat of one plant individual or a biocoenosis of a similar size.

In spite of the small space the microclimatic conditions may, however, differ greatly between the plant top and the ground or on two opposite sides of the plant. If we do not wish to take these contrasting microclimates together into one single climatic concept, we might call the whole the *habitat climate*, and call only one smaller subdivision the *microclimate*. Last in this order would be the *point-climate* to which I have already referred.

I must repeat, however, that all these principles of climate classification mentioned above depend on analytical data recorded by human beings and by instruments; both of them are not always comparable and often not even reliable. This unreliability has led the author to a completely different approach, the gradual building of a new branch of science, "ecological climatography", which was discussed first at the IUBS-Symposium in connexion with the sixth International Botanical Congress in Stockholm in 1950, then at the Ankara and the Montpellier Symposium of UNESCO in 1952 and 1954, and at the two predecessors of this Congress, the Founding Conference of our Society in Paris 1956, and the First Congress 1957 in Vienna (8).

Ecological climatography is based on the following considerations: The pure analytical principles and numerical data are not, or at least not entirely, satisfactory as basis for a climatic classification for *biological* purposes. This is probably quite generally valid but it is certainly valid but for biological purposes dealing with the *plant world*.*

The splitting up of the climatic complex affecting as a whole the biocoenosis of any locality, and the pure numerical approach to biological problems leads to too artificial generalizations. The main causes of this can be seen in biological rules, which might be expressed as follows:

(1) The biological *effect of the same climatic factor* can be very different, when one or more other factors are changed.

(2) A considerable shift in the numerical values of one single factor can result in *the same biological effect*, if the change of other factors re-establishes the balance.

These general bioclimatic rules can be proved by numerous examples, as everybody knows from his own experience. On a hot day with high humidity without wind we feel quite different than on a day of the very same temperatures, but with a dry wind; we would not even call it a hot day. With regard to the second rule I should like to mention the fog vegetation in arid zones described by Troll (23) and others, where precipitation alone would indicate a desert vegetation.

It may be argued that evapo-transpiration is incorporated in most of the newer climatic classifications. We know quite well, however, that we are not yet, or perhaps not at all, able to determine the actual evaporation and still less evapo-transpiration.

The general bioclimatic rules justified the use of biological yardsticks as principles of climatic classification.

Such a phytobioclimatic classification can be based also on *cultivated* plants. The correlation of cultivated plants with a classification of climate has repeatedly been tried. As examples I only mention Azzi's work on wheat (1), de Fina's work on Argentine fruit trees (14), and last but not least the many and manysided papers on phenology.

Although Ellenberg's (12) studies on weeds as climatic indicators belong too to this group of principles of climatic classification they lead already to the next group of principles: the *use of natural vegetation* and single wild plant species for this

* All speakers and participants in the discussion, dealing with this subject after this lecture, stressed this validity also from the viewpoint of their respective branches of science: meteorology, climatology, human ecology and animal ecology, in addition to phytology, itself. A review of the principles and methods of ecological climatography is now in preparation (10).

purpose. Such a phytobiological climate classification can be based on various principles, the main of which seem to be: (1) biological spectra, e.g. those of Raunkiaer (19); (2) life forms, e.g. those of Du Rietz (11); and (3) amplitudinal scales analogous to those worked out by Boyko (5) for the arid region of south-west Asia, as examples. Statistical evaluation based on any one of these three basic principles allows a quantitative classification.

The first two are applicable to macroclimatic concepts only, but the third one can be applied to the whole range from macroclimate to microclimate. We have as yet insufficient scales of ecological amplitudes, to be able to base global climatic classification on them.

There is much data from all countries to be utilized as starting points, but these data are scattered in many papers and are not yet systematically collected. Up to now we have discovered only that there is a well-developed and readable scripture in this open book of Nature but we are not yet able to read it fluently. Although plant world puts an excellent alphabet into our hands, we have still to decode most of its letters. We can, however, distinguish between quite a number of complementary species, as I called them in one of my first papers about this subject (3). Vernet (24) found a much better word for them, namely "alternates", which I shall use in future. Both terms, however, exclude the overlapping species indicating overlapping climatic conditions. This latter principle was the main basis for our climatic map of the Sinai peninsula (9).

Both principles are of high value. Alternate in Israel are, for instance, *Laurus nobilis* L. and *Quercus Aegilops* L., the latter occurring here mostly with its variety *Quercus ithaburensis* (Decne). Overlapping to a small degree in their border-regions are *Artemisia herba alba* Asso. and *Zygophyllum dumosum* Boiss. Each of these species indicates quite distinct climatic conditions, and so does the fact of overlapping itself for its area. We can clearly recognize this where, for instance, the desert species *Zygophyllum dumosum* occurs on the same hill as *Artemisia herba alba* which occupies a more humid and cooler geographical region. We need only to count the number of individuals in equal squares on slopes of 10—15° south and 10—15° north and we have determined with almost mathematical exactness the grade of transition between the two great climatic regions represented by these two species in their exclusive regions.

The finding of such quantitative keys to climatic classification is of course not to be based on investigations in the optimal region of such key species or plant associations. It is in the border areas where we shall achieve the best results. By working intensively on one single hill in a border-line region of great climatic units we shall soon be rewarded with results applicable to the two or more great regions which are to be dealt with. The following examples may elucidate this:

For several years I thoroughly investigated such a hill, the Heitary in the Carmel range, where the Mediterranean conditions are influenced by the more continental climate of the eastern parts of South-West Asia with their arid border forests and their steppe and desert belts (6, 20). All the species here which are actual representatives of climatic regions show a very distinct distribution according to the I.E.-factor. Four examples of alternatives may suffice: *Laurus nobilis* L., *Salvia triloba* L., *Quercus Aegilops* L. var. *ithaburensis* and *Stipa tortilis* Desf. were selected.

The entire hill lies in the *Quercus caliprinus* zone (we have here an ecoclimate with a rainfall of about 600 mm yearly). This oak species, or better perhaps, the subspecies of *Quercus coccifera* L., *Quercus calliprinos* Webb. is still at its optimum here, but near to its south-eastern fringe, and this indicates, quite generally speaking, an adjoining of a mainly east-Mediterranean macroclimate with the more continental and more arid climate of the South-West Asian interior.

Let us now analyse the climatic indications with these four species. On the Heitary hill the north-Mediterranean *Laurus nobilis* occurs only on northern slopes with gradients of 30° and over. According to Ashbel there exists on such slopes a thermal effect of direct solar radiation of 40—100 kcal/cm² per year, and the most humid climate of the entire vicinity. The actual *Laurus nobilis* climate is to be found in much more humid and cooler areas in north-Mediterranean countries, for instance on the southern slopes of the Mte. Maggiore in Istria at an altitude of 300 m, with 1,000 mm yearly rainfall. Less inclined slopes with a higher insolation but still with a northern and western exposure are covered with a dense shrubby vegetation, with *Salvia triloba* as the main component. Immediately as slopes of the Heitary hill start to flatten out, or if we examine an eastern or southern exposure, we are confronted with *Quercus ithaburensis*. This beautiful and valuable tree only grows here on slopes from 5° N. to 15° S. and again on slopes from 40°—60° S. Eastern and

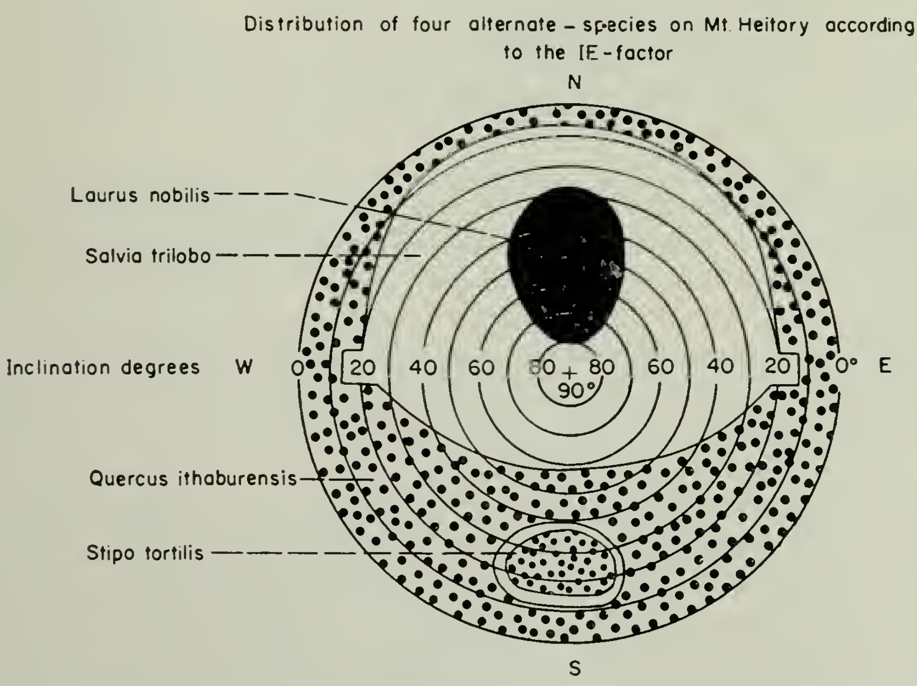


Fig. 1. Method of presentation of topographical plant distribution according to the I.E.-factor

western slopes are inhabited up to 20°. In all these cases this happens only in a specifically limited zone which has a yearly distinct insolation total of from 180 to 205 kcal/cm², leaving a gap on the hottest slopes, i.e. those between 15° S. to 40° S. The latitude of this place is about 32° N. These slopes of 15—40° are bare of bushes in

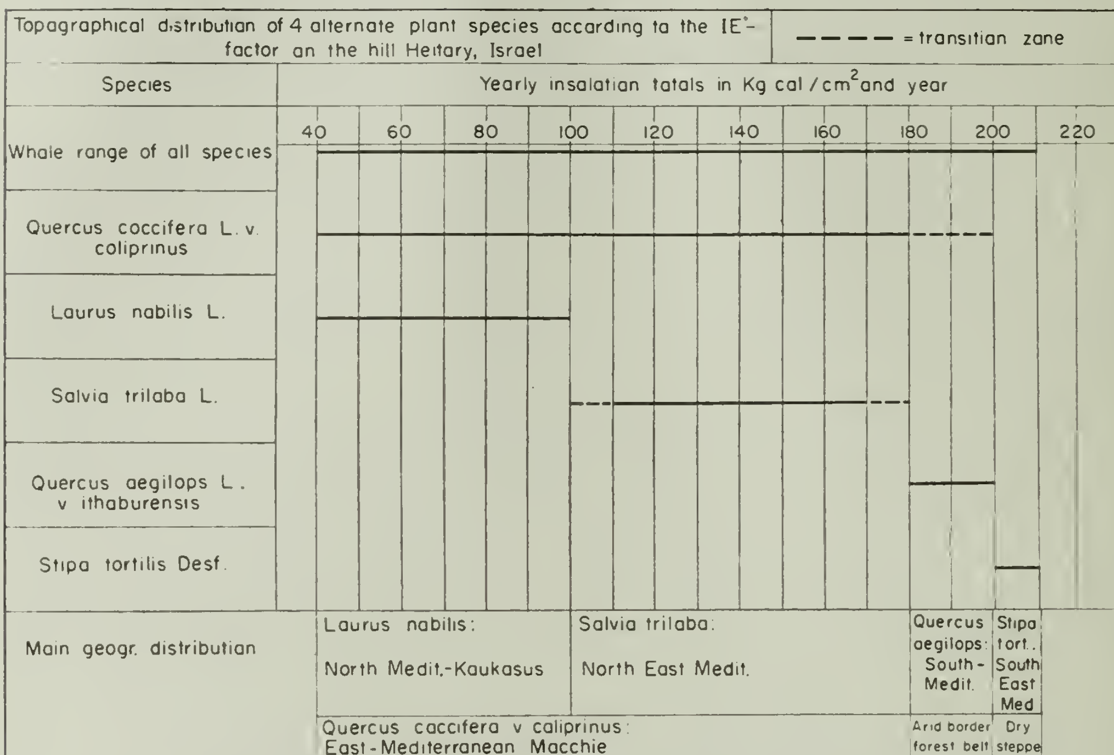


Fig. 2. Method of presentation of topographical plant distribution according to the I.E.-factor (insolation—exposure)

the years in which the investigation took place, and had a dense and exclusive cover of the thermophilous annual grass *Stipa tortilis*. This kind of sociability serves as an indicator of a dry steppe belt climate, characteristic of the belt which encircles the whole semi-desert and desert zone of south-west Asia and North Africa. The insolation figures of those places in which pure *Stipetum tortilis* occurs in the middle of a *Quercus calliprinos* climax region, are 205—210 kcal/cm². From this single hill we can discern a whole scale of climatic regions expressed by biological yardsticks as basis for a phytoecological climatic classification.

According to the geoecological law (3), microdistribution is a parallel function of macrodistribution, because both are dependent on the same ecological amplitude. This law was successfully used in such cases for assessing many plants and plant associations as yardsticks for climatic classifications. In combination with the meteorological and climatological data from the areas of the general geographical distribution of the respective species like the four mentioned above, i.e. from their macrodistribution, we can deduce many details.

Three different principles of presentation of microdistribution are to be seen in the graphs in Figs. 1—3.

The four alternates shown in these graphs have the following macrodistribution:

(1) *Laurus nobilis* is a humid north-Mediterranean species.

(2) *Salvia triloba* is a less humid east-Mediterranean species.

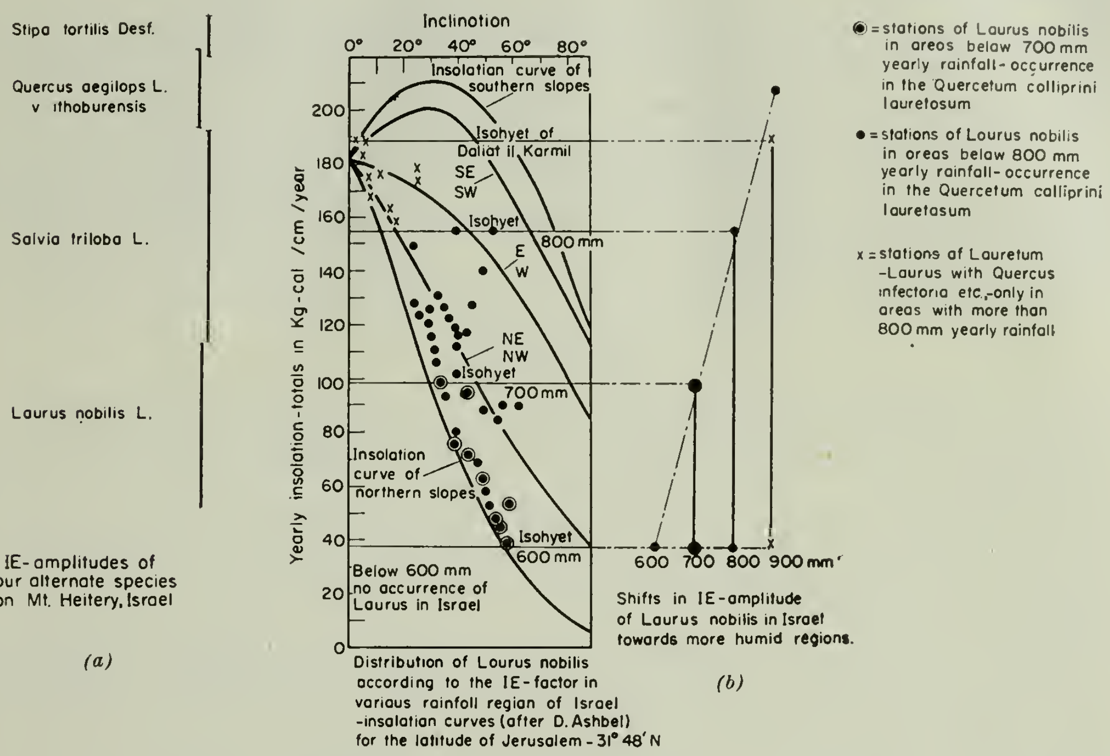


Fig. 3. Method of presentation of topographical plant distribution according to the I.E.-factor. The method of recording the plant individuals or groups, on insolation curves (b), is combined with the linear recording of I.E.-amplitudes (a)

(3) *Quercus ithaburensis* is the southern subspecies of *Quercus aegilops* which builds the arid border forest belt circling the Anatolian steppe and reaches far into the more continental but still warmer parts of Iran, also bordering the *Stipa tortilis* steppe belt.

(4) *Stipa tortilis* is a thermophilous steppe plant, surrounding the semi-desert and deserts of North Africa and south-west Asia and penetrating deep into the actual desert region but in single individuals only and not as a dense carpet as in places on the Heitary hill.

With regard to the climatic classifications we can speak — according to their alternation — of a *Laurus nobilis* climate, a *Salvia triloba* climate, a *Quercus ithaburensis* climate, and of a *Stipa tortilis* climate in a similar way as of an *Artemisia* *herba alba* climate, a *Zygophyllum dumosum* climate or a *Haloxylon salicornicum* climate in the respective desert parts of the Negev.

This can be attributed to the optimal region where these species are main components of the climax vegetation or we can attribute it to a specific habitat-climate.

In both cases these principles present a sound basis for bioclimatological conclusions as well as for conclusions with agricultural or forestry or any other development aims in mind.

Summarizing we can say that the approach of ecological climatography to the bioclimatological problems may well lead to that synthetic understanding of climate which climatologists and biologists have been striving for, for a long time.

By combining the synthetic principles of the ecologist with the analytical ones of the meteorologist we shall probably achieve the best practical results, particularly in those complicated land-use and development problems with which we are so seriously confronted these days.

REFERENCES

1. Azzi G., *Le Climat du Blé dans le Monde*. Inst. Internat. d'Agriculture, Rome (1927).
2. Barkman J. J., *Phytosociology and Ecology of Crytogamic Epiphytes*. Van Gorcum Verlag, Assen (1959).
3. Boyko H., On the role of plants as quantitative climate indicators and the geo-ecological law of distribution. *J. Ecol.* **35**, 1—2, 138—57 (1947).
4. Boyko H., On climatic extremes as decisive factors for plant-distribution. *Palest. J. Bot. Rehovot* **7**, 41—52 (1949).
5. Boyko H., On the climax vegetation of the Negev. *Palest J. Bot. Rehovot* **7**, 17—35 (1949).
6. Boyko H., A new plant-geographical Subdivision of Israel — as an example for Southwest Asia. *Vegetatio* The Hague 309—18 (1954).
7. Boyko H., "Climatic, ecoclimatic and hydrological influences on vegetation" *Unesco-Symposium (Montpellier* 1954*) on Plant-Ecology, Paris 1955*, pp. 1—8.
8. Boyko H., Report of the Committee for ecological climatography. *I. J. B. B.* Vol. II., pt. VII, sect. A 1 b, 1—5 (1958).
9. Boyko H. and E. Boyko, A climate map of the Sinai peninsula as example of ecological climatography. Internat. Soc. of Bioclimatology and Biometeorology, First Bioclimatological Congress, Vienna 1957. *I. J. B. B.* **2**, 1—6.
10. Committee on Ecological Climatography, Ecological climatography (Review of principles and methods). In press.
11. Du Rietz G. E., Life forms of terrestrial flowering plants I. *Acta Phytogeoraph. Suecica*, **3**, 1—95 (1931).
12. Ellenberg H., *Unkrautgemeinschaften als Zeiger für Klima und Boden*. Ludwigsburg (1950).
13. Emberger L., Une classification biogéographique des climats. *Recueil des travaux des labor. de bot, geol. et zool. de Faculté des sciences de l'Université de Montpellier*, 1955, pp. 3—45.
14. Fina A. L. de and Garbowsky, *Difusion Geographica de Cultivas Indices en la Provincia de Santa Fe y Sus Causas*. Inst. de Suelos y Agrotecnica, Tir. Int. 24 Buenos Aires, pp. 1—69 (1953).
15. Gaussen H., Théorie et classification des climats et des microclimats. *8e Congr. internat. Bot. Paris* 1954, sect. 7.
16. Geslin H., La caractérisation des climats locaux. *C. R. du Congrès de Pédologie, Montpellier-Alger* 1947, pp. 37—84.

17. KOEPPEN W., Klassifikation der Klimate nach Temperatur, Niederschlag und Jahreslauf. *Petermann's Mitt.* **64,** 193—203, 243—8 (1918).
18. McGINNIES W. G., Characteristics and distribution of arid zone vegetation as related to land-management in the USA. *Unesco Symposium on Plantecology in Montpellier, 1954, Paris 1955.*
19. RAUNKIAER C., *The Life Forms of Plants and Statistical Plant-Geography.* Clarendon Press, Oxford (1934).
20. SCHMID E., Prinzipien der natürlichen Gliederung der Vegetation des Mediterrangebietes. *Mitt. Bot. Museum Univ. Zuerich,* **185,** 69—200 (1949).
21. STETSON H. T., Note on possible effect of electric field on the growth of plants. *J. Franklin Inst.* **264,** 169—80 (1957).
22. THORNTHWAITE C. W., An approach toward a rational classification of climate. *Geogr. Rev.* **38,** 55—94 (1948).
23. TROLL C., Westensteppen und Nebeloasen im südnubischen Küstengebirge. *Z. ges. Erdk. Berlin* 241—88 (1935).
24. VERNET A., Climates and vegetation. *Arid Zone Research, Climatology, Review of Research, Unesco, Paris 1958,* pp. 75—101.
25. WALTER H. and H. LIETH, *Klimadiagramm-Weltatlas.* Gustav Fischer Verlag, Jena (1960).

HUMAN ASPECTS OF BIOCLIMATOLOGICAL CLASSIFICATION

KONRAD J. K. BUETTNER

Professor of Meteorology, Dept. of Meteorology and Climatology, University of Washington, Seattle, U.S.A.

Abstract—The degree of livability depends on local climate as well as on socio-economic and hygienic conditions. Age, profession, health and wealth are also important. In cool climates air temperature is still the leading parameter. For warm moist conditions the "desert equivalent temperature" (D.E.T.) is defined. The sum of heating degree days plus cooling degree days is a measure of climatic hardship. Airborne diseases and noxious aerosols are further controls. Solar radiation is frequently overrated. In "health resorts" the vacation effect might override the climatic effect. People in the U.S.A. who are entirely free to move permanently to places of their choice prefer the Cs climate.

Résumé—Le degré d'habitabilité dépend du climat local aussi bien que des conditions socio-économiques et hygiéniques. L'âge, le métier, la santé et les richesses sont aussi importants. En climats frais, la température de l'air est encore le paramètre principal. Pour conditions chaudes et humides, on définit la «température équivalente de désert» (D.E.T.). La somme de degré-jours de chauffage et degré-jours de refroidissement est une mesure de rigueur climatique. Les maladies portées par l'air et les aérosols nocifs sont des contrôles supplémentaires. La radiation solaire est fréquemment surestimée. A «stations de cure», l'effet de vacances surmène, peut-être, l'effet climatique. Les gens dans les États-Unis qui ont le choix de demeurer où ils veulent, préfèrent le climat Cs.

Auszug—Der Grad der Bewohnbarkeit hängt nicht nur vom Lokalklima, sondern auch von sozio-ökonomischen und hygienischen Bedingungen ab. Alter, Beruf, Gesundheit und Wohlhabenheit sind auch zu berücksichtigen. Für kalte Klimate ist die Lufttemperatur immer noch der wichtigste Faktor. Für heiss-feuchte Bedingungen wird die „Wüstengleiche Temperatur" (D.E.T.) definiert. Die Summe von Heizungs-Gradtagen und Kühlungs-Gradtagen ist ein Mass klimatischer Härte. Hinzu kommen durch die Luft transportierte Krankheitskeime und schädliche Aerosole. Die Bedeutung der Sonnenstrahlung wird oft überschätzt. In Klimakurorten kann unter Umständen die Erholungswirkung die des Klimas übertreffen. Grosse Bevölkerungsteile der USA, die freie Wahl des Arbeitsplatzes haben, scheinen das Cs Klima zu bevorzugen.

INTRODUCTION

PARIS, Vienna, and London, the three first meeting places of this society, form a triangle somewhat around the mainspring of bioclimatology in Davos. These cities also encompass the densely populated part of Middle and Western Europe, an area which has probably seen more studies of climatic effects on man than any other.

This fact is surprising if we look at the weather of this area. It lacks hurricanes, tornadoes, blizzards, dust and sandstorms, heat waves such as in New York, extremes of cooling power or windchill and extremes of effective temperature or sultriness. "Fine" weather is symbolized by a sunny spring day. Unpleasant aerosol is mostly

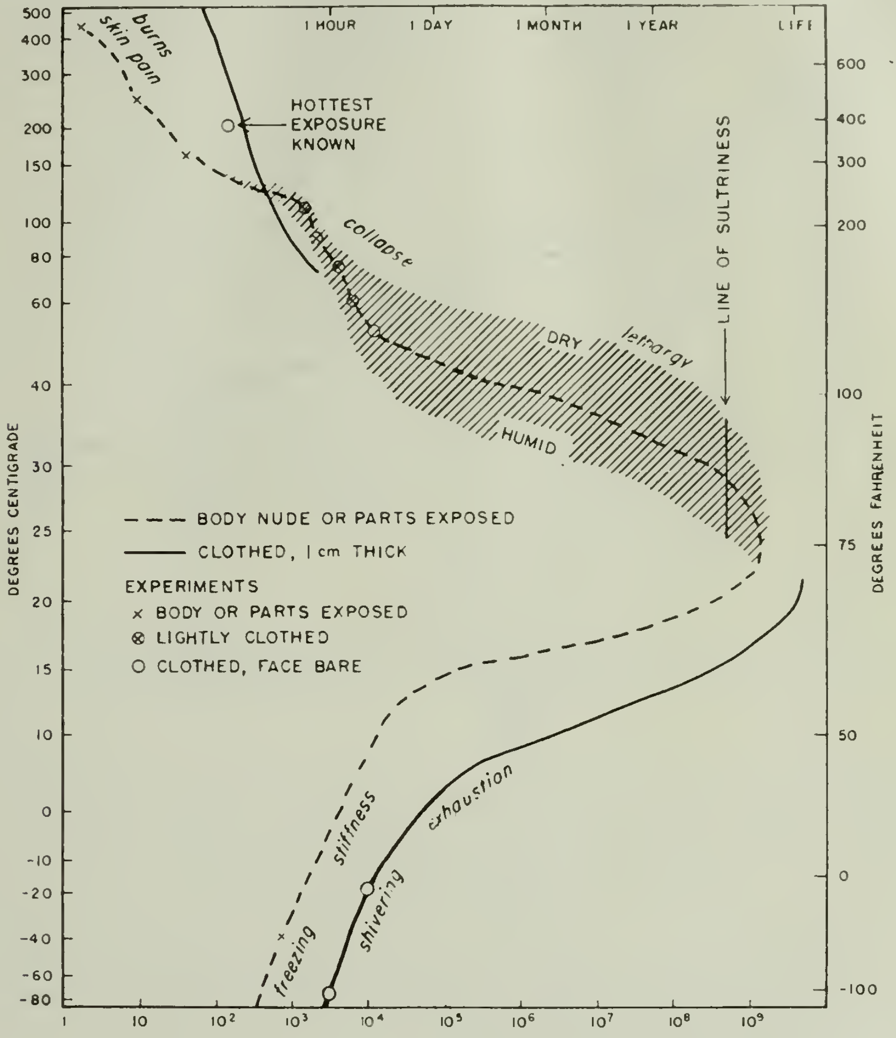


Fig. 1. Safe heat and cold exposure times in seconds for healthy, normal men at rest with body wholly or partly exposed. Room is free from artificial ventilation and radiation; air and wall have identical temperature. Humidity influence is shown by hatching. Max. N. Y. = highest data of temperature and humidity in New York City

man-made. Except for altitude the climatic variations affecting man are small and mostly of the microclimatic variety. We may well use this climate as a kind of reference point of other less even climes. Its only equivalent elsewhere is the U. S. west coast.

Judging any bioclimate one has to ask for whom and for which part of the day or year conditions are to be judged. The length of stay in a certain climate plays an obvious role. Man can stand any temperature G-force or oxygen partial pressure for a given period (Figs. 1—3). Homeothermic animals show limits of their natural habitat, mainly related to temperature and the availability of food and drink. Air humidity seems to play a role under hot conditions for species regulating heat through

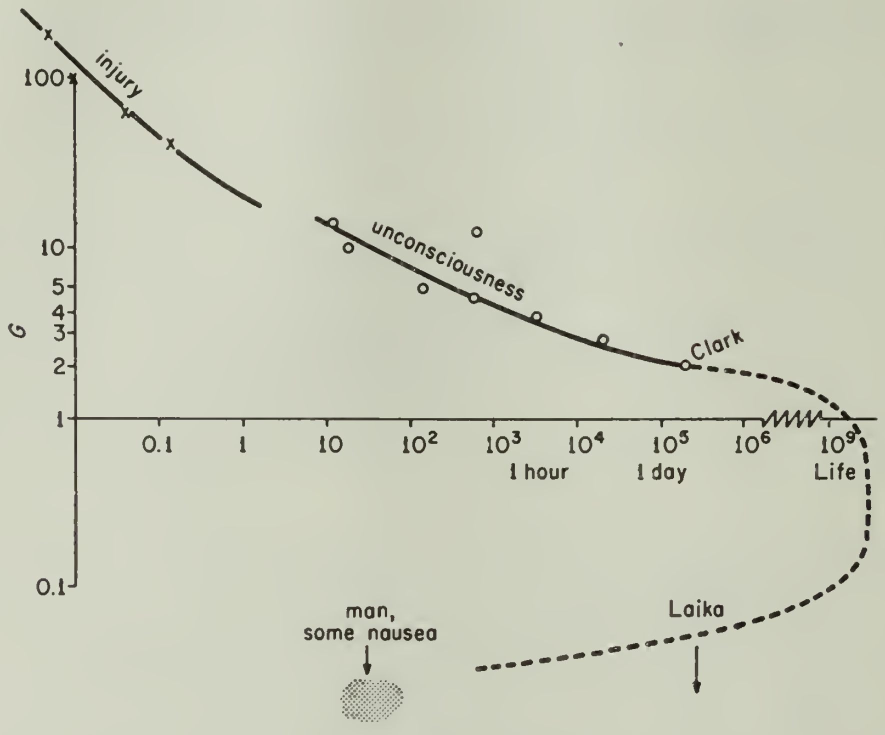


Fig. 2. Safe G-exposure times of man plotted in seconds. Dotted line is highly hypothetical (Data for near zero G refer to the dog in Sputnik III and to experiments of Geratewohl [3].)

panting (dog) or sweating (man, apes, equides, camel, some cattle). In man, health, age, sex, race, occupation and socio-economic conditions play a role in determining the ideal as well as the bearable conditions.

Of the factors mentioned poor health and low and high age limit safe exposure to many climatic extremes such as those of temperature, humidity, and low pressure.

The few known metabolic and skin temperature differences between the sexes do not warrant a special treatment. Concerning races the literature is filled with assumed platitudes stating essentially that the Eskimo is adapted to cold and the Negro to heat. Neither statement is generally true. Black skin is definitely a disadvantage in the tropical sun. The minimum requirements of shelter, clothing and food for survival are lower on a South Pacific island than in Alaska.

Some major factors controlling livability in a certain climate are:

(1) thermohygric conditions;

(2) infectious diseases as far as they or their spread are influenced by the climate;

(3) aerosol;
(4) ionizing and photochemically active radiations;
(5) indirect climatic effects.

Centuries ago (2) and (5) were leading. Shortly ago (4) in the form of solar ultraviolet and radium-spas were supposed to be vital. Today (1) and (3) are considered most important, provided, of course, that the danger of malaria, yellow fever, typhus

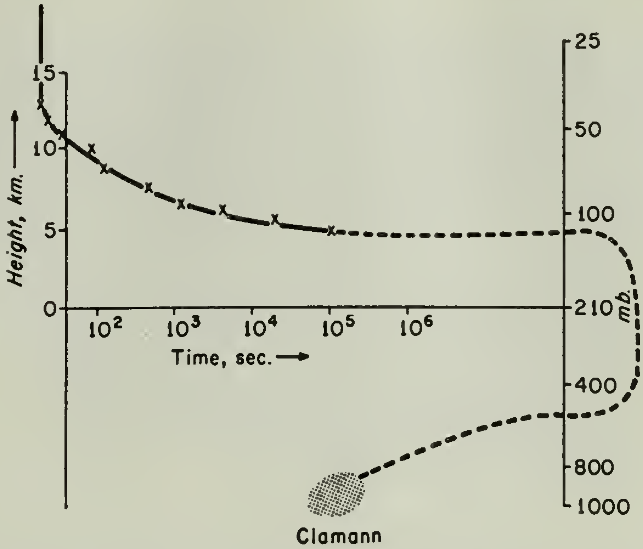


FIG. 3. Safe oxygen exposure times of man. Ordinate: O_2-partial pressures in millibars (right). Height in km (left). Dotted line is highly hypothetical

and other epidemics is averted and that modern farming, storing, packing and transportation methods eliminate the former indirect climatic disparity of food. For example, within the U.S. mainland prices and quality of food have ceased to be an indirect bioclimatic control. High-grade milk, fresh vegetables, meat and eggs are available the year round. Diseases of the digestive tract from climatic food spoilage are no longer of bioclimatic importance for the whole population of U.S.A. In many other areas on the globe this is unfortunately far from true. Food spoilage and lack of food calories and vitamins are not yet extinct as geographic phenomena; they still belong in the group of potential indirect bioclimatic effects. The same holds for many infectious diseases. Epidemic diseases are still an important part of medical geography and bioclimatology. The textbooks and periodicals on tropical medicine are mainly devoted to epidemic diseases prevalent in the tropics whether for climatic, microclimatic, or climatically controlled socio-economic reasons. These texts are little concerned with climatic comfort of healthy people.

COLD CLIMATES

The hygrothermal group includes effects of air temperature, air humidity, ventilation, solar and low-temperature radiation, heat conduction from solid and liquid environment and finally precipitation. Man's heat metabolism, body and skin temperature and skin and mucous membrane moisture are affected by these parameters. Climatic classification would request a just weighing of all these causes and effects for all kinds of climates and people and for all protective devices. This task is patently impossible. These are people living with very little or no protection in the stormy

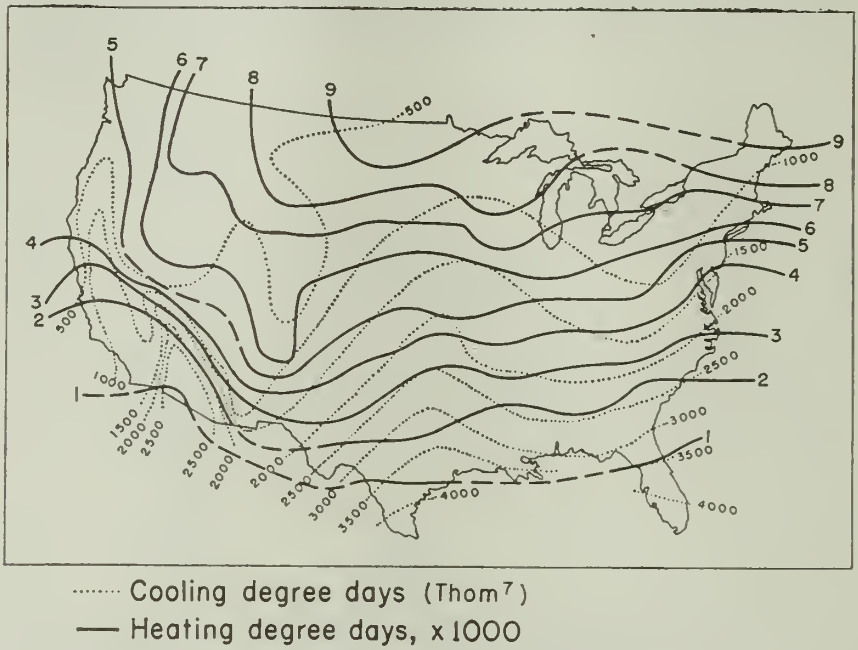
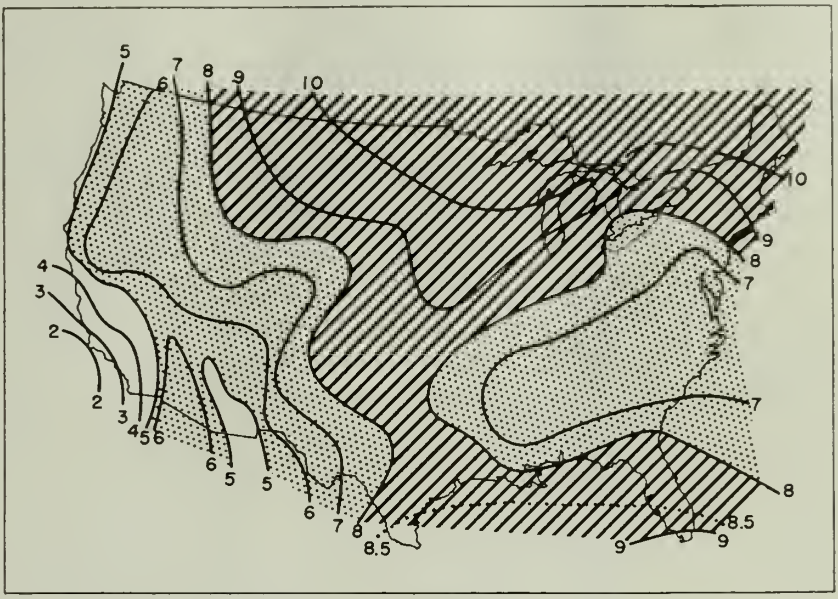


FIG. 4. Cooling (7) and heating degree-days for U.S.A. (units °F and day).

cold of Tierra Fuega and in the deserts of Australia. These stone age aborigines with an extreme degree of metabolic and temperature adaptation can hardly be used as a yardstick for the average man. Modern man through millenia has developed his protection against rain, hail, wind, sun and cold through the invention of shelter, fire and clothes. The speed of these inventions has accelerated to include now the central heating plant and the air-cooled house and vehicle. Thus bearability of indoor climate becomes strictly a matter of socio-economic conditions, i.e. of the price of heating and cooling.

These conditions can easily be mapped using heating and cooling degree days. The first parameter is the time integral of the difference (comfortable temperature minus outside air temperature). The second term uses instead equivalent temperature or a modified form of it. Both are proportional to the heating and cooling bill of a well insulated home. However, as shown later, the units of heating and cooling days are not equal in weight since around 30°C outdoors temperature a cooling by 1° effective temperature requires about as much energy as heating by 2° of plain temperature. Heating and cooling days are also a first measure of accumulated hygrothermal discomfort outdoors provided we restrict ourselves to temperature and effective temperature as sole measures of human comfort (Figs. 4, 5 and 6).

Outdoors the effect of temperature on man is modified by wind, precipitation, radiation and other factors. Human discomfort under cool conditions can be described in physiological terms since man counteracts body cooling by increase of heat metabolism and decrease of peripheral blood flow. Heat metabolism is raised either



Heating deg. days + 2x cooling degree days
units: 1000° F x days

FIG. 5. Sum of heating degree — days plus 2 × cooling degree — days. The larger the sum the larger is the integrated year round outdoors discomfort and also the total fuel and power bill for heating and air conditioning

passively by chemical regulation or actively by shivering and work. Finally clothes are a vital control. A comprehensive discussion of the rather involved role of all these factors is given by Carlson and Buettner(4). The greatest difficulty in assessing certain weather and climatic situations as being more or less cold to normal man rests in our lack of knowledge about clothes. If for any population group the relation of usually worn clothing versus climate were known, a cold discomfort index and a subsequent geographic bioclimatology could be evaluated essentially combining effects of wind, radiation and temperature. Unfortunately such studies are as yet known only for soldiers under extreme cold conditions.

Many attempts have been made to simplify this problem by omitting one or the other of the above-mentioned meteorological and physiological factors. The katathermometer and frigorimeter, for example, omit consideration of clothing and of variable skin temperature. The frigorigraph neglects clothing and variation of human metabolic heating. Similar shortcomings are true for globe thermometer, operative temperature, etc. Some of these systems reportedly help physicians to control the invigorating exposure of weak patients in climatic cures. No reproducible

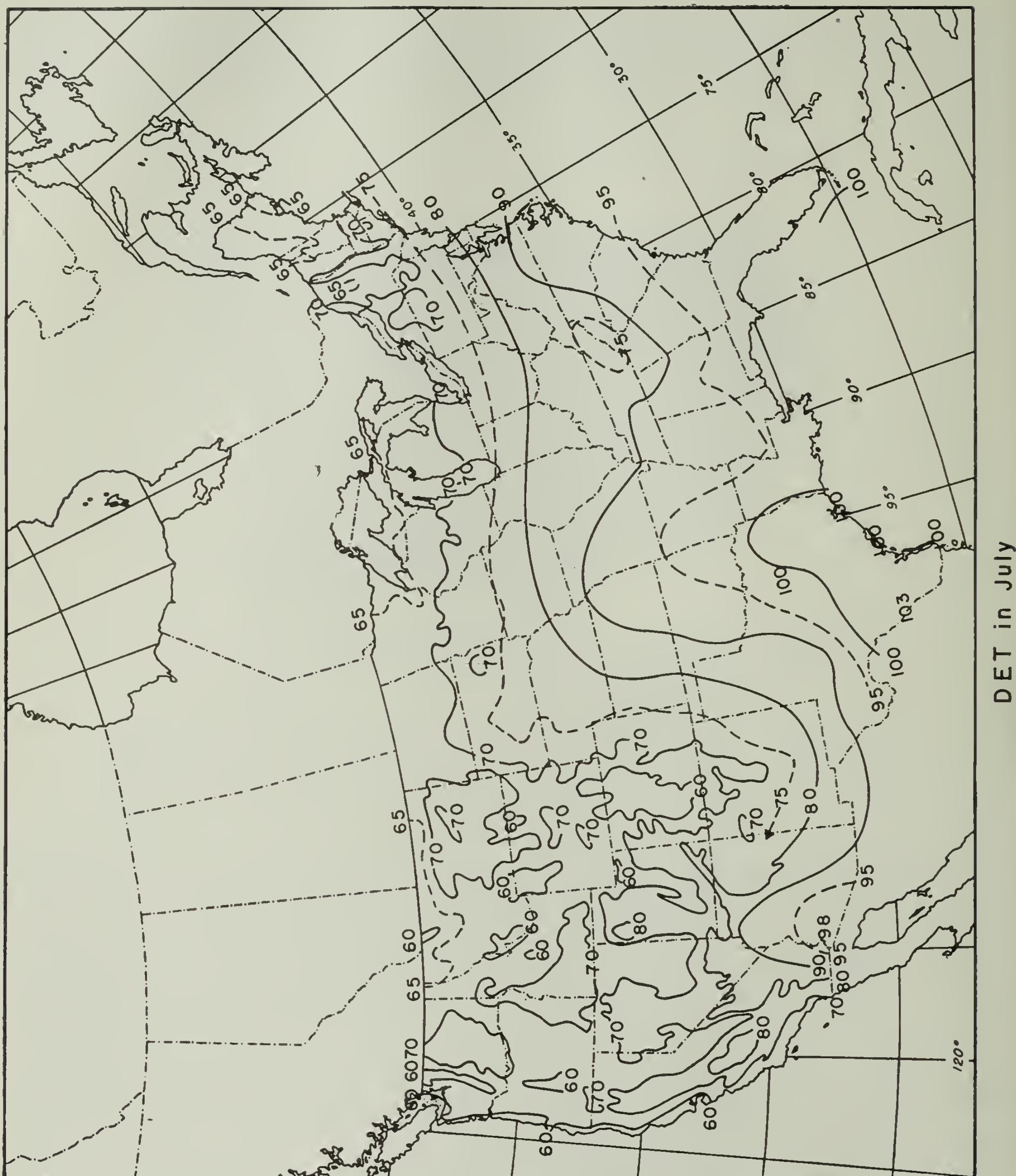


Fig. 6. Average July desert equivalent temperatures (D.E.T.).°F. Effect of humidity has been neglected for air temperatures below 70°F. All data are tentative.

and statistically valid study on the better use of climatic cures by their control through any of these cooling power devices has been published.

The cooling power systems are of little value not only when clothes are worn but, also when people sweat. Only the small comfortable area between cold and sultry may be correctly indicated. This basis is too small for bioclimatic geography.

HOT AND MOIST CLIMATES

On a sultry day in late summer 1959 the main fuses and transformers of Manhattan, New York blew out because the total electric load used for the air conditioning of homes, stores and factories exceeded all predictions. The effective temperature (E.T.) was very high. Analysis has shown a close correlation between electric load and effective temperature in New York; this correlation is much better than that for air temperature. Besides the thorough original study, many more verifications for the E.T. are known by now. Other measures such as different sultriness equations do not deviate enough from the E.T. scale to warrant a separate treatment. However, the original E.T. is hard to calculate, nearly meaningless to the layman and not a quantitative measure for the cooling load of a house or for the heat stress to the body.

The effective temperature belongs to the group of quasi-temperatures. All quasi-temperatures have a point of comparison. The point usually is realizable in nature and easily visualized. An increase by 1° should require the same amount of heat input at all degrees and in case of a physiological measure the same increase of physiological strain. For example, point of comparison for potential temperature is 1000 mbar which is realizable and easily visualized. The classical E.T. was originally meant for conditions in industry and mines, not for natural climate. It unfortunately has 100 per cent relative humidity as point of comparison. At higher E.T. this condition in not realized in open air and can be visualized by only a few hot-moist chamber experts. For example, an E.T. = 32°C (90° F) calls for 36 mm Hg vapor pressure, a value which never occurs in a natural climate. Around E.T. = = 20°C (68°F) humidity plays practically no role and the cooling load per gram of air per 1° of E.T. is 0.24 cal. Around E.T. = 30°C the cooling load is about two times larger per degree E.T., a major part of the load being spent for air drying.

On the physiological scale, a step from E.T. = 19° to E.T. = 32° is a change from comfort to extreme discomfort whereas a step down to 6° is rather harmless. Obviously each degree E.T. above 20°C becomes increasingly harder to bear.

To circumvent these difficulties the author asks indulgence for introducing one more quasi-temperature, the desert equivalent temperature (D.E.T.). This magnitude is still based on the ASHVE observations, but 10 mm Hg instead of 100 per cent relative humidity is chosen as a point of comparison. Fig. 7. shows tentative conversion factors. Detailed analysis of cooling load change and physiological strain change per change of 1° D.E.T. show certain variations with humidity conditions. However, our choice gives a correct overall relation of D.E.T. to cooling load and physiological strain. D.E.T. points of comparison are of course easily realized and visualized.

Comparative bioclimatic geography of hot-moist areas is best described in terms of E.T. or D.E.T. In this description the usual problems of statistics arise: are

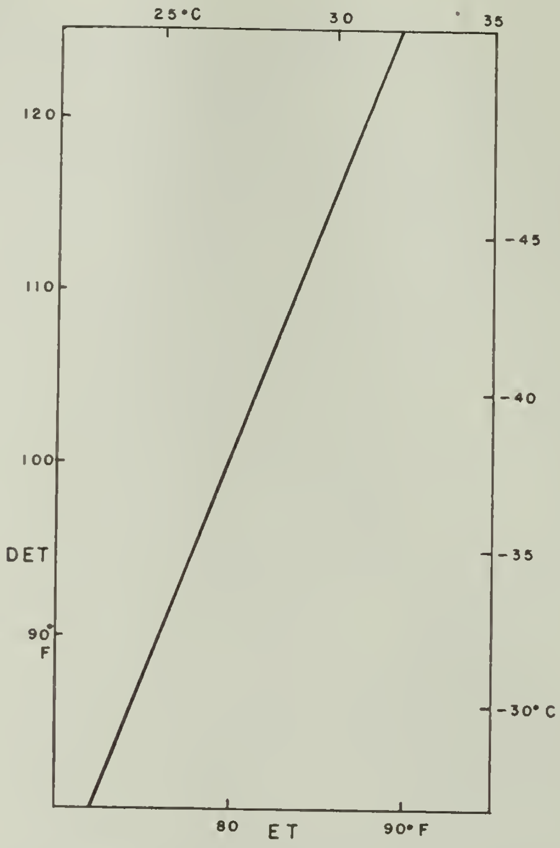


Fig. 7. Conversion of effective Temperature (E.T.) into desert equivalent Temperature (D.E.T.).

daily maxima, frequent values, summer averages or yearly averages more important? As the following survey shows, highest values are generally in the warm-moist jungle and not in the hot-dry deserts. Jungle climate shows generally small daily fluctuations. Yearly variations increase somehow with latitude. Consequently E.T. or D.E.T. values of the hottest month seem a promising first approach for the mapping of areas of discomfort. Fig. 6 is a first tentative step to such a map.

The following rules become evident from this pilot study (5,6).

(1) Extremely high summer D.E.T. occur generally where water meets hot deserts. The water may be that of the Red Sea or that of the Indus irrigation. The true desert never reaches summer values that high.

(2) High values are observed in tropical lowlands as well as around the lower Rio Grande and along the U.S. Gulf Coast.

(3) Area distribution of very high and high D.E.T. values shows no correlation to Koeppen climatic indices or to the socio-economy. The areas include the intense agriculture in the Rio Grande Valley as well as the lack of plant life in Port Sudan.

(4) Highest D.E.T values for a certain month are found around 20—30° latitude. Highest yearly averages are probably near the equator.

Cooling degree day based on E.T. are listed by Thom (7). His data are shown together with heating degree—days in Fig. 4. Judging roughly the importance of both units for human discomfort and for the fuel or power bill both units have been combined in Fig. 5. Thom's cooling degree—days have been given a double weight.

AEROSOL

Most aerosols except water and sea salts mean danger or at least some nuisance to man breathing them. Aerosols of bioclimatic concern are:

(1) Dust and sandstorms are restricted to dry areas and consequently are most frequent in *B* and *S* climates. They reportedly aggravate glaucoma.

(2) Pollens of plants cause many allergies. Geography and time of these hayfevers is that of location and blooming of the species concerned. High seas, high mountains and deserts are rather free. Rainy areas have less pollen than semi-dry ones.

(3) Smoke and smog may be caused by nature (e. g. forest fire, volcano) or by man. They are in any case strongly influenced by weather and climate. Their geographic distribution follows from these facts:

   (a) Solid smoke aerosol is emitted by the stacks. Part of it is coal, another part metal compounds. The latter may be quite dangerous. The classical city of this smog is London. High humidity and stagnant air are important controls, most frequent occurrence is in winter.

   (b) Auto exhaust and industrial effluents with rather low humidity and sunshine cause a different but also quite dangerous smog, prevalent in summer.

One essential reaction seems to be:

$$2NO \text{ (from exhaust)} + O_2 = 2NO_2$$

$$NO_2 + \text{sunlight} = NO + O$$

$$O + O_2 + N_2 = O_3 + N_2$$

Ozone is highly toxic to man, animal, plant, rubber, etc. This smog is prevalent in areas with stagnant air during strong insolation. This meteorological paradox occurs in summer along the subtropical west coast of continents. Best knownexample is Los Angeles. Ozone of stratospheric origin also arrives near ground but never in toxic quantities.

Too little is known on possible effects of non-industrial ozone, radon, ions and other air contents of sub-toxic concentration to warrant an inclusion in this list.

WHICH CLIMATES ARE PREFERRED?

Most people still live where farming, mining, power and industrial opportunities force them to stay. Progress in economy, transportation, communication and lessening of political tension cause more and more people to move to places because they like the climate. This concerns first the vacationers and retired people. But whole industries have moved to or originated in areas just for the climate. What can we learn from this movement about the preferred climate?

In comparing resort area geography politics cannot be disregarded. The areas chosen are obviously different in a country where people are free to go where they please than in a country in which travel and resort spots are state controlled. In the first case we see the opinion of the people, in the second that of a group of public servants on what is good for the people. Use made of highways, hotels, beaches and ski lifts could give an indication of the actual number of vacationers in an unregulated society. Such a study should be made. From personal observation I know of the rapidly increasing number of people enjoying the high mountains near Seattle, the Mt. Rainier and Olympic National Parks. Some interesting aspects of Kurortology in Russia have been published recently by J. Kornblueh (11) showing how spas and climate are utilized on "doctors' orders".

Many countries with socialized medicine have large and efficient systems for sending ailing or weak people to certain resort areas for limited periods. These cures are usually medically supervised. They should yield a wealth of objective data on what is good for whom. For instance, the studies of Jungmann have shown that a three-week cure is generally too short (8) and that higher altitudes systematically change the circulatory system (9). As to specific climates and their merits, however, published results disappointingly stress the obvious, namely that climatic extremes, air pollution and extreme altitude are not recommended and that a vacation is a good thing. I never learned of a study comparing cure effects of, for example, the North Sea, lower Alps and of the Lüneburger Heide on ailing people from Berlin or the Ruhr. These people would be exposed on the sea and in the Alps to a different climate, in the Heide essentially to their home climate. The first two groups would show effects of climate plus vacation, the second that of vacation alone.

The population of the U.S. west coast is rising. California gained 50 per cent in 10 years, largely from internal immigration. These groups include pensioners, farmers returning twice a year to their far-off farms and a large proportion of young active settlers. On the U.S. west coast electronic and airplane industries spring up which could be located anywhere at the same transportation, power, housing and food costs. I know of no similar event in history. At least ten million people are involved. They are not hampered in their choice of location by socio-economic, political or linguistic barriers. The main control for their choice seems to be the climate.

The preferred climate is mainly, Cs of Koeppen's scale, the Mediterranean, summer-day type. The warmest part of Csa and the coldest part of Csb are not included. Also some desert areas and Florida near tropical areas enjoy this boom.

Cs climatic areas are scarce on earth and a competition for Cs real estate can easily be predicted. Usable Cs include most of the U.S.A. west coast, the cooler part of the Mediterranean coast (especially the Riviera), Chile around Valparaiso, Australia around Perth and a small corner in South Africa. There is no Cs in Asia.

The California movement might herald a new era of bioclimatic geography. Fewer and fewer people will be forced to live where raw products such as food, oil, power, coal and ore occur; more people and more industries will be free to go where they wish. Cs climates will soon be crowded. The not too hot BS and BW and some Cf areas will be next. Unpleasant summers and winters will be spent in the air conditioned home and factory.

STATISTICAL AND INDIRECT BIOCLIMATOLOGY

Numerous effects of weather and climate on man are claimed on a statistical basis only. The number of these effects is legion; very few could be, in recent times, advanced to qualitative or quantitative bioclimatology (10).

Many studies deal with the effect on man of sudden weather changes, fronts, atmospheric instabilities and some of their consequences such as'sferics. The possible hygrothermic effects of these changes as well as of auto-suggestion are obvious. Whether anything beyond these effects can be brought under laboratory scrutiny remains to be seen. If storminess and frequency of fronts are, *per se*, detrimental for certain heart patients they should avoid the belt of westerlies above 40—45° latitude.

Deaths from cancer and heart diseases show a marked geographic pattern in the U.S., even after a correction for age. Unfortunately socio-economic factors as well as climatic ones could cause this distribution.

We shall call indirect bioclimatology the sum of all climatic effects on animal, micro-organic and plant life which in turn affects man. The most striking aspect is that of locally bound infectious diseases. This aspect will be dealt with by Dr. Jusatz in the next paper.

The healthiness of a certain area is frequently judged by the well being of the population. These judgements should be carefully checked to ascertain whether really the health status is locally bound and whether the local climate is a contributing factor. A mention of a few examples of apparent mistakes follows:

Many illnesses in industrial areas such as rickets have been blamed on the smog and smoke absorbing solar ultraviolet. Mostly this absorption as well as the beneficial effect of ultraviolet were overrated.

Early maturing of young people may be a general sign of health. Geographical data on menarche, as one example, are confusing. Population groups compared may be quite heterogenous. Frequently a well fed and educated group of high school girls at higher latitude is compared with an ill fed and superstitious or bigot group in the South.

Presently social, economic and political unrest decreases the world over with increasing latitude. About everything could be concluded from this fact. But the part climate plays here is very indirect indeed.

CONCLUSION

The late Dr. Berg asked me to give a paper on classification. We both quite agreed on the difficulty of this task as compared to the geography of plants or that of population density. Year round human settlements exist on North and South Pole, the Indus valley, the inner Sahara and in the high Andes. Except for altitude there is no climatic element left which is inescapable, i. e. which cannot be altered indoors, at moderate costs.

Human tolerance limits outdoors may be exceeded in some of these situations:

(1) Extremely cold (Siberia, Alaska, winter).
(2) Cold—stormy (Antarctica, polar islands).
(3) Hot—dry—windy (Sahara sandstorms, summer).
(4) Warm—moist (high D.E.T. see above).

REFERENCES

1. K. J. K. BUETTNER, Reaction to extreme heat. *Mechanical Engineering* **79,** 1031 (1957).
2. K. J. K. BUETTNER, Space medicine of the next decade as viewed from an environmental physicist. *U.S. Armed Forces Medical Journal.* **10,** 416 (1959).
3. S. J. GERATEWOHL, Weightlessness. *Astronautics* **2,** 32 (1957).
4. L. CARLSON and K. BUETTNER, Thermal stress and plugnological strain. *Fed. Proc.* **16,** 631 (1957).
5. K. J. K. BUETTNER, *Thermal Comfort as a Criterion for the Classification of Climates.* Meteorological Monograph, 2, No. 8, p. 99 (1954).
6. J. B. JONES, Unpublished.
7. E. C. THOM, A new concept for cooling degree — days. *Air Conditioning, Heating and Ventilating* June (1957).
8. H. JUNGMANN, Akklimatisationsprobleme bei Gesunden und Kreislaufkranken *Arch. phys. Ther.* **7,** 357 (1955).
9. H. JUNGMANN, Untersuchungen zur Anpassung des Wintersportlers an 2000 bis 3000 m Höhe. *Med. Klinik* **53,** 256 (1958).
10. K. J. K. BUETTNER, Our present knowledge on correlations between weather changes sferics and air electric space charges and human health and behavior. *Fed. Proc.* **16,** 631—7, (1957).
11. H. KORNBLUEH, Spas and Health Resorts in U.S.S.R. *Clin. Med.* **7,** No. 5 (1960).

THE WORLD ATLAS OF EPIDEMIC DISEASES AND ITS SIGNIFICANCE FOR BIOCLIMATOLOGICAL CLASSIFICATIONS

H. J. JUSATZ

Geomedical Research Unit, Academy of Sciences, Heidelberg (Germany)

Abstract—Bioclimatic geography describes living conditions for man or other species. This paper tries to describe some ways to compare livability for man. There is no generally valid rule for livability since age, sex, profession, health and clothing are additional controls. In cool climates air temperature is still the leading parameter; cooling power is of little value in view of protection from clothing and hoises. For hot moist climate the desert equivalent temperature (D.E.T.) is defined. It leads to a convenient definition of cooling degree days as a measure of climatic hardship and of the cost of cooling. Areas of high D.E.T. will be depicted.

Livability in extreme climates depends much on socio-economic factors such as availability to all of air-conditioned houses and offices, fresh vegetables, milk and general cleanliness. If these factors are absent indirect climatic effects such as seasonal infections, diseases, malnutrition, social unrest play a strong role.

Airborne infectious disease germs, pollen, noxious vapors from motor cars and industry and other aerosols are of obvious concern. Solar ultra-violet or other possibly photochemically active rays seem not to warrant special consideration.

Résumé—La géographie bioclimatique décrit les conditions de vie de l'homme ou d'autres espèces. Cet article est un essai de description de quelques méthodes permettant de comparer la viabilité de l'homme. Il n'y a pas de règle générale valable pour la viabilité, puisque l'âge, le sexe, la profession, la santé et l'habillement sont des critères supplémentaires. Dans les climats froids la température reste toutefois le paramètre déterminant, par rapport à l'habillement et aux maisons le pouvoir réfrigérant est un facteur bien faible. Pour des climats chauds, humides, la température équivalente du désert (D.E.T.) a été définie. Elle conduit à une définition convenable des degrés jours de rafraîchissement comme mesure de rigueur et de dépense due à ce rafraîchissement. Des zones de fortes D.E.T. sont décrites.

La viabilité dans des climats extrêmes dépend beaucoup de facteurs sociaux-économiques, tels que les conditions de vie dans des maisons et bureaux à air conditionné, régime de légumes frais et de lait et propreté générale. Sices facteurs font défaut, les effets climatiques, indirects, tels que les infections saisonnières, les affections, l'alimentation défectueuse, le malaise social jouent un rôle important. Des infections provenant du milieu atmosphérique, des gaz provoquant des troubles, le pollen, les vapeurs nocives des automobiles et de l'industrie et d'autres aérosols présentent un intérêt évident. Les rayons solaires ultra-violets ou d'autres radiations photochimiquement actives ne semblent pas justifier une étude particulière.

Auszug—In der «Bioklimatischen Geographie» werden die Lebensbedingungen für Menschen sowie sonstige Spezies beschrieben. In diesem Beitrag wird der Versuch der

Beschreibung einiger Arten des Vergleichs der Lebensfähigkeit für menschliche Lebewesen unternommen. Es besteht keine allgemein gültige Regel für die Lebensfähigkeit, da Alter, Geschlecht, Beruf, Gesundheit und Kleidung zusätzliche Einflüsse darstellen. In kühlen Klimaten ist die Lufttemperatur immer noch der bestimmende Parameter; die Kühlleistung ist im Hinblick auf den durch Kleidung und Gebäude gewährten Schutz von geringem Wert. Für feuchtheiße Klimazonen wird die vergleichbare Wüstentemperatur bestimmt (desert equivalent temperature, D.E.T.). Dies führt zu einer geeigneten Definition der Kühlungs-Grade für die einzelnen Tage, zwecks Messung der klimatischen Belastung sowie der Kosten für die Kühlung. Gebiete mit einer hohen vergleichbaren Wüstentemperatur werden beschrieben.

Die Lebensfähigkeit in extremen Klimaten hängt in einem großen Ausmaß von sozialwirtschaftlichen Faktoren ab, wie z. B. die Verfügbarkeit von Wohnhäusern und Büros mit Klimaanlagen, frischem Gemüse, Milch sowie Einrichtungen zur Sauberhaltung für alle Bewohner. Falls diese Faktoren nicht gegeben sind, so haben indirekte klimatische Auswirkungen, wie jahreszeitlich bedingte Infektionen, Erkrankungen, Unterernährung und soziale Unruhen einen starken Einfluß.

Aus der Luft kommende, ansteckende Krankheitserreger, Pollen, von Autos und der Industrie herrührende schädliche Gase und sonstige Aerosole geben klaren Anlaß zur Beunruhigung. Die Wirkungen ultravioletter Sonnenstrahlen oder sonstiger möglicherweise vorhandenen photochemisch aktiven Strahlen brauchen anscheinend nicht besonders berücksichtigt zu werden.

The weather, the season of the year and the climate all exercise a considerable influence on the occurrence of communicable diseases of man and on their distribution in almost all parts of the world.

This knowledge is based not only on long years of medical experience but also on recent statistical research. However, we are still in need of a generally accepted theory on the way in which the weather, the season of the year and the climate can affect man, the causative agents of disease and the vectors of such diseases.

An explanation of the influence of weather, season and climate on the outbreak and the course of epidemics will not be found until we have managed to classify these factors according to geomedical and bioclimatological points of view. There are two ways of making a bioclimatological classification:

(1) One can proceed by investigating how *individual epidemics and diseases* behave under the varying climatic and seasonal conditions found in the different parts of the world — this is a geomedical investigation.

(2) Alternatively one can proceed by determining in what way a *certain type of climate*, a certain season of the year or a certain meteorological process affects the occurrence or course of epidemics — this is a bioclimatological and meteoropathological investigation.

I should like to report today on the first of these two possibilities, on the manner in which geomedical facts and findings can be used for purposes of bioclimatological classification.

It is my intention to show you, with the aid of a few examples from the *World Atlas of Epidemic Diseases*, to what extent the representation of the distribution of diseases over the earth in geomedical maps can serve as an aid to bioclimatological classification.

Geomedicine covers all the factors inherent in the earth and the atmosphere which influence diseases in man, i.e. factors inherent in the shape of the earth's-surface, water, soil, vegetation and animal life, as well as in the meteorological processes, the climate and the seasons of the year. In order to classify these varied factors, we use ecological methods and create ecological or bioclimatological indicators. These indicators may take the form of the vectors of certain diseases, or the causative agents of certain diseases or in some cases even the diseases themselves. We could also call them "biological indicators", i.e. indicators which point to the totality of many or all factors with biological effects. These biological indicators are of greater value than meteorological readings since these can only deal with individual ecological factors, and by no means all of them.

Let us take *tropical diseases* as an example. In countries with a temperate climate, doctors have long been accustomed to speak of certain diseases which normally do not occur in countries with a temperate climate, or at least not in epidemic form, as "tropical diseases". The collective term "tropical diseases" already indicates the connection between all diseases of this category and the geographical and climatic conditions existing in a certain zone of the earths surface. "Tropical diseases" thus become the biological indicator for the geographical and climatic concept of the "tropics".

In the case of a few of these tropical diseases the area of distribution — the "nosozone" — is so closely tied to the tropical zone that it is absolutely impossible for sporadic autochthonous cases to occur outside the tropics. An example of such diseases is sleeping sickness in Africa, or filariasis in Africa, South America and south-eastern Asia. These diseases and their causative agents can therefore serve as biological indicators for the extreme tropical regions of the earth.

However, there are other tropical diseases which are not restricted to the *geographical* zone of the tropics, but are more connected with the *climatic* conditions which prevail in these regions. These diseases can therefore occur outside the geographical zone of the Tropics if the climatic conditions are correspondingly extreme, as in the case of amebiasis (= amoebic dysentery), the cysts of which can be found in the intestines of human beings almost all over the world in the form of a harmless infection of the lumina of the intestines, but which only give rise to amoebic dysentery, with the passing of blood with the stool, under certain external conditions. The isotherms of the warmest month in the northern and southern hemisphere can be used as boundary lines for grouping together regions in which the most serious cases of amoebic dysentery occur.

From a geomedical point of view it appears to be practical in any case to draw up boundary lines by means of which one can distinguish between regions with different bioclimatological conditions.

Examples can be found in the 10°C mean annual isotherms which represents the northern boundary for the development of phlebotomus in Eurasia, or the

55°F mean annual isotherms as the northern boundary for the conditions under which *Aedes aegypti*, the vector of yellow fever and dengue, can develop.

Tropics and non-tropics can also be bioclimatologically distinguished with great accuracy in another way if we define the concept of the tropics as the "zone without thermal seasons" (C. Troll). The concept of the tropics thus becomes in itself a bioclimatological classification, for in these tropical zones where there are no thermal seasons, diseases which in temperate zones have a seasonal rhythm, lost their rhythm. This significant geographical—bioclimatological phenomenon can be observed with typhus abdominalis, diphtheria, scarlet fever, measles and other diseases, as the corresponding world maps in the *World Atlas of Epidemic Diseases* show. The occurrence of these diseases will be found to be almost evenly distributed over the various months of the year in regions belonging to the zone without thermal seasons.

There are also diseases which have their own seasonal rhythm in the tropics, such as cerebrospinal meningitis. The peaks of the epidemics of this disease always occur at the end of the dry season. As soon as the first rain falls, the epidemics come to an end. In parts of Africa where there are two dry seasons, the annual curve of cerebrospinal meningitis shows two peaks. It thus shows a completely different rhythm to that found in the temperate zones, corresponding to the change in the hygric seasons from dry season to rainy season.

These few examples are intended to show that the predilection period, i. e. the situation of the month with the relatively highest average number of cases over a period of several years represents a valuable biological indicator in the case of communicable diseases, with the aid of which it will be possible to draw up a bioclimatological classification of the various bioclimatological zones of the earth.

The determination of the predilection period of communicable diseases also enables us to examine the effect of meteorological processes on the course of epidemics. One must only follow the course of epidemics in large regions of the earth, as W. F. Petersen did 25 years ago in the case of various epidemics in the United States of America.

The best example of the significance of the predilection period of an epidemic as a biological indicator for a *meteorotropic process* in the atmosphere is provided by the behaviour of cerebrospinal meningitis in Central Africa. It has been observed for the last 40 years in Africa that the most severe epidemics of cerebrospinal meningitis always occur in the months of the dry season from January—April, and that these epidemics are particularly severe in those regions where the harmattan, the dry dusty wind from the Sahara, blows. In Africa cerebrospinal meningitis is an excellent "biological indicator" for the large system of winds which prevail in spring over the north-western part of the continent of Africa up to the ITC, the inner-tropical zone of convergence (Fig. 1).

Whereas the entire system of winds in the interior of Africa turns out to be a seasonal influence, the harmattan appears to have an additional biotropical effect on the human organism in these regions, in which cerebrospinal meningitis epidemics have frequently occurred since the beginning of the century during the dry season, so that one can accept the working hypothesis that a *biotropical weather effect* is also additionally at work during the *seasonal predilection period* of cerebrospinal meningitis. This also accounts for the rapid increase in the number of cases in the peak month in the affected regions.

In the Central African regions discussed above does there appear to be special meteorotropic factor at work which leads to the formation of a pronounced peak in

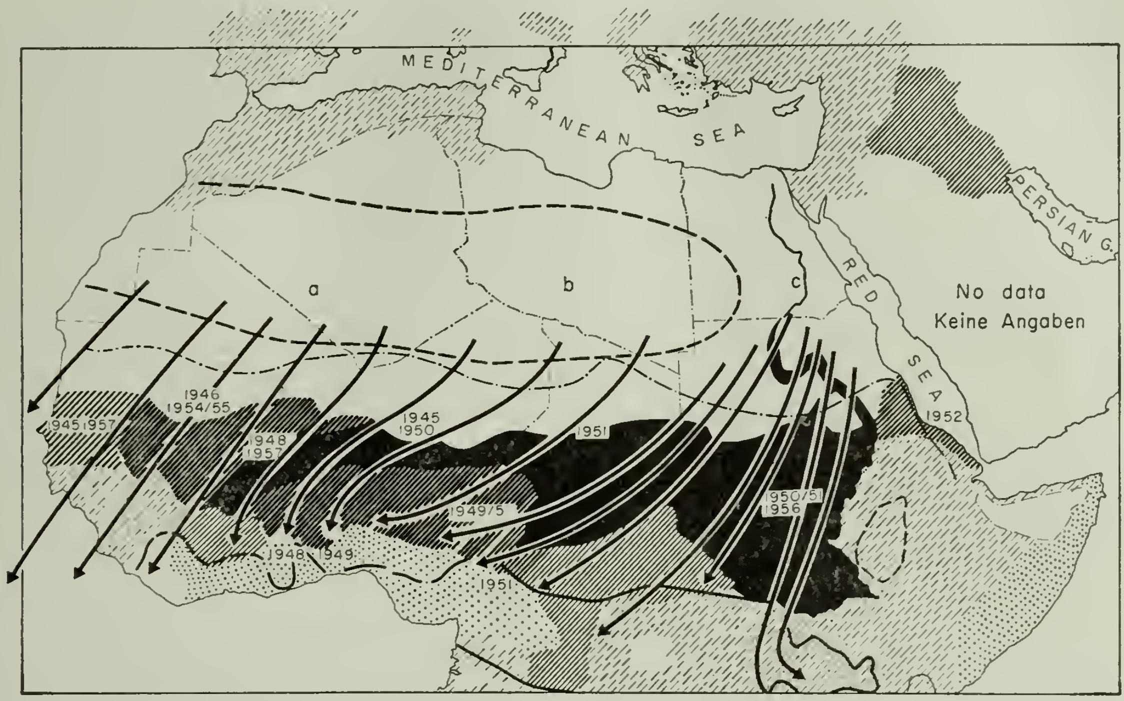


Fig. 1. Average annual morbidity of cerebrospinal meningitis in Central Africa, per 100,000 inhabitants, 1948—1959, and air movements over Northern and Central Africa in January (according to Brooks and Mirrless), (a) Atlantic NE. air current, (b) Harmattan. (c) Egyptian air current (N. winds in Nile valley)

the course of the epidemic in the sense that its occurrence during the dry season of the year has a debilitating effect on the human organism and thus weakens the powers of resistance to the disease to a greater extent than is the case in regions where only the dry season itself has a biological influence on the organism.

Maybe it would also be possible to determine with a similar degree of accuracy the meteorotropic effect of other wind systems, especially the monsoons in Asia, with the aid of a similar "biological indicator" in the form of a certain epidemic disease.

The predilection periods also point to another bioclimatological phenomenon, namely, the effect of the predominantly *continental climate* as opposed to the predominantly maritime climate in Europe. If we separate the various regions from one another by means of lines of the same "continentality" (calculated by S. Morawetz using Zenkers formula), then one can prove that the varying intensity of typhus abdominalis coincides with the degree of continentality.

It will also probably be possible, with the aid of one or several biological indicators, to draw up a bioclimatological classification of the various forms of climate in the world in a vertical direction but the vertical structure of the earth was not yet taken in consideration. However, the *World Atlas of Epidemic Diseases* cannot offer any examples for this.

In conclusion I should like to point out that the *World Atlas of Epidemic Diseases* contains a series of new climate maps on the rainfall and temperature conditions throughout the world, and especially in Africa and Europe. The *World Atlas* also contains a cartographical representation of thermic sultriness, based on values calculated by Scharlau. This map clearly shows the regions of the earth in which bioclimatological conditions for human well-being are significated as "sultry" either permanently, periodically or for short periods of time.

This short article was intended to show, by means of a few examples, to what extent the results of geomedical research can assist the drawing up of a bioclimatological classification. Biological indicators are required, as is usual in ecology. The maps of the *World Atlas of Epidemic Diseases*,* in which the results of recent geomedical analysis of communicable diseases and the behaviour of their vectors under varying climatic conditions are laid down, are hereby recommended as valuable aids to bioclimatological research.

DISCUSSIONS

H. E. Landsberg: It is important to stress the fact that there is no universally valid climatic classification. (For an excellent summary of many of the existing classifications see the monograph by Knoch and Schultze.) Thus there will also always be a multiplicity of bioclimatic classifications. Various climated are almost never separated by sharp boundaries. Therefore, lines on climatic maps have to be interpreted as zones of transition. Climates have no clearly distinguishable genera or species as exist in the plant or animal world. Hence there can be as many climatic classifications as there are purposes for which one might want to subdivide climates.

If the biologist or pathologist can define values of climatic elements which are important for biological processes the climatologist will be able to furnish frequencies of these values at various localities or to give approximate boundaries for specific values of these elements within an area. Such work is now greatly facilitated by the availability of an enormous amount of climatological information on punched cards. (The archives of the U.S. Weather Bureau alone hold more than 350 Million punched cards with weather data.) Modern machines can sort data in this form quickly and according to almost any desired scheme.

Let me point out in this context particularly the desirability for defining for bioclimatic purposes *critical values* of climatic elements which migh affect the viability of an organism or define the threshold of a biological or pathological process. (The temperature of the freezing point of water is a very simple example of such a critical value.)

R. W. Gloyse: Much of what I wanted to say has just been said by Dr. Landsberg.

* *World Atlas of Epidemic Diseases*, edited under the sponsorship of the Academy of Sciences in Heidelberg by Professor Dr. E. Rodenwaldt and Professor Dr. H. J. Jusatz, bilinguistic German—English, in 3 volumes 1952—1960. Falk-Verlag, Hamburg 1, Burchardstr. 8.

We in the British Meteorological Office are, I think, rather doubtful as to the possibility of overall climatological classification — if only for the fact that differences in micro-climate at adjacent sites can be greater than differences in macro-climate of places at great distances apart. Furthermore, agroclimatic classification is likely to be much more feasible in countries where only one element, e. g. temperature or moisture is likely to be critical than is the case in the British Isles where more than one feature can be limiting within any given growing season.

I happen to be interested in an attempt to increase the productivity of some hill-land in Scotland. Apparently even when sod differences are minimized, the lower land is much more productive than the higher areas — yet the differences in climatic parameters, at least those we try to measure or estimate, seem indefinite and somehow insufficient.

A gap in our techniques, which seems to need early attention, concerns sequences of events. The order in time of weather phenomena is obviously of first importance yet there seems to have been little effort given to the task of expressing sequential behaviour statistically and cartographically.

The fact that so many special classifications appear necessary raises the point as to whether the main role of the national meteorological services should not be that of the provision of adequate basic data to be processed by the various individual workers in other sciences according to their special needs. The provision of such data is easier said than done. I should like to see much greater effort given to what our friends from the United States would call "network methodology" so that we may be able to sample adequately in space and time, and to any predetermined degree of accuracy, any meteorological variable.

Speaking personally, I do not think that the possibility of devising useful agroclimatic classification is quite as hopeless as many of my colleagues seem to think. As a contribution, I am currently engaged in studying the interactions between, on the one hand, air-flow and radiation, and on the other the geometry of the ground surface. It seems to me that if we can sort out some of the major interactions, we should be on the way to providing a broad framework into which some of the more specialized classifications might be fitted.

One small final point — Dr. Boyko mentioned the effect of wind on plants. We have come to the conclusion, quite empirically but from rather extensive observation, that many leafy plants suffer a depression in growth when in areas with a mean annual wind-speed of 10 miles/hr at ordinary anemometer height. Has he any comment on this?

A. N. Dingle: Both Dr. Boyko and Professor Jusatz have pointed to the practical usefulness of ecologically determined classifications of climate. I am indeed impressed with the neatness of Dr. Boyko's technique, and I agree heartily that this is a highly practical approach to the problem. I should be interested to know to what extent differences of soil would complicate the bioclimatic interpretations that might be made in regard to temperature and moisture conditions.

As an engineer and meteorologist, I should like to say a word in support of continue and redoubled effort toward the isolation of individual climatic factors. It is my opinion that only by persistence in this direction can we arrive ultimately at quantitatively determined cause and effect relationships.

I should like to specify in terms of two points that were brought to mind by Dr. Boyko's remarks. The first has to do with his observation that rainfall intensity and duration are not sufficient to specify the state of soil moisture. I agree, but I should like to go further and say that rainfall intensity and duration are bot adequate to characterize the rain itself.

It has been well established that the effect of rain upon soil is largely a function of the drop sizes characteristic of the rain. Dr. Ekern, who is present, has studied these effects in terms of the energy relationships involved. In essence, a rain of large drops strikes exposed soil with high kinetic energy having three distinct mechanical effects:

(1) it packs the soil;
(2) it seals the soil surface by floating the finest particles to the surface;
(3) it splatters surface particles of soil, producing soil erosion.

As the drop sizes decrease, this action is rapidly reduced.

Now, it is true that there are problems in observing rain according to its drop size distribution. Observations of this type are only beginning to be made. As they accumulate, it is to be expected that adequate criteria for describing rain will be developed, and that these will relate much more satisfactorily to the biological variables than the traditional measurements of rain do.

The second point which I wish to comment upon is the problem of accounting for the antecedent condition of the soil in evaluating the biological effectiveness of rainfall. On the one hand, it is clear that rain beyond the amount necessary to bring the soil to field capacity does not contribute to the bioclimate in any positive way. It may contribute negatively by erosion or by the leaching of nutrients out of the root zone. On the other hand, it is well-known that an excessively dry soil is capable of absorbing moisture only slowly at first. The biological value of a rainfall thus depends heavily upon information which is not present in rainfall intensity and duration figures, and so it should be clear that these figures will not provide the best correlations with biological effects.

It is therefore my point that, in the search for cause and effect relationships in bioclimatological work, one needs to give careful attention to the question whether the data available actually contain the required information. When we are concerned with the availability to plants of nutrients in solution, it is folly to use rainfall statistics without properly accounting for the soil moisture in the root zone on a continuous basis.

W. Menger: Bei der Frage der bioklimatischen Klassifikation interessieren den Arzt auch Räume mit geringeren klimatischen Gegensätzen, als sie bisher hervorgehoben wurden. In Mitteleuropa, und zwar in Deutschland zwischen Nordsee und Alpen wirken zunehmende Kontinentalität und die orographischen Einflüsse, also die Bodenformen, so auf die Wettervorgänge ein, daß ihre Intensität gemindert und damit ihr Einfluss auf den Menschen verringert wird.

Als Beispiel dient die Meningitis cerebrospinalis, die ebenso wie in Afrika einen Saisongipfel und Abhängigkeit vom Wetter zeigt. Die biotropen Wetterlagen sind aber interessanter Weise völlig verschieden.

Die Erkrankungen sind für 6 Jahre für Küstenvorland (Bremen), Mittelrheingebiet (Mainz) und Alpenvorland (München) bearbeitet und von Brezowski mit den Wetterphasen nach Ungeheuer-Brezowski korreliert. Es ergibt sich eine signifikante Häufung bei beginnendem Wetterumschlag (Wetterphase 4) mit warm-feuchtem Temperatur-Feuchte-Milieu, wobei aber für München kaum noch Unterschiede zwischen den Wetterlagen bestehen. Diese von Norden nach Süden abnehmende Biotropie-Bilanz wird Aufschlüsse für die Klimatherapie geben können.

W. Hesse: Die Grundsätze der Klimaklassifikation wurden von verschiedenen Verfassern, wie Köppen, Geiger, Thornthwaite u. a., behandelt. In der deutschen Literatur ist das Werk »Methoden der Klimaklassifikation« von Knoch—Schulze sehr aufschlußreich.

Die Darstellung von Klimakarten hat vorwiegend den Charakter einer physikalisch—meteorologischen Interpretation. Für biologische Fragestellungen ist im allgemeinen die Klimaklassifikation nicht ausreichend. Wenn schon in der physikalischen Klimatologie eine Verbesserung in der Weise geschehen muß, daß weitere klimatologische Faktoren, wie Evaporation, Tau usw. erfasst werden müssen, scheint eine internationale Zusammenarbeit besonders in der Koordinierung von Meßgeräten notwendig.

Für eine ökologische Klimaklassifikation sind die bisherigen Methoden, beispielsweise der Phänologie, keineswegs ausreichend. Man muß vielmehr nach Indikatoren suchen, die der Fragestellung völlig gerecht werden. Eine enge Zusammenarbeit zwischen biologisch interessierten Klimatologen auf der einen Seite und klimatologisch geschulten Biologen auf der anderen Seite scheint unbedingt notwendig und müßte mehr als bisher gefördert werden. Die Erarbeitung von Indikatoren und Methoden im Rahmen einer Sektion, die auf internationaler Grundlage arbeitet, scheint notwendig zu sein.

H. Boyko: The discussion produced a general agreement on the necessity to use the methods of ecological climatography as a basis for climatic classifications, either alone or complementary to conservative methods.

I agree with Dr. Landsberg that it is up to the biologists to offer more co-operation with and to give continuous assistance to the meteorologists and to inform them which particulars are needed and how existing meteorological material can best be evaluated for biological purposes.

There is no doubt about the usefulness and necessity of overall climatic classifications as mentioned by Dr. Gloyne. They too, however, have to be complemented by biological classifications as described in the lecture. Only then can they gain their full value.

To the very interesting remarks of Dr. Gloyne with regard to the wind factor, it can be said that for this factor too we can use plants as quantitative yardsticks and one chapter in the forthcoming book of the Committee on Ecological Climatography will deal with them (a slide was presented as an example of quantitative evaluation of a flagtree).

Generally speaking, it can be said that the methods of ecological climatography based on plant life are of the highest importance for all border regions and particularly for all arid countries. This is true for phytological problems as such, including agroclimatological ones, but in addition the results may give us the basis for a much better understanding of animal and human life in these regions (see remarks of Dr. Bourke and Dr. Batisse).

With regard to an international terminology of climatic classification a Subcommittee will work out relevant proposals before the next Congress (It consists of: H. and E. Boyko (Israel), K. J. K. Buettner (U.S.A.), W. Hesse (D.D.R.), R. Intribus (Czechoslovakia), H. Jusatz (Germany), A. Mäde (D.D.R.), S. Paterson (Sweden), W. Undt (Austria).

4th Session

METEORO-PATHOLOGICAL FORECASTING

Chairman: P. M. A. Bourke

PLANT DISEASES AND PESTS AS INFLUENCED BY WEATHER

P. M. AUSTIN BOURKE
Assistant Director, Irish Meteorological Service, 44 up. O'Connell Street, Dublin, Eire.
President of the Commission for Agricultural Meteorology
of the World Meteorological Organisation

Abstract—The paper consists of a provocative discussion, with examples, of the principles and problems of using weather data to forecast the trend of drop diseases and pests. The inherent defects of simplified models of the disease—weather relationship, whether based on empirical or scientific studies, are examined. When the model is rigidly applied, as in mechanical forecasting devices, these defects become painfully apparent, but they can be corrected for in a qualitative way in a flexible use of the model. Ways of improving current forecasting methods are discussed.

Résumé—L'étude consiste en une controverse, avec exemples, des principes et problèmes de l'utilisation des données météorologiques dans la prévision de la tendance des maladies et infections des récoltes. Les imperfections inhérentes aux modèles simplifiés de la relation maladie — conditions météorologiques, basés sur des études empiriques ou scientifiques, sont examinées. L'utilisation rigoureuse du modèle comme elle est pratiquée dans les combinaisons habituelles de la prévision met en évidence ces imperfections, cependant elles sont susceptibles d'être améliorées au point de vue qualitatif, en maniant le modèle d'une façon plus souple. Les moyens de perfectionnement des méthodes de prévision courantes sont discutés.

Auszug—Der Artikel bildet eine zum Widerspruch herausfordernde und durch Beispiele erläuterte Behandlung der Grundsätze und Probleme in der Verwendung von Witterungsangaben zur Voraussage des Verhaltens von Ernteschäden und Ungeziefer. Die Schwächen vereinfachter Muster des Verhältnisses zwischen Pflanzenkrankheit und Wetter, sei es auf empirischer oder wissenschaftlicher Grundlage, werden untersucht. Wenn das Muster wie in mechanischen Voraussagegeräten streng gehandhabt wird, machen sich diese Schwächen empfindlich bemerkbar, können jedoch in qualitativer Weise durch eine elastische Anwendung des Musters ausgeglichen werden. Es werden Maßnahmen zur Verbesserung der gegenwärtigen Voraussagemethoden besprochen.

INTRODUCTION

When, in 1929, C. E. Foister reviewed the relation of weather to plant diseases for the benefit of the Agricultural Section of the London Conference of Empire Meteorolcgists, the practical examples of forecasting plant disease were few and, for the most part, still experimental. Van Everdingen had recently provided a basis for forecasting potato blight in the Netherlands, and warning systems of downy mildew *(Plasmopara viticola)* of the vine had been in force for some years in France and Italy. The following thirty years have seen a rapid development in this field, and much solid achievement has been recorded, particularly with diseases due to fungi.

I do not intend here to review recent work on practical forecasting of specific diseases; this has been fully covered by surveys made by Miller and O'Brien (1) and by Bourke (2). As regards potato blight, the subject of the most intensive research and the most clearcut practical success, it would be difficult to add to the excellent review of potato blight epidemics throughout the world, prepared by Cox and Large (3).

Instead of duplicating these surveys, I propose that we should raise our noses from the operational grindstone for long enough to discuss something of general principles, problems and lines of future progress.

I shall, therefore, philosophize broadly on general aspects of plant disease forecasting, with some passing reference to insect pests — in other words, I shall take the opportunity to air some personal prejudices.

METHODS OF APPROACH: (A) "EMPIRICAL"

In attempting to reach a quantitative expression of an apparent relationship between weather factors and a particular plant disease, there are two main possible lines of approach.

First, there is the empirical method of correlating many years records of the disease in field crops with corresponding weather observations. The history of the derivation of the Beaumont rules for forecasting potato blight shows that this can be successfully done. Normally, however, there are formidable difficulties in this method of approach. The need for objective numerical assessments of disease incidence will be discussed later; here it is sufficient to mention that long-term series of disease data are normally couched in subjective terms (severe, average, slight, etc.), and are sometimes radically influenced by incidental changes in observing technique. (Thus, in the long series of data on the location of the first reported appearance of potato blight in Ireland each year, Clifden, Co. Galway appears several times. It is significant that each of these years falls within the period when Pethybridge had organized a field laboratory on potato diseases in that area!).

On the weather data side, the usual difficulty is the reverse, i. e. the problem of selecting from the wealth of observations on different meteorological parameters those that are relevant to the problem in hand. This normally involves some preselection, based on a general knowledge of the biological requirements of the pathogen. Again, the meteorological parameters are not entirely independent of each other, and there is a distinct risk of by-passing a factor of major importance in favour of another parameter, more or less closely related. Thus, for those diseases which require high air humidity, a broad correlation may be established with level of rainfall as an alternative criterion, in those areas where air humidity and rainfall are closely related. But an indirect and insecure relationship of this type will break down completely in humid areas of little rainfall, such as parts of the Californian and Chilean coasts.

Even where these difficulties are overcome, there remains an inherent defeat, from the world-wide point of view, in the empirical approach, i. e. that the results

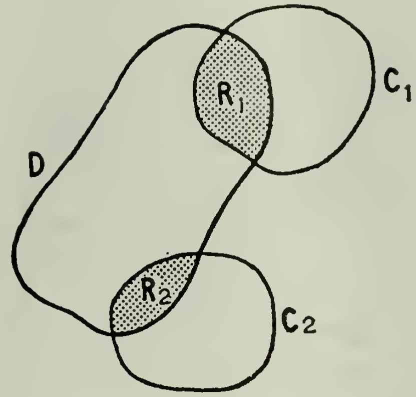


FIG. 1

are normally applicable only in areas climatically analogous to those in which they were originally derived, and may not be universally true.

Thus (Fig. 1), if figure D symbolizes the environmental conditions in which a certain plant disease or pest will thrive, and C_1 similarly represents the climate of the area in which an empirical determination of disease—weather relationship is carried out, then the common area R_1 represents the basis of the derived "rules". If the process is repeated in a radically different climate, C_2, a different set of rules, represented by R_2, will result. In other words, relationships derived empirically in one area are not "exportable" to other climatic conditions.

METHODS OF APPROACH: (B) "EXPERIMENTAL"

THE alternative line of attack is to take experimental determinations of the meteorological requirements of the life cycle of the pathogen, whether these were derived from laboratory work or field experiments, and to construct a simplified model of these results. In theory, rules so derived have a universal application, assuming that the causal organism has consistent climatic requirements throughout the world. This is not to say that a set of universal rules cannot be further simplified in local application. Thus, assuming that propagation of the potato blight fungus is favoured by temperatures between 10°C and 20°C in conditions of high air humidity, the upper limit can be ignored in temperate regions such as NW. Europe, whilst the lower limit is of no practical importance in potato-growing areas of the U. S. A.

However, this approach has its own problems (Fig. 2). Again the diagram is purely symbolic, and D represents the range of environmental conditions favourable to the disease or pest. In many cases these conditions have been only partially determined experimentally; in some cases not at all. The results obtained by experimenters are not always consistent. Even where substantial and reliable work has been done, the determined conditions (D_1) necessarily represent an approximation only to the true facts (D). In constructing a simplified model based on the experi-

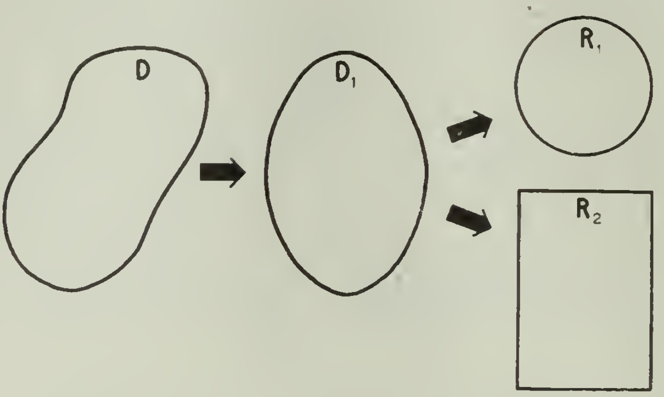


FIG. 2

mental results, there is usually a fairly wide field of choice. Thus, working from D_1, several different models (R_1, R_2, etc.) may be derived, each approximately of the same shape as D_1.

In theory, the relative merits of rival models should be determinable by practical test. In practice, this determination is not so simple. Complicating factors are

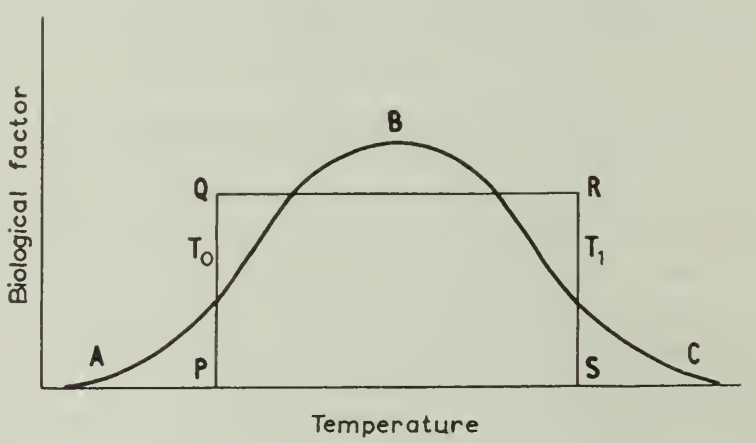


FIG. 3

not confined to proprietary prejudices, or the marked human tendency to find what is expected. In fact, most reasonable models contain some facet of the truth and, in the experienced and flexible hands of those accustomed to their use, give satisfactory results.

INHERENT DEFECTS OF MODELS

THE need for a measure of flexibility in handling disease forecasting systems arises from the fact that the models are only crude approximations to nature and suffer from certain unavoidable defects. Two of these are singled out for mention, in order to illustrate how certain qualitative adjustments may be made to allow for them:

(a) *The effect of microclimate*

Of necessity, practical systems for forecasting diseases and pests make use of routine weather data, which differ to a greater or lesser degree from actual microclimatic conditions within and around plant populations. It is possible to exaggerate these differences, for the macroclimate largely controls and determines the microclimate, and, further, the differences are least in the moist cloudy weather of importance for fungal diseases. Some allowance can, however, be made particularly in the important case of a dense plant cover (e. g. later stages of the potato). If soil moisture is high, the humidity within the plant cover will be maintained at a higher level than where the soil is dry, and a corresponding degree of importance can be assigned to macroclimatic moist spells.

(b) *Artificial discontinuities*

The curves of response to climatic elements (e. g. temperature) of biological factors do not show sharp discontinuities but often take a form like *ABC* in the diagram. For simplicity's sake, in constructing models, we normally substitute a discontinuous curve *PQRS*, specifying, for example, limiting upper and lower values of temperature T_0 and T_1. In a rigid application of the model, we thus ignore the slow growth outside these limits and also assign equal importance to all temperature values within the limits. If this deficiency of the model is kept in mind, it is possible to assign greater weight to temperatures near the optimum, and lesser weight to those distant from the optimum and even somewhat outside the arbitrary limits specified in the rules.

THE PRACTICAL USE OF MODELS

THE trend of what I have argued thus far, is that the use of a simplified model can give excellent results, provided that the fact that it *is* only an imperfect model is always kept in mind, and that its main deficiencies are known to the operator and corrected for, qualitatively, as far as possible.

It is significant that probably the greatest degree of practical success in operating potato blight warnings for the guidance of growers has been achieved in the U.K. and in Ireland. In both cases, the identification of blight-weather by mechanical rules is not automatically the signal for a warning; rather such identification at individual stations is co-ordinated and interpreted at a central station, and related to biological, phenological and general weather data before a warning is issued.

It cannot be too strongly emphasized that in this complex field of weather—plant—pathogen relationships, there is no simple "open sesame" to roll away the barriers of difficulty, no elementary set of rules that is more than a crude rule-of-thumb. Belief in the simplicity of nature is a pathetic fallacy; it is we who are simple in our methods and require a simplified approach. Occam's Razor is, for this reason, a useful tool but, if we interpret it as denoting a corresponding simplicity in nature, we run the risk of slitting our scientific throats with it.

For this reason, the interpretation of weather—disease relationships, at least in its present state of development, can be satisfactorily carried out only by plant pathologists and meteorologists working in unison, and in full knowledge of the complexity of the subject and the relative inadequacy of the working rules. It seems to me particularly unwise, to say the least of it, to attribute merit to mechanical devices based on any "model" of disease—weather relationships, if these are to be used as automatic alarm signals by uninformed growers. Such a procedure can only retard development in the field of plant disease forecasting; it is, in fact, exactly so if we were to ignore a hundred years of progress in weather forecasting and, recommend that the public should revert to consulting the fixed prognostications which appear opposite certain pressure values on old-fashioned barometers. The objection is not to the instrument, *per se*, but to the fact that its reading needs to be interpreted in a far wider context before its true significance becomes clear.

POSSIBILITIES OF IMPROVING FORECASTS

From the risk of misuse of current methods, I turn to possibilities of consolidating and improving present techniques. Some factors which might contribute to this end, in order of ease of achievement are:

(a) Independent quantitative estimates of the seasonal impact of diseases and pests.

(b) A simplified assessment of weather factors, in a form which facilitates the forecasting of weather conditions favouring a disease or pest.

(c) Better knowledge of the life cycle of the pathogen or pest, and of its response to different environmental conditions at various stages of its development.

These three factors are next considered in turn.

IMPROVEMENT OF SURVEY TECHNIQUES

Objective and reliable observations of the appearance and development of plant diseases and pests are necessary to check and refine forecasting techniques. (Although it may be remarked, *en passant*, that the *practical* value of a forecasting method is not necessarily proved by its success in indicating the trend of disease. The purpose of most warning systems is to help in the timing of control measures, and the true criterion of their value is whether, over a series of seasons, the excess of yield value over cost of control measures is greater when the timing and frequency of the latter is determined on the basis of disease forecasts rather than on the basis of regular or arbitrary applications. I know of no published results of yield trials where control measures timed by agrometeorological warnings have been tested against other techniques).

As regards survey methods, a big step forward was the development in Britain of objective scientifically based keys for observing degree of infection or decay, and the recording of these data on disease progress curves (4).

A promising development in the U.S.A. is the method of aerial photo-interpretation. Colwell (5) has applied the method to cereal stem rust and to virus disease yellow dwarf in oats, and found it satisfactory for the early detection of disease infection foci and for the accurate estimation of the severity of disease in infected fields.

ALTERED APPROACH TO WEATHER DATA

It is not easy to strike a happy medium in deciding the scale of meteorological observations to accompany agricultural research work. Formerly they were almost always too few and too crude. Now, at times, they appear to be too many and too complex. Something has gone wrong in those cases when the total of recorded weather data is accumulating at a rate which makes it impossible to classify or utilize them.

Certain new weather observations have been needed for phytopathological work. One of these is the duration of wetness of foliage, an important factor in many plant diseases. Several instruments have been devised to record this parameter. The subject is at present under review by a Working Group of the World Meteorological Service; its report will be published as a Technical Note.

The value of a "synoptic approach" to disease and pest forecasting, using air-mass and frontal analysis and pressure systems rather than the individual weather parameters, has been strongly urged of recent years. It has the following advantages:

(a) It simplifies the approach, substituting broader concepts for a mass of detail.

(b) It eliminates the sharp discontinuities inherent in a series of quantitative rules, and makes use of a natural classification of weather types, to one or other of which the disease or insect is well adapted. As might have been expected, each major disease or pest is shown by investigational work to have life cycle requirements which are closely met by recurrent weather sequences in the area where it flourishes. Sharpe and his co-workers (6) for example, comment on how wheat stem rust is adapted to an environment of cool dewy nights and warm sunny mornings.

(c) It facilitates the forecasting of weather conditions favourable to a disease or pest. Mere identification of such weather as it occurs brings us only part of the way towards a satisfactory warning system.

The synoptic approach has been used since 1952 in the potato blight warning system in Ireland, and has also been successfully tried in the same connexion in the U.S.A. (7). In a later paper on "Weather map analysis — an aid in forecasting potato late blight" (8) the same authors show that not only ordinary surface weather charts, but also 5-day and 30-day prognostic maps and upper air charts can be utilized in studying the epidemiology of potato blight. They suggest that the method may also prove useful in the case of other crop pathogens such as the cereal rusts.

Similar methods in insect studies are described by Wellington (9) and have found even wider application. Thus Köhn (10) illustrates how traffic accidents increased following the movement of a cyclone eastwards across Holland to Northern Germany.

The older approach using climatic data retains its value in questions of long-term prospects and planning, e. g. in delineating the probable geographical limits of serious attack by insect or disease. Where, however, the problem is one, not of overall strategy but of seasonal tactics, a more dynamic approach is called for, and in this field, the biosynoptic viewpoint is proving most effective.

BETTER KNOWLEDGE OF DISEASE OR PEST

When I first took up the study of potato blight, I was much impressed by the clarity and sweep of nineteenth century work and the comparative aridity of corresponding research in the first half of the present century. Part of the explanation may be the comparative ease of the initial advance once the right path had been found; another part may have been that, in days before expensive equipment and generous research grants were available, men had no alternative but to use their brains. But this is by no means the whole story.

It seems to me that the dead hand of statistics has effectively retarded agricultural research over the greater part of this century. An example will make the point clearer. In 1892, Professor Carroll of Dublin carried out an experiment which Large (11) rightly describes as pleasingly original. To test whether spores from blighted potato foliage really did wash down with the rain to infect the tubers underground, he covered the soil around a number off potato plants with a layer of cotton-wool to serve as a spore-filter. He marked of an equal number of plants which he left uncovered by way of comparison. When the tubers were dug in the autumn, those protected by the spore-filter numbered 75 sound and none diseased, while those unprotected numbered 40 sound and 33 diseased. The demonstration was neat and convincing.

But a modern worker, conscious of the statisticians breathing down his neck, would think twice before adopting so naïve an approach. What with replicates and Latin squares and the rest of the academic paraphernalia, it would require acres of ground and lorry-loads of cotton wool, and instead of a simple personally conducted experiment we should have an impersonal "project" requiring the facilities of a large institute. And the final result would be a scientific paper made up in great part of a self-satisfied exposition of the statistical methods used and of acknowledgment of the grants from this and that fund; and, sandwiched somewhere between, the cautious and uncertain results.

There is some evidence, luckily, that in recent years agricultural research is waking from the coma induced by the bludgeoning of the statisticians, and the word "significance" is gradually coming back into its old fundamental meaning and no longer being confused with a mathematical concept which bears no relation to the importance, or otherwise, of the results of research. There is hope, then, that some of the major lacunae in our knowledge of the pests we seek to control will be filled, and that thus our forecasting methods will be improved.

Particularly promising as regards the forecasting of airborne diseases are the investigations of Hirst, Hill and others (12) on the release and transport of spores. The use of radioactive materials to track the dispersion of pollen grain and the flight of insect disease vectors is reported from the U.S.A. (13). Work on aerobiology in relation to plant disease can readily be related to the much wider field of transport by the atmosphere, on which considerable research has been and is being carried out, in connexion with such subjects as air pollution, soil erosion by wind, the effects of windbreaks and shelterbelts, aerial spraying, etc.

A fresh approach has enabled progress to be reported in the case of diseases in respect of which only limited success has hitherto been achieved. Sharpe and others (6) attribute the failure of previous forecasting methods for wheat stem rust to a too crude approach. They divide the infection process into two phases with radically differing environmental requirements and put forward a corresponding two-phase numerical prediction formula.

Similarly a more refined investigation has thrown light on the problem of why certain pests do not, in fact, always flourish most in the climate most suited to their life cycles. An example is citrus red scale in California, which is most abundant, not where the climate is optimal to it, but where the climate hinders its main parasite. All of which brings us back again to the essential complexity of nature and the dangers arising from too simple an approach.

CONCLUSION

In a short paper of this kind, it is possible to deal only with a few selected aspects of the problem of phytopathological forecasting, and to treat of these but superficially. It is not at all suggested that these are the only, or even the most important points that merit the consideration of this Congress, and no doubt the discussion will range over a wider field.

REFERENCES

1. Miller and O'Brien, *Bot. Rev.* **18**, 547—601 (1952); *Annu. Rev. Microbiol.* **2**, 77—110 (1957).
2. Bourke, Tech. Note No. 10 of the World Meteorological Organization (1955).
3. Cox and Large, Agricultural Handbook U. 174, United States Department of Agriculture (1960).
4. Large, *Ann. Appl. Biol.* **42**, 344—54 (1955); *Plant Path.* **1**, 109—17 (1952).
5. Colwell, *Hilgardia* **26**, 223—86 (1956).
6. Sharpe *et al.*, *Phytopathology* **48**, 469—74 (1958).
7. Wallin and Riley, *Phytopathology* **48**, 399 (1958).
8. Wallin and Riley, *Plant Dis. Reptr.* **44**, 227—34 (1960).
9. Wellington, *Ann. Rev. Ent.* **2**, 143—162 (1957).
10. Köhn, *Ann. Meteorol., Med. Met.* **13**, 88—93 (1958).
11. Large, *Advances of the Fungi*, p. 268 (1940).
12. *Nature, Lond.* **185**, 940 (1960).
13. *Plant Dis. Reptr.* **44**, 6 (1960).

DISEASES OF LIVESTOCK AS INFLUENCED BY WEATHER

M. CRAWFORD
Director Commonwealth Bureau of Animal Health, Weybridge, Great Britain

Abstract—Some of the ways in which weather factors influence diseases of livestock are discussed with examples taken from diseases caused by viruses, bacteria, protozoa. helminths and metabolic disorders.

Examples of the use of meteorological data for forecasting disease outbreaks are furnished by facial eczema of sheep in New Zealand and liver fluke disease of sheep in Anglesey. Reference is made to the fact that acquired immunity is a factor which does not arise in disease of plants but which has to be considered in attempts to forecast diseases in animals.

Résumé—On discute quelques-uncs des manières desquelles les facteurs météorologiques influencent les maladies du bétail. Des exemples sont tirés des maladies à virus, à bactéries, à protozoaires, à helminthes et du métabolisme.

Des exemples de l'emploi des données météorologiques pour la prévision de foyers de maladies se trouvent dans l'eczéma facial du mouton en Nouvelle-Zélande et la fasciolíase du mouton en Anglesey, Galles du Nord. On fait mention du fait que l'immunité acquise est un facteur qui ne survient pas dans les maladies des plantes mais qui doit être considérée quand on essaie de prévoir des maladies dans les animaux.

Auszug—In welcher Weise Witterungsfaktoren Tierkrankheiten beeinflussen können, wird an einigen Beispielen aus dem Bereich der Krankheiten, welche durch Viren, Bakterien, Protozoen, Helminthen, oder metabolische Störungen verursacht werden, besprochen.

Es werden Beispiele angeführt für die Verwendung meteorologischer Daten in der Vorhersage von Ausbrüchen von Gesichtsekzem bei Schafen in Neuseeland und von Leberegelverseuchung bei Schafen in Wales.

Es wird darauf hingewiesen, dass erworbene Immunität ein Faktor ist, der zwar bei Pflanzenkrankheiten nicht besteht, bei Tierkrankheiten jedoch in Erwägung gezogen werden muss.

THAT weather conditions have a very marked effect on the well being of farm animals is widely recognized, indeed they determine to a considerable extent the type of animal kept and the kind of husbandry adopted in any particular area. This is particularly true of grazing animals which spend the greater part of their lives in the open.

Weather conditions affect livestock indirectly by determining the types of fodder plants which can be grown in any particular area and this indirect effect on the nutrition of the animals influences the incidence of the various metabolic disorders and deficiency diseases to which they are subject.

Direct effects of weather are perhaps more apparent in relation to the infective and parasitic diseases. The incidence of these diseases can be influenced by weather conditions acting upon the infective agent, the vector, the intermediate host or the host animal.

Poisonous plants and toxic fungi are important causes of disease in livestock in many parts of the world the incidence and severity being conditioned not only by the abundance or scarcity of the poisonous plants or fungi but also in many cases by the stage of their growth. These two factors of abundance and stage of growth are often very dependent upon weather factors.

Weather conditions then play a large part in determining the disease picture in any particular area. That this is very generally recognized can be illustrated by the fact that when a disease problem is being investigated one of the first questions the veterinarian is likely to ask is "Does the incidence vary with the season of the year". Information on this aspect of a disease problem can be very helpful in elucidating its nature and causation.

While it is true that the interplay between weather and animal disease is generally recognized and that the value of meteorological data is appreciated in investigating these diseases which exhibit seasonal fluctuations, very little fundamental work seems to have been done in determining the precise mechanisms by which the various factors which go to make up the weather produce their effects on diseases and there are comparatively few examples of meteorological data being used systematically to forecast outbreaks of diseases.

That being so I have thought it best to introduce the subject by considering briefly some examples, drawn from different types of disease, to illustrate how weather affects diseases. First of all one or two examples where climatic factors seem to be the direct cause of disease.

ANHIDROSIS OR NON-SWEATING OF HORSES

The disease occurs in horses, particularly racehorses, imported from the temperate zone into such places as Calcutta in India, Colombo in Ceylon, and Penang in Malaya, all places where atmospheric humidity is very high for most of the year.

The characteristic sign of the disease is the progressive loss of the ability to sweat when exercised even in very hot weather. When galloped in warm weather a normal horse will sweat profusely but the anhidrotic horse will finish a race with its skin dry.

This failure to sweat seriously upsets the heat regulating mechanism, the horse's temperature rises very rapidly and the respiration rate is excessively increased in an attempt to lose surplus heat in the expired air.

During a race such a horse will become very distressed, hyperpyrexia with temperature up to 110°F, may occur and the horse may die during the race.

The disease occurs only in places with a hot and humid climate, no infective or toxic agent or nutritional factor is concerned in causation so far as is known. It does not occur in arid climates even where the air temperature is very high. The crucial factor appears to be high relative humidity together with high air temperature. In such conditions the horse responds to the high air temperature by sweating but as the sweat does not evaporate the body temperature is not lowered and so the sweat glands produce more sweat. The result is that the sweating mechanism becomes exhausted from over-stimulation (Evans *et al.*, 1957).

This disease is one of the few diseases of animals which appears to be caused by climatic influences alone. Another which might be mentioned briefly is the so-called "altitude" or "brisket" disease of cattle which occurs in Colorado and in Peru in the mountains at altitudes over 8000 ft.

The disease is essentially a condition of slow cardiac failure with dyspnoea, weakness and oedematous swelling of the subcutaneous tissues of the ventral body wall. The cause is hypoxia arising from the low oxygen content of the air at such high altitudes (Smith and Jones, 1957).

DISEASES TRANSMITTED BY ARTHROPOD VECTORS

The incidence of diseases which are transmitted by arthropod vectors is to a large extent determined by climatic conditions which affect the abundance of the vector in any particular region. Some examples of such diseases are the various tick-borne piroplasmoses; Rift Valley fever; trypanosomiasis; rickettsia infections; equine encephalomyelitis; ephemeral fever of cattle; bluetongue of sheep; African horse sickness; some of the pox-diseases including myxomatosis of rabbits and many others.

In such diseases once the particular species of arthropod responsible for transmission has been determined. Entomological studies have generally provided considerable information on the conditions of temperature and humidity which influence its life cycle. Such information is very useful in mapping out areas in which any particular disease may be expected to occur and in indicating when outbreaks of disease may be expected. While that is so, the value of meteorological data as a means of forecasting outbreaks is limited by other factors, among which the immunological status of the population of animals at risk is important. In many of these diseases climatic conditions favourable to the vector can normally be expected to occur annually at some particular season but a serious outbreak of the disease will not necessarily occur simply because the vector is abundant.

Rift Valley Fever

This point is rather well illustrated by Rift Valley fever, a virus disease affecting particularly sheep but also goats, cattle and man, with a wide distribution in Africa. It is transmitted by certain species of mosquito and usually appears in the summer and autumn in wet seasons in valleys and low-lying areas. A feature is the tendency for quiescent periods of about 5 years to occur between severe outbreaks. The most probable explanation is that after an epidemic 5 years is required to build up a new population of susceptible sheep. With such a disease a method of forecasting based purely on weather observations and which did not take into account the immunological state of the host animals would be of little value.

This question of acquired immunity is probably one reason why meteorological forecasting has found less application in animal pathology than in plant pathology.

TICK-BORNE DISEASES

Many important diseases of livestock are transmitted by ticks and studies of the biology of ticks indicate that climatic factors such as temperature, humidity and exposure to sunlight largely determine the tick population in any given area. The tick which is responsible for transmitting babesia infection of cattle in Australia is *Boophilus microplus* and the climatic conditions required for its survival and multiplication on pastures have been closely studied in Queensland (Wilkinson and Watson, 1959). The size of the tick population depends upon the survival of adult female ticks on pasture long enough to lay their eggs, the hatchability of the eggs and the survival of the larval ticks which hatch from the eggs. Desiccation is inimical to both adult and larval ticks and it has been found that ticks may lose water during the day and gain it at night depending on the atmospheric humidity. Where loss of water during the day exceeds the gain at night survival may be prolonged by ingestion of dew. During drought, survival depends not only on the relative humidity of the atmosphere but on the availability of dew which may be relatively abundant in certain situations in the early morning.

These studies showed that the survival time of larval ticks on pasture in central Queensland in a normal summer was comparatively short (about 3 months) and indicated the practicability of controlling the tick population by temporarily destocking pastures. The authors were also of the opinion that prediction of the dates of hatching of eggs could be made from meteorological data with sufficient accuracy to be of practical value.

Other studies in Australia have shown that a prolonged drought can completely eradicate ticks from the drought affected area.

Paradoxically, however, complete eradication of the tick and so of the disease from an area is not always desirable.

This is because the population of cattle built up after the drought will grow up without acquiring immunity to the disease. This particular disease is relatively mild in calves but very fatal in adult non-immune cattle. So long as there are sufficient infected ticks on the pastures to ensure that the calves become infected at an early age the losses from the disease will not be serious. Most of the infected calves will recover, become resistant and their immunity will be maintained throughout their lives as a result of periodical reinfection by the ticks. If on the other hand the calves grow up free from the disease and contract it only after they have become adult they will be very severely affected and many will die. Here then we have an example of how meteorological factors could be utilized as an aid to the control of a disease provided always that the possible adverse effects of loss of immunity are borne in mind.

HELMINTH INFECTIONS OF ANIMALS

Farm animals are parasitized by a great many different kinds of helminths including roundworms, tapeworms and flukes. All these worm parasites spend part of their life cycle within and part outside the body of the host animal. While inside their host they are protected against climatic variations but may be indirectly affected since the herbage on which the host is feeding is subject to wide seasonal changes. Such indirect effects of weather on worm parasites need not detain us here beyond mentioning that the phenomenon known as the "spring-rise" in egg-laying which is a feature of certain worm parasites of sheep is possibly an indirect effect of weather conditions.

It is of course the free-living stages of worm parasites outside the animal body which are most affected by meteorological conditions. These stages of the life cycle may be passed on the ground or a sojourn in an intermediate host such as a snail, a slug, an earthworm or a mite may be necessary.

A typical simple life cycle would comprise the adult male and female worms living in the intestinal canal of the host. There they feed, grow and produce eggs. The eggs cannot develop within the body and are passed out with the faeces. Outside the body the eggs hatch and the larvae develop into the infective stages which must gain entrance to the body of their host, usually being swallowed along with the food. The hatching of the eggs, the development of the larvae until they reach the infective stage and the length of time which the infective larvae can live outside the host are largely dependent on the temperature and humidity of the environment in which they find themselves. Since the eggs and larvae of worm parasites of herbivorous animals are normally deposited on pasture it is the microclimate of the herbage cover which is critical.

If the microclimate is optimal the eggs will hatch quickly, a high proportion of the larvae will reach the infective stage and a high proportion of them will remain alive long enough to have a good chance of being swallowed by the host animal.

The rapid hatching of eggs and development of the larvae are very important but apart from that the length of time which the eggs or infective larvae can remain dormant but viable so maintaining infection on a pasture are very important to the epidemiologist attempting to assess the likelihood of an outbreak of disease in animals grazing any particular pasture.

Such an assessment will depend not only on meteorological effects on the eggs and larvae but will be influenced by: (a) the number of eggs deposited upon the pasture; (b) the intensity of stocking of the infected pasture, and (c) with many parasites, the immunological status of the animals exposed to infection.

What has just been said outlines the situation in the case of a parasite having a simple direct life cycle, it is more complicated when the life cycle involves the intervention of an intermediate host which may itself be affected by weather factors.

However, in addition to the meteorological conditions which affect the life cycle of the worm parasite other factors are involved in the development of an epidemic. These factors are such things as the density of animals on the pasture, their nutritional state, their immunological state, stress to which they may be exposed by inclement weather and the presence of other infections which may adversely affect their general state of health.

This quite complicated situation renders it difficult to devise a formula based on meteorological data alone for assessing the probability of severe disease occurring.

Accurate information on the effects of temperature and humidity on the free-living stages of worm parasites in nature is not easy to obtain and results from laboratory experiments are often little more than a guide.

In a country such as Gt. Britain with a marked difference between summer and winter conditions it is important to know what effects low winter temperature will have on infective larvae on pastures. During the winter pastures are often not grazed and one wants to know whether infective larvae will survive the winter in sufficient numbers to initiate outbreaks of disease when livestock are grazed on them in the spring. It would seem to be quite a simple problem to solve but it is surprising how difficult it has been to get reliable data for each of the very numerous species of worms which parasitize farm animals.

Information on such points is, however, accumulating and it may be possible in future to make greater use of meteorological data as a guide to safe utilization of pastures.

METABOLIC DISORDERS

The diseases which are grouped together under this heading comprise such conditions as ketosis, grass tetany, milk fever and pregnancy toxaemia of sheep, they seem to be increasing in importance as methods of management become more intensive.

Grass Tetany

A good example of this group is grass tetany. This disease occurs in cattle and sheep particularly in grazing cattle. Clinically it is characterized by suddenly developed tetanic convulsions frequently causing death. The condition is associated with a fall in the magnesium content of the blood. An interesting feature is that in a herd blood magnesium values may be low without any of the cattle exhibiting signs of the disease.

This state of hypomagnesaemia without symptoms of disease has a marked seasonal rhythm (Allcroft, 1947).

Low levels occur: (a) when the mean minimum temperature is below 42°F; (b) when there is little sunshine; (c) when rainfall has been high; (d) when strong winds, force 6—8 on the Beaufort scale, have been frequent preceding the wet period; and (e) when hail, sleet and snow have occurred.

Clinical cases of the disease occur after spells of hard weather when temperatures are lowest and rainfall highest. Allcroft has postulated that the magnesium level in the blood is under endocrine control and that the regulating mechanism is markedly influenced by cold, wet and windy weather. It is possible that the thyroid and adrenal glands have a role in the regulation of magnesium levels and that adverse weather may act as a stress factor and precipitate clinical cases of the disease.

The association between weather and the occurrence of clinical cases of grass tetany in grazing cattle is generally accepted and is utilized as a guide to the time of year at which precautionary measures should be taken but our knowledge of the weather factors involved is not as yet precise enough to form the basis of a forecasting system.

BACTERIAL DISEASES

Different species of bacteria vary greatly in their ability to withstand heat, desiccation and exposure to light. Most of the species which cause disease can multiply only within the body of their host where they are protected from the direct effects of weather factors. To cause epidemics they must, however, be able to pass from one host to another and it is during this period between hosts that weather factors may affect them.

Generally speaking direct sunlight and dryness are inimical to bacteria except those which produce spores. Some bacterial diseases are spread by droplets coughed up by the sick animal and the survival of the bacteria in droplets is favoured by dull humid weather. Spore-producing bacteria such as those which cause anthrax and the clostridial infections are extremely resistant to adverse weather factors and can remain viable for very long periods on or in the soil.

There is comparatively little precise information on the influence of weather conditions on the bacterial diseases of animals and I will mention only two. First braxy in sheep, a very acute fatal disease caused by infection of the stomach and intestinal wall by a sporulating organism *Clostridium septicum*. The organism is quite widely distributed in the soil and must be frequently ingested by sheep. However, mere ingestion of the organism is not sufficient to cause the disease, some other factor is necessary to lower the resistance of the tissues to infection. The first deaths frequently coincide with the onset of the first severe frosts in late autumn and early winter. Sheep which were to all appearances healthy the day before are found dead in the morning after a severe frost and it has been suggested that by eating very cold grass the stomach has been chilled and devitalized so permitting the bacteria to invade. Whether that is the correct explanation or not there is certainly a correlation between the occurrence of deaths in a flock and severe frosty weather.

Another bacterial disease in which there is a marked correlation with weather is haemorrhagic septicaemia of cattle. This is caused by *Pasteurella septica* and causes very severe losses in India and other parts of Asia. Outbreaks occur soon after the onset of the monsoon rains. The reasons are not very well understood; possibly the sudden flush of young grass upsets the digestive system of cattle weakened by shortage of food in the long dry summer.

VIRUS DISEASES

Some of these are transmitted by insect vectors and weather conditions favouring the multiplication of the vector are of importance in determining whether epidemics will or will not occur. I have already spoken about Rift Valley fever which is a typical example of this group of insect-transmitted virus diseases.

Others, especially the respiratory virus infections, are mainly spread by droplet infection. Carriage of infected droplets by the wind over any considerable distance has generally been considered to be a rare occurrence but recent experience of the behaviour of Newcastle disease especially in large broiler houses has directed attention to the importance of spread of infection by winds. Recent field experience suggests that this is very probable and further study of the effects of light, humidity and temperature on wind-borne droplets is very necessary.

Another virus disease of livestock of great importance is foot and mouth disease. This is the most highly infectious of all diseases of animals and it has always stood out from all other diseases by reason of the rapidity with which it can spread and its tendency to jump from one herd to another without any very obvious means of transport of infection.

Wind-borne infection has often been considered to be possible but no very convincing evidence has been obtained. In recent years Dr. Primault of the Swiss Meteorological Institute, Zürich, has been studying the relationship between atmospheric pressure and outbreaks of the disease and has published several papers on the subject. He considers that outbreaks are related to a considerable fall in atmospheric pressure and to changes in the number of electromagnetic waves of great length, and is of the opinion that meteorological data may be of value in control of the disease (Primault, 1958). Dr. Primault is with us today and will speak about his work.

Apart from influencing the causal virus, weather factors may affect the host animal in such a way as to alter the severity of the disease syndrome.

For example Marshall (1959) has shown that the ambient temperature profoundly affects the mortality rate and the severity of the symptoms in outbreaks of myxomatosis in rabbits. At summer temperatures about 70 per cent of rabbits infected with an attenuated strain of virus recovered while at winter temperatures only 8 per cent recovered. Kötsche (1959) has shown that the morbidity in mice experimentally infected with foot and mouth disease was reduced by high atmospheric pressure, low humidity and low temperature.

UTILIZATION OF METEOROLOGICAL DATA IN FORECASTING DISEASE

There are a few examples of the use in practice of meteorological data for systematic forecasting of the likelihood of outbreaks of disease in livestock with the object of enabling farmers to take appropriate steps to prevent or to minimize losses.

The first which I would like to outline concerns the serious disease of sheep known as fascioliasis or liver fluke disease. This disease is the result of liver damage caused by the trematode parasite *Fasciola hepatica*.

The adult parasites are found in the bile ducts of the liver where they lay very large numbers of eggs which are passed out on to the pasture in the faeces of the sheep. On the ground, provided conditions of temperature and moisture are suitable, the eggs hatch and produce miracidia. These are capable of swimming actively and depend for their further development on gaining entrance to the body of snails of the species *Lymnaea truncatula*. Inside the snail the miracidia divide and multiply producing one or more generations of redia and ultimately large numbers of cercaria which leave the body of the snail and encyst on blades of grass or other herbage. There they remain dormant until ingested by a sheep. Once in the alimentary tract of the sheep the young flukes emerge from the cysts, penetrate the wall of the intestine, gain entrance to the abdominal cavity and ultimately reach the outer surface of the liver which they penetrate to reach the bile ducts. In the bile ducts they grow to maturity and produce eggs. The extent of damage caused to the liver depends very largely on the number of encysted flukes ingested. Small numbers cause only trivial damage but large numbers cause very severe and often fatal damage. The disease is endemic in many areas of Gt. Britain and in many other countries. In endemic areas a very high proportion of sheep, cattle and rabbits harbour small numbers of the parasites which cause little or no observable damage.

However, a feature of the disease is that although in some years it causes little loss, in other years very acute outbreaks with heavy loss occur.

It has long been realized that bad fluke years were related in some way to weather conditions but the precise relationship was not known. Obviously if it were possible to know in advance when severe losses could be expected it might be possible to prevent them either by dosing the sheep with appropriate anthelmintics at strategic times, by taking steps to reduce the population of the snail which acts as intermediary host, or by moving the sheep from dangerous to safer pastures. These considerations induced Ollerenshaw and his colleagues (Ollerenshaw and Rowlands 1959) to study very closely the influence of weather conditions on: (a), the free-living stages of the parasite, namely the development and hatching of the egg, the cercaria and the encysted young fluke; (b) on the snail population; and (c) on the multiplication within the host snail. At each of these stages of its life cycle the young fluke is vulnerable to weather influences. At first sight it might appear that the problem was a relatively simple one and that the main factor determining an outbreak of acute disease would be the size of the snail population. Ollerenshaw's work has shown, however, that even more important than the size of the snail population are such things as: (a) the success or failure of the fluke eggs to hatch; (b) the rate at which the parasite multiplies once inside the snail; and (c) the length of time the encysted young fluke can remain alive on herbage.

The work was extended to field observations in Anglesey in Wales and over a period of 10 years from 1948—1957 meteorological data were correlated with the incidence of disease as recorded at the Veterinary Investigation Centre at Bangor. As a result of this work it was shown that there was sufficient correlation on which to base a reliable method of forecasting the incidence of acute outbreaks in Anglesey and there is now evidence that the system of forecasting can be extended to areas other than Anglesey.

At this point I would like to mention that the complication caused by acquired immunity of which I have spoken earlier does not seem to arise in liver fluke disease. So far as we know any immunity which follows infection is not of sufficient degree to protect against the massive infections which can occur in a bad year. Dr. Ollerenshaw is with us today and will be able to explain his method of forecasting much better than I can.

Another example concerns a very different type of disease, namely facial eczema.

Facial Eczema in New Zealand

This disease affects mainly sheep but also cattle and horses and in some years causes very heavy losses. The common name of the disease is not a very appropriate one as it refers to a symptom which is not constant and is relatively unimportant. The essential lesion is a cholangitis of the liver, one effect of which is to upset the metabolism of phylloerythrin, a product of the digestion of chlorophyll in ruminants. Normally this substance is eliminated in the bile but as a result of the liver damage it reaches the peripheral circulation. Phylloerythrin is a photodynamic substance and when sheep in whose blood it is circulating are exposed to sunlight quite severe damage is caused to the skin.

The disease is seasonal and occurs in sheep grazing ryegrass pastures in certain parts of New Zealand.

Transmission experiments established that the disease was not infectious and pathological studies indicated that the liver damage was such as could be caused by ingestion of a toxic substance. Studies with the object of establishing the nature of the hypothetical toxic substances were hampered by the irregular occurrence of the disease but a chemical test for its detection in pasture grass was evolved and quite recently it has been established that the toxic substance is produced by a fungus *Sporidesmium bakeri* which is saprophytic on ryegrass.

Long before the fungal origin of the toxic substance had been established the seasonal occurrence of the disease had attracted attention and attempts had been made to correlate the occurrence of outbreaks with meteorological data. Outbreaks occur in the autumn but not every autumn. The years in which outbreaks occur are warmer than normal either throughout summer and autumn or over a shorter period. The disease is most common in an autumn which follows a hot dry summer, it seldom occurs after a cool wet summer and it has never been known to occur in a late cold autumn. Outbreaks are likely to occur soon after sufficient rain has fallen to stimulate new growth of the dried up pasture. The amount of rain required is about $\frac{1}{2}$ in.

Based on such observations a forecasting system was devised. Every Monday from the 1 November to the 30 April (summer and autumn in New Zealand) the

Weather Office supplies to the Department of Agriculture, from eleven strategically placed recording stations, data on temperature deviations from normal during the preceding week. This information is sent to all officers of the Department in districts prone to the disease and enables them to broadcast warnings when temperatures are above normal. Farmers are encouraged to have their own rain gauges since rainfall can vary greatly in small areas.

This system based on air temperature and rainfall has been in operation for a number of years and has been of value. It is not highly accurate in as much as while it has never failed to give warning of serious outbreaks; warnings have quite frequently not been followed by outbreaks. Filmer (private communication) summarizes experience over many years by saying that if precautions were taken following all warm autumn rains they would be taken at least twice as often as necessary.

Mitchell *et al.* (1959) have sought to improve the accuracy of forecasting by taking into account soil temperature and soil moisture. They consider that a season can be considered potentially dangerous either if the soil temperature at 8 in. measured at 9 a.m. has reached an average of 62.5°F, or over during November, *or* if the main body of moisture in the soil has reached a deficit of 1.50 in. by the end of November. A more definite judgment can be made by the end of December since there is a high probability of subsequent outbreaks if the 8 in. soil temperature average is over 65°F, during December and no soaking rain has fallen during the month. The critical conditions were grass-minimum temperatures of 54°F, or over with suitable quantities of rain. The meteorological conditions which give rise to such a situation could generally be foreseen a day or two ahead.

A forecasting system based on the work of Mitchell and his colleagues has been under trial during 1959 and 1960 but it is yet too soon to say whether it has greatly improved the accuracy of forecasting.

This, so far as I know, is the only example in the field of veterinary medicine of systematic forecasting based on meteorological data.

CONCLUSION

To conclude there is ample evidence of a relationship between weather and many different diseases of animals. There are obvious possibilities that meteorological data could be of value in giving warning of possible occurrence of outbreaks but the epidemiology of most diseases involves the interaction of other factors besides the weather. Further knowledge of the many factors involved is necessary and its accumulation will I think depend more on studies in the field than in the laboratory. With grazing animals proper managements of the pasture is an obvious key to prevention of losses from helminth infections and as both the pasture grasses and the helminth parasites are greatly affected by weather conditions it should be rewarding to devote more attention to meteorology. The degree of success which has been attained in the prediction of outbreaks of liver fluke disease and facial eczema indicates what can be done and should stimulate work with other diseases.

REFERENCES

ALLCROFT, W. M. (1947) Seasonal hypomagnesaemia of the bovine without clinical symptoms. With special reference to the influence of climate on the level of serum magnesium and the incidence of clinical hypomagnesaemia. *Vet. J.* **103,** 75—100.

EVANS C. LOVATT, SMITH D. F. G., ROSS K. A. and WEIL-MALHERBE H. (1957) Physiological factors in the condition of "dry coat" in horses. *Vet. Rec.* 69, 1—9.

FILMER J. F. (1957) *Losses from Facial Eczema can be Prevented. New Zealand Dept. Agric.*, Bulletin No. 388.

KÖTSCHE W. (1959) Beitrag zur Frage der Abhängigkeit der Maul- und Klauenseuche von meteoren Faktoren. *Arch. exp. Vet. Med.* **13,** 141—56.

MARSHALL I. D. (1959) The influence of ambient temperature on the course of myxomatosis in rabbits. *J. Hyg., Camb.* **57,** 484—97.

MITCHELL, K. J., WALSHE, T. O. and ROBERTSON, N. G. (1959) Weather conditions associated with outbreaks of facial eczema. *N.Z. J. Agric. Res.* **2,** 584—604.

OLLERENSHAW C. B. and ROWLANDS W. T. (1959) A method of forecasting the incidence of fascioliasis in Anglesey. *Vet. Rec.* **71,** 591—8.

PRIMAULT B. (1958) Eléments météorologiques agissant sur l'apparition et l'extension de la fièvre aphteuse *Schweiz. Arch. Tierheilk.* **100,** 383—99.

SMITH H. A. and JONES T. C. (1957) *Veterinary Pathology*, pp. 702—3. Henry Kimpton, London.

WILKINSON P. R. and WILSON, J. T. (1959) Survival of cattle ticks in central Queensland pastures. *Aust. J. Agric. Res.* **10,** 129—43.

MEDICAL-METEOROLOGICAL FORECASTING — AN APPLICATION OF FUNDAMENTAL BIOCLIMATOLOGICAL CONCEPTS

*

FREDERICK SARGENT, II, and DANIEL S. ZAHARKO
Prof. of Physiology, Dept. of Physiology, 524 Burrill Hall, University of Illinois, Urbana, Illinois, U.S.A.

Abstract—The assumptions and uses of medical—meteorological forecasts are critically examined. Current prognostications are based primarily on statistical meteorotropisms or on the application of "indices" derived from studies made in climatic chambers. The limitations of these bases are discussed. The conclusion is reached that indices derived from studies in climatic chambers must be applied with considerable caution to the problem of forecasting man's reactions to the weather. The medical—meteorological forecast is not a precisely formulated mathematical prognostication; it is in reality a value judgement.

Résumé—Les hypothèses et les applications des prévisions météorologiques médicales sont examinées au point de vue critique. Les pronostics courants sont en principe basés sur des météorotropismes ou l'application d'«indices» provenant d'études faites en chambres climatiques. Les limites de ces bases sont discutées. On arrive à la conclusion qu'il faut prendre de grandes précautions, en basant le problème de prévision des réactions de l'organisme humain au temps qu'il fait sur des «indices» provenant d'études faites en chambres climatiques. La prévision météorologique médicale n'est pas un pronostic mathématique formulé d'une façon précise, elle n'est en réalité qu'un avis d'estimation.

Auszug—Die Voraussetzungen und die Verwendung medizinisch—meteorologischer Voraussagen werden kritisch geprüft. Gegenwärtige Prognosen beruhen in erster Linie auf statistische Erscheinungen der Wetterempfindlichkeit oder auf der Anwendung von »Indices«, die durch Versuche in Klimakammern ermittelt wurden. Die Beschränkungen dieser Grundlagen werden besprochen. Es wird der Schluss gezogen, dass Indices aus Untersuchungen mit Hilfe von Klimakammern bei der Lösung des Problems einer Prognose der menschlichen Reaktionen auf das Wetter mit äusserster Vorsicht zu verwenden sind. Die medizinisch—meteorologische Voraussage ist keine genau formulierte mathematische Prognose, sondern vielmehr eine Beurteilung bestimmter Werte.

INTRODUCTION

In order to make a reliable and realistic prognostication in any area of science, it is necessary that the dependent and independent variables be related in more than mere empirical terms. In bioclimatology the relationship should be capable of explanation in terms of the fundamentals of biology and, ideally, it should be capable of a mathematical formulation which involves a minimum of assumptions. In this discussion we shall examine the uses of medical—meteorological forecasts and the degree to which this practice fulfills these basic requirements. Furthermore, we shall consider the general problems that arise when the medical—meteorological forecaster overlooks the simultaneous effects of non-meteorological factors.

POSSIBLE USES OF MEDICAL-METEOROLOGICAL FORECASTS

The medical—meteorological forecast is not simply a weather forecast but rather a prognostication of the action and consequences of anticipated meteorological conditions and weather types on man. The forecasts may be either short- or long-term. The short-term prognostication has been extensively practiced by the German Weather Service and, to a more limited extent, by American military training installations. Long-range forecasts have not generally been made but it seemed to us that they indeed constituted a fundamental aspect of climatotherapy.

Short-Term Forecasts

A daily or 5- to 10-day medical—meteorological forecast might be utilized in helping individuals and organizations to prepare more realistically for environmental encounters. Behavioral alterations and aberrations, such as traffic accidents, inefficiency in industry, clerical errors in banks and sleep, have all been correlated with certain weather types (12, 14, 16). For the private physician, the clinic, and the hospital, the foreknowledge that certain illnesses might suddenly become more prevalent or that patients might exhibit sudden exacerbations could conceivably be useful in planning disposition of available beds, in scheduling of surgical procedures, and in the management of patients. According to Schnur (45) just such a practice is followed in Texas. There hospital admitting personnel provide additional beds for "coronaries" whenever a "blue norther" is forecast. Many illnesses have been listed as meteorotropisms. The toxicity of drugs and the response of the patient to surgical trauma also may be meteorologically conditioned (14, 38). Forewarned, the weather-sensitive or cyclonopathic type might be given appropriate environmental protection. In like view, the physician might avoid bringing about iatrogenic disease (13). The incidence of heat illness among military trainees and men exposed to intense environmental heat in the heavy industries could be sharply curtailed by appropriate modification of environmental exposure, moderation of physical work, and adequate environmental protection (37, 51). Industrial and domestic pollution of the lower layers of the atmosphere could be controlled by regulating these activities according to whether meteorological conditions favored accumulation or dispersal of man-made contaminants (23—25, 29). In the realm of air travel a new application for medical—meteorological forecasting can be envisaged. The traveler may be exposed to abrupt and rather extreme weather changes. Travel from port of embarkation to port of debarkation is rapid, little time is permitted for development of any acclimatization since the journey is made in an air-conditioned space. For some persons, especially cardiac patients, the strain of the new weather might be serious unless appropriate environmental protection has been planned in advance. From the medical point of view, more intelligent operation of air-conditioning equipment at home, in stores and theaters, and in places of work might be anticipated from appropriate forecasts.

Long-Term Forecasts

The long-range medical—meteorological forecast has an important relationship to migrations of people to new countries, extended pleasure cruises and climatotherapy. For the migrant or the passenger on an extended cruise, there is need for advise on environmental protection during the sea voyage which may well encompass a variety of weather conditions. The migrant may be a civilian who plans to adopt a new country as his home. The transition and eventual settlement could be greatly facilitated by medical—meteorological advice. The migrants, on the other hand, might be military personnel. They should be provided with adequate environmental protection to meet undue meteorological extremes at the port of debarkation. Likewise, their commanders need counsel regarding the management of the troops during the period when they are adjusting to the new climatic conditions and regarding climatic diseases which may develop either spontaneously or as a consequence of mismanagement.

The fundamental assumption in the practice of climatotherapy is that residence under a special set of physical environmental circumstances will ameliorate a medical or surgical condition, hasten the cure of an illness, or retard the development of the chronic diseases of old age. In essence the advice given to patient by the physician is a medical—meteorological forecast. One of several climatic types may be chosen. A particular climatic region has certain meteorological characteristics. If the patient moves to that region, the biological consequences will be so and so, and certainly beneficial in the long run. If this view of climatotherapy is correct, it brings this venerable branch of bioclimatology into closer relation to current iatro-meteorological thinking and allows us to broaden our discussion of the application of bioclimatological concepts to medical meteorological forecasting. For the purposes of the present contribution, we shall adopt this view of climatotherapy.

BASES FOR MEDICAL—METEOROLOGICAL FORECASTS

Empiricism is the basis of all medical—meteorological forecasts. The maturity of the empiricism ranges from qualitative observations (proverbs and aphorisms) through statistical associations to experimentally established relations. The aphorism or proverb cannot be formulated mathematically and are based on a maximum of assumptions. Although the statistical meteorotropism can be described mathematically, many assumptions must be made and generally the biological mechanisms are not all established.

The meteorotropisms which can be reproduced experimentally, on the other hand, may be described rather precisely in mathematical terms involving fewer assumptions than the foregoing. Furthermore these meteorotropisms can be rather fully explained in terms of current physiological knowledge. Thus, an analysis of the bases of the medical—meteorological forecast involves three important considerations: the assumptions, the mathematical formulation, and the biological rationale. We shall examine the levels of maturity of medical—meteorological forecasting from these viewpoints.

Aphorism and Proverb

The aphorism and the proverb are statements which record the impressions that people have gained through repeated observations of associations between certain types of weather and human behavior and illness. While some of these statements represent extremely astute observations, they nevertheless are based on a great many assumptions, they cannot be formulated mathematically, and are frequently inexplicable in terms of biological knowledge. The reliability of these statements for forecasting purposes is very low primarily because we have no knowledge of the closeness of the association described, nor have we any idea of the factors which were assumed to be negligible. An excellent collection of aphorisms may be found in the writings of Hippocrates (1). Many others have been compiled by Inwards (27).

Statistical Meteorotropisms

Biological events have a tendency to develop episodically. Swings in human behavior, variations in mood, and the onset of a variety of human ailments exhibit an inclination to group in time. When this characteristic biological phenomena can be demonstrated to have a high degree of correlation with the weather at a particular time, the episode is termed a *temporal meteorotropism*. When the association is geographical, it is identified as a *spatial meteorotropism* (43).

Let us consider temporal meteorotropisms. In terms of depth of understanding and sophistication of mathematical description, there are two types of temporal meteorotropisms: those which have a firm basis in physiology and those which do not. The former comprise the so-called climatic diseases and will be discussed in the next section. Among the latter are a variety of conditions which Buettner (12) labeled "statistical meteorotropisms" primarily because the only evidence supporting their reality is statistical correlation between weather and biological event. It has been customary to identify such meteorotropisms by the super-epoch or n-method. The "key day" can be identified either in terms of a particular meteorological parameter or in terms of a particular biological episode. If the investigator hypothesizes that the variations of a particular weather element have an important impact on the organism, he then searches for evidence to support this hypothesis in the fields of medical and biological science. Berg (8) has recently reviewed some of the studies reporting a correlation between solar activity and mortality from a variety of diseases. In many of these studies, particularly those of Duell, the solar parameter provided the criterion for the key day. A similar approach has been used by Reiter (41) to establish correlations between variations of his "biological indicators" (atmospheric electricity and 'sferics) and psychomotor tests on healthy and weather-sensitive individuals, the pain of the cyclonopath, the occurrence of road accidents, and the frequency of births. The other approach is to find some aspect of the weather which shows a relationship with the episodes of a particular biological process. The key day is identified in terms of the biological event and a search is made among weather parameters to find one or a group shows a significant correlation. Examples of this approach are described in the symposium on medical—meteorological forecasting which was held in Hamburg in 1955 (3). Other references have recently been compiled by Dordick and Thuronyi (16).

When by either of these approaches a statistical correlation can be found, one is in a position to make a medical—meteorological forecast. However, the step from the statistical study to the prognostication is a big one and involves a considerable number of assumptions. Early work on meteorotropisms demonstrated that only suggestive correlations could be established between a biological event and meteorological parameters, such as pressure, temperature, humidity and the like. Consequently a search began for other meteorological factors and weather characteristics which might exhibit a higher degree of correlation with biological events. In recent years the trend has been to characterize the weather in terms of fronts, air masses, weather types, convective and advective processes, upper air situations, and even solar and cosmic events. When the weather is so characterized one is fundamentally dealing with the integrative action of individual weather elements on the organism. In other words, he is describing weather in terms of an index or indicator, although in most cases he cannot sort out in mathematical terms the separate effects of the individual meteorological parameters. The major result of this activity in the study of meteorotropisms has been to demonstrate a remarkable statistical association between the weather and biological events. Because of the high probability of the correlations, some bioclimatologists have begun to make biological—meteorological prognostications based on these statistical studies (3).

There are four important assumptions which must be validated before the forecast has any degree of reliability. First, the forecaster must assume that the statistical correlation represents a true cause and effect relation. Second, he must assume that there are no other possible environmental events which could have caused the biological episode. In other words, he is tacitly assuming that the weather is determining and that there are no other significant correlates of the event. No one to our knowledge has made a critical study of the relative importance of the weather as a determinant in these meteoro-biological episodes. Third, he must assume that the relative effects of the individual meteorological parameters which comprised the statistically established weather-type will have the same relative effectiveness in forecasted weather situation. This, it seems to us, is unlikely and until we can describe the constants which can be assigned to the individual components of the meteorotropic weather types, there will always be a great uncertainty in the weather forecast. Finally, the forecaster must assume that all of the unknown environmental conditions which he assumed to be relatively unimportant will remain constant and unimportant in the forecast situation. Zink (53) has emphasized that such factors as diet, body habitus, and degree of weather sensitivity do in fact markedly reduce the accuracy of the medical—meteorological forecast.

Not only is there a considerable amount of uncertainty in the description of a meteorotropism but also there is a paucity of knowledge of the physiological mechanisms. The usual bioclimatic discussion of these mechanisms is stochastic. There are those who attribute meteorotropisms to autonomic imbalance, and those that attribute meteorotropisms to disturbances of the body colloids. For neither of these theses is there a sound structure of uncontested knowledge (12, 43).

Experimentally Derived Weather Indices

For several decades physiologists have sought to define physical environmental conditions which are limiting for men engaged in various types of activity. Their descriptions, which are commonly called indices, serve to predict whether or not a man doing a given degree of work can tolerate the environment for a given period of time. In short, these indices constitute the basis for making a medical—meteorological forecast of the reactions of men to extremes of weather. The indices which have been used most extensively are those relating to man in a hot environment, and we shall limit our discussion to these formulations.

The majority of these indices are derived from physiological studies made on healthy young acclimatized men. Customarily these investigations have been carried out in climatic chambers where physical environment, clothing and metabolic rate can be precisely controlled. Over the years many indices have been proposed. They can be broadly classified into two groups: those which require only meteorological data for their calculation and those which require physiological information, in addition to meteorological data, for their calculation.

Meteorological Indices

The most commonly used meteorological indices are: dry bulb temperature, wet bulb temperature, effective temperature, corrected effective temperature, and wet bulb-globe temperature. The dry bulb temperature is the oldest of these indices and is the temperature customarily used by meteorologists in their daily forecastings of the weather. Although we are aware of no generally accepted definition of a heat wave, such a meteorological occurrence is usually associated with a large deviation of the temperature from the expected normal for a particular place and season (48). Phillips (39, 40), some years ago, suggested that a deviation of the dry bulb temperature by 8° to 10°F above normal, an average daily mean dry bulb temperature equal to or greater than normal maximum temperature, and a night temperature in excess of 75°F, provided reliable criteria by which to predict a heat wave which might provoke an outbreak of deaths from heat stroke. His conclusions were based on a study of 2038 deaths from heat stroke in the United States.

The wet bulb temperature is not very frequently used alone as an index. Some years ago Haldane (20) suggested that a wet bulb temperature in excess of 92°F represented the upper limit of tolerance for the working man. These predictions have been modified so that now the wet bulb temperature is only one of several measures used in the calculation of more comprehensive indices.

Neither the dry bulb nor wet bulb temperatures, when taken singly, gives an adequate description of the physiological effects of weather on man. When this fact was first appreciated, investigators began to search for a quantitative description of the interaction among dry bulb temperature, wet bulb temperature, and air motion on the human being. The effective temperature scale (52) represented the first effort in this direction. The effective temperature scale was originally a sensory scale, and the effective temperature was defined as the temperature of still air saturated with water vapor which induced the same sensation of warmth as that experienced in a given environment.

The scale, as originally conceived, did not allow for the effects of environmental radiation. Bedford (6) discovered that if one substituted the temperature of the black globe for the dry bulb temperature, adequate allowance could be made for the effects of radiation. When the globe temperature replaced the dry bulb reading, the value derived from the nomogram was called corrected effective temperature.

Yaglou and Minard (51) proposed a simple and practical substitute for the corrected effective temperature which they called the wet bulb globe temperature. This heat index could be calculated from a weighted equation involving measurements from only the wet bulb and black globe thermometers. More recently Minard *et al.* (37) have calculated this heat index in a slightly different way. They employ the dry bulb temperature in addition to the wet bulb and black globe temperatures.

Physiological Indices

As a consequence of extensive studies carried out during World War II, it became apparent that these purely meteorological indices did not give an adequate description of the effects of heat on man. In order to achieve a more precise formulation, investigators found that they had to introduce one or more physiological parameters. In particular it was found that the corrected effective temperature had four main faults (46). First, it did not make allowance for the deleterious effects of low air speeds in hot humid atmospheres. Second, at high dry bulb temperatures it exaggerated the stress of air moving at speeds above 100 ft/min. Third, in hot environments it underestimated the importance of the wet bulb temperature. Fourth, it did not allow for an accounting of the metabolic work performed.

Two heat indices have been proposed since World War II, both of which presume to correct these deficiencies. In 1947 McArdle and his associates published a nomogram for the prediction of the sweat loss by fit acclimatized young men exposed to heat for a period of 4 hr. In order to utilize the nomogram one needs to measure globe or dry bulb temperature, wet bulb temperature, air motion, and rate of heat production. Several recent statistical and physiological studies have shown that the index is an excellent predictor of response that young men make during exposure to heat in climatic chambers (19, 28, 35, 46, 50).

In 1955 Belding and Hatch (7) published an "index of heat stress". Their index was derived from the heat balance equation. They based their calculations on a standard man and had to make a number of assumptions regarding the best constants to employ. Like the preceding index this one depended largely on the demands which the hot environment imposed on evaporative heat regulation during an 8-hr work period. To calculate the index of heat stress one must use, in five different "flow charts", data obtained from measurements of globe temperature, dry bulb temperature, wet bulb temperature, air motion and metabolic heat production.

Considerations of Some Uses of Indices

Indices derived from chamber experiments have been extensively applied to a wide variety of human activities. From a long list of possible examples we have selected five, both because there has been considerable current interest in them and also because they have practical importance. These five are: meteorological criteria for the prevention of heat casualities among men engaged in military training programs and mining operations, medical—meteorological forecasting of epidemics of heat disease in civilian populations, planning for environmental protection, physiological basis for the classification of climate, and biometeorological definition of the comfort zone.

Psychometric presentation of indices

Studies of the reactions of man to heat, particularly healthy, fully acclimatized, young males, under carefully controlled conditions, have permitted investigators to rank environmental conditions (heat stresses) according to the strains imposed on the thermoregulatory and circulatory systems. Although the several rankings exhibit disagreement in detail, a general concordance can be discerned in the results. The disagreements arise primarily because of differences in exact amount of clothing worn, work performed, nutritional state of the men, velocity of air motion, and radiant heat. Because of these discrepancies, when the rankings are plotted on a psychometric chart different slopes result (Fig. 1).

From a large number of possible curves we have selected seven as representative (Fig. 1). Two groups can be distinguished: those which delineate safe limits of heat stress for *acclimatized* men (A-1, A-2, and A-3), and those which delineate safe limits for *unacclimatized* men (UA-1, UA-2, UA-3, and UA-4). It should be emphasized, however, that these curves do *not* represent the upper limits of heat tolerance for human beings but safe limits below which effective physical and mental work can be carried out for reasonably long periods of exposure.

(1) *Curves for acclimatized men*—Curve A-1 is derived from the nomogram for the P4SR (46) for conditions under which men can comfortably and safely do light work

(100—150 kcal/hr) and lose 2.5 l. of sweat in 4 hr. A-2 is Brunt's (10) line separating very warm conditions (risk of heat stroke) from intolerably hot conditions (heat stroke likely). A-3 is the line proposed by Largent and Ashe (32) as a safe limit for employees in mines and textile mills. This line approximates Lee's (33) line no. 30 which represents thermal stresses under which deterioration in mental function begins.

(2) *Curves for unacclimatized men*—UA-1 is Brunt's (10) line separating warm conditions from very hot conditions. UA-2 Schickele's (44) "heat death line" below which no cases of heat stroke occurred among 157 military personnel stationed in the U.S. UA-3 is the line for an effective temperature of 80°F with an air motion of 500 ft/min. Ladell (30) recommends this line as distinguishing warm from too hot environmental conditions. UA-4 is Lee's (33) line no. 18 which represents the upper limit of thermal stress for daily work by unacclimatized men of mesothermal zones. A similar delineation can be derived from the index of heat stress of Belding and Hatch (7).

Heat casualties among mining and military personnel

From the viewpoint of medical—meteorological forecasting the question one asks is, do these chamber-based indices predict those natural environmental conditions under which heat casualties may occur among mining and military personnel? Largent and Ashe (32) have recently examined this question for miners. We shall summarize several investigations on the epidemiology of heat disease among trainees at American military installations.

Largent and Ashe (32) found that the majority of cases of mild, moderate and severe heat-induced collapse and heat cramps, among acclimatized miners occurred under environmental condition more severe than those delimited by lines for acclimatized men (Fig. 2, unshaded zone). Furthermore, these lines marked the zone above which several cases of heat-induced fatalities among unacclimatized miners occurred. Thus, if environmental conditions more severe than those described by lines A-1, A-2, and A-3 are anticipated, there is a strong probability that heat disease will develop among men acclimatized to heat.

Heat casualties among military trainees provide another body of data for examining the usefulness of these indices. Can medical—meteorological forecasting be used to prevent the development of these conditions? Before dealing with this question we must inquire about those natural conditions under which heat diseases actually develop among military personnel. We have summarized a large body of observations on both morbidity and mortality from heat disease in Fig. 2. The hot—dry rectangle for Ladell *et al.* (31) marks conditions under which 124 cases of border-line hyperpyrexia, hyperpyrexia, heat exhaustion type I, and heat exhaustion type II were observed among British troops garrisoned in the Middle East during World War II. The intermediate rectangle for Heffernon *et al.* (21) delimits those conditions under which some 227 cases of heat exhaustion developed among troops training at Fort Lee, Virginia. The hot humid rectangle of Borden *et al.* (9)

defines the zone within which occurred some 265 cases of heat disease, primarily heat exhaustion and heat cramps, among troops at Fort Eustis, Virginia. The ovoid region of Schickele (44) outlines the conditions under which 157 fatal cases of heat stroke developed in trainees at military camps in southern and south-western United States.

Several points stand out on analysis of the 873 cases of heat disease shown in Fig. 2. First, all heat diseases among these troops occurred in the region between the limits of thermal stress for acclimatized (A-2) and unacclimatized (UA-1) men. It is reasonable to surmise that all of Ladell's *et al.* subjects were acclimatized. Of the 265 cases studied by Borden *et al.* 23 per cent had been in training at Fort Eustis for more than 8 weeks. Of the fatal cases investigated by Schickele, 25 per cent had been in the south more than 8 weeks. Even the broadest interpretation of conventional laboratory standards suggest that such men were acclimatized (5). Since these groups contained sizable proportions of acclimatized men, we must conclude that the lines A-1, A-2, and A-3 seriously neglect significant factors within the natural environment which predispose to heat disease. Actually lines A-1, A-2, and A-3 delineate thermal conditions which are seldom encountered in the natural environment. Thus, they are not useful indices for medical—meteorological forecasting except under the special circumstances encountered in mines, textile mills and so on.

Second, line UA-3 under-emphasizes the deleterious effects of moisture at low atmospheric temperatures. Study of the original reports on these heat casualties indicates that the heat waves of late spring and early summer are responsible for the major of illness developing at these moderate temperatures. This temporal factor is an important consideration which must not be neglected in formulating a medical—meteorological forecast. Line UA-4 does not seem to be predictive at any level of temperature or vapor pressure.

Third, study of Fig. 2 suggests that there are no unique environmental conditions which bring on special types of heat disease. This inference may not be strictly true, for Horne (26) points out that in hot dry climates heat stroke and dehydration heat exhaustion and collapse are more common than in hot humid regions while in the latter prickly heat and tropical anhidrotic asthenia (heat exhaustion type II of Ladell) are more common. Also tropical neurasthenia is more common in hot humid regions than in hot dry zones. Exercise-precipitated heat exhaustion and collapse and chloride deficiency syndromes are equally common in both types of environments.

Finally, these data demonstrate that morbidity and mortality from heat diseases develop under comparable environmental conditions. In other words, weather conditions which bring on illness from heat are not necessarily less severe than those associated with death from heat.

The problem of applying such indices as we have been discussing to the prevention of heat illness among military trainees has received considerable attention in recent years. Heffernon and his associates (21) proposed that when the effective temperature approached 84°F, all training involving physical activity out-of-doors should be stopped in order to reduce heat casualties. They emphasized, however, that this criterion depended upon the state of acclimatization of the men. Minard and his associate (37, 51) have recommended that training should be adjusted to state of acclimatization and to standard readings of the wet bulb-globe thermometer.

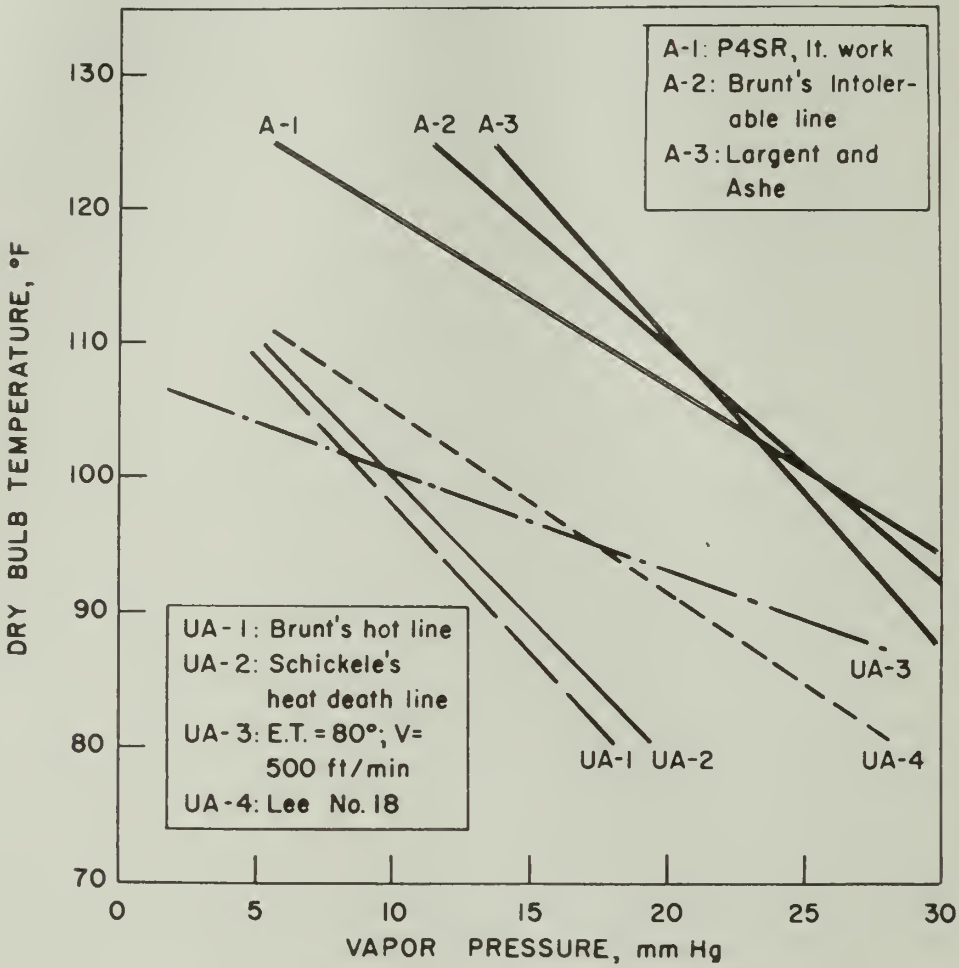


FIG. 1. Limits of thermal stress for acclimatized and unacclimatized men. Lines A-1, A-2 and A-3 are for acclimatized men; UA-1, UA-2, UA-3, and UA-4 are for unacclimatized men. See text for discussion of these lines

From 1 to 3 weeks of limited but regulated physical activity is allowed for acclimatizing new recruits. To inform administrative officers of anticipated severe heat stress, these investigators employ yellow and red flags. When the wet bulb-globe temperature reaches 85°—88°F, the yellow flag is displayed and training of recruits is modified so as reduce exposure to heat. When the wet bulb-globe temperature rises above 88°F, all training which can not be conducted in the shade is curtailed for both recruits and seasoned trainees. Application of these rules brought about a significant reduction in the incidence of heat illness. These criteria yield lines intermediate between those for unacclimatized and acclimatized men (Fig. 1) and confirm our view that the latter lines may be too high. The lower lines are the safer limits, for above them heat casualties increase unless severe restrictions are placed on the activities permitted trainees.

These reports of Minard and his colleagues strongly suggest that the wet bulb-globe temperature is a good criterion for medical—meteorological forecasting heat casualties among military trainees. The general validity of this index has recently been questioned by Stallones *et al.* (47). This epidemiological team investigated 138 cases of heat injury which occurred at Camp Chaffee, Arkansas, in the summer of 1955. Of these cases 104 were diagnosed as heat exhaustion, 27, as heat exhaustion with cramps, and 7, as heat cramps. Regression lines were calculated for the relationship between the occurrence of heat illness and various indices of heat stress: maximum dry bulb temperature, wet bulb-globe temperature, corrected effective temperature, wet bulb temperature, globe temperature and heat stress index of Belding and Hatch. The best relationship was that between the occurrence of heat disease and maximum dry bulb temperature. The authors attributed the poor correlation with other indices to small daily fluctuations in the wet bulb temperature. Although there was a high correlation between heat illness and maximum daily temperature, the onset of cases was usually well before the daily maximum had been reached. Consequently, the authors concluded that the maximum temperature was not a suitable guide for prediction of cases or for the curtailment of training. This was an extremely interesting conclusion. It demonstrated the caution one must exercise when transforming statistically established regressions into formulae for making medical—meteorological forecasts.

Heat casualities among civilians

When a heat wave sweeps across the central regions and the Atlantic States of North America, there is a frequent rise in total morbidity and mortality, an outbreak of heat illness, and not infrequently a large number of fatalities from heat stroke. From the viewpoint of medical—meteorological forecasting, it is of great interest to ask whether the environmental conditions under which veritable epidemics of heat stroke in the civilian populations develop bear any relation to the various heat stress indices which we have been discussing. We selected from the literature several reports of outbreaks of heat stroke which included meteorological data for the period of the epidemics. Unfortunately no micrometeorological data were available; all the information had been taken from official observations of the United States Weather Bureau. The papers used were Root's (42) analysis of 304 deaths from heat stroke in Detroit in 1936, the study by Ferris *et al.* (18) of 44 cases of heat stroke in Cincinnati during this same heat wave, and the observation of Austin and Berry (4) on 100 cases of heat stroke which were treated in St. Louis during the summers of 1952, 1953 and 1954. The meteorological conditions prevailing at the time when these 448 cases of heat stroke developed have been depicted on a psychometric chart in Fig. 3.

Analysis of Fig. 3 brings out several significant findings. First, the lines UA-1 and UA-2 provide satisfactory description of safe limits of thermal stress for unacclimatized men. Second, in contrast to their limitations as predicators of heat disease among military personnel, lines UA-3 and UA-4 now also describe safe limits for

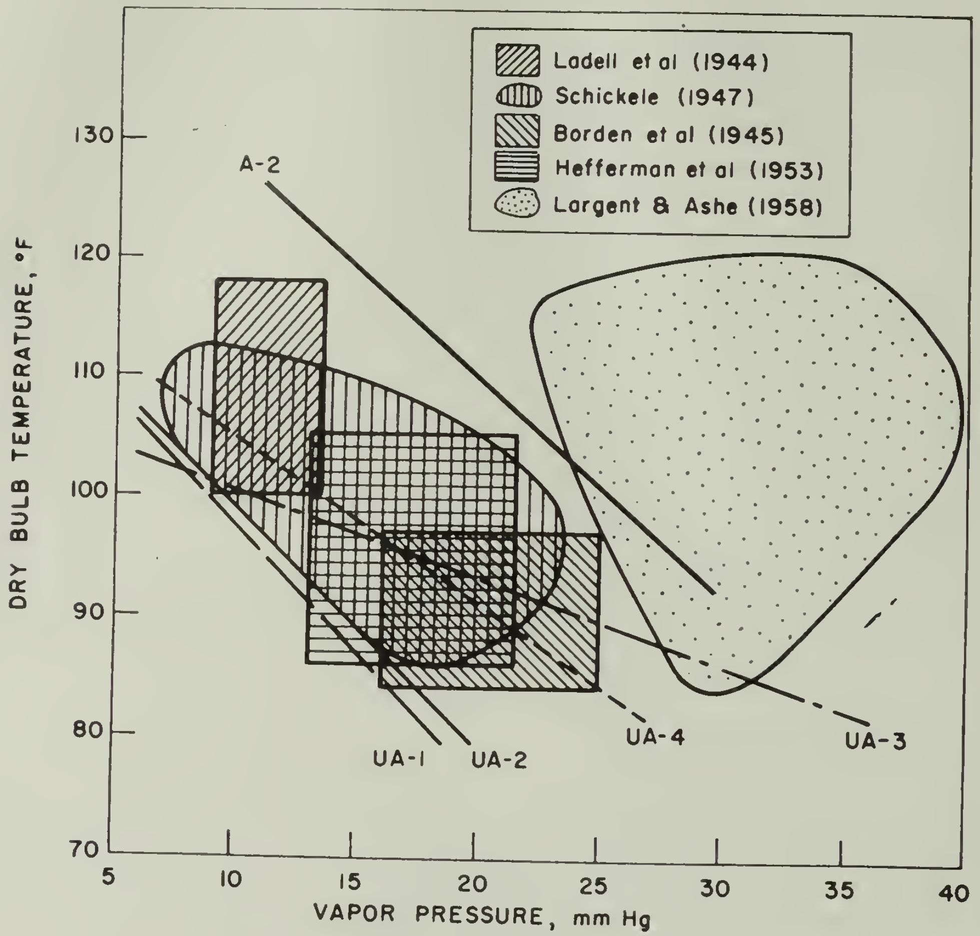


FIG. 2. Morbidity and mortality from heat disease among mining and military personnel in relation to limits of thermal stress. This psychometric presentation is modified after Largent and Ashe (32) and Schickele (44). The lines are the same as those shown in Fig. 1. The various shaded and unshaded zones roughly delimit the thermal conditions under which heat illnesses developed. See text for a discussion of the details

civilian populations suffering from epidemic heat stroke. Such epidemics seldom develop with seasonally early heat waves and this fact may provide the reason for the present agreement with these occurrences of heat disease. Third, individuals who became ill and died in the heat waves summarized in Fig. 3 were older, generally less fit, and certainly much less acclimitized than the young men whose illnesses were depicted in Fig. 2. Both groups, however, were struck down by comparable meteorological conditions. This fact suggests that factors other than geophysical ones conditioned and predisposed these widely different groups to be meteorotropically identical. For practical purposes, then it would seem that lines UA-1 and UA-2 might be generally useful in the medical—meteorological forecasting of out-

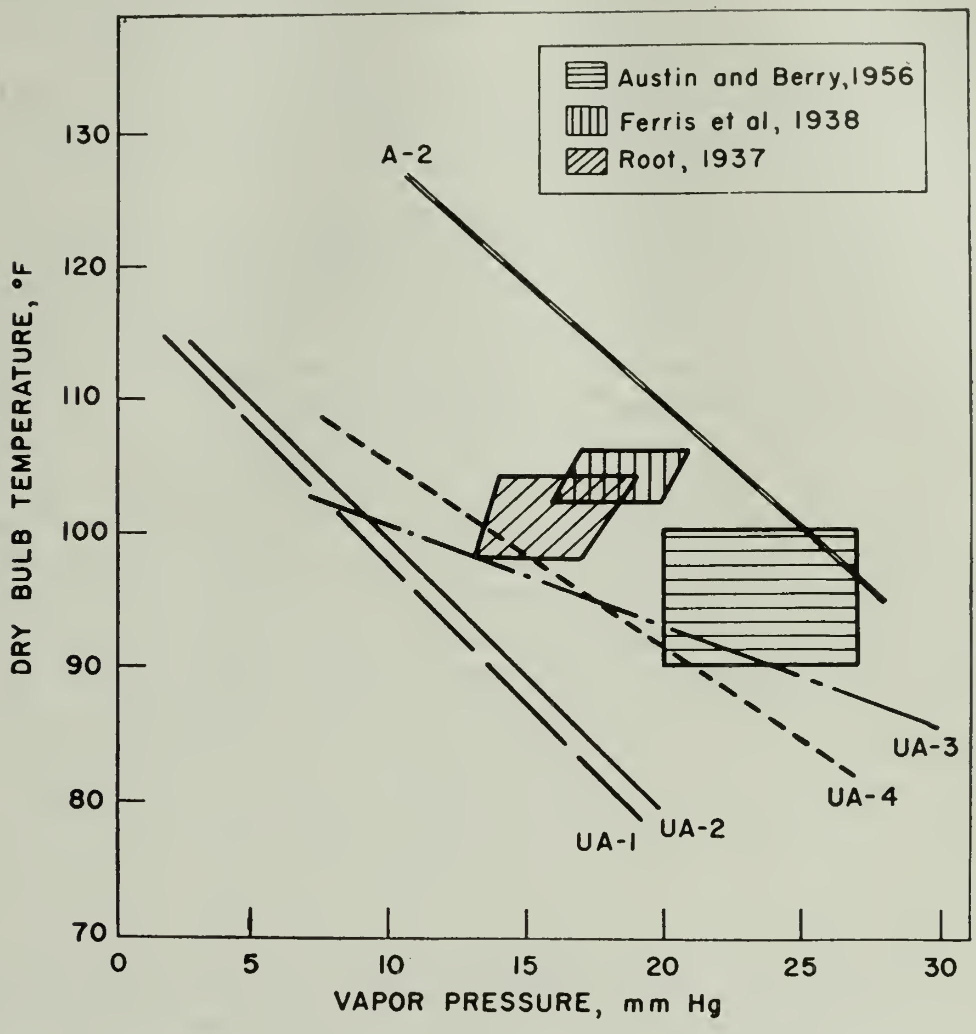


FIG. 3. Morbidity and mortality from heat disease among civilians in relation to thermal stress. The lines are the same as those shown in Fig. 1. The shaded zones roughly delimit the thermal conditions under which heat illness developed. See text for a discussion of the details

breaks of heat illness among both civilian and military persons, expecially when these groups contain a large proportion of unacclimitized individuals.

Environmental protection

Both meteorological and physiological indices have been widely used in the area of environmental protection. The Quartermaster Corps of the United States Army has published numerous maps of clothing requirements for military personnel stationed both at cold and hot stations of the world (34). These maps have been very useful in military planning. Adolph (2) some years ago published a number of maps which showed estimated survival time and water requirements of castaways attempting to maintain life anywhere on the earth's surface. These maps were based on the same type of meteorological and physiological considerations required in the formulation of the indices described.

Physiological classification of climates

At the present time the only generally acceptable classifications of climate are based on the distribution of plants. There has been a growing concern among physiologists in recent years that we should attempt to devise a physiological classification of climates. Such classifications would be extremely useful in studying many current and important medical—ecological problems.

Brunt (11) has strongly urged that this important problem be given careful consideration. More recently Ladell (30) and Lee (33) have suggested criteria for such a classification. Both men have based their classifications on physiological indices such as we have been discussing. The limitations which these indices have for medical—meteorological forecasting are equally pertinent for classifying climates. Ladell clearly brought out the serious deficiencies which arise when one attempts to use Brunt's lines or the Lancaster—Castens lines. For Nigeria, at least, use of line UA-3 (Fig. 1) yielded quite reasonable results. These two original attempts have been sufficiently suggestive to encourage others to make a more detailed treatment of this extremely complicated question.

Comfort zones

Certainly the widest use of indices is in the definition of the comfort zone. The most commonly used scale for delimiting comfort zones is that of corrected effective temperature. This scale is used by most heating and ventilating engineers in planning for the air conditioning of homes, office buildings, department stores, auditoria and ships. During the past few years there have been attempts to transfer the indoor requirements to the out-of-doors. Whereas the indices are quite predictive for the development of heat disease, they have not been successful in prognosticating comfort. One of the major problems in proposing a satisfactory index for comfort out-of-doors is the wide individual variation of subjective feelings of comfort or discomfort under comparable meteorological conditions. The United States Weather Bureau's "discomfort index" (49) which was derived from the effective temperature scale, was severely criticized by the lay public in summer of 1959 simply because a large number of people did not like to be told that they were supposed to be uncomfortable. Some of the problems which arise when one attempts to allow for these individual subjective reactions and to extrapolate standard meteorological observations to the microenvironment of the man-in-the-street are illustrated in a recent article by Hendrick (22).

Relative Importance of Weather

No matter how convincingly one may argue that weather change is determining in the meteorotropic conditions — and Dexter (15) certainly argued eloquently and convincingly along these lines 50 years ago — one is still making an assumption which in many cases has yet to be validated. So long as there is an unvalidated assumption involved in discussions of meteorotropisms, the doubt always exists that the weather may not really be as important as one might be led to believe by large arrays of so called "highly significant" statistical correlations. The bioclimatologist must certainly always ask the question: What is the relative importance of the weather? He must always carefully and exhaustively search for other explanations for his meteorotropisms and carefully weigh the relative contribution of other environmental or organismal factors.

In the case of heat diseases the relative significance of the weather can be rather easily evaluated. The reason that heat diseases are meteorotropisms is that certain weather conditions impose such a strain on the thermoregulatory and circulatory systems that some individuals cannot adequately adjust; therefore they become sick. However, any condition which produces a positive heat balance in the organism may result in a heat disease. Thus, in considering the relative importance of the weather in relation to occurrences of heat disease, one must be familiar with other factors which might bring about a positive heat balance or which might impair the efficiency with which the organism might adjust to the weather. Here we have in mind such important factors as clothing, state of hydration, nutritional condition, exercise, degree of acclimatization, and existence of pulmonary, cardiovascular, or renal disease. For example, one of the best ways to avoid heat disease is to keep the body hydrated and avoid exercise. Indeed some of these variables are so important that their influence is allowed for in the formulation of some of the indices of heat stress. There is an effective temperature scale for men stripped to the waist (basic scale) and for men wearing standard clothing (normal scale). The predicted 4-hr sweat rate also allows for clothing, and a factor can be introduced to account for the additional heat strains on the organism as a consequence of performing physical work.

When we come to the statistical meteorotropism, the same arguments and comparable reservations must be considered. However, here we deal with pathological conditions about which we know much less than in the case of heat disease and with geophysical factors whose biological actions are less comprehended than the biological action of heat, humidity, air motion and radiation. Because there are so many uncertainities one should be most cautious about accepting statistical correlations at their face value and being misled by the many assumptions underlying conclusions regarding the interpretation of statistical correlations. Eloquent testimony supporting this conservative interpretation of statistical meteorotropisms is provided many times in the history of bacteriological diseases which, not more than 100 years ago, were thought to be meteorotropisms (36, 43).

PROBLEMS REQUIRING FURTHER STUDY

The problems involved in making a medical—meteorological forecast are really the same problems which face one when he attempts to arrive at the fundamental concepts of bioclimatology. Thus, the forecasting problems, which we feel are important, are relevant to the science as a whole.

Individual Susceptibility

The most important, and at the same time the most neglected, problem is that of the tremendous range of susceptibility to change in the physical environment. Every index which we have discussed is based on a standard or average man and none describe the limits within which each is applicable. Human beings range in susceptibility from the one unaffected by weather to the weather-sensitive person who is known as the cyclonopath or human barometer. What proportion of the population is made up of these people and to what extent do they account for meteorotropisms is not known.

Duration of Weather Conditions

None of the indices of heat stress take into account the deleterious effect of cummulative stress due to heat lasting several days. It is certainly true that many more people can endure the effects of a heat wave of 1 day's duration than one of several days. As a matter of fact, the death rate usually becomes maximal after 2 or 3 days of heat rather than after 1. The ideal solution to this problem would be a psychometric chart portraying a time axis.

The Season of the Heat Wave

In the late spring when the first heat waves of the season may develop, one finds that the absolute degree of temperature which is stressful as judged by the occurrence of heat illness is much less than the absolute degree of temperature which is correlated with a similar amount of heat illness later in the summer. In part, this phenomenon is a manifestation of progressive acclimatization to gradually increasing temperatures. It has been demonstrated that acclimatization is specific in the sense that when one is acclimatized to a moderate degree of heat, he is relatively unacclimatized to a more severe degree of heat (17). Perhaps the time axis suggested earlier might aid in introducing this important condition into the forecast.

Acclimatization

One of the intriguing problems which has emerged from this consideration of the indices of heat stress is the fact that many men who should be acclimatized by conventional standards have serious and sometimes fatal cases of heat disease at levels far below those recommended as safe for acclimatized men. This fact might, in part, be a manifestation of individual susceptibility to heat. On the other hand, it also suggests that it might take longer than 2 or 3 weeks to acclimatize fully to a particular environmental condition. Indeed when we consider that 25 per cent of two large groups of military personnel who had been continually exposed to heat in military training for more than 8 weeks succumbed to levels of heat stress predicted as safe, we are inclined to conclude that acclimatization does require more time than has been thought by laboratory investigators. Yaglou (pers. comm.) has recently uncovered evidence that acclimatization takes 10 years.

Physiological Basis of Correlations

For most of the statistical meteorotropisms there is yet no generally accepted physiological explanation. Neither is it known how the geophysical factor results in the production of the particular clinical condition. The only way in which these vital problems can be elucidated is by team work between meteorologists and biologists collaborating in controlled investigations in climatic chambers where simulated weather changes can be produced. By this team work we would tend to validate the numerous assumptions which now have to be made in formulating medical—meteorological forecasts.

A Test of the Relative Importance of Weather

Under the hypothesis that the practice of climatotherapy is really a long-range medical—meteorological forecast, it follows that a controlled experiment designed to demonstrate that a change of climate really brought about improvement in a particular clinical condition would permit one indirectly to arrive at a judgement concerning the relative importance of weather. The basic question in climatotherapy is whether the change *per se* brings about the clinical improvement or whether the new physical environment in which the patient finds himself is the cause. How much of the improvement can be assigned to the regulated life which the patient leads at the health resort and how much can be assigned to the weather at that particular place?

CONCLUSION

The medical—meteorological forecast is not a precisely formulated mathematical prognostication; it is in reality a value judgement. Because of this fact the forecaster must carefully weigh numerous intangibles in applying any index to a given situation. He must use common sense based on long experience to allow properly for those variables which have not yet been accurately quantitated.

ACKNOWLEDGEMENT

We wish to acknowledge with appreciation the assistance we received from Mrs. Nancy W. Zaharko in the preparation of this manuscript. Mr. Charles H. Beiger executed the illustrations. The Senior author is grateful to the National Science Foundation for a travel grant which made attendance at the Congress possible.

REFERENCES

1. Adams F., *The Genuine Works of Hippocrates.* Williams & Wilkins, Baltimore (1939).
2. Adolph E. F. *et al.*, *Physiology of Man in the Desert.* Interscience New York (1947).
3. Anonymous, Series of papers on medical-meteorological forecasting. *Ann. Meteorol., Medizin-Meteorol. Hefte,* No. 11, 3—53 (1956).
4. Austin M. G. and J. W. Berry, Observations on one hundred cases of heat stroke. *J. Amer. Med. Ass.* **161,** 1525—9 (1956).
5. Bass D. E. *et al.*, Mechanisms of acclimatization to heat in man. *Medicine* **34,** 323—80 (1955).
6. Bedford T., *Environmental Warmth and its Measurement.* Med. Res. Council, War Memorandum No. 17, London (1946).
7. Belding H. S. and T. F. Hatch, Index for evaluating heat stress in terms of resulting physiological strains. *Heating, Piping, and Air Conditioning* **27,** 129—36 (1955).
8. Berg H., *Solar-Terrestrische Beziehungen in Meteorologie und Biologie.* Akad. Verlagsgesellsch. Leipzig (1957).
9. Bordon D. W., J. F. Waddill and G. S. Grice, III, Statistical study of 265 cases of heat disease. *J. Amer. Med. Ass.* **128,** 1200—5 (1945).
10. Brunt D., The reactions of the human body to its physical environment. *Quart. J. Roy. Meteorol. Soc.* **69,** 77—114 (1943).
11. Brunt D., Some aspects of human ecology in hot tropical regions. In *Biology of Deserts* (edited by Cloudsley-Thompson) pp. 213—18. Institute of Biology, London (1954).
12. Buettner K. J. K., Present knowledge on correlations between weather changes, sferics and air electric spaces charges, and human health and behavior. *Fed. Proc.* **16,** 631—7 (1957).
13. Chapman J. and W. B. Bean, Iatrogenic heatstroke. *J. Amer. Med. Ass.* **161,** 1375—7 (1956).
14. De Rudder B., *Grundriss einer Meteorobiologie des Menschen,* 3rd ed. Springer, Berlin (1952).
15. Dexter E. G., *Weather Influences* pp. 58—9 Macmillan, New York (1904).
16. Dordick I. and G. Thuronyi, Selective annotated bibliography on medical meteorology. *Meteorol. Abstracts and Bibliog.* **8,** 1518—54 (1957).
17. Eichna L. W. *et al.*, The upper limits of environmental heat and humidity tolerated by acclimatized men working in hot environments. *J. Industr. Hyg.* **27,** 59—84 (1945).
18. Ferris E. B. *et al.*, Heat stroke: clinical and chemical observations on forty-four cases. *J. Clin. Invest.* **17,** 249—62 (1938).
19. Clickman N. *et al.*, Physiologic examination of the effective temperature index. *Trans. Am. Soc. Heat. and Ventil. Engin.* **56,** 51—74 (1950).
20. Haldane J. S., The influence of high air temperatures (No. 1). *J. Hyg., Camb.* **5,** 494—513 (1905).
21. Heffernon G. A., H. J. Hittner and S. L. Kocis, Effective temperature as a measure of heat effect. *U.S. Armed Forces Med. J.*, **4,** 73—80 (1953).
22. Hendrick R. L., An outdoor weather-comfort index for the summer season in Hartford, Connecticut. *Bull. Amer. Meteorol. Soc.* **40,** 620—3 (1959).
23. Hewson E. W., The meteorological control of atmospheric pollution by heavy industry. *Quart. J. Roy. Meteorol. Soc.* **71,** 266—82 (1945).
24. Hewson E. W., Meteorological problems in air-pollution control. *Problems and Control of Air Pollution*, pp. 50—63 (Edited by Mallette F. S.) Reinhold, New York (1955).

25. Hewson E. W., Meteorological factors affecting causes and controls of air pollution. *J. Air Pollution Control Ass.* **5**, 1—8 (1956).
26. Horne G. O., The effects of environmental heat. *Edinb. Med. J.* **61**, 349—66 (1954).
27. Inwards R., *Weather Lore.* Rider and Co., London (1950).
28. Irwin J. O., The study of the physiological effects of hot climates. *Biometrics* **12**, 475—90 (1956).
29. Kleinsasser T. W. and R. C. Wanta, The development of a forecasting service for use in air-pollution control. *A.M.A. Arch. Indust. Health* **14**, 307—18 (1956).
30. Ladell W. S. S., Physiological classification of climates, illustrated by reference to Nigeria. *Proc. Intern. West African Congress, Ibadan,* 1949 pp. 1—18 Jos, Dept. Antiquities (1955).
31. Ladell W. S. S., J. C. Waterlow and M. F. Hudson, Desert climate. Physiological and clinical observations. *Lancet* **247**, 491—7; 527—31 (1944).
32. Largent E. J. and W. F. Ashe, Upper limits of thermal stress for workmen. *J. Amer. Indust. Hyg. Ass.* **19**, 246—50 (1958).
33. Lee D. H. K., *Climate and Economic Development in the Tropics.* Harper, New York (1957).
34. Lee D. H. K. and H. Lemons, Clothing for global man. *Geog. Rev.*, **39**, 181—220 (1949).
35. Lind A. R. and R. F. Hellon, Assessment of physiological severity of hot climates. *J. Appl. Physiol.* **11**, 35—40 (1957).
36. McGuire J. K., Climate and cholera. *Trans. N. Y. Acad. Sci.* **21**, 541—50 (1959).
37. Minard D., H. S. Belding and J. R. Kingston, Prevention of heat casualties. *J. Amer. Med. Ass.* **165**, 1813—18 (1957).
38. Petersen W. F., *The Patient and the Weather,* vols. 1—4. Edwards Brothers, Ann Arbor (1935—1938).
39. Phillips W. F. R., Sunstroke weather of August, 1896. *Monthly Weather Rev.* **24**, 409—13 (1896).
40. Phillips W. F. R., Meteorological conditions of sunstroke. *Trans. Amer. Climat. and Clin. Assoc.* **13**, 223—37 (1897).
41. Reiter R., Neuere Untersuchungen zum Problem der Wetterabhängigkeit der Menschen. *Arch. Meteorol. Geophys. u. Bioklimatol.* B **4**, 327—77 (1953).
42. Root C. J., Deaths during the heat wave of July, 1936 at Detroit. *Bull. Amer. Meteorol. Soc.* **18**, 232—3 (1937).
43. Sargent F., II, Changes in ideas on climatic origin of disease. *Bull. Amer. Meteorol. Soc.* In press.
44. Schickele E., Environment and fatal heat stroke. An analysis of 157 cases occurring in the army in the U.S. during World War II. *Military Surgeon* **100**, 235—56 (1947).
45. Schnur S., Mortality rates in acute myocardial infarction IV. The seasonal variation in morbidity and mortality. *Ann. Intern. Med.* **44**, 476—81 (1956).
46. Smith F. E. *Indices of Heat Stress.* Med. Res. Council, Memorandum No. 29 (1955).
47. Stallones R. A. *et al.*, An epidemiological study of heat injury in army recruits. *Arch. Industr. Health* **15**, 455—65 (1957).
48. Thiessen, A. H., Weather glossary—Weather Bureau Publ. No. 1445, Washington: U.S. Dept. Commerce (1946).
49. Thom E. C., The discomfort index. *Weatherwise* **12**, 57—60 (1959).
50. Wyndham C. H. *et al.*, Examination of heat stress indices. Usefulness of such indices for predicting responses of African mine laborers. *A.M.A. Arch. Indust. Hyg. and Occup. Med.* **7**, 221—33 (1953).
51. Yaglou C. P. and D. Minard, Control of heat casualties at military training centers. *Arch. Indust. Health* **16**, 302—16 (1957).
52. Yaglou C. P., The thermal index of atmospheric conditions and its application to sedentary and industrial life. *J. Industr. Hyg.*, **8**, 5—19 (1926).
53. Zink O., Die Therapie meteorotroper Krankheitserscheinungen und ihre Problematik. *Ann. Meteorol., Medizin-Meteorol. Hefte* No. 13, 33—37 (1958).

COMMENTS ON PAPER OF P. M. A. BOURKE

E. C. Large: In serving as a "moderator" of Mr. Austin Bourke's most stimulating paper, I do not think I can do better than to tell you, very briefly, something of the story of potato blight forecasting in England. This will provide a specific example, and serve to illustrate many of the points that Mr. Bourke has made.

In this country the incidence of potato blight varies very greatly from year to year and from district to district. Often the disease does little harm, but in some years and some districts it causes quite heavy losses by stopping the growth of the plants too soon (1). Spraying the plants with fungicides will reduce the losses; but for spraying to be fully effective the first applications are best given *just before the disease would have appeared on the crop if it had been left unsprayed*. That time may be as early as June or as late as August: hence the need for forecasting.

The work was begun in England by my former chief, Mr. A. Beaumont, at Seale-Hayne College in Devon. After observations over a period of 15 years or more, he was able to simplify the Dutch rules of van Everdingen (2). Beaumont said that *more often than not*, but not invariably, potato blight outbreaks-occurred in the south-west of England within about 15 days of a weather spell during which the relative humidity was over 75 per cent and the temperature not less than 50°F for 48 consecutive hours.

In 1950 we started a national investigation to see whether we could find a way of using the Beaumont rule to provide a practical forecasting scheme for the whole of England and Wales. Mr. L. P. Smith of the Agricultural Branch of our Meteorological Office arranged for the recording of Beaumont periods at a network of some fifty standard weather stations well distributed over England and Wales; and our National Agricultural Advisory Service recorded the blight outbreak dates, as defined by a standard blight key, in a field survey of crops throughout the country. The meteorological and agricultural observations were correlated at our Plant Pathology Laboratory (3, 4).

The two sets of observations were entered on an operations chart. The field survey and the meteorological recording has continued each year since 1950, and as the years went by we learned by hard experience how best to interpret our charts. With their aid we are now able to give correct forecasts for each of our main potato growing regions each year. The forecasts are issued through the Press, by the B.B.C. and on television, as well as through the Advisory Service.

Our main rules in the interpretation of our charts are:

(1) We do not rely on individual stations, even for forecasts in their immediate area. We take the indications of the whole network of stations into account, and work on "flushes" of Beaumont periods occurring at a number of stations.

(2) Except in the south-west, we take June flushes as being too early to serve as warnings for maincrops, except where the growth of the plants is exceptionally forward, when we take flushes in the last week of June into account.

(3) In our judgement of the significance of early flushes we take into account the presence or absence of primary foci of infection, and of blight on the early varieties which can spread to maincrops. We are also influenced by the general weather prospects.

Our system is suited to our country, where we have a good network of stations taking *hourly* readings of instruments in the screens. The occasional failure of these readings to reveal blight conditions in the crops is overcome by our "flush" system of working.

The Beaumont rule is not the only temperature—humidity rule used in potato blight forecasting. We have reviewed a number of the rules used in other countries in a recent study of potato blight epidemics throughout the world (5). We have tested the Smith 90 per cent humidity rule in this country, and know that it would be better than the Beaumont rule in some ways if it were not more difficult to operate. The Irish rules of Bourke (6) are excellent; and the new rules of Post (7) may have real advantages. The choice of rule must depend on the meteorological facilities in the country where the rule is to be used; and whatever rule is employed, success in practical forecasting depends on experience of its use, and constant checking of the forecasts against actual blight records in the field. The use of synoptic weather maps as proposed by Bourke (8) is a valuable supplement to forecasting by any temperature—humidity rule.

Finally, I would like to promote discussion by mentioning an entirely different kind of forecasting. In the course of our surveys of common scab on potatoes (9) we have found that the percentage of badly scabbed potatoes in our national crop depends almost entirely on the rainfall over the growing period. Knowing the rainfall in June, July and August, we can foretell what proportion of our crop will be badly scabbed before even the potatoes are lifted. The proportion varies from about 5 per cent in a very dry season to 1 per cent or less in a wet season (10).

REFERENCES

1. E. C. LARGE, Losses caused by potato blight in England and Wales. *Plant Path.* **7**, 39—48 (1958).
2. A. B. BEAUMONT, Dependence on the weather of the date of outbreak of potato blight epidemics. *Trans. Brit. Mycol. Soc.* **31**, 45—53 (1947).
3. LARGE E. C., Potato blight forecasting investigations in England and Wales, 1950—52. *Plant Path.* **2**, 1—15 (1960).
4. E. C. LARGE, Potato blight forecasting and survey work in England and Wales, 1953—55. *Plant Path.* **5**, 39—52 (1956).
5. A. E. COX and E. C. LARGE, *Potato Blight Epidemics throughout the World.* U. S. D. A. Agric. Handbk., No 174, Washington (1960).
6. P. M. A. BOURKE, *The Forecasting from Weather Data of Potato Blight and Other Plant Diseases.* World Met. Organ. Tech. Note No. 16, Geneva (1955).
7. J. J. POST, *Een nieuw Onderzoek naar de Samenhang Tussen het weer en het Optreden van Aardappelziekte.* Kon. Nederlands Met. Inst. Wet. Rapp. 59—5, 111—237, De Bilt (1959).
8. P. M. A. BOURKE, *The Use of Synoptic Maps in Potato Blight Epidemiology.* Ireland Dept. Indust. & Comm. Met. Service Dublin Tech. Note No. 23 (1957).
9. E. C. LARGE and J. K. HONEY, Survey of common scab of potatoes in Great Britain, 1952 and 1953. *Plant Path.* **4**, 1—8 (1955).
10. E. C. LARGE, Disease losses in potatoes. *Proc. Nutr. Soc.* In press.
11. L. P. SMITH, Potato blight forecasting by 90 per cent humidity criteria. *Plant Path.* **5**, 83—7 (1956).

A. Mäde: Die Diskussionsbemerkungen von Herrn Large über seine Untersuchungen zum Phytophthora-Problem haben die Notwendigkeit zu einer Zusammenarbeit zwischen dem Phytopathologen und dem Meteorologen sehr deutlich gemacht. Wir haben uns beim Aufbau agrarmeteorologischer Forschungseinrichtungen in der Deutschen Demokratischen Republik von vornherein auf diese Zusammenarbeit eingestellt. In Groß-Lüsewitz beispielsweise wurde die Frage der Phytophthoraprognose in gemeinschaftlicher Arbeit zwischen dem Biologen und dem Meteorologen aufgegriffen. Die allgemeinen klimatischen Bedingungen in unserem Land lassen die Beschränkung auf die synoptische Methode allein nicht zu. Die Abschätzung des Termins für das Auftreten der ersten Krautfäuleepidemie erfolgt deshalb in der Art, daß zunächst beobachtet wird, zu welchem Zeitpunkt der Sporenflug einsetzt. Die nachfolgende kritische Periode im Sinne Beaumont's und van Everdingen's führt dann zum Ausbruch einer Epidemie. Hier liegt ein Beispiel dafür vor, daß verschiedene Vorhersagemethoden der Krautfäuleepidemien zu einem allgemeineren Modell zusammengefaßt werden können. Das Suchen nach allgemeingültigen Regeln und deren Anwendung auf die besonderen Bedingungen des zu beurteilenden Gebietes erfordert zwar noch einen erheblichen Arbeitsaufwand, eine befriedigende Lösung dieser Aufgabe ist aber aus volkswirtschaftlichen Gründen unerläßlich.

In der Agrarmeteorologie wird man sich im wachsenden Umfange statistischer Prüf- und Analysenmethoden bedienen müssen. Herr Bourke hat in seinem Bericht von der toten Hand der Statistik gesprochen und damit deren überspitzte Anwendung kritisiert. Die zunehmende Bürokratisierung der Forschungsarbeiten hat vielfach zu einem fehlerhaften Einsatz der statistischen Methoden geführt. Man kann mit ein klein wenig Übertreibung sagen, daß manchmal die Statistik zum Selbstzweck geworden ist und nicht mehr als Hilfsmittel zur Prüfung des Aussagewertes der Beobachtungsunterlagen benutzt wird. Ich glaube, daß diese Entwicklung mit der wachsenden Kenntnis des Wesens der Statistik und einer besseren Beherrschung ihrer Methoden wieder in die richtigen Bahnen kommen wird. Als einen Beitrag zur Lösung des im Hauptreferat angeschnittenen Problems kann der Meteorologe meines Erachtens in zwei Richtungen wesentliche Hilfe leisten. Er wird einerseits einmal an Hand regionaler Untersuchungen zeigen können, welchen Werten die meteorologischen Elemente bei einer vorgegebenen Wetterlage im Beratungsgebiet der zuständigen Wetterdienststelle an den verschiedenen Orten zustreben werden. Mit dieser kleinklimatologischen oder geländeklimatologischen Ausdeutung der allgemeineren Angaben der Synoptiker lassen sich für die Entwicklung der Pflanzen und ihrer Schädlinge kritische Zustände sicherer erfassen als bisher. Wenn dazu noch Angaben über die Wahrscheinlichkeit für das Auftreten kritischer mikroklimatischer Bedingungen kommen, dann sollte es möglich sein, die Maßnahmen zur Bekämpfung von Pflanzenschädlingen und Pflanzenkrankheiten zielstrebiger durchzuführen.

Die andere Aufgabe besteht darin, in engster Zusammenarbeit mit dem Biologen die Reaktion der Schädlinge und Krankheiten auf die Witterungsverhältnisse zu erfassen und damit die Grundlagen für deren Abwehr zu erweitern.

H. Schrödter: Ich möchte darauf hinweisen, daß von den Pflanzenschutzdiensten in beiden Teilen Deutschlands die Ergebnisse der agrarmeteorologischen Forschung bereits in breitem Umfange benutzt werden für den praktischen Warndienst, der seinerseits in zunehmendem Maße konkrete agrarmeteorologische Unterlagen für seine Arbeit fordert. Daher bemühen wir uns, durch eine intensive experimentell-mikroklimatische Arbeitsweise unter richtiger und sinnvoller Anwendung moderner statistischer Methoden unsere Kenntnisse bezüglich der Zusammenhänge zwischen Witterung und Pflanzenkrankheiten zu erweitern. Ich nenne als Beispiel die Untersuchungen von Unger und Müller über die Witterungsabhängigkeit der Vektorwirkung der Aphiden für die Virusverseuchung der Hackfrüchte, die bereits jetzt in gewissem Umfang zur praktischen Abschätzung des zu erwartenden Kartoffel- bzw. Rübenabbaus benutzt werden. Ferner die Untersuchungen von Schrödter und Nolte über die klimatische Abhängigkeit von Rapsschädlingen, die für die Festlegung der günstigsten Bekämpfungstermine allgemein in der Praxis Verwendung finden.

Solche Ergebnisse sind nur zu erreichen durch eine enge Zusammenarbeit zwischen Meteorologen und Phytopathologen. Es sollte daher unser vordringlichstes Anliegen sein, eine solche enge Zusammenarbeit anzustreben, denn nur so werden wir die Lücken füllen können, die noch bestehen in unseren Kenntnissen bezüglich der meteorologisch-phytopathologischen Zusammenhänge. Die Wege, die hier beschritten werden können hinsichtlich der Methodik, werden verschieden sein. Wir befürworten eine exakte, experimentell-mikroklimatische Arbeitsweise unter Anwendung moderner statistischer Methoden. Sie scheint uns der beste Weg zu sein, um rasch zu praktisch brauchbaren Vorhersageregeln zu kommen.

J. M. HIRST (concerning Mr. Large's contribution and in reply to a question by Prof. Schein and comments by Prof. Mäde): Most forecasting criteria as Mr. Bourke pointed out define conditions when infection is heavy and are not, nor do they need to be, precise definitions of infection requirement. More precise study by exposing healthy plants in infected crops or diseased plants in healthy crops for consecutive 24-hr periods shows that infection may occur on days when either or both of the temperature-humidity conditions of Beaumont are not satisfied. Such occasions of infection may occur following rain or on nights with dew but the former are several times more common than the latter.

Professor Mäde referred to the use in potato blight forecasting of spore traps. We have operated suction spore traps before and during epidemics but have caught very few sporangia until the disease is well established. We have concluded that spore trapping is unlikely to be as much help in predicting the occurrence of diseases which start from minute sources like potato blight as it is in diseases like apple scab and stem rust of wheat where the initial spore doses are often massive. Could Prof. Mäde please enlarge on the methods which have been used in Germany?

A. N. DINGLE: I wish to comment upon a subject which was mentioned only briefly by our chairman in his address, namely, the atmospheric dispersion of particulate matter, and in particular I should like to mention our work in connection with ragweed pollinosis in south-eastern Michigan.

We have attacked the problem of ragweed pollinosis comprehensively in a "team research" effort in recognition of the need for specialized skills and knowledge of several kinds. Our allergists have concentrated upon clinical and immunological measurements in environments measured by the meteorological group. This year they will begin tests upon human subjects in a test chamber designed and constructed under the direction of the meteorological instrumentation men and our air-conditioning engineers. Pollen contamination of the test chamber air will be under the control of the operating engineer. Temperature and humidity are also to be varied within fairly wide limits.

Our botanical group has focused its attention upon the characteristics of the ragweed plant and has found numerous points of special interest. They have, for example, found that the ragweeds (Ambrosiae) are quite dynamic, actively hybridizing and migrating into new areas not previously occupied by *Ambrosia*. They have found a pattern of evolution of the local *A. elatior* which connects it genetically with two more primitive varieties and suggests that *A. elatior* is in fact a very vigorous and virile hybrid of the New England *(A. artemisiifolia)* and the south-eastern United States *(A. paniculata)* varieties of ragweed. Studies of the germination both of the ragweed pollen and of the seed have led to new information and workable techniques for laboratory work with the plants. One finding of interest is that pollen more than 2 hr old germinates (produces pollen tubes) only poorly, whereas fresh pollen will germinate quite well. Currently, studies of ragweed ecology and phenology are receiving emphasis.

The meteorological group has been concerned with problems of atmospheric transport and diffusion. This of course involves questions of the aerodynamics of our atmospheric sampling methods, the mechanics of pollen flotation and transport, and the use of tracer techniques in observing the patterns of pollen dispersion. Some attention has also been given to the problems of predicting pollen concentrations. Botanical—meteorological co-operation is expected to lead to schemes for both long term and day-to-day predictions of the amounts of pollen in the air. Medical—meteorological co-operation is directed toward the evaluation of patient response in relation to pollen exposure. And over all, the guidance of our statistical group in the adequate design of experiments and the complete evaluation of data provides a useful element of efficiency to the entire effort.

It should therefore be clear at this point that a comprehensive report of this research would span a large part of the subject material of the present Congress. Rather than to try to tell you about all this work here, I propose simply to point out that much of our work has been published in journals and as research reports, and that reprints may be had by requesting them of me. Following is a complete list of reports and published papers which have resulted from this work. In requesting reprints, please be specific, because the number available is, of course, limited.

REFERENCES

1. W. Gurney, and S. Cryst, Observations on the course of allergic rhinitis and bronchial asthma in ragweed-sensitive subjects. *Ann. Allergy*, **15**, 367—78 (1957).
2. A. N. Dingle, Meteorological considerations in ragweed hay fever research. *Fed. Proc.* **16**, 2, 615—27 (1957).
3. J. E. Goodwin, J. A. McLean, F. M. Hemphill and J. M. Sheldon, Air pollution by ragweed: medical aspects. *Fed. Proc.* **16**, 2, 628—31 (1957).
4. A. N. Dingle, Ragweed Pollen Concentrations in Relation to Meteorological Factors. *Proc. Air Pollution Control Association Semi-Annual Technical Conference* pp. 148—177, November (1957).
5. W. H. Wagner, Jr. and T. F. Beals, Perennial ragweeds *(Ambrosia)* in Michigan with the description of a new intermediate Taxon. *Rhodora* **60**, 177—204 (1958).
6. A N. Dingle, Comments on the diurnal variation of airborne ragweed pollen as determined by continuous recording, particle samples, and implication of the study by R. D. Smith and R. Rooks. *J. Allergy* **29**, 5, 472—4 (1958).
7. R. Patterson, J. N. Correa and K. P. Mathews, Studies on the neutralizing and eliciting activity of altered ragweed antigen. *Ann. Allergy* **17**, 444—52 (1959).
8. A. N. Dingle, G. C. Gill, W. H. Wagner, Jr. and E. W. Hewson, The emission, dispersion and deposition of ragweed pollen. *Advanc. Geophys.* **6**, 367—87 (1959).
9. W. H. Wagner, Jr. (Ed.), An annotated bibliography of ragweed *(Ambrosia)*. *Rev. Allergy App. Immunology* **13**, 353—403 (1959).
10. W. H. Wagner, Jr., The hybrid ragweed, *Ambrosia Artemisiifolia* X *Trifida*. *Rhodora* **60**, 309—15 (1958).
11. D. E. Bianchi, D. J. Schwemmin and W. H. Wagner, Jr., Pollen release in common ragweed *(Ambrosia Artemisiifolia)*. *Bot. Gaz.* **120**, 4, 235 (1959).
12. J. B. Harrington, G. C. Gill and B. R. Warr, High efficiency pollen samplers for use in clinical allergy. *J. Allergy* **30**, 4, 357—75 (1959).

13. R. Patterson and J. Correa, The demonstration of a quantitative relationship between skin-sensitizing antibody and antigen. *Int. Arch. Allergy Appl. Immunology* **15**, 6, 335—42 (1959).
14. R. Patterson, Ragweed allergy in the dog. *J. Amer. Vet. Med. Ass.* **135**, 178—80 (1959).
15. R. Patterson, Investigation of spontaneous hypersensitivity in the dog. *J. Allergy* **31**. 351 (1960).
16. S. Goldstein, Degradation of pollen by phycomycetes. *Ecology* **41**, 3, 543—5 (1960).
17. P. P. Barlow and A. I. Bortz, Studies on repository antigen preparations — I. Retention of antigen at the injection site in rats. *Univ. Michigan, Med. Bull.* **26**, 138—48 (1960).
18. K. Mathews and H. J. Spear, Comparative study of hemagglutinating and skin sensitizing activities of ragweed sensitive human sera. In press.
19. W. H. Wagner, Jr., Ragweeds. *Cranbrook Institute of Science News Letter* **30**, 1, 2 (1960).
20. K. Mathews and P. DeLong, Studies on the possible inhibitions effect of human gamma globulins or of human sera on passive transfer tests for skin sensitizing antibody. In press.
21. C. J. Maternowski and J. Mathews, The study of prevalences of allergy in foreign students. In *J. Allergy*. In press.
22. J. M. Sheldon and E. W. Hewson, *Atmospheric Pollution by Aeroallergens*. Progress Report No. 1, August 1, 1955 to April 30, 1957. Research Grant No. E-1379 (C), National Institutes of Health, UMRI (1957).
23. J. M. Sheldon and E. W. Hewson, *Atmospheric Pollution by Aeroallergens*. Progress Report No. 2, May 1, 1957 to April 30, 1958. Research Grant No. E-1379 (C), National Institutes of Health, UMRI (1958).
24. J. M. Sheldon and E. W. Hewson, *Atmospheric Pollution by Aeroallergens*. Progress Report No. 3, May 1, 1958 to June 30, 1959. Research Grant No. E-1379 (C), National Institutes of Health, UMRI (1959).

COMMENTS ON PAPER OF M. CRAWFORD

C. B. OLLERENSHAW: In his address to you today Mr. Crawford has indicated that few attempts have been made to forecast from climatic data the occurrence of animal disease. At the Central Veterinary Laboratory at Weybridge an attempt is being made to develop a system of forecasting the incidence of fascioliasis in England and Wales and it may be of interest to outline this approach. In so doing, you will see whether we have fulfilled the principles enunciated earlier by Professor Sargent.

Mr. Crawford has already told you of the importance of immunity to certain diseases which develops in farm animals, thus preventing any direct comparison between the incidence of disease and climate. Farm animals show little or no immunity to *Fasciola hepatica*, however, and since the intensity of the fluke infection on the herbage in Britain is very much dependent on climatic factors it is reasonable to suppose that a relationship between the incidence of disease and climate can be established.

The second phase in developing this relationship is a study of the ecelogy of the parasite. Factors of particular importance in these investigations are the constancy or otherwise of the output of fluke eggs from animals previously infected, and the occurrence of a sufficient number of snails which act as intermediate hosts. These investigations are still continuing, the information so far obtained indicating that in areas where the disease is endemic, an adequate reservoir of infected animals and snails occurs each year irrespective of conditions in the previous year. The incidence of the disease in any particular year is therefore very much dependent on the conditions occurring in that year.

The third phase is a detailed investigation both in the laboratory and under natural conditions of the effects of climate on the life cycle. This shows that moisture and temperature are most important. Below 10°C there is no development of the parasite outside the final host, so that in Britain temperature is the limiting factor from November to April. During the months May to October development is possible provided there is adequate moisture. A measure of the suitability of moisture conditions for development of the parasite is obtained by comparing the figures of rainfall and potential transpiration. When rainfall exceeds transpiration, moisture conditions in flukey areas are likely to be suitable for the development of the parasite. Before infection of the herbage can occur, however, these conditions must be maintained for at least three months, this being the period necessary for the development of the parasite from deposition of the fluke egg onto the pasture to the liberation of cercariae from the snail intermediate host.

In its simplest form, the forecast depends on a comparison of rainfall and potential transpiration during the months May to October. When rainfall exceeds transpiration in five or all of these months there is likely to be a high incidence of disease; in three or four, then some disease can be expected; but little or no disease is likely to occur if rainfall exceeds transpiration in fewer than three months. In areas where rainfall regularly exceeds transpiration this approach cannot be applied since such climatic conditions are conducive to the formation of peat, the acidity of which is inimical to the snail intermediate host.

In conclusion, I would like to raise two points for discussion, which arise when a system of forecasting has been devised. The first concerns the best way of getting the information over to farmers, and the second concerns the place in any system of forecasting of the so-called negative forecast, the year when the forecast indicates that there is no need to apply control measures.

R. W. GLOYNE: I should like to make a general remark on the approach to the problem.

It seems that, as regards the "forecasting" of potato blight, the overall synoptic method works in Eire, and in England one based upon a relatively small number of representative stations is successful; but this is not the case in Scotland where many more individual recording stations are needed—this is undoubtedly due to the rapid rate of change of climatic elements with distance which occurs in hilly country.

This suggests the thought that both climatic and biological phenomena might usefully be regarded as falling into groups or grades according to the acceptable tolerances. Some phenomena such as large scale movements of animals and insects, or the build-up of population, may well be associated with parallel movements in large scale weather — and so on. Thus we might, with advantage, scrutinize and appropriately classify biological phenomena in the hope of uncovering classes of problems which can be attacked as our knowledge of weather and climate, in comparable scales in time and space, increases.

A case involving sheep husbandry in Australia, mentioned to me by Dr. H. B. Carter (U.K. Animal Breeding Research Organization) might illustrate the approach.

Although the time of year at which mating and shearing can occur is subject to control by management, the subsequent lambing and fleece growth are events whose explanation involves time scales on something like a seasonal basis. The build-up of fly-population is also seasonally controlled, and the damage resulting from fly-strike is most serious when macroclimate and maximum fleece density combine to form the most favourable microclimate in the fleece for parasite development. In order to break this cycle of events, the time of shearing was altered, but the reduction in fly damage occurred at the expense of a drastic reduction in lambing percentage from 70—80 to 25—30 per cent. This reduction was traced to the fact that the "heat stress" on the breeding flock was seriously increased at time of mating, and through much of the following gestation period, by the alteration in phase of fleece development arising from the change in time of shearing. A return to nearer the previous (and incidentally, traditional) time of shearing restored the lambing percentage to its earlier levels.

Here then we have a biological situation which, although controllable in part, exhibits seasonal rhythms, paralleled by and partly explicable in terms of, the seasonal weather changes. A full appreciation of these aspects of the physical and biological phenomena at least pave the way to the possibility of further control.

H. B. CARTER: Dr. Gloyne has referred to this case which emerges from my correspondence rather than from my research notebooks, and has suggested that further details might be worth recording.

The environment was that of a large sheep grazing property, about 400—500 thousand acres in area, stocked with about 20—25 thousand Merino sheep (1 sheep per 20 acres, approximately), situated in the Gascoigne district of Western Australia near the tropics about 24—25° S. latitude.

The problem presented to me in 1954 was that since about 1957 when the regular date of shearing was changed from 1 August (early spring) to 1 May (late autumn/early winter) the number of lambs reared per cent of ewes mated (in January, mid-summer) had declined from the order of 70—80 to about 25—30.

The change in shearing date had been made to avoid the regular spring scourge of blowfly-strike (mainly due to *Lucilia cuprina)* among the breeding ewes when in full fleece.

My suggested solution to the grazier was to change the shearing date back from 1 May to one even later than 1 August and to adopt the husbandry practice of "crutching" (i.e. shearing away the breech wool) at one or two strategic intervals before and after lambing to alleviate attractiveness to the blowfly. This simple point was made primarily on a balance of evidence that probably the main factor in the lowered fertility of the ewes due to the May shearing was a physiological stress at mating due to the heavy fleece carried at the hottest and most humid season of the year. The later shearing, which was again adopted after 1954, greatly relieved this stress, and the percentage of lambs reared during the past 5 years has been restored from 25—30 to the order of 80 per cent again — in spite of worsening drought conditions which in itself might have been expected to reduce the figure. The case seems to be a significant example of one kind of meteoro-pathological forecasting, established on the widest ecological foundation involving the biology of host and parasite in relation to the meteorological and biotic factors of a tropical environment and of human economic demands.

A second type of case, within my experience, may also be worth noting here. Under certain climatic conditions the fleece and skin of some sheep may be pathologically affected with a number of species of microflora, leading to serious economic loss, ranging from gross discolorations to severe forms of dermatitis. Certain meteorological conditions, notably those of rainfall and temperature, favour the development of certain microclimates within the fleece favourable to microbial population growth. Certain genotypes of sheep possess genetically determined kinds of fleece and skin structure *more* or *less* resistant to the action of the macroclimate. On this general basis in one large flock it was possible to reduce the incidence of pathological fleece conditions from the order of 50 per cent to the order of 1 per cent by a change from genotype A (susceptible) to genotype B (resistant). In this case a *genetic*, rather than a *physiological* adjustment was made in the ecological situation.

J. M. HIRST (concerning Mr. Crawford's contribution and his remarks about the "Facial Eczema Disease of Sheep in New Zealand"): The work of Mitchell, Walshe and Robertson completed before the discovery of *Sporidesmium bakeri* as a causal agent, is a good example of the empirical forecasting method mentioned by Mr. Bourke. Wisdom after the event shows that it specified an initial dry period during which grass was killed, so providing plentiful substrate for its saprophytic growth during a subsequent warm wet period. Now it should be possible to refine the criteria using the parameters which determine the growth of the fungus.

In my opinion the prospects of controlling the disease by fungicides, pasture management or microbial competition are poor and avoidance of the fungus seems the surest way of protecting the grazing animal. It thus becomes necessary to define the periods when pastures are toxic. This raises a novel problem for not only must the start of the toxic period be indicated but also the date when the fungus declines below the toxic level.

B. PRIMAULT: De la littérature et des exposés, on constate que les chercheurs s'attachent à isoler des états déterminants jour l'apparition des maladies. Or, nous avons affaire à deux phénomènes que nous cherchons à mettre en relation l'un avec l'autre: le temps d'une part et la vie d'autre part. Ces deux phénomènes ne sont pas statiques mais en perpétuel mouvement. Si donc, ont ne trouve pas d'état statique déterminant, passons à l'examen des modifications des éléments. Mes recherches on montré que ce n'est ni la pression ni le nombre des chocs électromagnitiques qui sont déterminants pour l'apparition de la fièvre aphteuse mais leurs variations.

En outre, le fait qu'une corrélation a été trouvée entre un élément météorologique et un phénomène vital ne signifie nullement que cet élément soit déterminant en soi. Il peut n'être qu'un indicateur réagissant, comme le phénomène vital, à une incidence extérieur inconnue.

COMMENTS ON PAPER OF F. SARGENT II

W. MENGER: Eine Vorhersage für Krankheitsfälle kann genauer und aussichtsreicher werden, wenn nicht nur der Meteorologe die für sein Gebiet biotropen Wetterlagen kennt, und der Arzt ebenfalls damit vertraut ist, sondern wenn letzterer auch das Reagieren seiner Patienten kennt.

Als Beispiel dient der Diabetes mellitus: Bei 34 Mädchen wurden über 6 Wochen Stoffwechseluntersuchungen verfolgt und als KH-Insulin-Quotient (Kohlen hydratzufuhr minus Harnzuckerausscheidung in g dividiert durch Insulin in Einheiten) registriert. Es zeigt sich als Durchschnittskurve ein ferienbedingter vorübergehender Anstieg der Toleranz mit zum Teil erheblichen kurzfristigen Verschlechterungen, die eine gute Abhängigkeit von der interdiurnen Änderung der Äquivalenttemperatur ergeben.

Wesentlich ist nun die Auflösung der Durchschnittwertkurve des Gesamtkollektivs in fünf einzelne Reaktionsgruppen, deren Einzelpersonen gute Übereinstimmung zeigen. Zwei Gruppen erwiesen sich als stoffwechselstabil, zwei zeigten gutes Reagieren auf die Feriensituation mit ihrer verstärkten körperlichen Tätigkeit bei verschieden großer Stoffwechsellabilität, während die Gruppe der jüngsten Mädchen völlig labil war.

Eine Vorhersage des Wettereinflusses z. B. auf den Diabetes mellitus ist also besonders dann möglich, wenn die Stoffwechselverhältnisse der Patienten bekannt sind.

I. KÉRDŐ and I. ÖRMÉNYI: Medical—meteorology has a long tradition in Hungary. For about half a century Hungarian scientists have been occupied with research on this interesting subject. Observations have been reported on the correlation between weather changes and different clinical patterns. Attacks of bronchial asthma, postoperative bleedings, eruption of infectious diseases, etc. have been registered and related to various meteorological factors.

The degree of exactness of these investigations depends upon the methods used in physiology and meteorology. At first studies were made of the effect of single meteorological factors such as temperature, atmospheric moisture, wind, barometric pressure, solar radiation, etc., on physiological functions. However, the results obtained by this approach were not satisfactory, since the changes of weather could not be characterized by variations of one or two of the elements mentioned above.

The recognition of weather fronts was the first step towards modern medical—meteorological research. It became evident that a change of weather is generally caused by the arrival of a new air-mass. This made possible the establishment of a correlation in time between weather change and the occurrence of pathological phenomena.

Within a short time it could be stated that the two main types of weather fronts, i. e. the warm front and the cold front possessed a quite different and sometimes a completely opposite effect on physiological and pathological processes.

Warm fronts induce a higher degree of oxidation, elevated basel metabolic rate, higher blood pressure and body temperature, an increase in the pulse rate and in the calcium level of serum and they also promote the acute eruption of infectious diseases. It is to observe in acidosis, increase of haemorrhagic symptoms and an excited state of the sympathetic innervation.

Cold fronts cause a general tendency to spasms, alkalosis, lower blood pressure and body emperature, a decrease in basal metabolic rate, inclination to thrombosis and allergic maniestations, etc.

As these interrelations have been proved by statistical methods it became important to find a way of preventing the undesirable effects of meteorological factors.

With these in mind we started issuing, day by day, an experimental medical—meteorological forecast in March 1958. First of all we had to collect the biologically important weather factors and to group them according to their physiological and pathological effects. There were copious bibliographical data at our disposal especially from communications of the Hamburg school. But they could not be applied without certain modifications, because there are quite different meteorological conditions in Hungary and in Germany.

We began our activity with an extensive statistical investigation. We established a close co-operation with about fifteen clinics and hospitals in Budapest. They revived our medical—meteorological forecast every day and simultaneously, but quite independently from us, they registered all acute clinical events they had observed. By these means, we were able to control the correctness of our medical forecast and we obtained a large mass of statistical material for studying correlations.

It was observed that not only were the two main types of weather fronts effective but the other forms of air-mass interchange too. Some of them had an influence on the human organism like that of warm fronts and some modified vital functions similarly to cold fronts.

Types of interchange of air masses acting as warm fronts:

(a) upper warm front;
(b) warm front type occlusion;
(c) subsidence

Types of interchange of air masses acting as cold fronts:

(a) upper cold front;
(b) cold front type occlusion.

Stationary fronts have a mixed effect on the organism and the character of their action is dependent upon whether the warm or the cold sector of them exists above the district in question.

A further observation was that not only the type of interchange of air masses has to be taken into consideration, but also the type of air mass itself. As mentioned above, cold fronts cause a general tendency to spasms, but asthmatic patients suffer more attacks in a continental than in an arctic cold air mass.

We have studied the importance of the vertical distribution of air masses too. By means of atmospheric cross-sections it could be established that, for example, the appearance of tropical air in the higher layers produces biological effects similar to those of warm fronts.

Besides these factors we observed the effect of some special meteorological phenomena, such as jet streams and microbarographical oscillations. They make the general state of patients worse and promote the appearance of pulmonary embolism, haemorrhagic diseases and other clinical complications. The increase of solar activity acts in a similar way.

The different meteorological processes accompanying the change of weather such as fronts, air masses and their vertical distribution, etc., are not the only effective factors. The general trend of the weather situation is also of great importance as a cause of biological effects. We compared the various macrosynoptic situations with simultaneously observed clinical events. It was proved that weather processes influence the organism quite differently according to the path along which a cyclone is approaching.

As a result of these experiments we are preparing our medical meteorological forecast as follows:

At midday we get a summary of the weather situation in the past 24 hr and the weather forecast for the next 24 hr from the Hungarian Meteorological Institute. Then we compare it with our clinical observations and statistical data and draw our medical forecast.

Unfortunately, it was not possible to have ready the evaluation of our experiments before the present Congress because of the large volume of material, but we hope to be able to report it at a later date in the *International Journal of Bioclimatology and Biometeorology.*

S. W. Tromp: I wish to thank Professor Sargent for his inspiring lecture.

It seems to me that, apart from the examples given by Professor Sargent, two groups of human diseases deserve a special study in relation to meteoro-pathological forecasting, i. e. bronchial asthma and arteriosclerotic heart diseases and apoplexy. Biometeorological studies at our Bioclimatological Research Centre, Leiden (the Netherlands) since 1955 have shown the following meteorotropic relationships:

(1) Attacks of bronchial asthma usually increase in Holland during influx of polar air masses, passages of active cold fronts, particularly if they are accompanied by considerable air turbulence during a period of steep falling barometric pressure (for details see my paper submitted to the Congress).

(2) In winter (January, February) a sharp increase in mortality from coronary thrombosis, myocardial infarction, angina pectoris and apoplexy is observed in the Netherlands both for males and females. But also morbidity studies suggest an increase during periods of passages of active weather fronts accompanied by great air turbulence. During these periods we observed in a healthy group of blood donors a general rise in the average diastolic blood pressure, a high percentage of low blood sedimentation rates (1—2 mm) and high percentage of albumin of the blood serum.

In view of these rather consistent relationships it seems possible to give a timely warning to patients suffering from bronchial asthma, arteriosclerosis and heart diseases, to protect themselves against the meteorotropic effects created by periods of specially unfavourable weather conditions. If possible also serious operations should be postponed during such days.

However, in view of the psychological consequences of such warnings, future meteoropathological forecasting should be handled with the greatest possible care.

5th Session

URBAN BIOCLIMATOLOGY

Chairman: Prof. J. K. Page

LA PROTECTION THERMIQUE DES CONSTRUCTIONS EN PAYS TROPICAL

PRINCIPES GÉNÉRAUX NOTION D'INERTIE THERMIQUE

J. DREYFUS

Ingenieur en Chef des Ponts et Chaussées, Chef du Service des Études Fonctionnelles au Centre Scientifique et Technique du Bâtiment, 4 Avenue du R. Poincaré, Paris 16, France

Abstract—Thermal protection of buildings in tropical countries is all the more important because the buildings are made of more durable materials. The general principles of this protection follow from the relative requirements of comfort and climate as well as from the physical laws controlling ventilation and heat transfer.

In humid tropical zones buildings must be erected and conceived according to the needs of ventilation; they must be "light" in weight to provide comfort at night. In dry tropical zones buildings must be erected and conceived according to the needs of protection from the sun first and of ventilation after that. They must be "heavy" to provide comfort in day-time.

A study of thermal principles makes it possible to specify the conditions of heat transfer across a partition, the rate of cooling of a wall or partition and its ability to absorb heat in relation to the amount of heat entering a building, and it also allows to state what is meant by "light" and by "heavy" buildings.

The need to ventilate leads to dispersal of buildings. Vegetation is an efficient way to achieve protection from the thermal effects of solar radiation in built-up areas.

Résumé—La protection thermique des constructions en pays tropical est d'autant plus importante qu'il s'agit de constructions en matériaux plus durables. Les principes généraux de cette protection se déduisent des données relatives au confort et au climat ainsi que des lois physiques régissant les phénomènes de ventilation et de transmission de chaleur.

En zone tropicale humide, les constructions doivent être implantées et conçues en fonction des exigences de ventilation; elles doivent être «légères» pour des raisons de confort de nuit. En zone tropicale sèche, les constructions doivent être implantées et conçues en fonction des exigences de protection solaire d'abord, de ventilation ensuite. Elles doivent être «lourdes» pour des raisons de confort de jour.

L'étude de l'inertie thermique permet de préciser les conditions de transmission d'une onde de chaleur à travers une paroi, de définir la vitesse de refroidissement d'un mur ou d'une cloison ainsi que son pouvoir absorbant vis-à-vis de la chaleur entrant dans la construction et de préciser ce qu'il faut entendre par construction «légère» ou construction «lourde».

Les exigences de ventilation conduisent à un habitat dispersé. La végétation constitue un moyen efficace pour se protéger des effets thermiques du rayonnement solaire dans les zones bâties.

Auszug — Der Wärmeschutz von Bauten in tropischen Ländern ist umso wichtiger, als es sich hier um Bauten handelt, die aus dauerhafteren Materialien bestehen. Die allgemeinen Prinzipien dieses Schutzes lassen sich aus den Gegebenheiten hinsichtlich Komfort und Klima sowie aus den physikalischen Gesetzen für die Phänomene der Lüftung und des Wärmedurchgangs herleiten.

In feuchten tropischen Gegenden müssen die Bauten entsprechend den Erfordernissen der Ventilation erstellt und geplant werden; sie müssen "leicht" sein aus Gründen der nächtlichen Annehmlichkeit. In der trockenen Tropenzone müssen die Bauten in erster Linie entsprechend den Erfordernissen hinsichtlich Sonnenschutz und in zweiter Linie hinsichtlich Lüftung erstellt und geplant werden. Sie müssen "schwer" sein aus Gründen der Annehmlichkeit bei Tage.

Die Untersuchung der Wärmeträgheit ermöglicht es, die Bedingungen für den Durchgang einer Wärmewelle durch eine Wand zu präzisieren, die Abkühlungsgeschwindigkeit einer Mauer oder einer Trennwand sowie ihr Absorptionsvermögen gegenüber der Wärme, die in das Bauwerk eindringt, zu bestimmen und genau zu erklären, was man unter "leichter" bzw. "schwerer" Konstruktion zu verstehen hat.

Die Erfordernisse hinsichtlich Lüftung führen zu verstreut liegenden Einzelbauten. Der Pflanzenwuchs stellt ein wirksames Mittel dar, um sich gegen die Wärmewirkung der Sonnenbestrahlung in den bebauten Zonen zu schützen.

EN pays tropical, le problème essentiel qui se pose aus bâtisseur est d'assurer aux occupants des constructions une protection satisfaisante contre la chaleur. L'importance du problème n'en est pas moins souvent méconnue et il n'est pas rare que l'on attache plus de prix à la durabilité de la construction qu'à ses qualités thermiques, pensant, notamment, que la protection contre la chaleur est sans objet lorsqu'il s'agit de logements destinés à des autochtones vivant depuis toujours en pays tropical. Mais on oublie alors que les conditions existant à l'intérieur d'une construction en dur mal adaptée au climat sont souvent bien plus défavorables, par suite de l'influence combinée du rayonnement solaire, d'une ventilation insuffisante et de l'inertie thermique des parois, que celles existant à l'extérieur, la nuit notamment, plus défavorables aussi que celles existant à l'intérieur d'une case traditionnelle. Le fait est d'autant plus grave que de telles constructions, parce qu'elles sont en dur, serviront chacune d'abri ou de lieu de travail à une ou deux générations.

L'exposé qui suit, consacré à la protection thermique des constructions comprend deux parties.

La première partie, très générale, résume les données fondamentales du problème (notion de confort, données climatiques, lois régissant les phénomènes d'échange et de transmission de chaleur et de ventilation) et les principes généraux de construction et d'urbanisme en pays tropical.

La deuxième partie traite de façon détaillée du rôle de l'inertie thermique.

I. DONNÉES DE BASE ET PRINCIPES GÉNÉRAUX DE CONSTRUCTION EN PAYS TROPICAL

1. 1. DONNÉES DE BASE

1.11. *Le Confort Hygrothermique*

L'étude du confort hygrothermique est du domaine du physiologue. Nous rappellerons seulement ici les points les plus importants pour l'ingénieur ou l'architecte.

Les quatre éléments du confort hygrothermique sont la température de l'air (appelée encore température sèche), la température radiante moyenne, l'humidité et la vitesse de l'air.

En air calme, une élévation de 1° de la température radiante moyenne a la même influence sur le confort qu'une élévation de 1° de la température sèche. Lorsque la

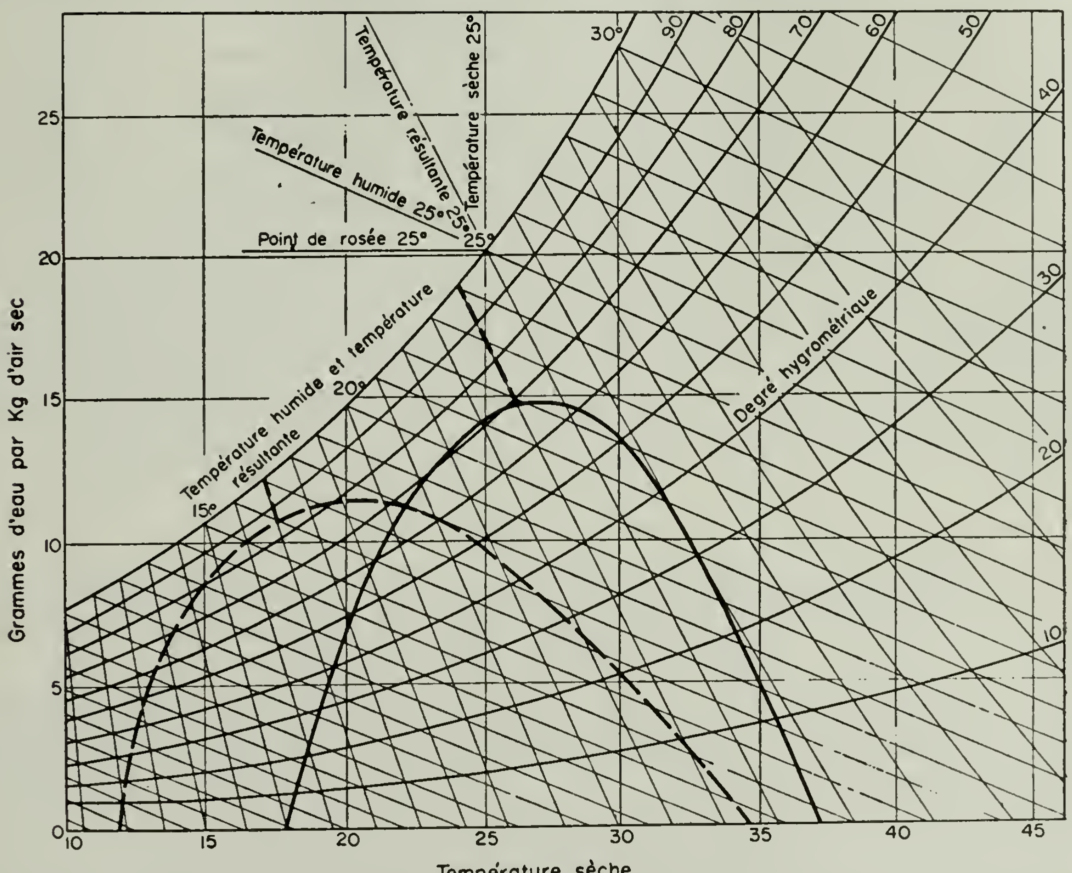


FIG. 1. Zones de confort d'après Lemaire (1). La courbe en trait plein donne la zone de confort pour un sujet adapté au climat tropical, celle en trait discontinu la zone de confort pour un sujet non adapté. Aux fortes humidités on passe sans transition d'un inconfort de chaud (partie droite du diagramme) à un inconfort de froid (partie gauche du diagramme). Les courbes de température résultante non portées sur le diagramme original sont celles du Ashve

vitesse de l'air est notable (de l'ordre de 1 m/sec), l'influence de la température radiante moyenne devient négligeable.

Aux températures normalement rencontrées dans les pays tropicaux, l'humidité de l'air a une influence considérable sur le confort. L'humidité absolue compte autant, sinon plus, que le degré hygrométrique.

Lorsque le degré hygrométrique est supérieur à 80% environ, il n'est plus de confort vrai, quelle que soit la température. Une vitesse d'air élevée permet seulement de pallier la sensation d'inconfort due à une humidité excessive de l'air. Fig. 1, par ailleurs, montre que lorsque l'air est voisin de la saturation, on passe sans transition d'une sensation de chaud à une sensation de froid. Ceci expliquerait — en partie du moins — pourquoi les autochtones des régions tropicales humides sont particulièrement sensibles à une diminution de la température.

Le confort pendant le sommeil est essentiel pour la santé des individus. Les conditions correspondantes paraîssent plus restrictives que pour une activité normale à la fois, semble-t-il, pour des raisons physiologiques (le repos demande la mise en veilleuse des fonctions d'adaptation) et physiques (pour un homme couché, la moitié de la peau environ ne peut, ni échanger de chaleur avec l'environnement, ni éliminer de chaleur par évaporation). Cependant, il n'existe aucune donnée précise à ce sujet.

Enfin, on notera que si, par des méthodes statistiques, il est possible de déterminer une ou plusieurs zones de confort (cf. notamment Fig. 1), un autre problème, important pour l'ingénieur en conditionnement, est de savoir s'il existe un écart maximal admissible entre les conditions extérieures et intérieures de température et d'humidité. Il serait nécessaire aussi de connaître avec précision les réactions physiologiques provoquées par le passage d'une ambiance extérieure sèche à l'ambiance humide crée par certains appareils de conditionnement (climatiseur saharien, conditionneur avec humidificateur).

1.12 *Données Naturelles*

1.121. *Zones climatiques de confort.*—Partant de la notion de confort, on est conduit à distinguer deux types climatiques de base, correspondant respectivement aux zones tropicales humides et tropicales sèches ou à mousson.

Les diagrammes des Fig. 2, 3 et 4 donnent les moyennes mensuelles des conditions de température et d'humidité correspondant aux maxima et minima diurnes de température pour:

(a) Abidjan, caractéristique de la zone tropicale humide.

(b) Bamako et Niamey, caractéristiques de la zone tropicale sèche.

Toutes ces localités se trouvent en Afrique Occidentale. Les écarts par rapport aux moyennes sont insignifiants en zone tropicale humide. Ils sont notables en zone tropicale sèche, tout en restant inférieurs à ceux que l'on observe en Europe. On notera:

Pour la zone tropicale humide—(a) Un régime de précipitations en général de type équatorial, avec deux saisons des pluies (en Juin—Juillet et Octobre—Novembre à Abidjan) correspondant à la période dite d'hivernage. (b) Un degré hygrométrique et une humidité absolue élevés à toutes les époques de l'année entraînant un inconfort permanent. (c) Un faible écart diurne de température.

Pour la zone tropicale sèche — (a) Une saison sèche marquée (de Novembre à Mai) à Bamako et Niamey, suivie d'un hivernage de quatre à cinq mois. (b) En saison

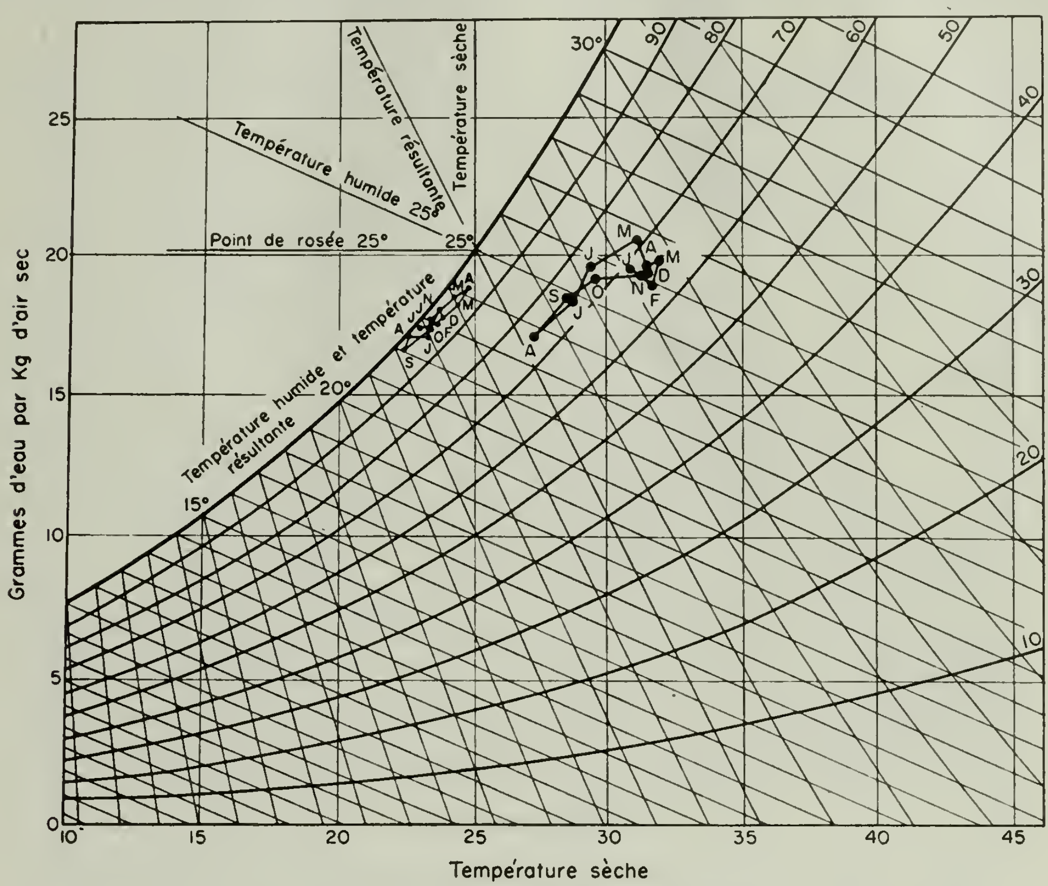


Fig. 2. Abidjan, altitude 16 m; moyennes mensuelles des conditions de température et d'humidité correspondant aux maxima et minima diurnes de température (Dreyfus (2), p. 324)

sèche, des humidités faibles ou très faibles, un écart diurne de température de l'ordre de 15°. En hivernage, les conditions de température et d'humidité se rapprochent de celles qui existent normalement en zone tropicale humide, quoique moins sévères. (c) L'inconfort maximum s'observe juste avant l'hivernage, les maxima de température précédant la période d'inconfort maximum. Le milieu de l'hivernage est une période de confort relatif. Le début de saison sèche, une période de confort vrai.

En dehors de ces trois types principaux, nous citerons:

Le type désertique, qui, au moins pour ce qui concerne les régions proprement tropicales — Sud du Sahara par exemple — peut être considéré comme un cas extrême du climat tropical sec. En Afrique Occidentale, on passe insensiblement de la zone tropicale sèche à la zone désertique en allant du Sud vers le Nord. L'hivernage tend à disparaître et devient la période d'inconfort maximum. Les problèmes qui se posent à l'ingénieur et à l'architecte sont sensiblement les mêmes qu'en zone tropicale sèche.

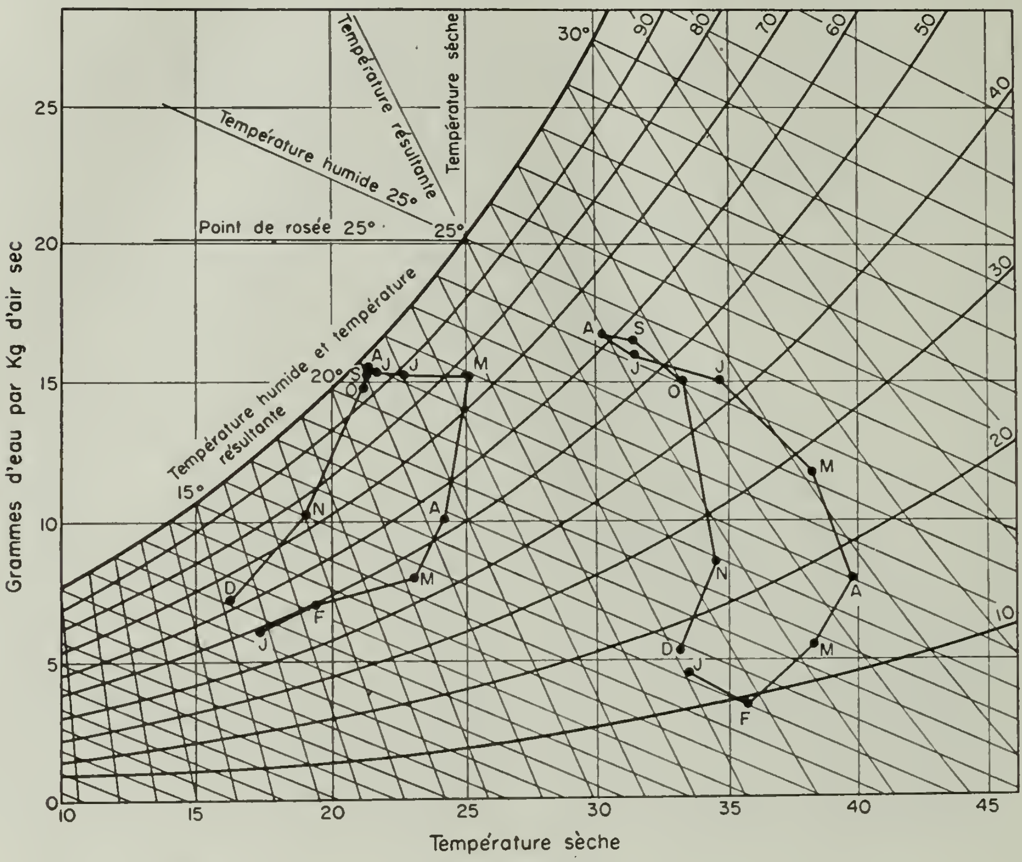


FIG. 3. Bamako, altitude 332 m; moyennes mensuelles des conditions de température et d'humidité correspondant aux maxima et minima diurnes de température (Dreyfus [2] p. 329)

Le type de transition, intermédiaire entre le type tropical humide et le type tropical sec.

Le type péruvien ou subcanarien, avec une saison fraîche marquée, due à la conjonction de l'alizé et d'un courant marin froid.

Les types d'altitude, intéressant les régions dont l'altitude est supérieure à 400 m environ, moins chauds, et même froids à certaines époques de l'année, lorsque l'altitude dépasse 1000 m.

Fig. 5 donne la répartition des zones climatiques de confort en Afrique Occidentale.

D'une façon générale, la zone tropicale humide intéresse une bande de 4 à 6° de part et d'autre de l'équateur s'étendant dans toutes les parties du monde. La zone tropicale sèche couvre une grande partie de l'Inde, de l'Afrique Occidentale, de la République Soudanaise. La zone subcanarienne intéresse en particulier la Côte occidentale d'Afrique, de Dakar à Port Etienne.

Le pourtour de l'Océan Indien, de la Mer Rouge à la Côte Indienne comprise, représente une des régions du monde les plus inconfortables pour l'homme, du fait des humidités élevées accompagnant des températures elles-mêmes très élevées.

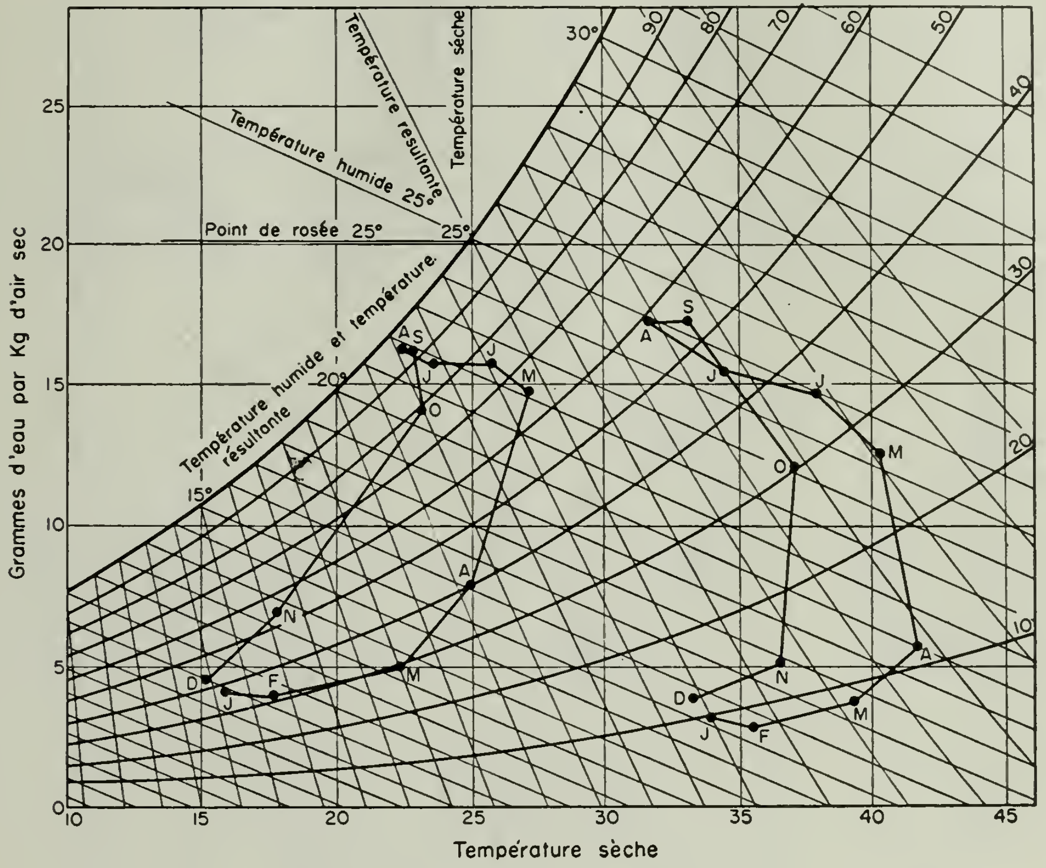


Fig. 4. Niamey, altitude 226 m; moyennes mensuelles des conditions de température et d'humidité correspondant aux maxima et minima diurnes de température (Dreyfus [2] p. 331)

1.122. *Le vent.* — Le vent est une donnée importante:

(a) Il détermine la vitesse de l'air à l'intérieur des constructions. Or, celle-ci a une action directe sur le confort. Elle a également une action indirecte dans la mesure où elle facilite le renouvellement de l'air intérieur aux heures fraîches et accélère le refroidissement des parois des locaux.

(b) Il neutralise, en partie du moins, l'action du rayonnement solaire sur les parois externes de la construction.

La vitesse du vent en pays tropical est souvent faible, mais plus particulièrement la nuit, comme il ressort du tableau 1 et de la Fig. 2.

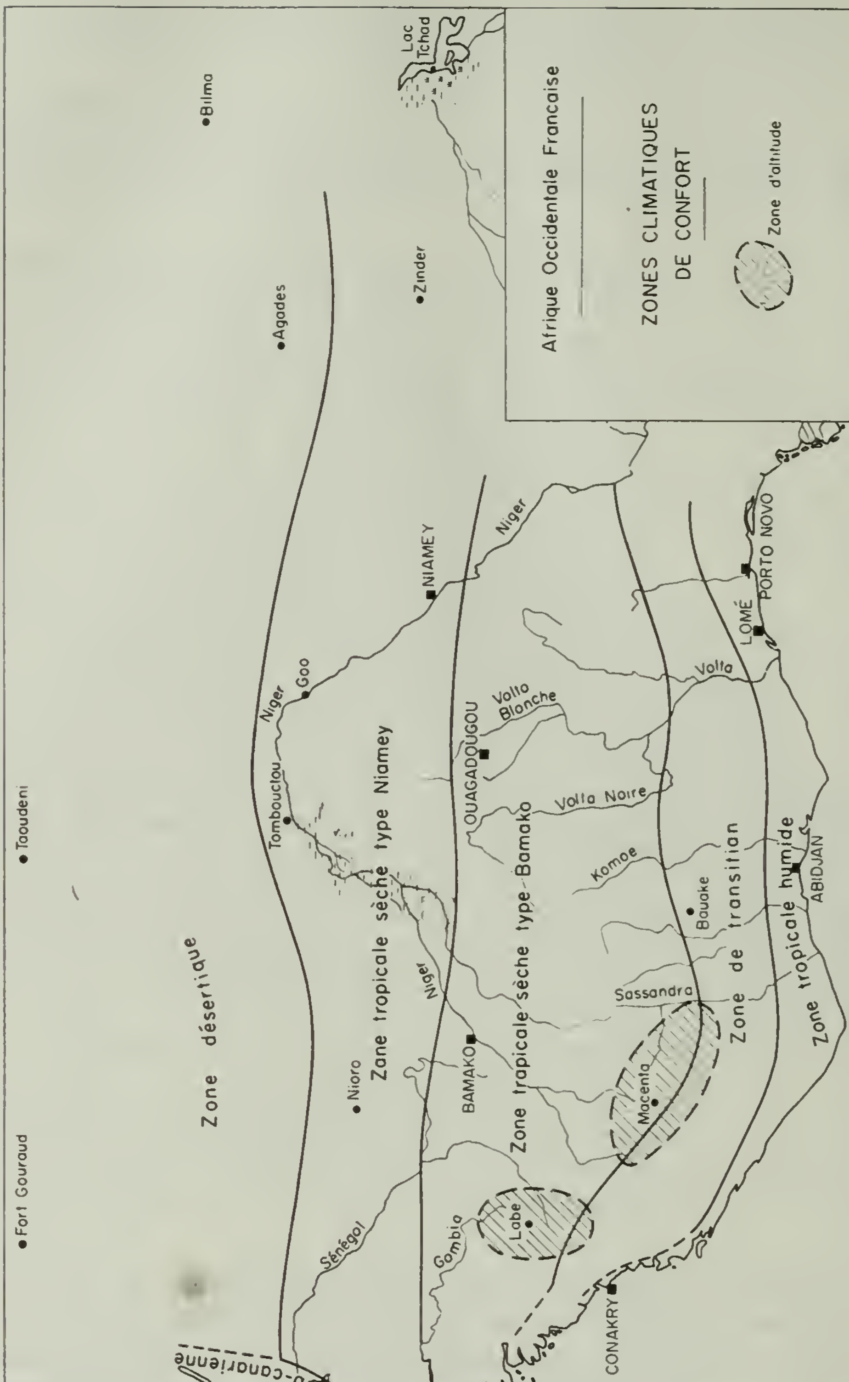


FIG. 5. Zones climatiques de confort en Afrique Occidentale (Dreyfus [2] p. 322)

Tableau 1. Pourcentages d'Observations Correspondant à une Vitesse de Vent Inférieure à 1,50 m/sec (Vents Calmes) à Abidjan, à Différentes Heures de la Journée et pour Différents Mois de Saison Sèche

(Hauteur au-dessus du sol: 10 m)

	Heure			
	9	15	21	03
Janvier	65%	2%	56%	74%
Mars	21%	2%	29%	38%
Mai	27%	4%	19%	50%

Les îles, cependant, bénéficient d'un régime de vent plus favorable, ce qui conduit quelquefois à distinguer un sous-type climatique dit «insulaire».

La vitesse augmente avec la hauteur au-dessus du sol. Inversement, au voisinage du sol, on observe une couche d'air pratiquement immobile, dite couche de transi-

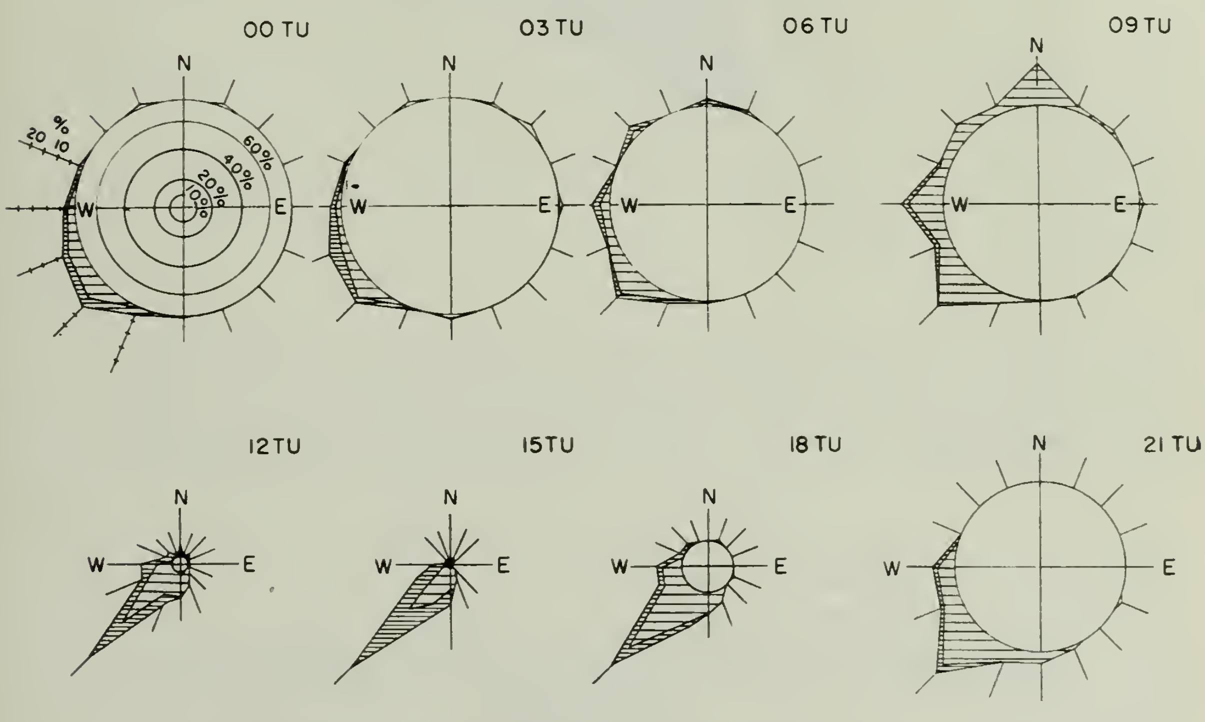


Fig. 6. Vitesses des vents aux différentes heures de la journée, au mois de Janvier à Abidjan, d'après les observations sur la période 1949—1953 hauteur au dessus du sol: 10 m. Pour l'interprétation du diagramme, on se reportera à la fig 6 bis

tion, dont l'épaisseur varie de quelques centimètres à un mètre suivant que le sol est nu ou recouvert de végétation, suivant aussi la nature et le nombre d'obstacles (haies, clôtures, etc.) existant à la surface du sol.

1.123. *Les rayonnements.* — Il faut distinguer:

(1) Le rayonnement solaire qui peut être une source d'inconfort dans les pays tempérés et l'est toujours en pays tropical,

(a) Les échanges par rayonnements de grandes longueurs d'onde avec le ciel et l'environnement, échanges qui définissent, notamment, la température radiante

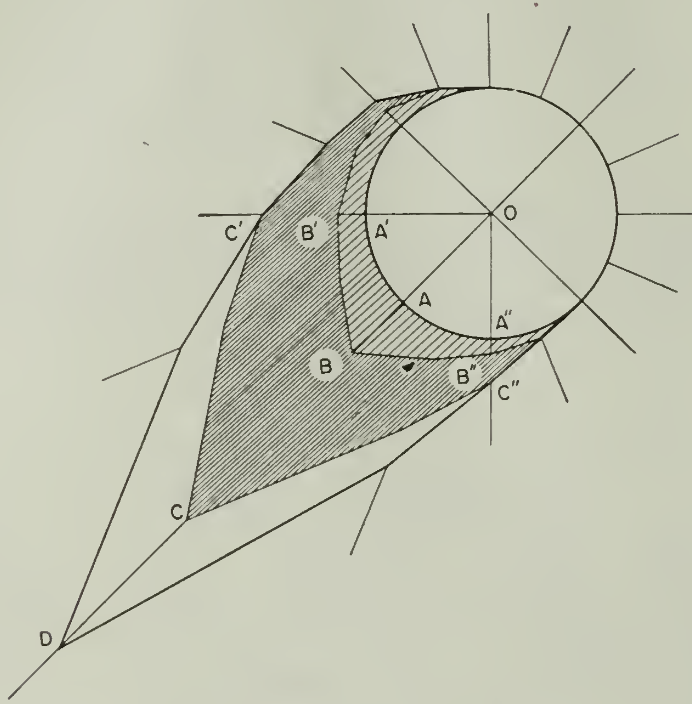


Fig. 6 (bis). Fréquences des vents en vitesse et direction, représentation conventionnelle. Le rayon du cercle est proportionnel au pourcentage d'observations de vents dont la vitesse est inférieure à 1,50 m/sec (vents calmes) Les segments AB, $A'B'$ . . . BC . . . sont proportionnels au pourcentage des vents dans la direction correspondante (c'est-à-dire, par exemple, pour AB, venant du Sud—Ouest) de vitesse:

comprise entre 1,50 et 3 m/sec (AB, $A'B'$ . . . . .)
comprise entre 3 et 6 m/sec (BC, $B'C'$ . . . .)
supérieure à 6 m/sec (CD)

L'échelle, différente pour les vents calmes et pour les vents de vitesse supérieure à 1.50 m/sec, est portée sur le diagramme 00 T. U. (T. U. = time unit) de la Fig. 6

moyenne du ciel. Celle-ci est inférieure, la nuit principalement, à la température météorologique, d'où l'expression fréquemment utilisée de «rayonnement nocturne».

Dans toutes les régions tropicales au sens géographique du terme, le soleil passe au zénith du lieu deux fois dans l'année. Ceci explique qu'en moyenne:

(1) Une toiture reçoit deux à trois fois plus de rayonnement solaire qu'un plan vertical, donc un mur.

(a) Les murs exposés au Nord et au Sud reçoivent moins de rayonnement solaire que des murs exposés à l'Est et à l'Ouest ou, même, au NE., NO., SE. ou SO.

Aux époques, par exemple, où le soleil passe au voisinage du zénith du lieu, l'ordre de grandeur des rayonnements direct et diffus reçus par différents murs et par journée de «très beau temps» est le suivant, en kilocalories par mètre carré:

	Direct	Diffusé par le ciel	Diffusé par l'environnement	Total
nord ou sud	négligeable	800*	600**	1400
est ou ouest	1500	800*	450**	2750
$\dfrac{\text{nord + sud}}{\text{est + ouest}}$	0	1	1,30	0,50

* Soit la moitié du rayonnement diffus reçu par un plan horizontal.
** Dans l'hypothèse où l'environnement a un albedo de l'ordre de 20%.

La valeur moyenne pour l'année du rapport des rayonnements reçus par des murs Nord et Sud, d'une part, Est et Ouest, d'autre part, est évidemment supérieure à 0,50. Au solstice d'été et au Sud de l'équateur, notamment, un mur exposé au Nord recevra un rayonnement direct important. Il n'en est pas moins vrai que, du point de vue de la protection contre le rayonnement solaire, il est toujours avantageux de choisir pour les façades principales une exposition plein Nord et plein Sud, d'autant plus qu'il est plus facile alors de réaliser des écrans efficaces.

On peut caractériser l'action des rayonnements sur les parois d'une construction (ainsi que l'action du vent) par t_{FS}, température fictive au soleil.* Celle-ci, qui définit «l'onde de chaleur extérieure», dépend en particulier du facteur d'absorption pour le rayonnement solaire du matériel ou de la peinture constituant la face externe de la paroi.

Soit, par exemple, une toiture à faible pente par journée de très beau temps. Avec les matériaux usuels de couverture, la valeur moyenne sur vingt—quatre heures de t_{FS} sera supérieure de 12° environ à t_a, température de l'air extérieur, mais aux heures d'ensoleillement maximum, l'écart $t_{FS} - t_a$ pourra atteindre 35°. Pratiquement, les calculs de flux de chaleur entrant par la toiture devront être faits, non pas à partir de la température de l'air extérieur, mais à partir de la température fictive au soleil qui, par conséquent, pourra, à certaines heures, lui être supérieure de 35°.

Enfin, on remarquera que, pour étudier la protection d'une construction contre le rayonnement solaire direct, il faut connaître la position du soleil aux différentes heures de la journée et époques de l'année. On peut utiliser à cet effet, soit un héliodon,

* En anglais "sun air temperature".

soit un diagramme solaire. Deux systèmes de diagrammes solaires nous semblent particulièrement commodes:

(a) Celui représenté sur la Fig. 7 qui donne l'ombre d'un baton placé au centre de la figure, pour une latitude donnée, aux différentes heures de la journée et époques de l'année,

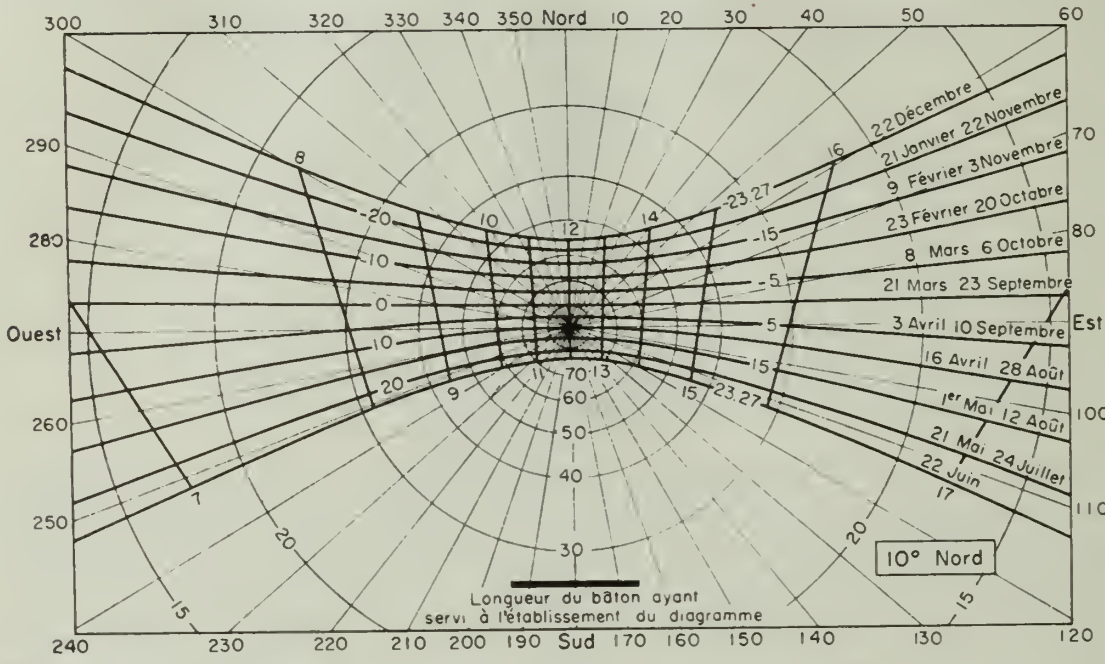


FIG. 7. Diagramme solaire pour la latitude 10° Nord. Le diagramme donne l'ombre d'un bâton placé au centre de la figure, aux différentes heures de la journée et époques de l'année

(b) Celui qui se déduit du précédent par retournement de la figure et donne les positions successives du soleil sur une carte photographique du ciel.

Ces diagrammes ne permettant pas de déterminer la position exacte du soleil au moment de son lever et de son coucher, ce qui semble sans importance dans la pratique.*

1.124. *Le microclimat* — Le terme de microclimat traduit en particulier le fait que les données climatiques sont essentiellement variables d'un point à un autre.

Par ailleurs, en bâtissant une ville ou seulement quelques logements, on crée un microclimat artificiel. Il importa que celui-ci soit aussi favorable que possible. Nous examinerons au paragraphe 1.22 les principes généraux que l'urbaniste devra respecter à cet effet.

* Le Centre Scientifique et Technique du Bâtiment doit publier prochainement une étude complète sur ce problème. Cf. aussi réf. (2).

1. 13. *Données générales sur la Thermique et la Ventilation des Constructions en Pays Tropical*

1. 131. *Thermique des constructions.* — Pour protéger une construction contre la chaleur et, plus particulièrement, contre le rayonnement solaire, on dispose des moyens suivants:

(a) Choisir pour la face externe des parois extérieures un matériel ayant une faible absorption pour le rayonnement solaire et une émissivité élevée aux températures ordinaires.
(b) Protéger la paroi par un écran.
(c) Augmenter son isolation thermique.
(d) Donner à l'ensemble de la construction une inertie thermique convenable.
(e) Profiter de la baisse diurne de température pour éliminer le maximum de la chaleur emmagasinée par la construction aux heures chaudes.

Les problèmes relatifs à l'absorption et à l'émissivité des matériaux (point *a*) sont liés à l'étude des rayonnements qui est présentée dans un autre rapport. L'isolation et l'inertie thermique seront examinées en détail dans la deuxième partie. On verra en particulier que si l'inertie thermique permet d'amortir à l'intérieur des constructions les pointes de chaleur diurnes, elle est toujours défavorable du point de vue du confort de nuit. Le problème des écrans est traité par ailleurs. Enfin, en ce qui concerne le refroidissement des constructions aux heures fraîches, on remarquera que le seul moyen dont on dispose pour utiliser au maximum la baisse diurne de température est d'activer la ventilation intérieure, ce qui implique notamment que l'on respecte les règles données ci-après.

1. 132. *Ventilation naturelle des constructions.* — La ventilation naturelle peut être due, soit au vent, soit à l'effet de cheminée, lequel vient de la différence de densité entre l'air chaud et l'air froid. Il y a toujours intérêt à profiter au maximum de l'action du vent, ce qui suppose d'abord que celui-ci puisse parvenir jusqu'aux abords immédiats de la construction. Les études d'Evans (3) ont montré que la distance minimale entre deux files continues de constructions perpendiculaires au vent doit être d'au moins sept à huit fois la hauteur de la file située en amont, si l'on veut éviter l'effet de masque sur celle située en aval. En outre, la disposition relative des obstacles proches (arbres et clôtures) a une certaine importance (4, 5).

En ce qui concerne la construction proprement dite, on devra tenir compte des facteurs suivants:

(1) Il faut que le vent puisse entrer par une façade et sortir par la façade opposée, c'est-à-dire encore que la ventilation soit transversale, d'où l'intérêt de la construction «à une seule pièce d'épaisseur». Pour une construction très élevée, une telle solution est difficilement applicable pour des raisons de stabilité et d'esthétique. On peut alors prévoir des ouvertures, à lames orientable, par exemple, dans les cloisons entre pièces (voir Fig. 7). La gêne apportée par les cloisons intermédiaires est compensée par l'accroissement de la vitesse du vent avec l'altitude.

(2) Les façades portant les ouvertures doivent être exposées face aux vents dominants. La vitesse de l'air intérieur, en effet, décroît sensiblement comme le cosinus de l'angle que fait la direction du vent avec la normale à la façade. En outre, Koenigsberger (6) a constaté que les grillages moustiquaires tendent à aggraver l'effet d'obliquité de vent.

(3) La section des orifices de sortie doit être supérieure à celle des orifices d'entrée (4), ce qui est contraire à l'opinion couramment admise.

(4) Les ouvertures doivent être disposées de manière que les filets d'air passent aux emplacements où la ventilation est le plus nécessaire.

Ces règles sont d'autant plus importantes que la vitesse du vent en pays tropical est souvent faible. Il faut tenir compte aussi du fait que des grillages moustiquaires réduisent de moitié environ la vitesse de l'air (6). Par contre l'effet de cheminée pourra contribuer au renouvellement de l'air intérieur aux heures fraîches. Il y aura donc intérêt à prèvoir systématiquement des ouvertures au niveau du plafond, ce qui assurera en même temps le balayage régulier de la sous-face et évitera l'accumulation d'air chaud dans la partie supérieure du local. Pour des locaux sous toiture, un plafonnage incliné est préférable.

Il faut reconnaître, cependant, que les données précises manquent sur les conditions réelles de ventilation, la nuit notamment, dans un local conçu en tenant compte de tous les principes que l'on vient de poser. Si l'on peut affirmer, en effet, qu'un local non ventilé ne se refroidit pratiquement pas aux heures fraîches, on ne sait pas, par contre, dans quelle mesure à l'intérieur d'un local ventilé naturellement, les phénomènes de convection le long des parois intérieures contribuent réellement au refroidissement de la construction.*

1. 2. PRINCIPES GÉNÉRAUX DE CONSTRUCTION ET D'URBANISME EN PAYS TROPICAL

1. 21. *Constructions en Zone tropicale Humide*

Les deux principes fondamentaux sont les suivants:

(1) Les constructions doivent être conçues en fonction d'une ventilation intérieure efficace à toutes les heures de la journée.

(2) Les constructions «légères», c'est-à-dire à faible inertie thermique doivent être préférées aux constructions «lourdes», c'est-à-dire à forte inertie thermique, sauf s'il s'agait de locaux destinés exclusivement à un usage de jour.

La première règle découle de l'humidité élevée de l'air. Seule, la ventilation intérieure permet de compenser la sensation d'inconfort que cette humidité entraîne. Une ventilation intérieure efficace impose la construction «à une seule pièce d'épaisseur» (sauf, comme on l'a vu, s'il s'agit d'une construction très élevée) et une orien-

* Les seules données expérimentales dont on dispose concernent le cas de locaux ventilés artificiellement (7).

tation telle que les façades principales soient perpendiculaires aux vents dominants. La construction en hauteur est préférable à la construction à rez-de-chaussée.

La deuxième règle est liée au confort de nuit dont on a déjà noté l'importance. Les conditions de confort, en effet, sont plus restrictives la nuit que le jour. Or, la vitesse du vent est toujours plus faible la nuit que pendant la journée, d'où il résulte que la vitesse de l'air intérieur est elle-même plus faible, ce qui en soi est un facteur d'inconfort. Mais dans le cas d'une construction «lourde», vient s'ajouter le fait que la température de l'air et la température radiante moyenne sont supérieures à la température extérieure et d'autant plus que la ventilation est moins satisfaisante.

Ces deux règles ne permettent pas toujours, il est vrai, une protection facile et efficace contre le rayonnement solaire, une construction légère étant plus sensible à ce rayonnement et les vents dominants pouvant conduire à exposer les façades principales à l'Est ou à l'Ouest. Ces inconvénients semblent faibles dans la pratique pour une construction ventilée en permanence, du fait que les vitesses de vent toujours notables aux heures d'ensoleillement permettront une ventilation intérieure particulièrement efficace à ce moment de la journée, et sous réserve, évidemment, que l'on assure une protection solaire satisfaisante des différentes parois.

La recherche d'une ventilation efficace conduit à prévoir largement les ouvertures. Cependant, il faut se garder d'imposer aux occupants des courants d'air permanents. Car, en période d'hivernage, notamment, les conditions hygrothermiques intérieures risquent d'entraîner un certain inconfort de froid. Il faut, par conséquent, que la ventilation soit réglable. En outre, les ouvertures doivent être conçues de façon à empêcher la pénétration de l'eau.*

Enfin, on notera que la hauteur sous-plafond est sans influence sur la confort à partir du moment où la toiture est convenablement protégée du rayonnement solaire.**

1. 22. *Constructions en Zone tropicale sèche*

Compte tenu de l'importance physiologique du sommeil, on pourrait penser que les constructions en zone tropicale sèche doivent être conçues en fonction du confort de nuit pendant la période de l'année la plus pénible pour l'homme, c'est-à-dire en fin de saison sèche.

Mais pratiquement, pendant la saison sèche, on cherchera à bénéficier de rayonnement nocturne vers le ciel, ce qui conduira à dormir dehors. Il suffira de prévoir un emplacement extérieur bien dégagé des obstacles proches.

Dans ces conditions, le problème le plus important est celui du confort de jour en fin de saison sèche ou, d'une façon plus générale, en saison sèche.

L'écart diurne de température étant alors très important, les locaux de jour seront maintenus fermés aux heures chaudes, comme c'est le cas en Europe pendant l'été, de façon à réaliser des conditions intérieures de température plus favorables

* Cf. réf. (6), en ce qui concerne les ouvertures fixes.

** Cf. notamment réf. (2).

que les conditions extérieures. Ceci suppose une construction «lourde», bien protégée du rayonnement solaire* et dont les parois intérieures pourront absorber la chaleur entrant pendant la journée.

Le plan devra être conçu en fonction d'une ventilation efficace de façon à éliminer la chaleur apportée par le rayonnement solaire. Mais la possibilité de réaliser une ventilation efficace est de toute façon nécessaire pendant l'hivernage où les conditions climatiques tendent à se rapprocher de celles existant toute l'année en zone tropicale humide. La construction à «une seule pièce d'épaisseur» doit donc être la règle comme en zone tropicale humide. Mais, pour faciliter la protection solaire, on est conduit à donner aux ouvertures une surface plus faible, soit, pour fixer les idées, le cinquième environ de la surface des pièces.

Les locaux intérieurs de nuit, c'est-à-dire les chambres, serviront à la sieste toute l'année et pendant les nuits d'hivernage et de début de saison sèche.

Ils devront être conçus sensiblement comme les locaux de jour, ce qui présentera quelques inconvénients en hivernage, compte tenu de ce qui a été dit plus haut pour la zone tropicale humide, inconvénients négligeables, cependant, car, pendant l'hivernage de zone tropicale sèche, les conditions restent moins sévères que celles existant normalement en zone tropicale humide.

Les façades principales doivent être exposées au Nord et au Sud, de façon à réduire les apports de chaleur dus au rayonnement solaire. Cette exposition est d'autant plus avantageuse qu'au moment de la période d'inconfort maximum, le soleil passe pratiquement au zénith du lieu. Toutefois, si les vents dominants viennent de l'Est ou de l'Ouest, on devra choisir l'exposition en fonction des impératifs de ventilation**, quitte à se protéger plus difficilement du rayonnement solaire.

La construction en hauteur est avantageuse, comme en zone tropicale humide, avec la réserve que s'il s'agit d'une maison individuelle, il y a intérêt à «coller» les pièces de jour au sol de façon à profiter de l'effet régulateur de celui-ci du point de vue thermique.

1.23. *Cas particulier des locaux conditionnés*

Dans ce qui précède, on a supposé implicitement qu'il n'y avait pas de conditionnement. Cependant, quelles que soient les précautions prises par le constructeur, il ne sera jamais possible en pays tropical d'atteindre, sans conditionnement, un confort vrai à toutes les époques de l'année aussi bien en zone tropicale humide, à cause de l'humidité toujours trop élevée qui crée un inconfort quasi permanent, qu'en zone tropicale sèche où, à certaines époques de l'année, la température moyenne diurne dépasse largement 30°. Le brasseur d'air, tout apprécié qu'il soit, par les usagers, ne constitue qu'un palliatif.

* On notera qu'en zone tropicale humide, même si ces conditions étaient réalisées, il ne serait pas possible, à cause du faible écart diurne de température, de maintenir la température intérieure aux heures chaudes au-dessous de la température extérieure.

** Le cas semble assez rare. On le rencontre en particulier au Sénégal.

Ceci explique la multiplication rapide des appareils de conditionnement mécanique. Mais le sous-développement actuel de la plupart des pays tropicaux rend impensable, dans un avenir proche, la généralisation de cette solution en ce qui concerne l'habitation. Il semble regrettable, par contre, que les locaux de travail (bureaux, petits ateliers, établissements d'enseignement, etc.) ne soient pas plus souvent conditionnés.

Dans le cas de locaux conditionnés, les principes généraux de construction sont notablement différents, en zone tropicale humide du moins:

(1) Il n'y a plus lieu de se préoccuper des inconvénients de l'inertie thermique des parois en ce qui concerne le confort de nuit. La construction «lourde» devient avantageuse parce que permettant de réaliser plus économiquement une protection solaire efficace.

(2) De même, les impératifs de ventilation ne jouent pas. Pour réduire les apports de chaleur dus au rayonnement solaire, les façades principales doivent être exposées au Nord et au Sud et la construction épaisse devient préférable à la construction à une seule pièce d'épaisseur; la surface des ouvertures doit être réduite au minimum compatible avec les exigences d'éclairage. Pratiquement, le coût de la construction sera plus faible de 10 à 15%, semble-t-il, pour des locaux conditionnés. L'économie correspondante compensera le coût du conditionneur.

En zone tropicale sèche, les locaux ne seront conditionnés que pendant une partie de l'année. Les problèmes de ventilation se posent donc de la même façon que lorsqu'il n'est pas prévu de conditionnement, c'est-à-dire que la construction à une seule pièce d'épaisseur reste préférable. La protection thermique devra être étudiée de façon à rendre aussi faible que possible la dépense d'énergie, ce qui pourra conduire à prévoir une isolation particulière des murs. C'est en fait le seul cas en pays tropical où une telle isolation est réellement utile. Le problème, à cet égard, est très différent en zone tropicale sèche et en zone tropicale humide où l'essentiel de la charge frigorifique vient de l'air de renouvellement dont il faut abaisser l'humidité absolue de 10 g d'eau environ par kg d'air sec. En zone tropicale sèche, au contraire, si la protection thermique est suffisante, on peut, à certaines époques de l'année, annuler la charge frigorifique, à condition d'humidifier l'air de renouvellement. C'est là le principe des climatiseurs adiabatiques.*

1.24. *Principes d'Urbanisme***

1.241. *Problèmes de ventilation.*—Les études d'Evans (3) concernant l'effet de masque par rapport au vent d'un immeuble ou d'une file d'immeubles, montrent que, lorsqu'il n'est pas prévu de conditionnement artificiel, les impératifs de ventilation conduisent à un habitat dispersé, aussi bien d'ailleurs en zone tropicale sèche qu'en zone tropicale humide. De même, on a déjà noté l'intérêt de la construction en hauteur. La densité maximale de pièces d'habitation à l'hectare semble de 100 environ dans le cas de constructions de hauteur moyenne à une seule pièce d'épais-

* Cf. aussi à ce sujet. réf (2).

** Cf. aussi réf. (8)

seur, de 150 dans le cas de constructions très élevées à deux pièces d'épaisseur. Dans la mesure où le conditionnement affranchit l'architecte des impératifs de ventilation, il permet d'accroître le facteur d'utilisation du terrain et, par conséquent, de réduire le coût de l'infrastructure par pièce habitable.

Un inconvénient de la construction en hauteur est la perte de la cour individuelle. supplément gratuit de surface habitable. C'est pourquoi, la construction individuelle à deux niveaux avec les chambres à l'étage semble une solution intéressante.

De toute façon, ces considérations ne s'appliquent qu'à des ensembles de logements construits suivant des méthodes européennes. En pays tropical, les logements seront fréquemment édifiés par les intéressés eux-mêmes, ce qui conduira à des constructions à un seul niveau dont la dispersion ne créera pas nécessairement les conditions d'une ventilation efficace.

Ceci joint au fait que les techniques locales ne permettent pas de réaliser des ouvertures se prêtant à une ventilation transversale et que les facteurs sociologiques, en zone tropicale sèche surtout, conduisent souvent les usagers à préférer un habitat fermé, suffit, semble-t-il, à expliquer que la physionomie des villes traditionnelles en zone tropicale sèche du moins, soit très différente de celle à laquelle devraient conduire les nécessités de la ventilation. Il y a quelque chose de choquant, cependant, à vouloir bouleverser des pratiques ancestrales. On peut se demander alors si les conclusions ci-dessus ne reposent pas sur une vue incomplète des choses. Nous ne pensons pas qu'il en soit ainsi, mais la question mérite d'être posée. De toute façon, le bâtisseur se trouve quelquefois devant un choix difficile entre des impératifs sociologiques et les impératifs de confort.

1. 242. *Température et humidité de l'air et température radiante moyenne de l'environnement, influence de la végétation.* — Au contact des surfaces de toute nature chauffées par le soleil (murs, sols nus, bitumés ou bétonnés), la température de l'air s'élève et, d'autant plus qu'à l'intérieur des zones bâties la vitesse du vent, au voisinage du sol surtout, sera plus faible qu'en dehors des agglomérations. Ceci explique que, dans les villes, la température de l'air soit plus élevée qu'en rase campagne, aussi bien la nuit d'ailleurs que le jour, par suite des effets d'inertie thermique. Cet écart de température augmente avec la superficie des villes, comme il résulte des valeurs données au Tableau 2 (9).

Tableau 2. Influence de la Concentration Urbaine sur la Température d'Air d'après Duckworth et Sandberg (9)

Ville	Superficie de l'agglomération (km^2)	Écart maximum de température de l'air entre la ville et la campagne avoisinante (° C)
San Francisco	18	11
San José	6	7,8
Palo Alto	3,5	7,2

De même, les surfaces chauffées par le soleil émettent des rayonnements de grandes longueurs d'onde, ce qui tend à élever la température radiante moyenne de l'environnement relativement aux murs de la construction. Le phénomène est d'autant plus important en valeur relative que les murs sont en général blanchis

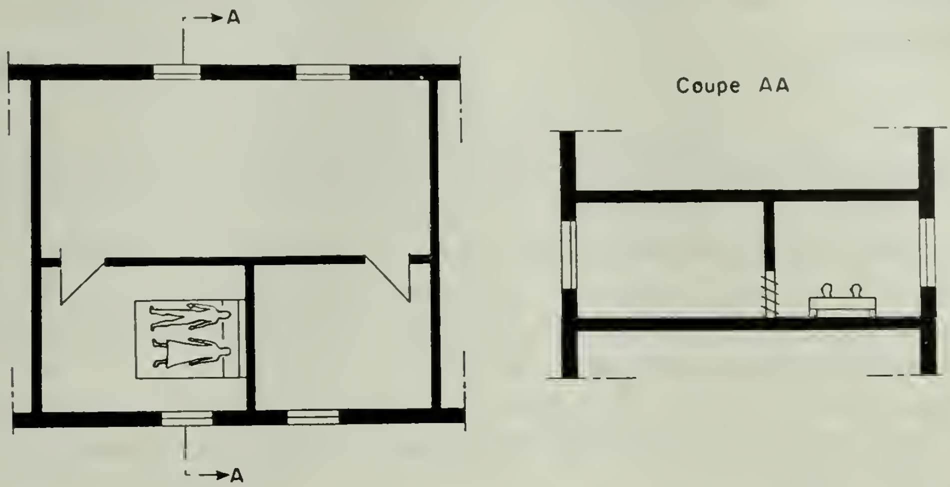


Fig. 8. Construction à deux pièces d'épaisseur avec cloison à lames orientables dans un immeuble à étages

à la chaux ou peints en clair et ont, par conséquent, une absorption faible pour le rayonnement solaire, mais élevée pour les rayonnements de grandes longueurs d'onde.

Pour remédier à ces inconvénients, l'urbaniste doit préserver ou favoriser la végétation de toute nature, celle-ci neutralisant par la photosynthèse ou l'évaporation le rayonnement solaire absorbé. Dans la mesure où l'on aura tenu compte en même temps des impératifs de ventilation, il y aura alors moins de risques de voir la concentration urbaine élever la température de l'air ambiant.

Accessoirement, la végétation tend à accroître l'humidité de l'air, ce qui est plutôt défavorable en zone tropicale humide, mais est favorable en zone tropicale sèche, pendant la saison sèche principalement, où cette humidification s'accompagne d'un abaissement de la température.* Malheureusement, le manque d'eau freine souvent le développement de la végétation, surtout aux confins de la zone désertique.

A défaut de végétation, les sols nus sont toujours plus «frais» que les sols bétonnés ou bitumés. Ceux-ci présentent en outre l'inconvénient d'accélérer la concentration des eaux pluviales.

Enfin, on remarquera que pour les murs d'une construction, c'est l'environnement immédiat qui importe. Par exemple, pour un mur de façade sur un sol plan indéfini uniformément ensoleillé et dont la température superficielle est elle-même uniforme, la moitié du rayonnement reçu par le mur est émis ou diffusé par la bande de so s'étendant du pied du mur jusqu'à une distance de celui-ci égale à la moitié de sa hauteur.

* Le sol protégé du rayonnement solaire par la végétation et la végétation elle-même se comportent un peu comme un climatiseur adiabatique.

Là encore, il y a toujours intérêt à favoriser la végétation sous réserve qu'elle ne constitue pas un obsatcle à la ventilation.

Un rideau d'arbres assure une protection parfaite contre les rayonnements de toutes longueurs d'onde.

Inversement, le cas la plus défavorable est celui d'une cour bétonnée avec une clôture en béton.

II. L'INERTIE THERMIQUE CONSTRUCTIONS LÉGÈRES, CONSTRUCTIONS LOURDES

Les expressions «constructions légères», «constructions lourdes», bien que consacrées par l'usage, sont quelque peu ambiguës, d'autant plus qu'en zone tropicale humide, on appelle souvent construction lourde ce qui est considéré comme une construction légère en zone tropicale sèche.

Pratiquement, ces deux expressions ne peuvent être définies d'une façon plus précise qu'à partir de la notion d'inertie thermique, qui recouvre elle-même plusieurs phénomènes distincts.

Sauf indication contraire, nous supposerons dans ce qui suit que les conditions extérieures de température se reproduisent identiques à elles mêmes d'une journée à l'autre et que les conditions d'ensoleillement sont celles d'une journée de «très beau temps clair».

2.1. AMORTISSEMENT D'UNE ONDE DE CHALEUR

L'onde de chaleur extérieure est définie par les variations au cours des vingt-quatre heures de la température fictive au soleil. Pour simplifier, nous prendrons comme origine de l'échelle température, la température moyenne intérieure, laquelle est en général peu différente de la température moyenne météorologique du lieu.

Dans ces conditions, la température fictive au soleil à un instant donné est égale à la somme de deux termes:

(1) Un terme constant a, égal à la valeur moyenne sur vingt-quatre heures de la température fictive au soleil.

(2) Un terme périodique, positif ou négatif suivant les heures de la journée, dont l'amplitude b est très superieure à a.

En zone tropicale sèche, par exemple, compte tenu des variations diurnes de la température météorologique, les ordres de grandeur des valeurs de a et b sont les suivants pour différentes parois:

	a	b
Toiture à faible pente en amiante ciment	12°	50°
Toiture terrasse blanchie à la chaux	4°	30°
Mur blanchi à la chaux exposé à l'Ouest, en présence d'un sol gazonné	3°	25°

Dans ces conditions, le flux de chaleur entrant dans la construction comprend:

(1) Un terme constant égal à $K \times a$, K représentant le coefficient de transmission de la paroi.

(2) Un terme périodique d'amplitude $\mu \times b$, ou μ représente le coefficient d'amortissement de la paroi; μ dépend lui-même du coefficient de transmission K et de l'inertie thermique de la paroi.

Le fait que le rapport b/a soit de l'ordre de 4 à 10 montre l'importance de l'inertie thermique et explique que, sauf s'il s'agit d'une toiture (et, encore, dans certains cas seulement), un élément de construction ayant un coefficient de transmission relativement élevé peut, néanmoins, assurer une protection efficace contre la chaleur à condition qu'il présente un coefficient d'amortissement suffisamment faible.

D'une façon plus précise, le coefficient d'amortissement peut se définir comme suit:

Supposons que la paroi considérée P limite un local dont la température de l'air intérieur et les températures superficielles intérieures des autres parois sont maintenues constantes.

La température superficielle intérieure de la paroi P va subir des variations périodiques, soit b' leur amplitude

$$\mu \text{ (coefficient d'amortissement)} = \frac{b'}{b}\cdot$$

Toutefois, cette définition suppose que l'onde de chaleur extérieure est sinusoïdale. Mais il est toujours possible de se ramener à ce cas par une décomposition en série de Fourier.

Mackey et Wright (10) ont donné une formule approchée permettant de calculer le coefficient d'amortissement pour les cas les plus usuels (parois multicouches).

On notera en particulier que la valeur de coefficient d'amortissement est la même, soit 0,04 environ, pour les types de parois suivants, dont les coefficients de transmission sont pourtant très différents:

(a) 18 cm de laine de verre ($K = 0{,}2$);
(b) 5 cm de laine de verre sur dalle pleine de 10 cm en béton ($K = 0{,}75$);
(c) mur à vide d'air en agglomérés creux de béton de 10 cm d'épaisseur avec enduit sur chaque face ($K = 1{,}4$).
(d) mur en terre de 45 cm d'épaisseur ($K = 1{,}5$).

D'une façon générale, il est particulièrement avantageux d'associer la masse et l'isolation (cas (b) et (c)). Mais l'isolation a alors une fonction très différente de celle qu'elle a en hiver dans les pays tempérés. En outre, elle n'est efficace que si elle est placée au voisinage de la face externe. On peut également obtenir un amortissement important avec la masse seule, d'où la confusion fréquente entre masse et inertie thermique. Pratiquement, on peut dire que si la valeur de coefficient d'amortissement est suffisamment faible (de l'ordre de 0,04 ou moins), l'action du rayonnement solaire se trouve presqu'entièrement neutralisée.

2.2. RETARD DE TRANSMISSION D'UNE ONDE DE CHALEUR

Lorsqu'une onde de chaleur traverse une paroi, en même temps qu'elle s'amortit, elle subit un retard de transmission, c'est-à-dire que le maximum de température et, par conséquent, du flux de chaleur sur la face interne se trouve retardé par rapport au maximum de l'onde de chaleur extérieure. Dans les cas (b), (c), (d) envisagés

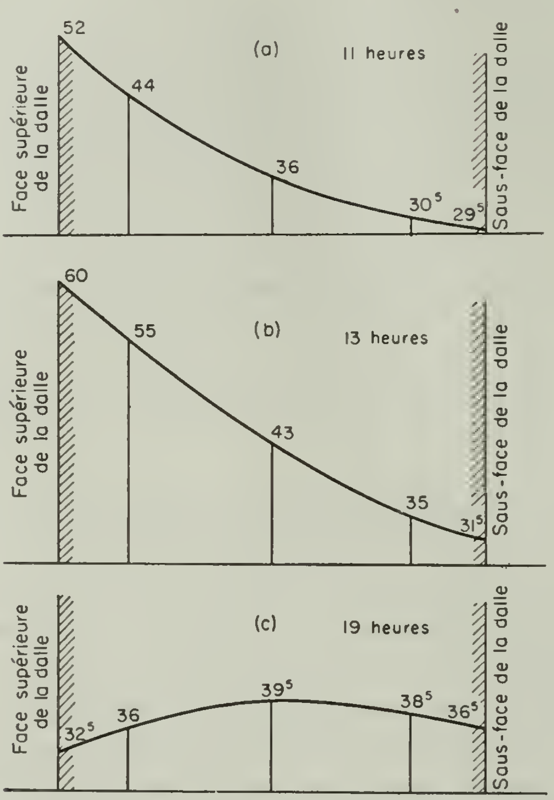


Fig. 9. Transmission d'une onde de chaleur dans une toiture terrasse. Dalle en hourdis creux de 19 cm. Distribution des températures dans la dalle à 11^h, 13^h, 19^h

ci-dessus, le retard de transmission est de l'ordre de douze heures. Dans le cas (a), par contre, il est négligeable, ce qui est caractéristique des parois entièrement légères, c'est-à-dire sans inertie thermique.

La notion de retard de transmission est surtout importante pour des parois dont le coefficient d'amortissement est de l'ordre de 0,20 ou plus. Tel est le cas, notamment, des murs en briques ou en agglomérés de 15 à 20 cm d'épaisseur couramment utilisés en zone tropicale humide. Le retard de transmission est alors de 6—8 hr, ce qui explique qu'une chambre dont le mur est exposé à l'Ouest et, par conséquent, reçoit le maximum de rayonnement solaire vers 16 hr, soit particulièrement inconfortable en début de nuit, ou d'une façon générale, que les constructions en maçonnerie de 15 à 20 cm d'épaisseur (murs ou toiture) soient inconfortables en fin de journée.

La formule de Mackey et Wright (10) permet de calculer le retard de transmission pour toutes les parois multicouches.

Fig. 9 et 10 illustrent les conditions de transmission de l'onde de chaleur exté-

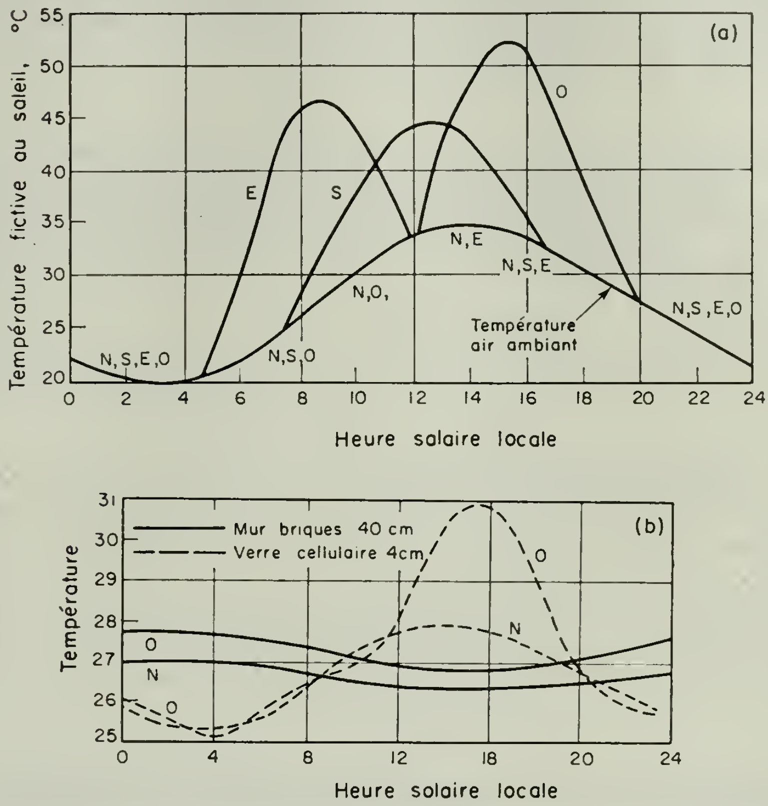


Fig. 10. Amortissement et retard de transmission d'une onde de chaleur à la traversée d'une paroi. Le diagramme (a) donne les températures fictives au soleil, le diagramme (b), les températures superficielles intérieures. Courbe en trait continu: mur ou briques de 40 cm d'épaisseur. Courbe en trait discontinu: mur en verres cellulaire de 4 cm d'épaisseur (d'après Mackey et Wright [10])

rieure à travers les parois d'une construction et mettent notamment en évidence l'amortissement et le retard de transmission.

2.3. ABSORPTION DE LA CHALEUR ENTRANT DANS LA CONSTRUCTION

Soit une construction en zone tropicale sèche pendant la saison sèche. Les ouvertures sont fermées aux heures chaudes de façon à amortir l'effet de maximum diurne de température. Quelle que soit la qualité de la construction, une certaine quantité de chaleur y pénètre. Pour que la température intérieure reste acceptable, il faut que cette chaleur puisse être absorbée par les différentes parois qui sont au contact de l'air intérieur. C'est là une autre aspect de la notion d'inertie thermique.

Tableau 3 donne en kilocalories par mètre carré l'ordre de grandeur du pouvoir absorbant de cloisons en maçonnerie lorsque la température à l'intérieur du local, supposé fermé, augmente régulièrement de 1° en 12 hr.* Le pouvoir absorbant d'une cloison en maçonnerie est pratiquement indépendant de l'épaisseur à partir du moment où celle-ci est égale ou supérieure à 20 cm environ. Le pouvoir absorbant d'une paroi en matériel léger isolant est négligeable.

Tableau 3. Quantités de Chaleur Pouvant Être Absorbées en 12 Heures par des Cloisons de Différents Types (d'après Dreyfus (2))

No.	Type de cloison	Flux absorbé en 12 hr	
		kcal/m²	Evalué en % de la valeur correspondant au type no. 1
1	Cloison en béton d'épaisseur indéfinite	25,8	100
2	Agglomérés pleins de 15 cm avec enduit de 2 cm sur chaque face	23,8	92
3	Cloison en terre de 22,5 cm	21,8	84
4	Cloison en terre de 17,5 cm	20,9	81
5	Agglomérés creux de 15 cm avec enduit de 2 cm sur chaque face	20,9	81
6	Briques creuses de 15 cm avec enduit de 2 cm sur chaque face	19,0	73
7	Briques creuses de 10 cm avec enduit de 2 cm sur chaque face	18,2	70

2.4. REFROIDISSEMENT DES PAROIS INTERIEURES AUX HEURES FRAICHES

C'est le phénomène inverse du précédent.

Aux heures fraîches, les murs ou cloisons restituent à l'air de la pièce la chaleur emmagasinée pendant la journée. Si le taux de renouvellement d'air est insuffisant, ce qui est fréquent à cause des faibles vitesses de vent la nuit, l'air intérieur demeure plus chaud que l'air extérieur. En outre, et quelles que soient les conditions de ventilation, les températures superficielles des parois du local restent supérieures à la température de l'air intérieur. Chacun de ces facteurs accroît l'inconfort. La nuit, l'inertie thermique des parois intérieures est donc toujours une cause d'inconfort.

Fig. 11 donne la répartition des températures à différents instants dans une cloison en agglomérés pleins de béton initialement à la température uniforme $\theta + 5°$, mise brusquement au contact d'air à la température $\theta°$. Après 8 hr, par exemple, la température superficielle de la cloison est supérieure de 1°, 8 à celle de l'air extérieur. Le flux de chaleur sortant de la cloisson est égal à:

$$1°, 8 \times h_i, \text{ soit } 13 \text{ kcal/m}^2/hr \text{ environ}$$

* Douze heures représentent l'intervalle de temps pendant lequel il y aura intérêt en zone tropicale sèche à maintenir fermé un local supposé bien adapté au climat.

D'une façon générale, il est commode de caractériser la vitesse de refroidissement d'un mur ou d'une cloison par le temps t nécessaire pour obtenir un refroidissement donné.

Supposons qu'à l'instant initial, une paroi à la température uniforme $\theta° + \Delta\theta°$ soit mise brusquement en présence d'air à la température $\theta°$, t représente l'inter-

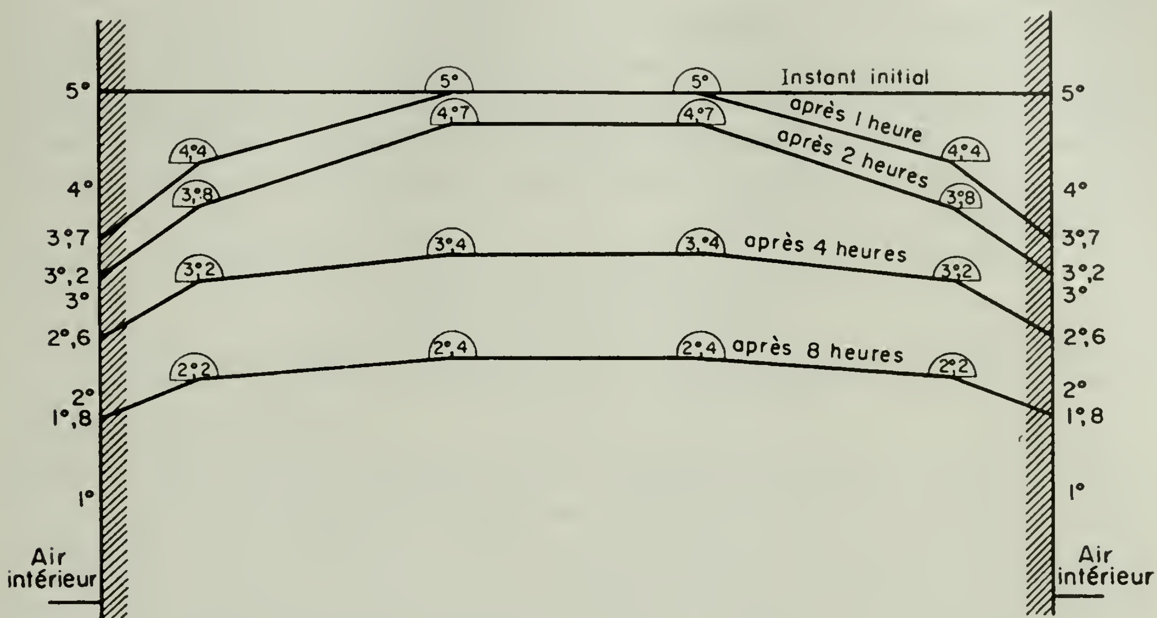


Fig. 11. Refroidissement d'une cloison initialement à température uniforme, mise brusquement au contact d'air plus froid de 5°. Cloison en agglomérés de béton de 15 cm d'épaisseur avec enduit de 2 cm sur chaque face. Les chiffres indiqués représentent les écarts de température entre la cloison et l'air (d'après Dreyfus [2])

valle de temps au bout duquel l'écart entre la température superficielle de la paroi et l'air ambiant est une fraction donnée f de θ (par exemple $f = 1/2$).

La vitesse de refroidissement dépend, dans une certaine mesure, de l'épaisseur de la paroi, mais, beaucoup plus du matériel constituant cette paroi ou, d'une façon plus précise, de la valeur du produit

$$\lambda \times p \times c$$

λ représente la conductivité thermique du matériel;

p, sa masse spécifique;

c, sa chaleur spécifique.

Pratiquement, la vitesse de refroidissement varie dans la proportion de 1 à 200 lorsqu'on passe des matériaux traditionnels de maçonnerie aux matériaux légers isolants, c'est-à-dire que si, pour une cloison en maçonnerie, l'intervalle de temps t

(correspondant à $f = \frac{1}{2}$) est égal à 4 hr, pour une cloison en panneau léger de fibre de bois, par exemple, on aura

$$t' = \frac{4 \text{ hr}}{200} = 72 \text{ sec.}$$

Le bois a des propriétés intermédiaires entre celles des matériaux ordinaires de maçonnerie.

Les matériaux légers isolants sont très favorables du point de vue du confort de nuit. On a vu, par contre, que leur pouvoir absorbant aux heures chaudes est négligeable. En zone tropicale sèche, il y a incompatibilité entre le confort de jour en saison sèche et le confort de nuit, ce qui n'est pas trop grave en définitive dans la mesure où l'on couche dehors, dès qu'il fait un peu chaud, de façon à pouvoir bénéficier du rayonnement nocturne.

2. 5. CONSÉQUENCES PRATIQUES

2. 51. *Cas de la Zone Tropicale Sèche ; ce que doit être la Construction Lourde*

Le problème important est celui des locaux de jour. On peut définir l'inertie thermique d'un local donné par la quantité A/B; A étant la quantité de chaleur entrant dans le local pendant le temps où celui-ci est fermé; B, la quantité de chaleur absorbée par les parois intérieures lorsque la température intérieure du local augmente de 1° pendant le même intervalle de temps.

A/B représente des degrés.* Une construction lourde est celle pour laquelle A/B a une valeur aussi faible que possible, de l'ordre de 3° au plus. On notera que A et, par conséquent, A/B augmentent avec la densité d'occupation, les occupants dégageant de la chaleur et ayant besoin d'un certain volume d'air frais qui apporte aussi des calories. Ceci revient à dire que les conditions techniques à réaliser sont plus sévères pour des locaux fortement occupés et qu'à la limite (classes) il n'est pas possible de maintenir au milieu de la journée des conditions intérieures de confort plus favorables que les conditions extérieures (d'où l'intérêt de la journée de travail continue).

La quantité A dépend du coefficient d'amortissement des parois extérieures, donc de leur inertie thermique, mais aussi de la qualité de la protection contre le rayonnement solaire.

La quantité B peut se calculer à partir du pouvoir absorbant par unité de surface des différentes parois du local. Elle dépend donc de la nature des parois, mais aussi de leur surface totale. On peut agir sur celle-ci par la disposition des cloisons intérieures et la forme des pièces. En augmentant la surface des parois, on augmente en même temps la quantité de chaleur qui pourra être éliminée par la ventilation aux

* Plusieurs auteurs ont proposé de définir l'inertie thermique par l'expression M/K où M représente la capacité calorifique de la construction, K le coefficient moyen de transmission des parois. Les deux définitions ne sont pas équivalentes.

heures fraîches. Les cloisons ou parois en matériaux légers sont à éviter. Une toiture avec plafonnage léger, notamment, est peu souhaitable, indépendamment du fait qu'il n'est guère possible pour des raisons d'économie de lui donner un coefficient d'amortissement suffisamment faible.

Les conditions à réaliser sont évidemment moins sévères pour les locaux de nuit.

Enfin, compte tenu des indications données plus haut, on voit qu'il est possible de réaliser des locaux pour lesquels la quantité A/B a une valeur très faible sans avoir à donner aux murs et cloisons une épaisseur considérable (pour les murs notamment, il suffit d'associer une isolation extérieure à un élément intérieur en maçonnerie). Ceci conduirait à dire que, contrairement à ce que l'on affirme quelquefois, la masse de la construction n'a aucun intérêt en soi. Cependant, une telle conclusion n'est exacte que dans la mesure où les conditions extérieures de température se reproduisent identiques à elles-mêmes d'une journée à l'autre, comme on l'a supposé en tête de cette étude. Dans le cas de pointes de chaleur exceptionnelles, de deux constructions ayant même A/B, où A est calculé à partir de la formule de Mackey et Wright et B à partir des valeurs données au Tableau 3 (ou d'une façon plus générale en utilisant la méthode exposée dans la réf. (2)), la plus lourde offrira plus de confort à ses occupants.

2.52. *Cas de la Zone Tropicale Humide ; ce que doit être la Construction Légère*

Le problème se pose surtout pour les locaux de nuit. Le premier facteur à considérer est la vitesse de refroidissement des parois limitant ces locaux, étant entendu que seules interviennent ici les températures superficielles. La construction légère idéale est celle dont toutes les parois sont constituées par des matériaux légers. A la limite, la case à «palabres» avec son toit en chaume ou en feuilles de palmier, simplement supporté par des piquets en bois, serait parfaite, si les autres fonctions d'un logement ou d'un bureau se trouvaient également satisfaites.

Dans la pratique, il est souvent difficile de réaliser une construction entièrement légère. Mais une chambre dont l'une des cloisons intérieures est traitée en placard, dont le plafonnage est en panneaux légers de fibres de bois et dont les cloisons ou murs parallèles aux façades principales sont traités avec de larges ouvertures de manière à faciliter la ventilation transversale, offre sensiblement un confort équivalent.

Une autre cause d'inconfort vient fréquemment des parois extérieures de 15 à 20 cm d'épaisseur en maçonnerie qui, pendant la journée, reçoivent le rayonnement solaire sur leur face externe et le soir restituent à l'intérieur de local la chaleur reçue. Mais il y a là un problème plus général et l'on peut dire que la protection solaire doit être d'autant plus soignée que la superficie des parois en maçonnerie capables d'absorber et d'emmagasiner la chaleur est plus grande.

Pour la protection des ouvertures, l'utilisation de brise-soleil, claustras ou dispositifs équivalents est devenue classique. Mais il semble que l'on ait souvent tendance à abuser des éléments verticaux en béton qui, la nuit, cèdent à l'air de ventilation la chaleur emmagasinée pendant la journée et «rayonnement» directement vers l'intérieur des locaux.

Pour la protection des parois pleines, en revanche, les écrans verticaux, fussent-ils en béton, devraient être plus largement utilisés qu'ils ne le sont actuellement. Associés à une paroi légère, ils constituent une solution fort satisfaisante.

Une autre solution, moins intéressante cependant, consiste à augmenter l'inertie thermique en réalisant des murs à vides d'air. Ce n'est donc pas la «masse» de la construction qui est mauvaise en soi.

BIBLIOGRAPHIE

1. R. Lemaire, Les bases physiologiques de la climatisation. *Bulletin des Forces Aériennes Françaises*, No. d'Août-Septembre (1958).
2. J. Dreyfus, *Le Confort dans l'Habitat en Pays Tropical*. Éditions Eyrolles, Paris (1960).
3. B. M. Evans, *Natural Air Flow around Buildings*. Texas Engineering Experiment Station, Research Report 59 (1957).
4. R. M. Reed, *Design for Natural Ventilation in Hot Humid Weather*. Building Research Advisory Board, Conference Report No. 5, Housing and Building in hot humid and hot dry climates, pp. 45—57, Washington (1953).
5. S. J. Richards et J. F. Van Straaten, Considérations sur la ventilation et les conditions thermiques dans l'étude des constructions adaptées au climat. *2ème Session de la Conférence Interafricaine sur le Logement et l'Urbanisation*, Nairobi, Janvier (1959).
6. O. Koenigsberger, J. S. Millar et J. Costopoulos, Window and ventilator openings in warm and humid climates. *Architectural Science Review* **2** (2), 82—96 (1959).
7. Commonwealth Experimental Building Station (Australia), *Attic Exhaust Fans for Summer cooling*. Notes on the Science of Buildings, S. B. 7.
8. J. K. Page, *Climate and Town Planning with Special Reference to Tropical and Subtropical Problems*. Overseas Building Notes, No. 52, Juin (1958).
9. F. S. Duckworth et J. S. Sandberg, The effect of cities upon horizontal and vertical temperature gradients, *Bull. Am. Met. Soc.* 35 (5), 198—207 (1954), d'après Page J. K., Overseas Building Notes No. 52 Juin (1958).
10. C. O. Mackey et L. T. Wright, Summer Comfort as influenced by the thermal properties of building materials. *Transactions of the American Society of Heating, Air Conditioning and Ventilating Engineers* **43** (1943).

THE EFFECT OF ROOF CONSTRUCTION UPON INDOOR TEMPERATURES

B. GIVONI

Research Engineer, in charge of indoor climate research, Building Research Station, Institute of Technology, Haifa, Israel

Abstract—The paper summarizes several investigations of the thermal effect of roof types and various roof treatments which have been carried out in Israel.

Comparison has been made between flat concrete and pitched tiled roofs. The effect of colour and insulation of flat concrete roof and of colour and natural ventilation of pitched tiled roof is discussed.

It was found that for summer conditions, an uninsulated whitewashed flat concrete roof is the most suitable. Adding insulation to the whitewashed roof did not change appreciably the maximum temperature but resulted in higher night temperatures. Colour has very pronounced effect on maximum temperature, both in flat concrete and in pitched tiled roofs. Attic ventilation of tiled roofs has negligible effect.

Résumé—Le present article décrit quelques recherches sur les effets thermiques des différents toitures executées en Israel.

On a comparé le comportement different des toits plats en béton armé et ceux inclinés, couverts de tuiles. Successivement sont discutés les effets de la couleur et de l'isolation thermique sur les deux sortes des toits, ainsi que l'influence de la ventilation naturelle sur le toit incliné, couvert de tuiles.

On a trouvé que le toit plat, blanchie à la choux presente la meilleure solution pour les chaleurs d'été. L'isolation thermique sur ce type de toit n'a pas donnée des effets considerables, mais par contre augmentait la température nocturne des locaux. L'effet de la couleur est d'une grande importance dans les deux types de toits décrits.

La ventilation naturelle à l'aide des larges ouvertures dans la mansarde sous toit incliné, peut être negligée.

Auszug—Der Artikel bringt die Ergebnisse von mehreren Untersuchungen der thermischen Wirkung von Dacharten und verschiedenen Dachbehandlungen, die in Israel ausgeführt wurden.

Es wurde ein Vergleich gezogen zwischen flachen Betondächern und steilen Ziegeldächern. Der Einfluss von Farbe und Isolation eines flachen Betondaches sowie von Farbe and natürlicher Ventilation eines steilen Ziegeldaches wurde diskutiert.

Es wurde festgestellt dass für Sommerbedingungen ein nicht isoliertes, weissgewaschenes flaches Betondach das geeignetste ist. Hinzufügen von Isolation zu einem weissgewaschenem Dache änderte die maximale Temperaturen nicht wesentlich, führte aber zu höheren Nachttemperaturen. Die Farbe hat eine sehr ausgesprochene Wirkung auf die Maximaltemperaturen, sowohl bei flachen Beton- als auch bei steilen Ziegeldächern. Ventilation des Dachraumes unter Ziegeldächern hat einen unwesentlichen Einfluss.

The roof is one of the most important building components, from the point of view of indoor climate, and therefore is one of the main subjects of research in building climatology.

Two of the most common types of roofs in Israel are the flat reinforced concrete roof, usually whitewashed, and the pitched tiled roof, usually covered with red or grey cement tiles. The choice between these two types depends upon various factors: functional, architectural and economical. Consideration of the problem of the desired roof type is restricted in this paper to the climatological point of view and summer conditions only. In several investigations these two main roof types were compared and various methods for improvements were examined. Some of these studies are summarized below.

EFFECT OF INSULATING A FLAT CONCRETE ROOF

In 1955, the effect upon ceiling temperatures of insulating a flat concrete roof was studied by Neumann *et al.* (1). They compared the ceiling temperature of a reinforced concrete roof 8 cm thick, which was divided by beams into twenty equal bays, each being 2.4 m (8 ft) wide in both directions. The windows in the hall underneath the roof were open.

Table 1. Temperatures on the Underside of the Roof

Means of thermal protection	The Temperature in °C at the hour							Difference $t_{max} - t_{min}$
	6.00	8.00	10.00	12.00	14.00	16.00	18.00	
Not protected	21.4	23.4	27.7	30.3	29.7	28.8	27.8	8.9
"Ytong" blocks 20 cm high 2½ cm apart	22.7	23.5	24.6	25.9	26.0	25.9	25.6	3.3
"Ytong" blocks 20 cm high closely arranged	23.3	23.4	24.8	25.9	25.9	25.9	25.5	2.6
Burnt-clay hollow blocks 2 cm apart	22.9	23.6	25.0	26.3	26.3	26.0	25.8	3.4
Burnt-clay hollow blocks 2 cm apart, whitewashed	23.0	23.6	24.5	25.8	25.9	25.8	25.7	2.9
Hollow concrete blocks 20 cm high, 2½ cm apart	23.2	23.9	25.1	26.1	26.3	26.0	26.1	3.1
Layer of sea-shells, 6 cm thick	23.1	23.6	24.7	26.1	26.1	26.1	26.2	3.1
Layer of sea-shells, 12 cm thick	23.1	23.6	24.2	25.5	25.7	25.7	25.6	2.6
Covering of wooden boards, white-washed	23.1	23.5	24.8	25.9	26.2	26.3	26.1	3.2
Sand lime bricks 2 cm apart	23.0	23.4	25.4	26.7	26.4	26.5	26.1	3.7
Layer of vermiculite—concrete, 10 cm thick	23.5	24.0	24.8	25.9	25.7	25.8	25.7	2.4
Sand—lime bricks, closely arranged	23.3	23.7	24.2	25.8	25.8	26.1	26.1	2.8
Whitewash	21.9	22.6	23.8	25.7	26.1	26.1	25.8	4.2

Several methods were tested as a means for protecting the roof against excessive heating:

(a) Reflection of solar radiation by whitewashing.

(b) Increasing the thermal resistance by means of layers of insulating materials such as sea shells, vermiculite—concrete, burnt clay blocks, etc.

(c) Shading by means of wood boards placed at a distance of 2½ cm. (lin.) above the roof surface.

(d) Combination of the various methods.

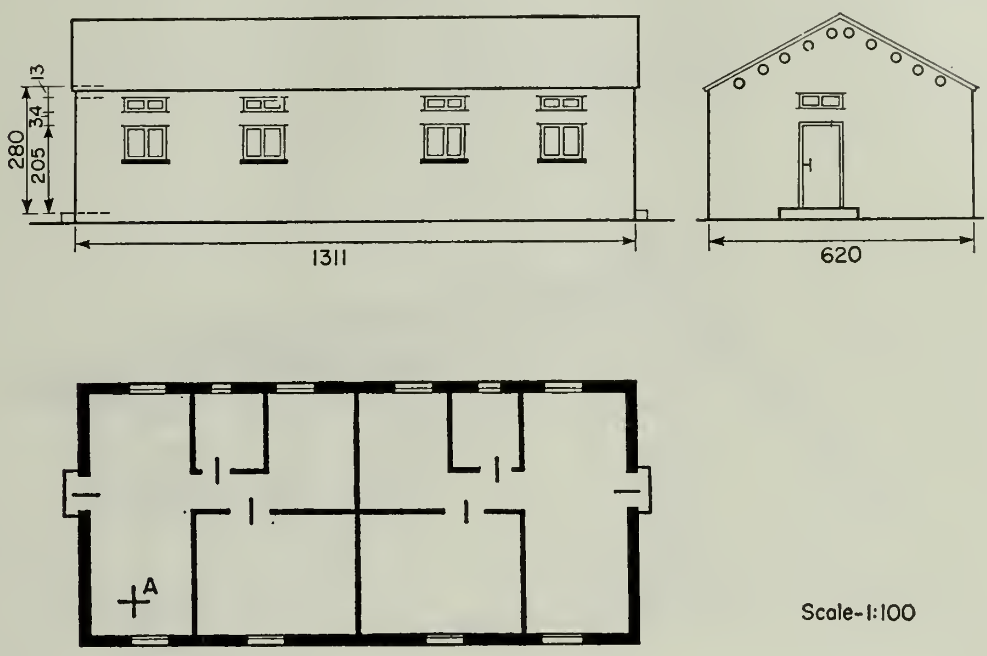


Fig. 1. Ground plan of the house. Elevations of pitched roof houses

The temperatures of the underside of the roof were measured in the middle of the various bays by means of thermocouples.

Table 1 summarizes the different methods of protection and the test results. Each figure constitutes the mean of 5 days' measurements.

The conclusions from this study were that all the different methods of protection showed very similar effect upon maximum ceiling temperature, reducing it by about 5 °C in comparison with the unprotected section. As regards the minimum temperature, the whitewashing proved to be more efficient, permitting the ceiling to cool down as much as the unprotected section, whereas all the insulating layers caused a reduction in the cooling rate at night and consequently a higher minimum.

From the comparison of the results of whitewashing the red burnt blocks and the effect of whitewashing the un-insulated roof, it appears that the effect of colour decreases appreciably as the thermal resistance of the roof increases. The whitewashing of the protected roof reduced the maximum temperature by as little as 1°C, compared with the reduction of 5°C in the case of the unprotected roof.

The effect of the insulation layer is not proportional to its thickness but decreases progressively as extra insulation is added. This can be seen in the case of the seashell layers. While the 6 cm layer reduced the maximum temperature by 5°C, a layer of 12 cm reduced the ceiling temperature by 6°C, so that doubling the thickness of the insulation produced only one fifth of the effect of the first layer.

A comparison of flat reinforced concrete roofs and pitched tiled roofs in full scale building has been made in two regions: in 1956 in the coastal region near Haifa (2) and in 1957 inland at Beer-Sheba (3).

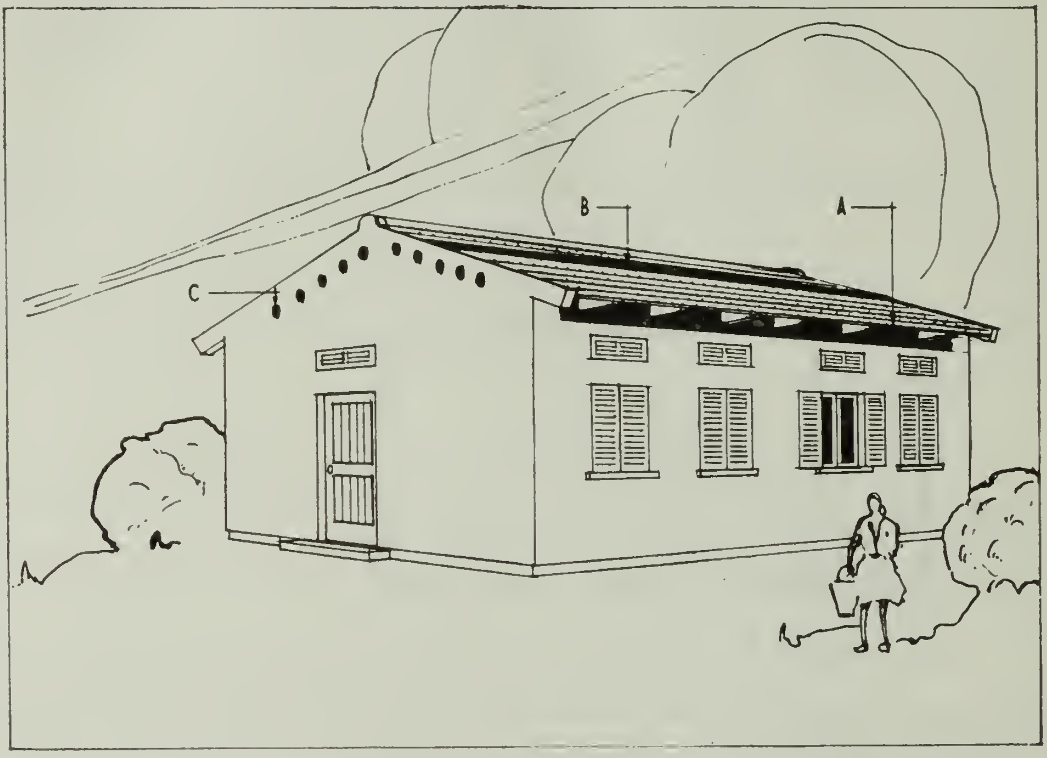


Fig. 2. Perspective picture of pitched roof house, showing ventilation arrangements

In the Beer-Sheba study the effect of colour on both types and the effect of ample natural ventilation of the pitched roof attic were also investigated. In this paper only the results of the Beer-Sheba study will be summarised.

This investigation was carried out with nine one-storey semi-detached houses. The ground plan was identical and is shown in Fig. 1. Four of the houses had pitched roofs, covered with red cement tiles and plastered expanded-metal mesh ceilings. Five houses had reinforced concrete roofs, 10 cm thick. The elevations of the pitched roof houses are shown in Fig. 1 and a perspective view is shown in Fig. 2.

COMPARISON BETWEEN PITCHED ROOF OF RED TILES AND WHITEWASHED FLAT CONCRETE ROOFS

The comparison of these two types has been made when the tiles of the pitched roofs were in their original red colour and the flat concrete roofs were whitewashed.

The windows and shutters during the test period (13 days) were closed at daytime (from 6 a. m. to 6 p. m.) and open at night. The average daily temperatures of the ceiling (point 1), the air layer 10 cm underneath the ceiling (point 2) and the air 1.20 m above the floor (point 3) are shown in Fig. 3.

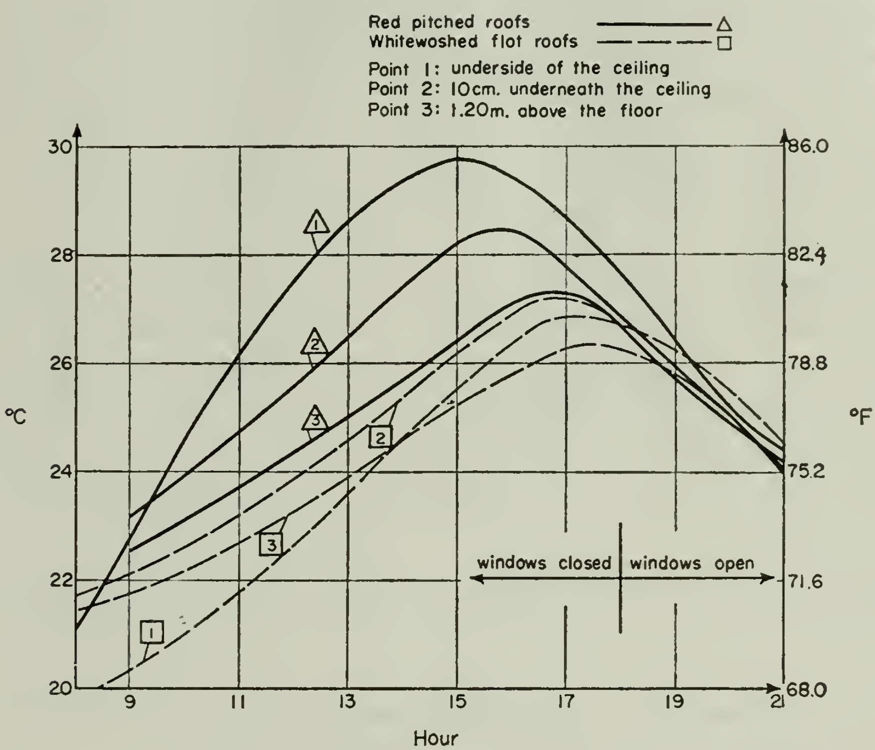


Fig. 3. Comparison between whitewashed reinforced concrete flat roofs

The ceiling temperature (point 1) of the red pitched roof was higher than that of the whitewashed flat roof between 7 a. m. and 10 p. m. The average difference was approximately 4°C, and the maximum difference about 6°C (during 3 hr). The maximum temperature of the ceiling was 3° higher. In the afternoon the pitched roof cooled faster and at 10 p. m. temperature became equal.

During the night the ceiling of the pitched roof was somewhat cooler than that of the flat roof.

At the air layer underneath the ceiling (point 2) the difference was smaller, about 2°C, and at the air 1.20 m above the floor (point 3) the difference was about 1°C. Comparison of the temperature at the different points, and examination of the thermal gradient between them show that the ceiling temperature of the pitched roof was higher almost all day than that of the air 10 cm below it. It means that the heat flow was from the ceiling towards the room, whereas in the case of the whitewashed flat roof the ceiling temperature was lower than that of the air underneath it till 6 p. m. and the heat flow was from the room to the roof.

This phenomenon can be explained by the reasoning that the room air is heated during day-time mainly through the windows (even when closed and protected by shutters), because of the low thermal resistance of the glass areas (relative to the walls or roof) to heat flow from the outside air to the inside air. In this way the temperature of the air rises faster than that of the ceiling of a whitewashed concrete roof which does not absorb much heat and has a relatively high thermal capacity.

The ceiling of the pitched tiled roof on the other hand, is heated faster, for the reason that the small thickness of the plaster ceiling presents little resistance to the heat flow from its upper side which is heated mainly by radiation from the tiles. In addition, a given quantity of absorbed heat will raise the ceiling of the pitched roof temperature to a higher degree, due to its small heat capacity.

It can be seen from Fig. 3 that the thermal gradient from point (2) to point (3) was positive all the time, meaning that the air in the upper part of the room space was higher than that in the height of 1.20 m above the floor. But while the average difference in houses with whitewashed flat roofs was about ½°, and the maximum difference about 1°, approximately, the average difference in the temperatures of these points in houses covered with pitched roofs of red tiles was about 1° and the maximum difference about 2°. In both types of houses the thermal gradient almost disappeared when the windows were opened at 6 p. m., and the resulting air flow.

In the houses with whitewashed flat roofs the ceiling temperature was lower than the air temperature at the height of 1.20 m till 2 p. m. approximately. It means that the higher temperature of the upper air layer was caused only by the stratification of the air into layers of different temperatures. On the other hand, in houses covered with red tiles the ceiling temperature was appreciably higher than the air temperature, and resulted in an additional heating of the upper air layer, doubling the thermal gradient between the layers of different height.

EFFECT OF ROOF WHITEWASHING UPON CEILING TEMPERATURE (FIG. 4.)

Ceiling temperatures of flat concrete roofs in their natural grey colour were compared with the same type roof, but whitewashed. Likewise, a comparison was made between red-tiled pitched roofs and the same roof whitewashed. The windows and shutters were closed during day-time, from 6 a. m. to 6 p. m., and open during the evenings and nights.

CEILING TEMPERATURES OF FLAT CONCRETE ROOF

The ceiling temperature of the grey roof was higher than that of the whitewashed roof, during day and night.

It means that the extra heat which had been accumulated in the grey roof during the day had not been dissipated entirely during the night, in spite of the fact that the windows had been kept open at night.

The smallest difference occurred in the morning, when it was about 0.75°C, and then increased during the day and reached its maximum value at 3 p. m. approximately, when the ceiling temperature of the grey roofs was about 6°C above that of the whitewashed roofs. After that time the difference became smaller (meaning

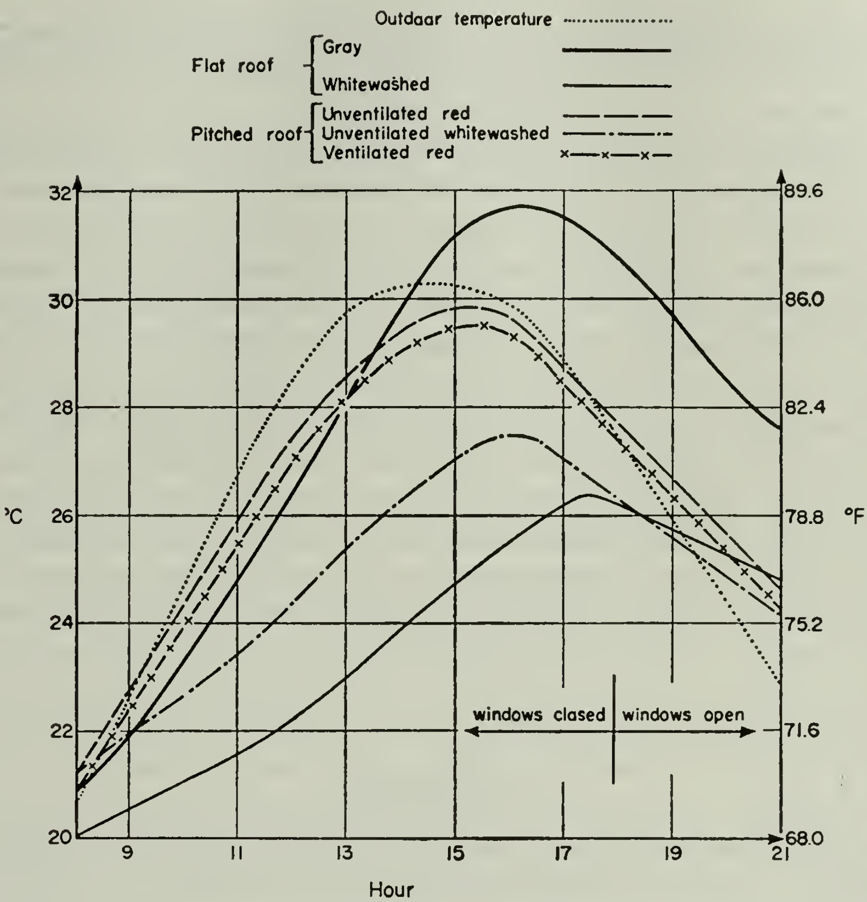


Fig. 4. Ceiling temperatures of various roof types

hat the rate of cooling of the grey roof was higher) and at 9 p. m. the difference was about 2.5°C.

CEILING TEMPERATURES OF TILED PITCHED ROOFS

The ceiling temperature of the whitewashed and the red pitched roofs were equal during the night till 8 a. m. Then the ceiling of the red roof became warmer, the difference reached its maximum value of 3.5°C at 1 p. m. and then diminished gradually till it disappeared at 10 p. m.

EFFECT OF ATTIC VENTILATION OF PITCHED RED TILED ROOFS UPON CEILING TEMPERATURE (FIG. 4.)

Ordinary roof tiles made of cement or burnt clay, are usually dark-coloured and absorb most of the incident solar radiation and are heated up to a temperature much higher than that of the air. Part of the absorbed heat is given off by convection to the ambient air, another part is re-radiated into space, and the rest is transferred through the tiles and elevates the temperature of the lower side of the tiles. Since the tiles are thin, and made of a material that has relatively high thermal conductivity, the temperature of the underside of the tiles will usually rise appreciably above air temperature. The heat is transferred by convection and radiation from the tiles to the ceiling, and elevates its temperature. When the space between the tiles and the ceiling is ventilated, another factor enters into the picture, namely ambient air temperature. The introduction of ventilation will reduce the temperature of the underside of the tiles and also the heat flow from the roof to the ceiling. At the same time the higher air flow, in places and roof types where air temperature rises more rapidly than the temperature of the upper side of the ceiling of an unventilated roof, may heat the ceiling at a rate which increases with air temperature and velocity. A condition may be reached when the additional heating at the ceiling by the outside air flow will equal or exceed the reduction in the heat flow from the tiles.

It can be assumed that if the roof covering is thinner, darker and has a higher thermal conductivity — the ventilation of the attic will be more effective in preventing excessive heating of the ceiling. But if the roof cover is thick, light coloured and has low conductivity — the beneficial effect of ventilation will decrease and may even become negative.

The ventilation of the roof (see Fig. 2) was achieved by leaving an opening of 17 cm height, above the two long walls of the house between the tiles and the ceiling (A), and also an opening of 7 cm height below the upper row of tiles (B). In addition there were ten round openings of 15 cm diameter in both gables (C). These ventilation openings resulted in ample air flow through the attic so that its effect upon the temperatures at various points in the attic and of the ceiling could be detected even if it was small. In order to eliminate the effect of variability among similar houses the "treatments" of the roofs were reversed every 3 days, for a total of about 18 days.

A comparison of the temperature patterns of various points in the attic of unventilated roofs and the outside air in the Beer-Sheba region, shows that the attic air temperature is elevated only slightly above air temperature (about 1—2°C) and the temperature of the upper side of the ceiling is approximately the same as that of the air, and only in the evening does it rise above outside air temperature by 1—1.5°C. This small difference explains the results of the attic ventilation upon ceiling temperature which is illustrated in Fig. 4.

The temperature on the underside of the tiles was lowered by about 1—2°C by the attic ventilation. The temperature of the attic air was lowered by about 1°C and the surface temperatures above and underneath the ceiling were lowered by about 0.5°C. Taking into account that these results were achieved with ventilation rates which exceeds appreciably ordinary natural ventilation rates, the conclusion must be reached that the improvement of the thermal conditions which could be expected from the ventilation of pitched roofs covered with cement tiles is negligible.

A COMPARISON OF THE RESULTS WITH THOSE OF AN INVESTIGATION MADE IN SOUTH AFRICA

In South Africa the problem of attic ventilation of pitched roofs covered with corrugated galvanized steel sheets was studied (4). The ceiling has been constructed of asbestos cement ceiling boards. Attic ventilation, both natural and mechanical, reduced the ceiling temperature by as much as 3°C. The difference of the results between these two investigations can illuminate the interdependence between the material of the pitched roofs and the effect of attic ventilation. The attic temperature in the South African study rose appreciably above outside air temperature, because of the excessive heating of the steel sheets and the good sealing between the sheets of the roof. On the other hand, the attic temperature of the roof covered with cement tiles as in the present study, exceeds very little the temperature of the outside air, because of the higher thermal capacity of the tiles and the air flow through the cracks between the tiles, even in the absence of special ventilation openings. The difference between the results of these two investigations shows that as the roof structure is thinner, its thermal capacity smaller and its sealing better, the cooling effect of attic ventilation will become more pronounced.

REFERENCES

1. M. Neumann, N. Peleg and Robinson, *Experiments on Thermal Protection of Concrete Roofs*. Report No. 4, Station for Technical Climatology (Now B. R. S.), Technion, Haifa, Israel (1955).
2. R. Shalon, A. Alweyl, L. Landsberg, A. Mansfeld, H. Neumann, R. C. Reinitz and B. Givoni, *A Study of the Influence of Ceiling Height in Dwelling Houses*. Research Paper No. 6, Building Research Station, Technion, Haifa, Israel. (1957).
3. R. Shalon, B. Givoni and S. Preger, *Indoor Climate Research in Beer-Sheba*. Research Paper, Building Research Station. Technion, Haifa, Israel, In press.
4. J. F. Van Straaten, A. J. A. Roux and S. J. Richards, *The Effects of Attic Ventilation on the Indoor Thermal and Ventilation Conditions in Dwellings of Conventional Construction*. Bulletin No. 15, National Building Research Institute, Pretoria, Jan. (1957).

BIOCLIMATIC EVALUATION METHOD FOR ARCHITECTURAL APPLICATION

VICTOR OLGYAY
Associate Professor, School of Architecture, Princeton University, U.S.A.

Abstract—The importance of translating climatic data on a unified base is discussed. The outline of the comfort zone, relation of winds with high temperatures, air movement on vapor pressure, effect of evaporative cooling, and radiation effect on low temperatures is described. From those climatic variables a Bioclimatic Chart is constructed. There the comfort zone lies in the middle and from its perimeter in scale of their magnitude are indicated the climatic elements which are needed to revive the comfort feeling at other temperatures.

By plotting on the bioclimatic chart temperature and relative humidity data at regular intervals one can get a graphical climatic "diagnosis of the region". From it one can read the needed climatic elements for any time of the year. Their relative importance gives a measure for their use.

The usefulness of the method is illustrated by describing its application to architectural principles, such as shading, orientation and use of materials.

Résumé—L'importance de la reproduction des données climatologiques sur une base unifiée est discutée. Le tracé de la zone de confort, la relation des vents avec les températures élevées, l'influence du vent sur la tension de vapeur, l'effet du refroidissement par évaporation et l'effet de rayonnement sur les basses températures sont étudiés. D'après ces variables climatiques une carte bioclimatique a été tracée. Sur cette carte la zone de confort se situe au centre et à partir de son périmètre, à l'échelle de leur grandeur, sont indiqués les éléments climatiques permettant de remonter à la sensation de confort à d'autres températures.

En portant sur la carte bioclimatique les données de la température et de l'humidité relative à des intervalles réguliers, on peut obtenir graphiquement au point de vue climatique un «diagnostic de la région». Cette carte donne les éléments climatiques demandés pour n'importe quelle période de l'année. Leur importance relative indique une limite pour leur mode d'emploi. L'utilité de la méthode est illustrée par la description de son application aux principes architecturaux, tel que l'ombrage, l'orientation et l'utilisation des matériaux.

Auszug—Die Notwendigkeit klimatische Factoren auf eine einheitliche Grundlage zu übertragen wird diskutiert. Der Umfang der Komfortzone, der Einfluss des Windes auf die oberen Temperaturen, der Einfluss der Luftbewegung auf den Dampfdruck und Wirkung der Verdunstungskühlung und der Strahlung auf die unteren Temperaturen wird beschrieben. Mit diesen Faktoren wird eine bioklimatische Karte konstruiert. In deren Mitte liegt die Komfortzone und der Abstand vom Umfang dieser Zone zeigt masstäblich jene klimatischen Elemente die erforderlich sind das Komfortgefühl bei anderen Temperaturen wiederherzustellen.

Durch das Eintragen von Temperatur- und relative Luftfeuchtigkeitsmessungen in die bioklimatische Karte kann eine repräsentative Klima-Diagnose der Zone erhalten werden von welcher die erforderlichen klimatischen Elemente für jegliche Jahreszeit abgelesen werden können.

Die Nützlichkeit der Methode wird erläutert an architektonischen Grundbeispielen für Sonnenschutz, Orientierung und materialgerechten Baustoffeinsatz.

Climate control for architectural purposes is an involved problem. It is intricate because its solution does not lie in one specific territory; but it lies between several fields of knowledge. Therefore it requires the co-ordination of diverse respective disciplines.

With accumulated data, practical knowledge and experience one can deduct applicable considerations for certain building elements. However, such empirical knowledge generally has its limitations. Namely, first the results usually tend to investigate only one single climatic factor of the several involved. Second, the conclusions can be adapted in full only to the territory and specific time which was under investigation.

There seems to be a definite need for a methodical and universally applicable method where through bioclimatic consideration climate analyses can be evaluated. Such an approach will be discussed here. The outlined evaluation method is applicable to any climatic situation. And as it indicates the needs of the climatic variables throughout the year, it supplies a convenient index for architectural applications.

Let us start the investigation with the role of man in this problem, and how man constitutes the physiological measure in architecture.

APPROACH TO THE CLIMATIC COMFORT ZONE

The climatical environment has four main variables with which to operate: the air temperature, radiation, air movement and humidity. They act on the human body in interrelated action.

At first, the air temperature and the radiant temperature have a complementary relationship. To maintain comfort in high temperatures, a low radiant temperature is required. Conversely, at low air temperatures, radiant temperature has to be kept high to be comfortable.

Secondly, the temperature (the average air and radiant temperature) is interlocked with the humidity. As the air warms up, the relative humidity falls. This gives us leeway to use evaporation as a cooling effect. Temperatures combined with high absolute humidities cause a depressed feeling (vapor pressure) because the body has no way to perspire. On account of that, the comfort zone in this relationship at low temperatures remains at one level while, at high temperatures, it tends to be smaller near the high relative humidities. This effect can be counteracted up to a certain degree with air movements.

Thirdly, the air movement has a relationship with both temperature and humidity. High temperatures can be compensated up to a certain range to revive the comfort feeling. At low temperatures, we feel the wind effect more intensely. At very high temperatures, the air movement becomes insufficient to compensate for the heat. And at high humidities and high air temperature combinations, there is a point where the wind can bring us an even more undesirable heat effect.

Since evaporation is aided by air movement, it is desirable at high humidities as previously stated. As velocity increases, the comfort level is raised with diminishing rate towards high temperatures.

From these relationships a conclusion can be drawn. As the temperature rises, we can counteract it (within certain limits) with increased air movement, with lowered radiant temperature, and with added moisture effects. The low temperature can be balanced by reduced air movement or by high radiant temperature. On this basis, we shall try to construct a chart. The comfort zone should be in the middle of the observation. Starting from the perimeter of this zone, we should measure the influences of the climatic elements.

We naturally can not expect to solve uncomfortable conditions by natural means only. As we shall see, the environmental elements aiding us have their limits. Over those boundaries we should apply mechanical tools. But it is expected that the architect should build the shelter in such a way as to bring out the best of the natural possibilities.

ATMOSPHERIC COMFORT ZONE

Some writers consider sunstroke and heatstroke as the upper limit line for man and the freezing point as a lower limit. As the ideal climate should be between those contours, it might be assumed that the ideal is about midway between those two extremes, between 32°F and 100°F which would mean 66°F. But the problem is more complex than this.

It seems that if the human being with a body temperature of roughly 98.6°F wants to find a comfortable condition, he picks by intuition a circumstance which is about half-way between what he can tolerate in cold sense without being grossly uncomfortable, and the point which would require real effort on the part of his circulatory and sweat secretion system in order to permit him to adapt to heat (1).

Investigations in this field led to experiments to define comfort conditions. The British Department of Scientific and Industrial Research headed by Dr. H. M. Vernon and Dr. T. Bedford came to certain conclusions. Vernon states that the ideal temperature with slight air movement (i. e. 50 ft/min., or less) is 66.1°F in summer and 62.1°F in winter and a comfort zone which ranges from 55.8° F to 73.7°F (2). The comfort zone standards vary according to climatical zones because of age, race, type of clothing, and nature of activity carried on.

Brooks shows (3) in a figure that the British comfort zones lie from around 58°F to 69°F, that in the U.S.A. from 69°F to 80°F, and in the tropics, the range is from around 74°F to 85°F, between the 30 per cent and 70 per cent relative humidity lines.

In the U.S. itself, there is a difference, according to locations, sexes and ages. There were field studies conducted in the summer season with persons engaged in customary office activity (4). The result showed that between New York and San Antonio men residents, the difference of comfort need was over 2°F. There is also a variation between summer and winter comfort ranges.

The American physiologic observations tended to find a combination of temperature, humidity and air movement inducing the same feeling of warmth. This scale of thermoequivalent conditions not only indicates the sensations of warmth, but also to a considerable degree determines the physiological effects on the body inducted by heat or cold. This scale which combines the above factors into a single index is called effective temperature scale (E. T.). It was developed by Houghten, Yaglou, Miller and Lincoln at the Research Laboratory of the American Society of Heating and Ventilating Engineers with the co-operation of the U.S. Bureau of Mines in Pittsburgh, Pennsylvania (4).

From the above observations, the comfort lies between the 30 per cent to 70 per cent relative humidity contours (5).

Investigators	Effective temperature		
	Optimum line	Range	
Houghten and Yaglou	66	63—71	Winter non basal; at rest normally clothed. Men and women.
Yaglou and Drinker	71	66—75	Summer non-basal; at rest normally clothed. Men.

The above zones were outlined in the previous ASHVE guides. Later, they were removed because practical experience showed that they extended to temperatures where too large a percentage of the people would be uncomfortable, as revealed in later studies.

The Australian Commonwealth Experimental Building Station has performed physiological experiments (6). It appeared that in their climatic conditions, the dry-bulb temperature provided better correlation with the onset of general perspiration.

Many laboratory and field workers have found that the E. T. index overestimates the influence of humidity on sensations of warmth and comfort at ordinary temperatures, and underestimates the effect in very high temperatures which approach the limit of human tolerance to heat (7).

Yaglou (8) offered a method for improving the Effective Temperature index on the basis of mean skin temperatures, which is used to outline the comfort zone in the following charts.

The charts were built up with dry-bulb temperature as the ordinate and relative humidity as the abscissa, with the thought in mind that those are the most known and available climatical data for architects. The comfort zone would be valid for American moderate-zone inhabitants.

The range lies between the 30 per cent to 65 per cent relative humidity lines as the desirable comfort zone. For general purposes, we can enlarge the comfort territories to include both lower and higher humidity percentages as practical comfort zones.

RELATION OF WINDS AND HIGH TEMPERATURES

Air movement affects body cooling. It does not decrease the temperature, but only affects body sensation, due to heat loss by convection and due to increased evaporation from body. As air velocity increases, the upper comfort limit is raised. The

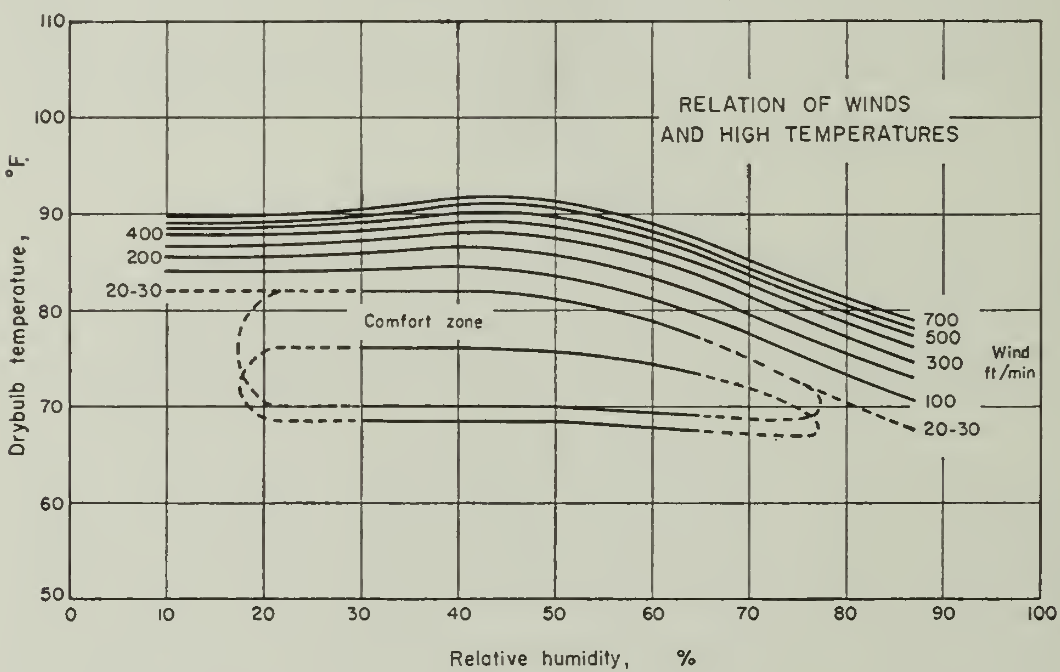


Fig. 1

effect decreases towards high temperatures. In calculating the extended comfort zone, the ASHVE effective Temperature Normal Scale was used. (Applicable to persons at rest and dressed in customary indoor clothing.) (Fig. 1.). The calculations show the effects from still air (20—30 ft/min) to 700 ft/min effect, considering that the effect should bring back the sensation to the outer limit of the comfort zone.

At this point it is necessary to describe the non-thermal effect of air velocity (10):

Velocity (ft/min)	Probable impact on persons
Up to 50	Unnoticed
50 to 100	Pleasant
100 to 200	Generally pleasant but causing a constant awareness of air movement
200 to 300	From slight drafty to annoyingly drafty
Above 300	Requires corrective measures if work and health are to be kept in high efficiency

EFFECT OF AIR MOVEMENT ON VAPOR PRESSURE

Atmospheric air contains a variable quantity of water vapor. The pressure exerted by vapor is called vapor pressure. If this surpasses the 15 mm Hg mark, a depressed feeling can be noticed.

Siple (11) states that for over 15 mm vapor pressure, each additional millimeter of pressure can be counteracted with 1 mile/hr wind effect (88 ft/min).

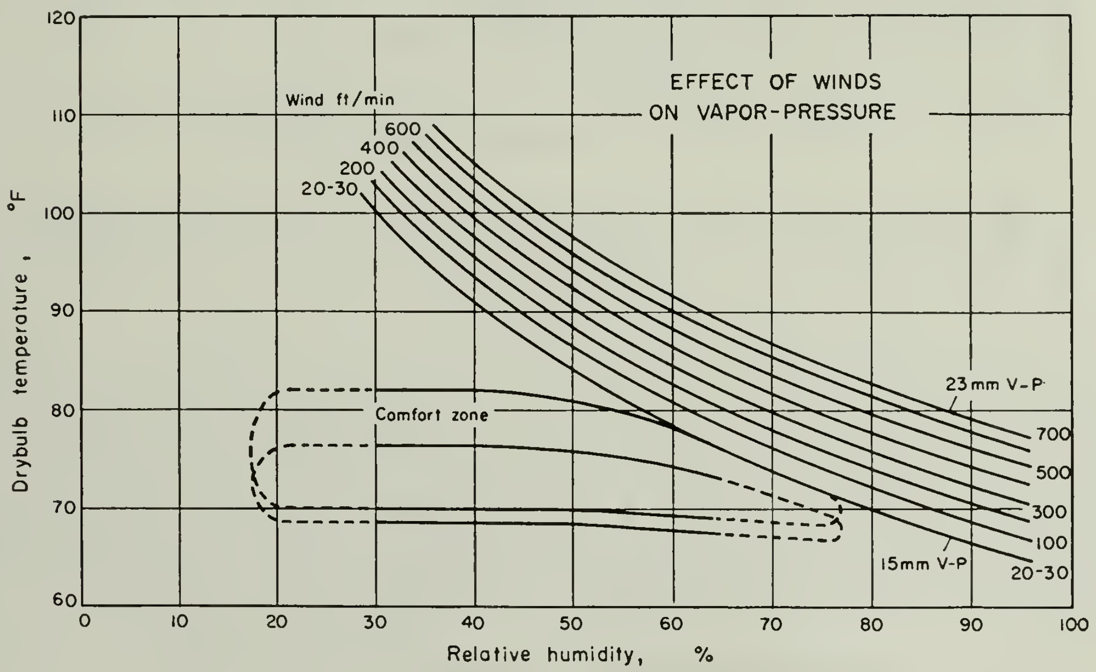


Fig. 2

The John B. Pierce Foundation (Yale) has developed more detailed calculations on this effect, but Dr. Herrington considers the above approximation as applicable in practice. On that basis, the chart was developed (Fig. 2.). It shows the range from 15 mm to 23 mm vapor pressure, counteracted with wind velocities from still air (20—30 ft/min) up to 700 ft/min air movements.

EFFECTS OF EVAPORATIVE COOLING ON HIGH TEMPERATURES

Evaporation decreases the dry-bulb temperature. The calculations were based on the assumption that the increased humidity fully absorbs the heat energy of the air.

The Carrier psychrometric chart was used (barometric pressure 29.92 in. mercury, vapor pressures are those of water), to determine the amount of grains of moisture per pound of dry air in obtaining lower temperatures (Fig. 3.).

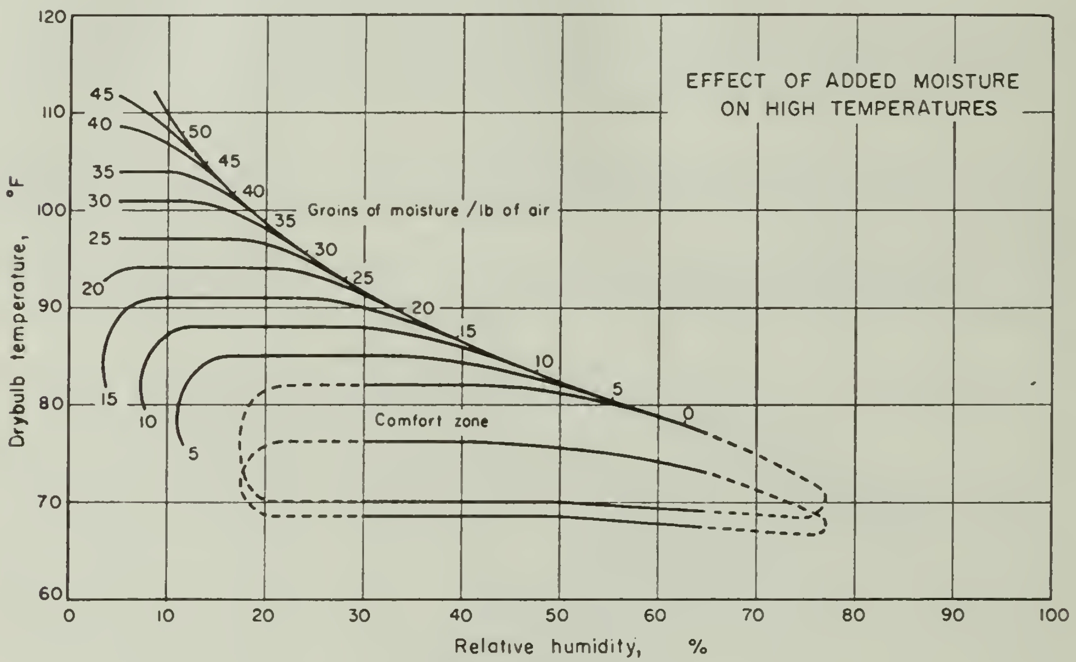


Fig. 3

The curves are calibrated in 5 grains of moisture/lb intervals, considering that the temperature decreased should be lowered to the outer limit of the comfort zone. This effect has importance in dry hot climatic zones, where the wind effect in lowering high temperatures is of little help. The effect can be achieved by mechanical means and also to a certain degree by architectural means. That is, with trees, vegetation, pools or sprinklers, the evaporative cooling effect can be utilized.

THE RADIATION EFFECT ON DRY-BULB TEMPERATURES

At the fringe of the comfort zone, the assumption was made that the air and the walls of the shelter are approximately at the same temperature. Higher or lower air temperatures can be balanced up to a certain degree by mean radiant temperatures.

At lower temperatures (under 70°F), every Fahrenheit degree drop in air temperature can be counteracted by elevating the mean radiant temperature with $\frac{8}{10}$ °F, (after Bedford and Yaglou) (12). This counteraction has its limits. In practice, we shall not find more than 4° or 5°F difference between air and wall temperatures. Over that the dry-bulb temperature will rise.

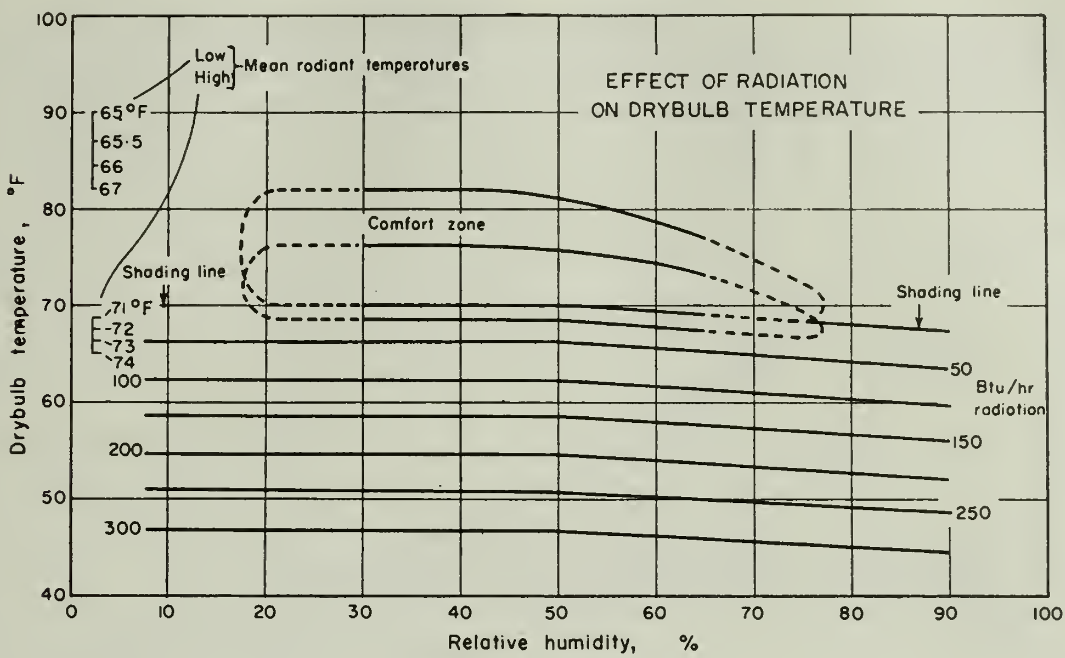


Fig. 4

At high temperatures, Dr. Yaglou did experiments on radiant cooling. The mean radiant values in the chart have been evaluated after his studies. In the light of these studies, it became apparent that great air—wall temperature differences are impractical, particularly when the humidities are high. Wall cooling is also impractical in rooms occupied by many persons, owing to the possible interception of the body radiation to the cold walls.

The lower lines of radiation, expressed on the chart in B. t. u.'s refer to outside conditions. This was considered with reference to the human "solair" temperature. That means that we can be comfortable at low temperatures if the heat loss of the body can be counteracted with the sun's radiation effect.

To determine the outside effect of the sun's radiation, the following equation was used after Yaglou's formula:

$$\text{heat loss by } R + C = S \times S_c \frac{(t_s - t_a)}{Clo/c + V.Clo/c}$$

$$\text{heat loss by } E = Ec$$

The result of the equation is that at lower temperatures, 50 B.t.u. of sun radiation can counteract 3.85°F drop in dry-bulb temperatures. This formula gives us a measure for the needs of radiation although it is a relative index depending on the exposure and the possible absorption of the radiant energy (Fig. 4).

THE BIOCLIMATIC CHART

The previous discussion is a study of the effects of single climatic elements. We can superimpose the results in a combined graph on the basis of those considerations. We then obtain a chart on which the comfort zone lies in the middle, and from its perimeter, the effects of the climatic elements are indicated in scale of

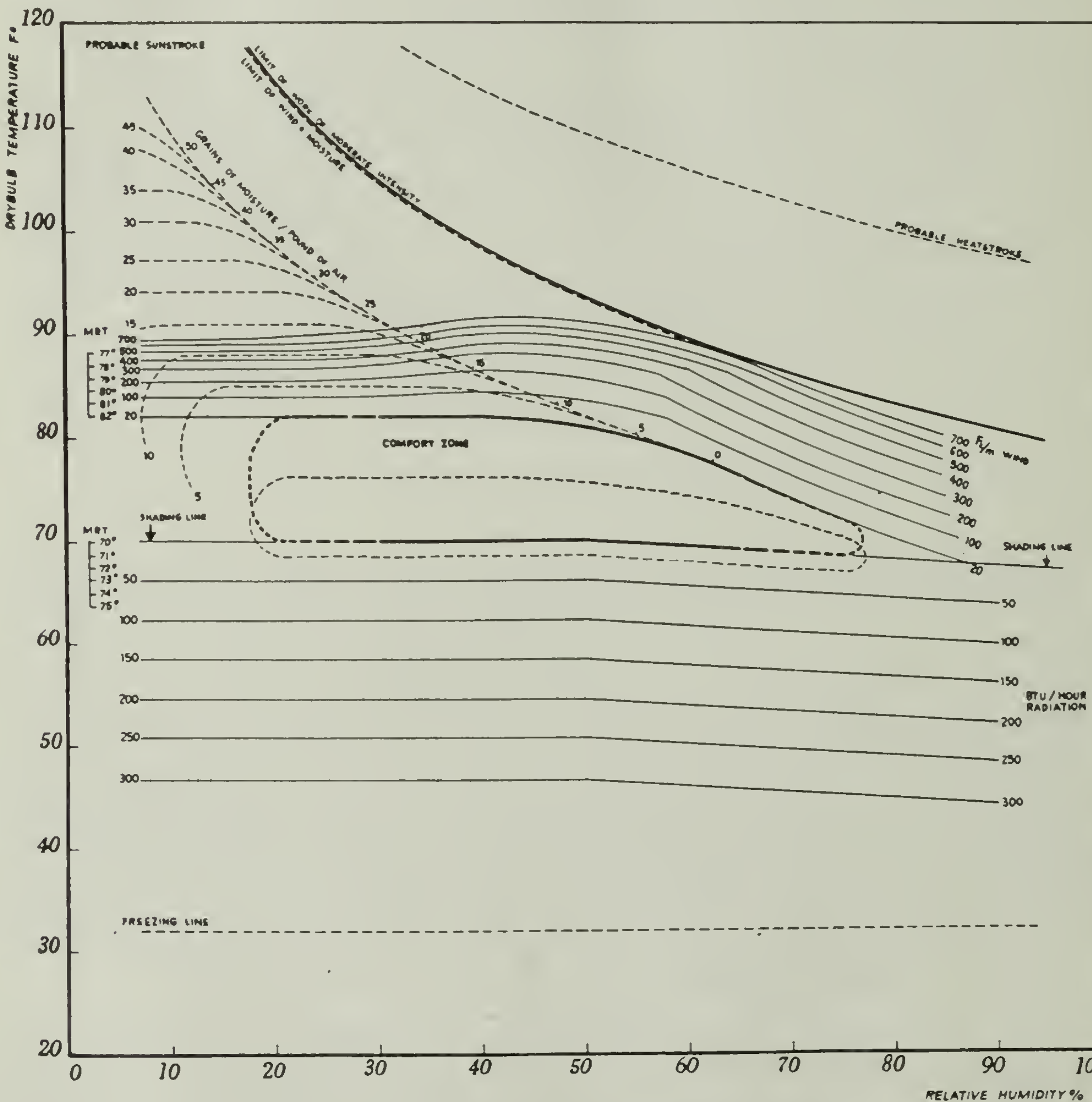


FIG. 5. Bioclimatic chart for U.S. moderate zone inhabitants

their amounts needed to receive the comfort feeling at other temperatures. The chart is applicable to inhabitants of the moderate climatic zone in the United States with customary indoor clothing and doing sedentary or light work, not in excess of 1000 ft above sea level (Fig. 5).

Explanation of the Chart

The chart was built up with dry-bulb temperature as the ordinate and relative humidity as the abscissa. In the middle, we can see the summer comfort zone lightly divided into the desirable and practicable ranges. A little lower, the winter comfort zone is indicated.

At higher temperatures, the wind effects can bring back the feeling of comfort. This is charted with nearly parallel lines following the upper limit of the comfort perimeter. The numbers indicate in feet per minute the wind velocities needed. The wind effect counteracts the high temperatures. At humidities over the 60 per cent relative humidity line, the vapor pressure is counteracted by the winds. This change of role in the winds can be observed at the light breaking points in the wind-lines.

At low humidities, the effects of winds are of little help. We can gain only around 8°F reduction in feeling at comparatively strong air movements. Here evaporative cooling is the tool with which to fight high temperatures. This effect is charted on the graph with dotted lines, showing the needed grains of moisture per pound air which brings down the temperature to the upper comfort perimeter. The higher dotted line shows the limit of the combined effect of winds and evaporative cooling. At high temperatures, there are curves indicating the limit of work of moderate intensity and showing the probability of heatstroke as the danger zone.

At the lower perimeter of the comfort zone is the line from which shading is needed towards higher temperatures, and conversely, radiation is necessary to counteract the cold feeling towards lower dry-bulb temperatures. For outside conditions, there is a tabulation expressed in B.t.u.'s which are needed by "solair" action to bring back the sensation of comfort. At the left-hand side are charted the mean radiant temperature values which can bring comfort feeling in a short range both up and down the comfort zone.

CLIMATE ANALYSES AND EVALUATION OF NEEDS

Plotting of temperature and relative humidity data on the bioclimatic chart a regular intervals will show general characteristics of the region. This can be plotted with data for average conditions, maximums, or minimums according to the purpose. This will show a graphical "diagnosis of the region" with the relative importance of the various elements, as for example, need of radiation, winds, etc.

The number of points falling into various categories divided by the total registered data will give the relative importance of the categories. The chart shows aver age hourly data at 10-day intervals throughout the year, each point representing 10 hr (the example shown is in New York—New Jersey region at average conditions) (Fig. 6.). The results of the above process can be tabulated on a yearly time table. The various needs will show in time areas, registering when we need:

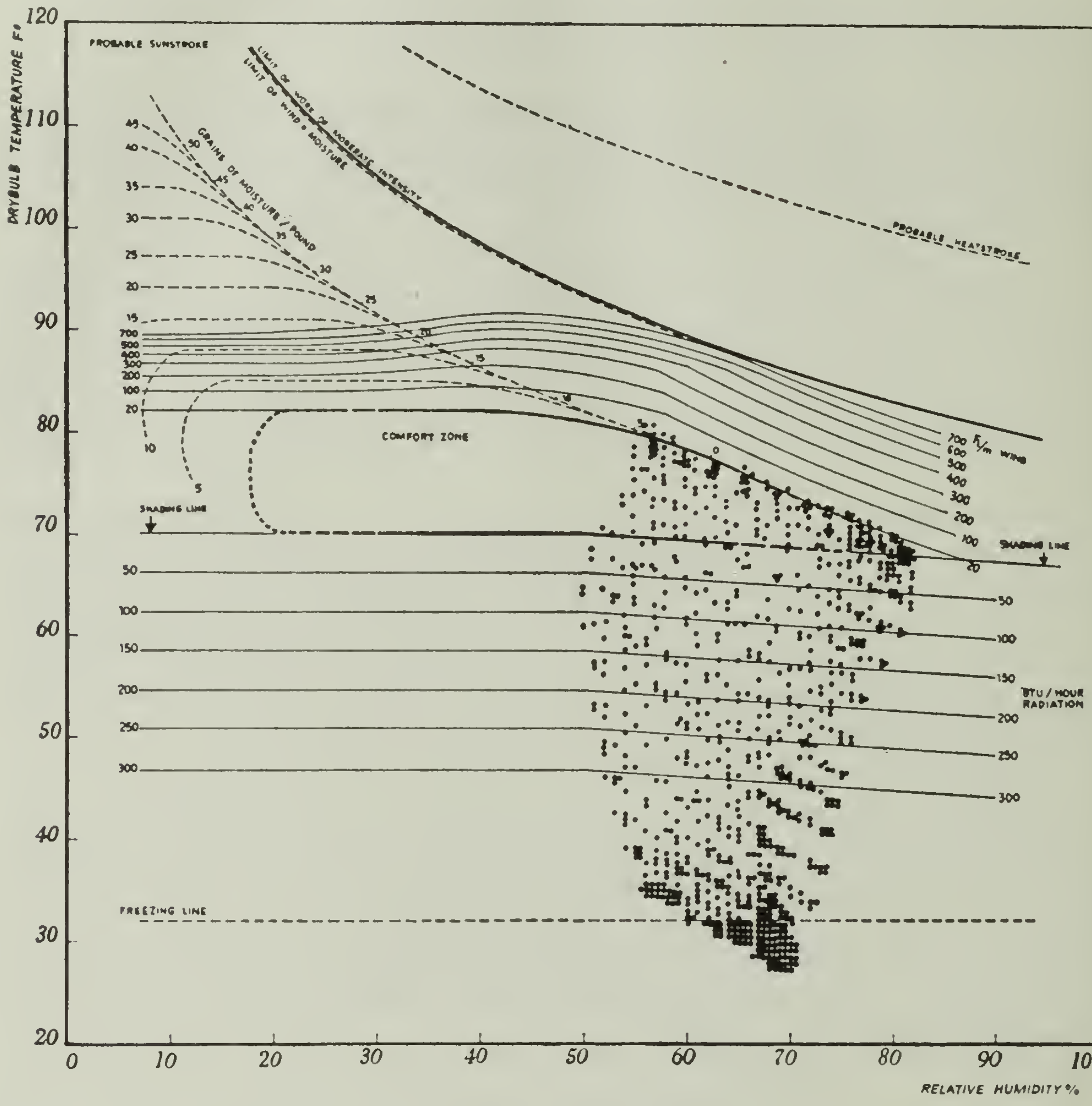


FIG. 6. Climate analysis in New York—New Jersey Area. Times indicated: hourly average data in 10-day intervals in a year. Each point (864) represents 10 hr

(a) *Radiation*. This time-area is called the underheated period. The needs are charted in B.t.u./hr intensities. The obtained radiation isopaths show needs which are relative because we cannot obtain intensities over 300 B. t. u./hr, partly because of the limitations of the sun's radiation and partly because of limitations of the absorbtivity, both of the human being and of shelters. We can, however, say that the higher the B. t. u. need, the more important it is to supply higher radiation intensities. This can be a guide for orientation, distribution of openings, choice of materials, etc.

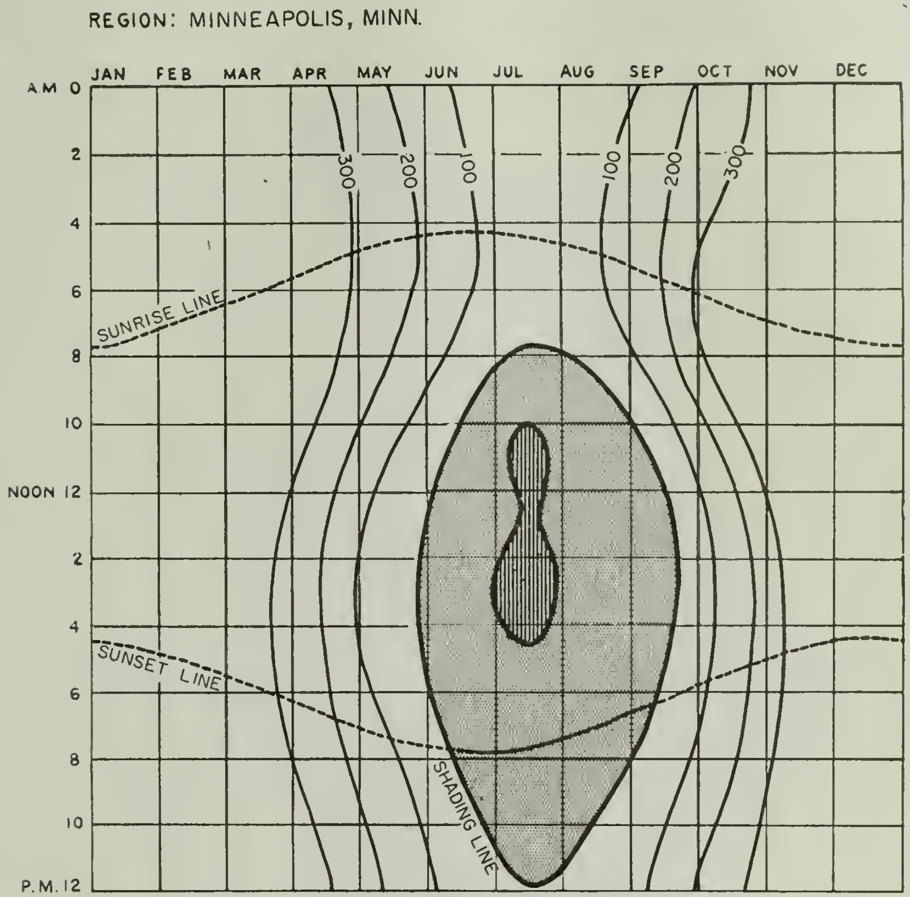


FIG. 7. Yearly evaluation of climatic needs in Minneapolis, Minn.

(b) *Shading.* This time-area is called the overheated period. To determine this, the outside dry-bulb temperature and relative humidity data can be used between certain limits.
(c) *Winds.* Their needed velocities can be expressed in feet per minute. These can be expressed in feet per minute. These can be plotted for average conditions, which show their relative importance or for design conditions when plotted with near maximum temperature data.

As a demonstration of the method, four typical regions may be compared. In these examples the radiation needs are shown in lines with B. t. u. intensities indicated. The shading period is shown as a dotted area. The vertical-lined area expresses the period when both shading and winds are needed to preserve the feeling of comfort. In some of the charts there is an area indicated within a dotted line showing that during those periods we would need air velocities over 300 ft/min. Here, since too high velocities would cause annoying results, other remedies should be applied

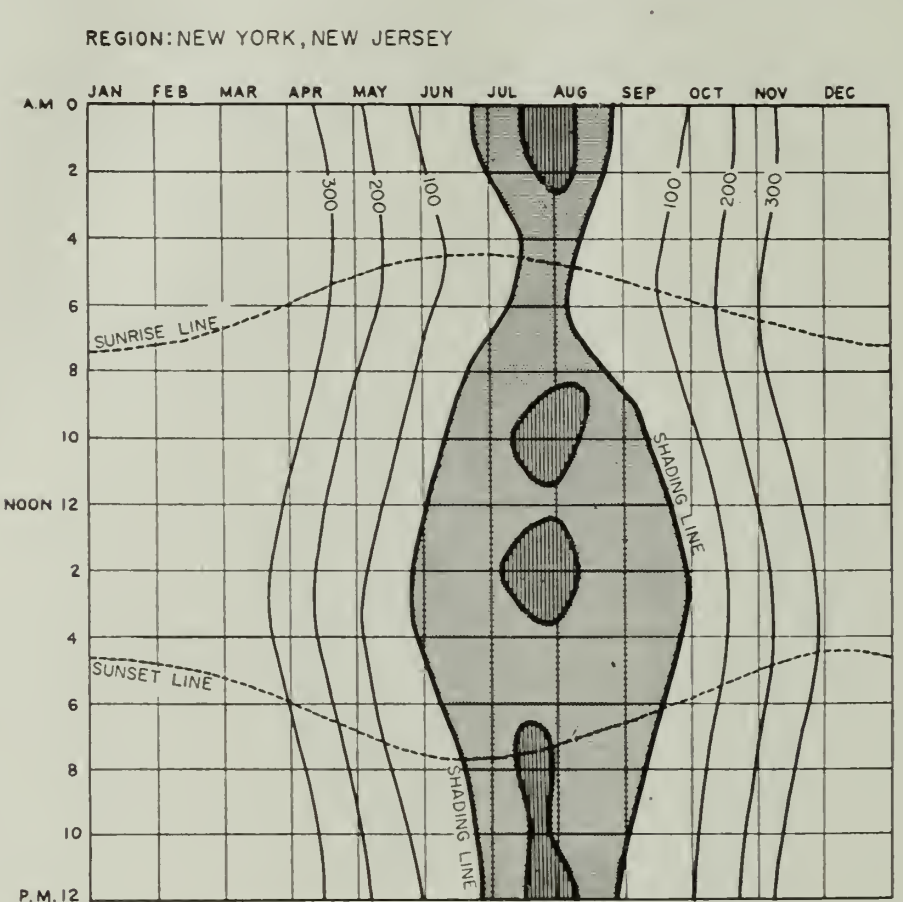


Fig. 8. Yearly evaluation of climatic needs in New York area

such as evaporative cooling, balance with the heat capacity of materials, etc. The charts show the evaluation of a cool area (Minneapolis, Minn.), a temperate region (New York—New Jersey), a hot-humid area (Miami, Fla.) and a hot-arid area (Phoenix, Arizona), where for any day-time hour of any day throughout the year, the needs can be read off which bring the physical sensations into the comfort range under average climatic conditions (Figs. 7, 8, 9 and 10). We should mention here again that for certain purposes (as for example calculating air movements to determine needed sizes of openings) the charting of near maximum temperatures will give the necessary answer: as in other cases the charting of ambient temperatures will be needed.

BIOCLIMATIC APPROACH TO ARCHITECTURE

The previous yearly evaluation charts can now be translated to solve architectural principles. Here are outlined some of the engineering problems and their method of approach.

Shading calculations can be based on the maxim that throughout the year in "underheated" times the sun should strike the building and in "overheated"

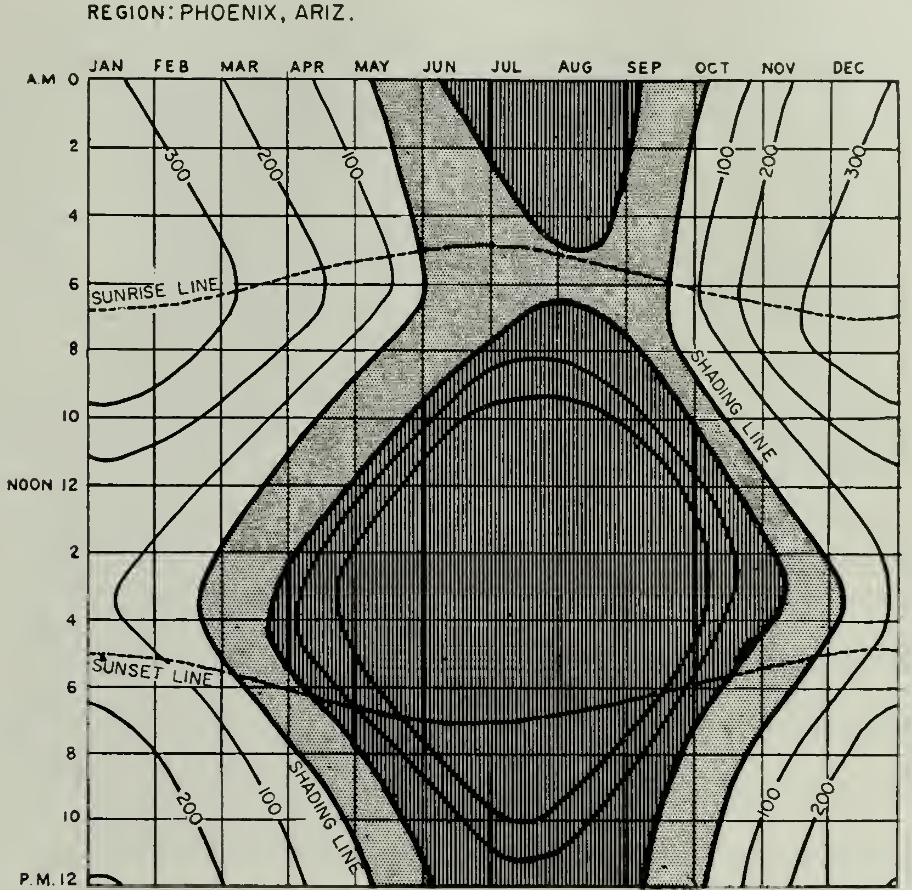


Fig. 9. Yearly evaluation of climatic needs in Phoenix, Arizona

times the structure should be in shade. Geometric considerations and B. t. u. calculations can describe the effectiveness of shading devices.

The orientation of the sun's heat is important both positively (in cold periods) and negatively (in hot periods). This segregation according to the "underheated period" (when we seek radiation) and to the "overheated period" (when we want to avoid it), is the guide to the balanced orientation.

Air movements can be divided into two categories: winds and breezes. Superimposing the overheated period diagram on the wind chart one can evaluate the desirable breezes occurring in the "overheated period" and the undesirable winds prevailing in the "underheated" period. The indoor air movements should satisfy the bioclimatical needs, based on ambient temperature conditions. Calculations can be based on the rate of air-flow through the buildings on the rate of air-flow through the buildings in combination with the inside flow patterns. This method can be a guide for location, arrangement and sizes of openings.

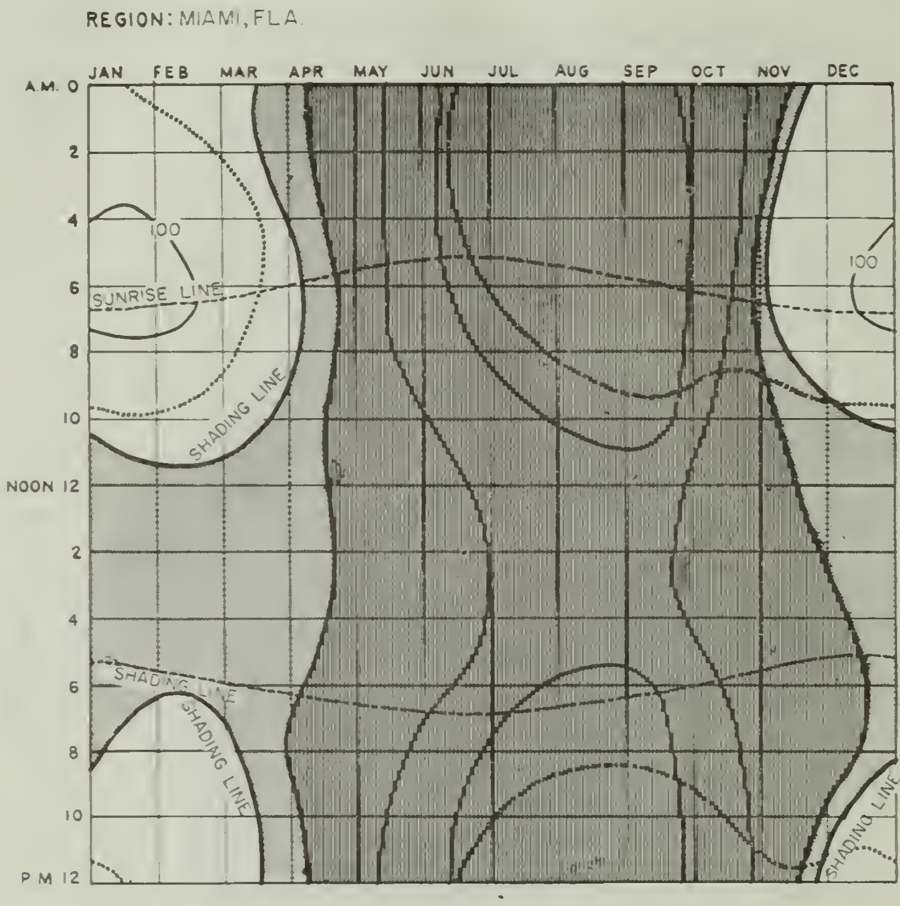


FIG. 10. Yearly evaluation of climatic needs in Miami, Florida

Temperature balance can be achieved to a certain degree with materials. The time lag and temperature amplitude decrease characteristic of materials can be utilized for improved indoor conditions. With the reversed heat flow method, structures can be designed which have a desirable heat balance according to climatic conditions.

With such methodology one can systematically approach the architect's task concerning climatic conditions: to create an environment in which man by devoting his energies to his creative aims shall cultivate a more healthy and more wholesome life.

REFERENCES

1. L. P. Herrington, Human factors in planning for climate control. In Building Research Advisory Board, *Weather and the Building Industry ; A Research Correlation Conference on Climatological Research and Its Impact on Building Design, Construction, Materials and Equipment,* January 11 and 12, 1950. Washington, D.C., pp. 85—91. Research Conference Report No. 1.
2. T. Bedford, Environmental warmth and human comfort. *Brit. J. App. Phys.* Feb. 33—8 (1950).
3. C. E. P. Brooks, *Climate in Everyday Life.* Ernest Benn, London (1950).
4. *Heating Ventilating Air Conditioning Guide, 1951,* 29th ed. pp. 117—316. American Society of Heating and Ventilating Engineers, New York (1951).
4. F. C. Houghton and C. P. Yaglou, *Cooling effect on human beings produced by various air velocities. American Society of Heating and Ventilating Engineers, Transactions,* **30,** p. 193 (1924). ASHVE Research Report No. 691. F. C. Houghton and C. P. Yaglou, Determination of the comfort zone. *American Society of Heating and Ventilating Engineers, Transactions* **29,** p. 361 (1923). ASHVE Research Report No. 673. C. P. Yaglou and W. E. Miller, Effective temperature with clothing. *American Society of Heating and Ventilating Engineers, Transactions* **31,** p. 89 (1925). ASHVE Research Report No. 717.
5. *Heating Ventilating Air Conditioning Guide, 1951,* 29th ed. pp. 117—316. American Society of Heating and Ventilating Engineers, New York (1951).
6. J. W. Drysdale, *Climate and House Design ; Physiological Considerations.* Commonwealth Experimental Building Station, Sidney, Australia (1948). (Duplicated Document No. 25.) J. W. Drysdale, *Climate and Design of Buildings ; Physiological Study No. 2.* Commonwealth Experimental Building Station, Sidney Australia (1950). (Duplicated Document No. 32.)
7. C. P. Yaglou, Method for improving the effective temperature index. Heating piping and air conditioning. *ASHVE Journal Section* p. 131, Sept (1947). Rowley, Jordan and Snyder, Comfort reactions of workers. Heating piping and air conditioning. *ASHVE Journal Section* p. 113, June (1947).
8. C. P. Yaglou, Method for improving the effective temperature index. *ASHVE Journal Section* p. 131, sept. (1947).
9. *Heating Ventilating Air Conditioning Guide, 1951.* 29 th ed., pp. 117—316. American Society of Heating and Ventilating Engineers, New York (1951).
10. R. H. Emerick, Comfort factors, affecting cooling design. *Progressive Architecture* p. 97—99. December (1951).
11. Climatologist and Military Geographer, General Staff, Department of the Army.
12. C. P. Yaglou, Radiant cooling-investigated in tests of Harvard and discussed at New York Meeting by Dr. Yaglou. *Heating and Ventilating,* 102, 104, May (1947).

DIRECT SOLAR RADIATION ON AND INSIDE BUILDINGS

N. ROBINSON and **M. PELEG**

Professor. N. Robinson and M. Peleg (civil engineer), Solar Physics Lab., Inst. of Technology, Haifa, Israel

Abstract—In order to estimate the heat balance of a building, the quantity of heat reaching the building through insolation should be known. The calculation of this quantity involves some difficulties; one of them is to find the combined influence of the position of the sun in the sky and of the orientation of the building.

For, while the position of the sun can be found for every day and hour from astronomical tables, the orientation of buildings may vary indefinitely. The method described in this paper enables the calculation of the amount of solar radiation on buildings of different shape, whatever their orientation may be.

By the use of the "insoloscope" the actual state of insolation on a building-model of any shape and orientation may be reproduced for any day and hour of the year as well as the penetration of the radiation through the openings.

Thus the most desirable position of a building to be erected may be decided in advance from the point of view of insolation falling on its walls and roof and penetrating into the building through the openings.

Résumé—Afin d'évaluer le bilan calorifique d'un bâtiment, il faudrait déterminer la quantité de chaleur reçue par le bâtiment et due à l'insolation. Le calcul de cette quantité présente quelques difficultés; une de ces difficultés réside dans l'influence associée de la position du soleil dans le ciel et l'orientation du bâtiment.

Or tandis que la position du soleil figure pour chaque jour et chaque heure dans les tables astronomiques, l'orientation du bâtiment peut varier indéfiniment. La méthode présentée dans cette étude permet le calcul de la quantité de rayonnement solaire sur des bâtiments de configuration différente, quelle que soit leur orientation.

En utilisant un «insoloscope», l'état actuel de l'insolation sur un modèle de bâtiment, de n'importe quelle forme et orientation, peut être reproduit pour chaque jour et heure de l'année, de même que la pénétration du rayonnement à travers les ouvertures.

Ainsi la position la plus avantageuse d'un bâtiment à construire peut être fixée d'avance au point de vue de l'insolation donnant sur ses murs et sur son toit et pénétrant dans le bâtiment à travers les ouvertures.

Auszug—Zur Ermittlung des Wärmehaushalts eines Gebäudes muß die Wärmemenge bekannt sein, die das Gebäude durch Sonnenbestrahlung erhält. Die Berechnung dieser Wärmemenge ist mit gewissen Schwierigkeiten verbunden, von denen eine in der Feststellung des kombinierten Einflusses von Sonnenstellung am Himmel und Lage des Gebäudes besteht.

Während die Sonnenstellung für jeden Tag und jede Stunde aus astronomischen Tabellen entnommen werden kann, ist die Lage von Gebäuden äußerst unterschiedlich und unbestimmbar. Das in dieser Abhandlung beschriebene Verfahren ermöglicht die Berechnung der Sonnenbestrahlung von Gebäuden verschiedenster Form und in jeder Lage.

Durch die Verwendung des sogenannten Insoloskops kann das tatsächliche Ausmaß der Sonnenbestrahlung eines beliebigen Gebäudes anhand von Modellen für jeden Tag und für jede Stunde des Jahres ebenso wie die Eindringung der Sonnenstrahlen in das Gebäudeinnere ermittelt werden. Dadurch läßt sich die günstigste Lage eines zu errichtenden Gebäudes nach Gesichtspunkten der Sonnenbestrahlung von Wänden und Dach sowie der Eindringung der Strahlung durch die Gebäudeöffnungen im voraus festlegen.

THE indoor climate of a building depends heavily on the amount of heat which penetrates it through the roof, the walls and the openings of the building. One of the main sources of this heat is the direct solar radiation (S, measured in cal cm^{-2} min^{-1}). Part of the radiation is reflected by the outside surface of the building, the rest is absorbed into it.

This paper demonstrates a simple way of calculating the total amount of S on a building of any simple shape and any orientation, and a way to regulate both the amount of radiation penetrating through the openings or falling on the outside surface.

The usual method of calculation is to determine separately the amount of radiation reaching each wall during the day in question (in accordance with the orientation of the wall and the apparent movement of the sun in the sky), and to summarize the results for the whole building. The method suggested in this paper allows one to calculate the amount of radiation on all the walls of a building as a whole by means of diagrams which are valid for any orientation of the building.

The geometrical body mostly used in building construction is the rectangular box (parallelopiped). The intensity of solar radiation on the horizontal roof of such a building is

$$I_{\text{hor}} = i_0 \sin h_0$$

The altitude h_0 of the sun during the day may be found from astronomical tables for each hour of the day and from this the values of $\cos h_0$ may be obtained. The intensity of normal incidence solar radiation i_0 is taken from observation carried out by a suitable pyrheliometer.

The calculation of the solar radiation intensity on the vertical walls of the "box" is based on the use of the "width of flux" of the radiation falling on it. Suppose the width of the building is a_1 and the length is a_2; a_1 faces north (and south) and a_2 faces east (and west) (Fig. 1). The azimuth of the sun is 0°, the width of flux of the radiation on the walls of the building is a_1 and the total energy of radiation per minute on the walls is

$$i_{\text{vert}} = i_0 \, a_1 \cos h_0.$$

The azimuth used in this paper is used in geodesy, i.e. the azimuth of north is 0°, then it increases towards east (90°), south (180°), west (270°) and again north (360°).

When the sun is in the east its azimuth is 90° and only the east wall is insolated. The width of the flux of the radiation is then a_2 and the total energy of radiation per minute on the walls of the building is then

$$i_{\text{vert}} = i_o\, a_2 \cos h_o.$$

In the meantime as the sun moves on the sky from north to east its azimuth attains

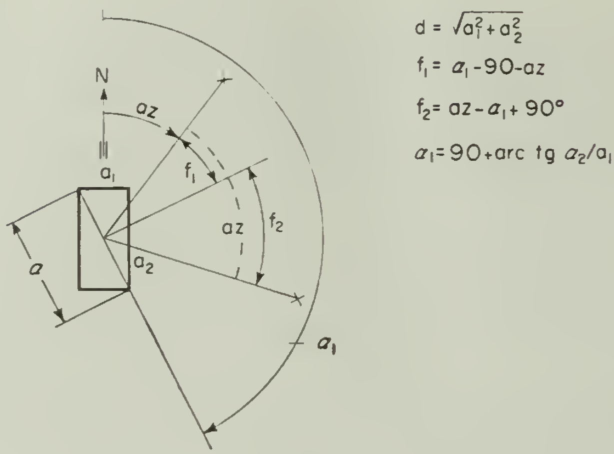


Fig. 1.

values between 0° and 90° and two walls of the building are insolated. The "width of the flux" of the radiation is then:

$$m = \sqrt{(a_1^2 + a_2)} \cos (\alpha_1 - 90^\circ - az)$$

where az is the changing azimuth of the sun and α_1 is the constant azimuth of the diagonal connecting both insolated walls:

$$\alpha_1 = 90^\circ - \text{arc tan}\, \frac{a_1}{a_2}$$

or

$$\alpha_1 = 180^\circ - \text{arc tan}\, \frac{a_1}{a_2}$$

as the case may be.

The total energy per minute of direct radiation on the walls is:

$$i_{\text{vert}} = i_0 \cos h_0\, m = i_0 \cos h_0 \sqrt{(a_1^2 + a_2^2)} \cos (\alpha_1 - 90^\circ - az)$$

The expression of the width of the flux of radiation on the walls of the building

$$m = \sqrt{(a_1^2 + a_2^2)} \cos (\alpha_1 - 90^\circ - az)$$

is valid until the azimuth of the sun becomes $az = 90^\circ$ (the sun is due east). From then on the azimuth a_2 of the second diagonal of the building enters the expression for m

$$m = \sqrt{(a_1^2 + a_2^2)} \cos (a_2 - 90° - az) \text{ (Fig.2)}$$

until the sun exactly faces the southern wall of the building and then $m = a_2$. As the sun moves in the sky towards the west, the azimuth a_3 of the "third diagonal"

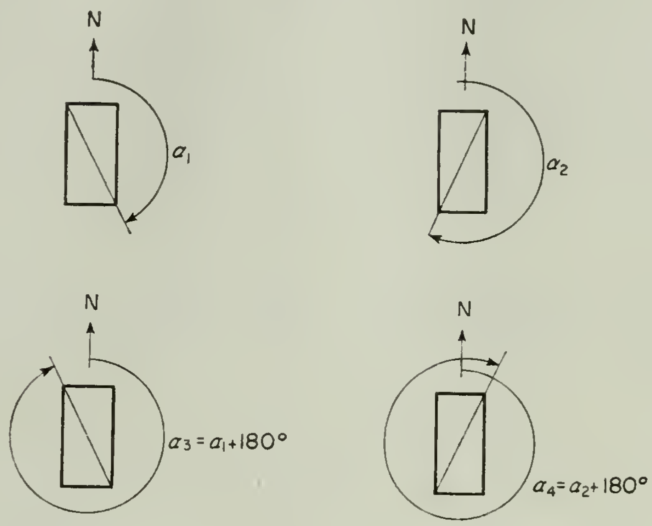


Fig. 2.

(i. e. the inverted azimuth of the first diagonal) appears in the expression for m and finally in the fourth quadrant, the azimuth of the fourth diagonal a_4 (inverted azimuth of the second diagonal) appears.

Only in the polar regions at certain seasons does the sun describe complete circles in the sky. In most locations of the earth the sun describes only a part of the complete circle in the sky, and only during part of the 24 hr are the walls of the buildings insolated.

If the values of m are calculated for a "box" having an area of 1.0 m^2 and a certain ratio of a_1 and a_2, and a diagram of the values m is drawn (provided a_1 faces north and a_2 faces east), only part of values of m should be considered when calculating the energy per minute of radiation on the walls of the box. Therefore if the walls of the box are turned at an angle φ, the same diagram as the initial (north-west) orientation can be used, but the angles of the diagram should be adjusted by the angle φ, i.e. the origin of the diagram should be pushed in the direction of the angle φ.

In Table 1 the values of a_1, a_2, a_3, a_4, are given and m is given as a function of az (the azimuth of the sun) for a few frequently used ratios of a_1 and a_2 (a_1 faces north and south, a_2 faces east and west).

Suppose then that we have to calculate the amount of direct solar radiation at a certain day on the walls of a rectangular building having an area of A m^2, a height of H m, the ratio of bases of the rectangle $a_1 : a_2$ for which the values m are calculated and drawn, and suppose that the base a_1 is turned by an angle φ from the north

Table 1 *For Construction of m-diagrams* $a_1 = a_2 = 1 \sqrt{(a_1^2 + a_2^2)} = 1.414$, $\alpha_1 = 135°$, $\alpha_2 = 225°$, $\alpha_3 = 315°$, $\alpha_4 = 45°$ 0.1

$az°$	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270
$\varphi = (az - \alpha + 90°)$	45	30	15	0	15	30	45	30	15	0	15	30	45	30	15	0	15	30	45
$\cos\varphi$	0.707	0.866	0.966	1.000	0.966	0.866	0.707	0.866	0.966	1.000	0.966	0.866	0.707	0.886	0.966	1.000	0.966	0.866	0.707
$m = 1.414 \times \cos\varphi$	1.00	1.23	1.37	1.41	1.37	1.23	1.00	1.23	1.37	1.41	1.37	1.23	1.00	1.23	1.37	1.41	1.37	1.23	1.00

$a_1 : a_2 = 1 : 2$ $a_1 = {}^1/_2 \sqrt{2}$ $a_2 = \sqrt{(2)}$ $\sqrt{(a_1^2 + a_2^2)} = 1.58$, $\alpha_1 = 153°30'$, $\alpha_2 = 206°30'$, $\alpha_3 = 333°30'$, $\alpha_4 = 26°30'$ 0.2

$az°$	0	3°30′	18°30′	33°30′	48°30′	63°30′	79°30′	90	101°30′	116°30′	131°30′	146°30′	161°30′	176′30′	180′
φ	63°30′	60	45	30	15	0	15	26°30′	15	0	15	30	45	60	63°30′
$\cos\varphi$	0,446	0.500	0.707	0.866	0.966	1.000	0.966	0.894	0.966	1.0	0.966	0.866	0.707	0.500	0.446
$m = 1.58 \times \cos\varphi$	0.71	0.78	1.12	1.37	1.53	1.58	1.53	1.41	1.53	1.58	1.53	1.37	1.12	0.78	0.71

$a_1 : a_2 = 1 : 3$ $a_1 = {}^1/_3 \sqrt{3}$ $a_2 = \sqrt{(3)}$ $\sqrt{(a_1^2 + a_2^2)} = 1.82$ $\alpha_1 = 161°35'$ $\alpha_2 = 198°25'$ $\alpha_3 = 341°35'$ $\alpha_4 = 18°25'$ 0.3

$az°$	0	11°25′	26°25′	41°25′	56°25′	71°25′	86°25′	90	93°25′	108°25′	123°25′	138°25′	153°25′	168°25′	180
φ	71°35′	60	45	30	15	0	15	18°25′	15	0	15	30	45	60	71°35′
$\cos\varphi$	0.316	0.500	0.707	0.866	0.966	1.000	0.966	0.949	0.966	1.000	0.966	0.866	0.707	0.500	0.316
$m = 1.82 \times \cos\varphi$	0.58	0.91	1.29	1.58	1.76	1.82	1.76	1.73	1.76	1.82	1.76	1.58	1.29	0.91	0.58

$a_1 : a_2 = 1 : 4$, $a_1 = {}^1/_2$, $a_2 = 2$, $\sqrt{(a_1^2 + a_2^2)} = 2.06$, $\alpha_1 = 166°$, $\alpha_2 = 194°$, $\alpha_3 = 346°$, $\alpha_4 = 14$ 0.4

$az°$	0	1	16	31	46	61	76	90	104	119	134	149	164	179	180	181	196	211
φ	76	75	60	45	30	15	0	14	0	15	30	45	60	75	76	· 75	60	45
$\cos\varphi$	0.242	0.259	0.500	0.707	0.866	0.966	1.000	0.970	1.000	0.966	0.806	0.707	0.500	0.259	0.242	0.259	0.500	0.707
$m = 2.06 \times$ $\times \cos\varphi$	0.50	0.53	1.03	1.46	1.79	1.99	2.06	2.00	2.06	1.99	1.79	1.46	1.03	0.53	0.50	0.53	1.03	1.46

$a_1 : a_2 = 1 : 5$ $a_1 = {}^1/_5 \sqrt{5}$ $a_2 = \sqrt{(5)}$ $\sqrt{(a_1^2 + a_2^2)} = 2.28$ $\alpha_1 = 168°40'$ $\alpha_2 = 191°20'$ $\alpha_3 = 348°40'$ $\alpha_4 = 11°20'$ 0.5

$az°$	0	3°40′	18°40′	33°40′	48′40′	63°40′	78°40′	90	101°20′	116°20′	131°20′	146°20′	161°20′	176°20′	180	185°40′
φ	78°40′	75	60	45	30	15	0	11°20′	0	15	30	45	60	75	78°40′	75
$\cos\varphi$	0.197	0.259	0.500	0.707	0.866	0.966	1.000	0.981	1.000	0.966	0.866	0.707	0.500	0.259	0.197	0.259
$m = 2.28$ $\times \cos\varphi$	0.45	0.59	1.14	1.60	1.95	2.20	2.28	2.24	2.28	2.20	1.95	1.60	1.14	0.59	0.45	0.59

The values of m may be taken from the diagram according to the value of a_2 at the corresponding hour; as the building is turned through an angle away from the initial north orientation, the origin of the corresponding diagram of the values m should be pushed in this direction by the same angle as shown on the attached diagrams (for turning angles of 30, 60, 90°, etc.).

The area of the building is A m², instead of 1.0 m² of the basic rectangle and its height is H m instead of 1.0 m; it is clear therefore that the linear dimensions of the building (its width and length) are $r = A/1{\cdot}0$ times larger than those of the basic rectangle; the insolated area of the walls of the buildings is therefore larger than that of the basic rectangle by the ratio of $H\sqrt{A}$. The expression of the solar radiation energy per minute on the walls of the building at a certain moment will therefore become:

$$i_{\text{vert}} = i_0 \, Hr \cos h_0$$

A diagram of the values i_{vert} may be drawn for every hour of a day and the area of this diagram will give the amount of solar radiation on all the walls of the building during the whole day.

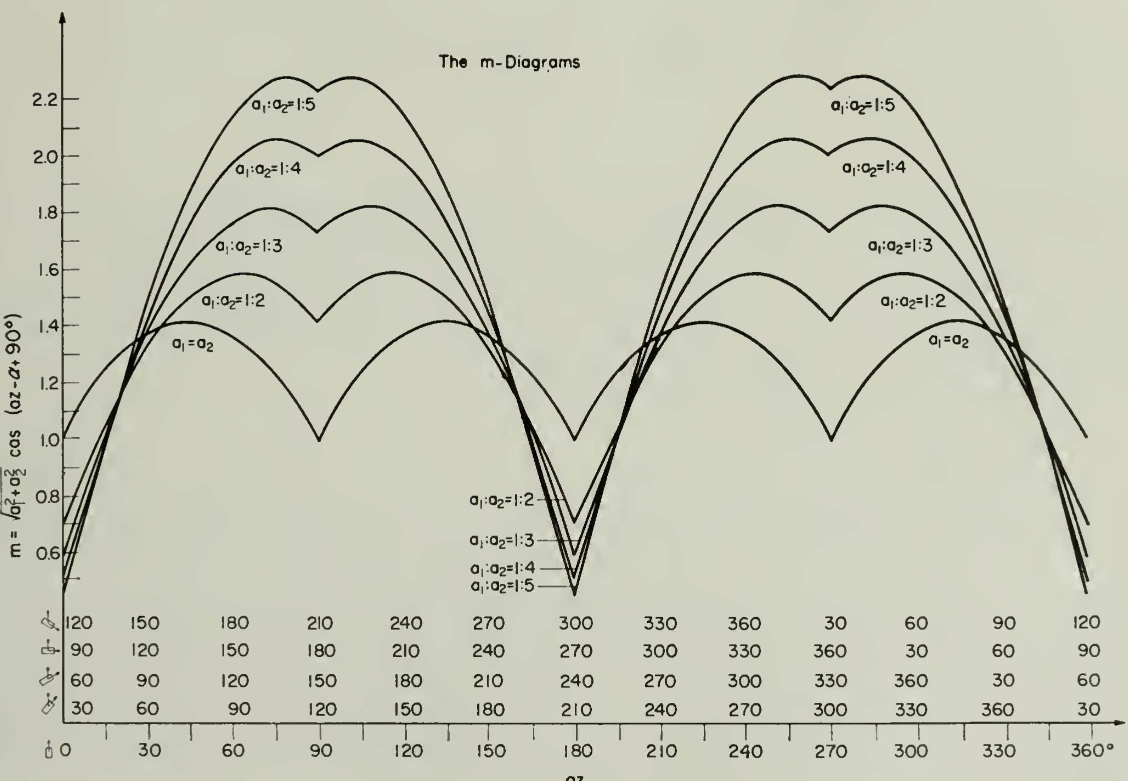


Table 2.

After the amount of heat falling on a certain building is calculated it might appear that on some days during the hot season of the year it is advisable to diminish this amount; during other days it might be desirable to get the maximum from it.

This may be achieved by proper change of some factors such as orientation of the building, the area of the openings and their shape, their location and also the proper arrangement of the shadings.

It is not simple in practice to achieve the optimum of all these factors as it depends also on the purpose of the building and the hours it is used by the dwellers (schools, hospitals, etc.). Not only has the insolation of the outer surface of the building to be

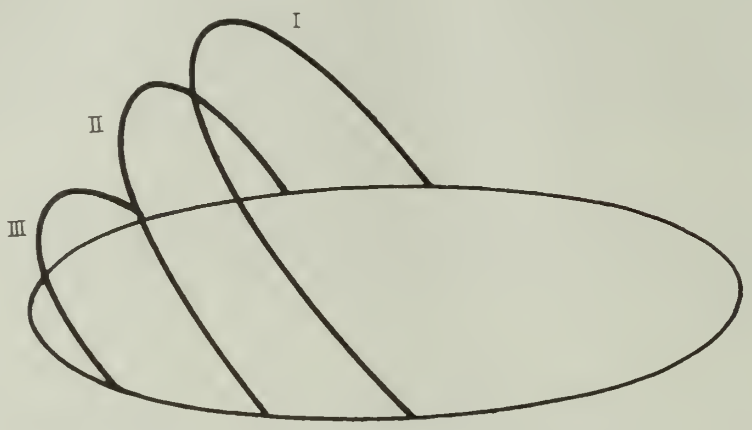


FIG. 3.

considered, but also the penetration of the sun radiation inside through the openings, which should affect to a great measure the inner design of the buildings.

A convenient method for this analysis is the use of building models; in this case no difficulties are involved since these are pure geometrical problems and no moduli (such as Reynold's numbers) are necessary.

The investigation of the model is carried out by means of the newly-designed so-called "Insoloscope" (Fig. 3).

An investigation of a model can be carried out by two kinds of instruments: (a) a source of a parallel and horizontal light beam is fixed and the model is put on an inclined plane which can be rotated on a vertical axis. A source of parallel light moves along a fixed arc imitating the apparent movement of the sun as observed at the desired date at the place inquestion. The arc I represents the path at the summer solstices, the arc II at the equinoxes and the arc III at the winter solstices. By this arrangement the source of light irradiates the model just as the sun does the building. The number of arcs used depends on the accuracy required; usually three as seen in Fig. 3, are sufficient.

For an investigation of a building model, the model is put in the desired orientation on the plate H. The shadings and other projections of the model given first in any chosen dimension can be changed afterwards if necessary. The first check provides a clue to the practical dimensions necessary for the desired optimum a_s determined above. The final dimensions are determined by the brims of $shade_s$

on the walls. For the investigation of the direct solar radiation penetrating into the building, the roof of the model is removed in order to enable the investigator to look inside the model and see the distribution of the sunlight. The inside of the model must be protected from light penetrating other than through the openings.

In this way the insolation of the interior can be checked and the partitions can be arranged according to the needs and use of the building.

By this method not only separate buildings, but also groups of buildings and even quarters can be checked and plans improved.

6TH SESSION

THERMOREGULATION IN ANIMALS AND MAN IN RELATION TO BIOCLIMATOLOGY

CHAIRMAN : PROF. H. HENSEL

THE INFLUENCE OF CLIMATIC AND TEXTILE FACTORS ON THE HEAT LOSS IN DRYING OF MOIST CLOTHING

F. W. BEHMANN

W. G. Kerckhoff-Institut der Max-Planck-Gesellschaft, Bad Nauheim, Germany

Abstract—In physiological experiments heat loss through technologically similar fabrics of wool and polyamide fibres was investigated, when drying on the human body at various wind speeds. The heat loss through the polyamide fabric is greater than through wool. At high wind speeds this difference increases. At low moisture contents the difference is so great that the heat loss through the polyamide at the lower wind speed is greater than that through the wool fabric at the higher wind speed.

In physical experiments the physiological findings could be attributed to the rougher surface and lower capillary conductivity of the wool fabric.

In the theoretical treatment, the "transition point curve" of a textile fabric is shown to be a useful practical index, characterizing the physiological performance of a textile fabric with varying secretion of sweat and showing the possibility of modifying these properties in a fabric by altering of textile parameters.

Résumé—Par des expériences physiologiques la perte de chaleur à travers des tissus de laine et de fibres polyamides a été contrôlée alors qu'ils séchaient sur le corps humain à des vitesses de vent différentes. La perte de chaleur à travers le tissu polyamide est plus grande qu'à travers la laine. Pour de fortes vitesses de vent cette différence augmente. Pour des teneurs en humidité faible la différence est si grande que la perte de chaleur à travers le tissu polyamide pour une vitesse de vent plutôt faible est supérieure à celle qui se produit à travers le tissu de laine pour une vitesse de vent plus forte.

Dans les expériences physiques les constatations physiologiques pouraient attribuées à la surface plus rugueuse et à la conductibilité capillaire plus faible du tissu de laine.

Dans l'analyse théorique le point de transition de la courbe d'un tissu en textile s'est révélé comme un indice pratique utile, caractéristique de «la performance» physiologique du tissu en textile avec sudation variable et donnant la possibilité de modifier les propriétés de ce tissu par un changement des paramètres du textile.

Auszug—In physiologischen Experimenten sind Hitzeverluste durch technologisch einander ähnliche Gewebe aus Wolle und aus Polyamid-Fasern untersucht worden, u. zw. wenn diese am menschlichen Körper bei verschiedenen Windgeschwindigkeiten trocknen. Der durch das Polyamid-Gewebe auftretende Hitzeverlust ist größer als der beim Wollgewebe erscheinende. Bei hohen Windgeschwindigkeiten erhöht sich dieser Unterschied. Bei geringen Feuchtigkeitsgehalten ist die Differenz so groß, daß der Hitzeverlust durch das Polyamid-Gewebe bei niedrigen Windgeschwindigkeiten größer ist, als der durch das Wollgewebe bei höheren Windgeschwindigkeiten auftretende.

In durchgeführten physikalischen Experimenten konnte festgestellt werden, daß diese physiologischen Ergebnisse der rauheren Oberfläche und der geringeren Kapillar-Leitfähigkeit des Wollgewebes zuzuschreiben waren.

Bei der theoretischen Behandlung wird die «Übergangspunkt-Kurve» eines Textilgewebes als ein nützlicher praktischer Maßstab aufgezeigt, der die physiologische Leistung eines Textilgewebes bei schwankender Ausscheidung von Schweiß charakterisiert, und der die Möglichkeiten einer Modifizierung dieser Eigenschaften eines Gewebes durch Änderung der Textil-Parameter angibt.

INTRODUCTION

Since the physiological importance of human clothing has been recognized, there has been a great deal of work done to clarify the interrelationship between the body of the wearer, his clothing and the climatic conditions.The first investigations were made on the thermal insulation of dry textiles. Later, the influence of water vapour diffusion was also taken into account. It was demonstrated that with a simultaneous temperature and vapour pressure gradient across the material, it is possible for moisture to condense in the fabric. The condensed moisture then increases heat loss (9). The question of the dependance of this heat loss upon the amount of moisture present and more especially upon the alteration of the moisture content with variable work-loads and climatic conditions has up to now been investigated; thus, the following work reports an investigation of the particular case when wet clothing is drying on the body at various wind speeds.

EXPERIMENTAL METHOD

The textile materials chosen were heavy, technologically similar knitted fabrics, one made from wool, the other from polyamide fibres (85 per cent nylon, 15 per cent perlon). The specific fibre volume was 18.0 per cent for wool and 20.2 per cent for the polyamide fabric; the air permeabilities were 55.7 m^3/m^2 min for the wool, 71.8 m^3/m^2 min for the polyamide ($\Delta P = 0.5$ in. water). For the physiological experiments, strips of these fabrics about 4 cm wide were sewn together alternately to make a band, which was worn round the calf of an otherwise normally clothed subject. Using this arrangement, experiments were carried out in a climatized room. The band was first wet through with water and allowed to dry under wind speeds of 0.3 and 2 m/sec. The experiment was repeated up to a total of ten times, using the two wind speeds alternately. Throughout, air temperature and temperature of the wall of the chamber was 15°C, the relative humidity 50 per cent. The heat losses between the skin and the fabrics were measured by means of thin heat flowmeters (5), and the moisture content of the fabrics was determined by drying and weighing small samples cut from the fabrics.

Physical experiments were also carried out in which a sample of fabric was hung on a balance, and the rate of evaporation of moisture from the fabric and the moisture content of the fabric during drying were recorded at different wind speeds.

RESULTS

Fig. 1 shows the heat losses plotted against moisture content for a typical single experiment on a human subject. In the dry state, the magnitudes of the measured heat losses through the two fabrics are very much the same, thus confirming numerous data in the literature (6—8) showing that the thermal insulation of a *dry* fabric is practically independent of the nature of the fibre material. But at low and moderate moisture contents, such as will occur in clothing under varying work-loads and climatic conditions, large differences can be seen from Fig. 1. Thus, at low and

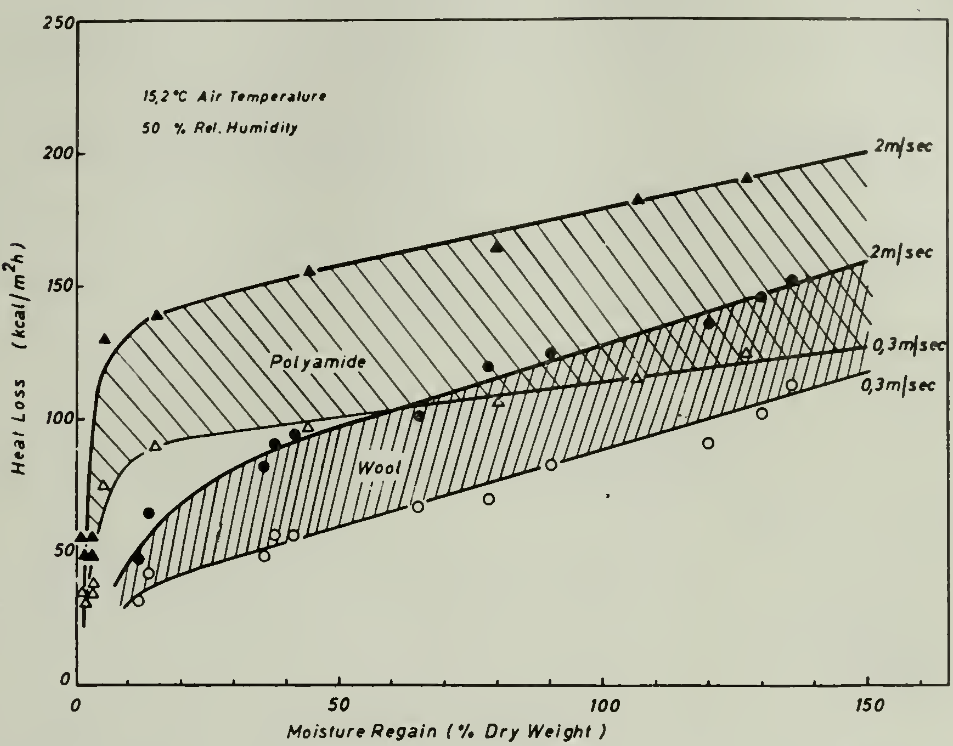


FIG. 1. Heat losses from the human body in the drying of technologically similar fabrics made from wool and polyamide fibres plotted as a function of the moisture regain at wind speeds of 0.3 and 2 m/sec

moderate moisture contents not only are the heat losses through the polyamide higher than through the wool fabric at *identical* wind speeds and moisture contents, but the difference between the fabrics at lower moisture contents is so great that the heat loss through the polyamide fabric at the *lower* wind speed (0.3 m/sec) is greater than that through the wool fabric at the *higher* wind speed (2 m/sec). This difference in heat loss through the two fabrics could have two distinct causes:

(1) The characteristic fall in the drying curve, seen particularly clearly for the polyamide fabric, occurs at a higher moisture content for the wool fabric.
(2) The heat losses through the polyamide fabric rise more than those through the wool fabric as the wind speed increases.

This behaviour was observed in all cases without exception, and since the scattering effect of variable physiological factors on the results was eliminated by the experimental method, statistical testing of the results is not necessary.

18*

DISCUSSION

Since it appeared to be impossible to analyse the results directly without further experiments (2), the rates of evaporation from the fabrics were measured in a physical experiment as a function of moisture content (Fig. 2). The values from the various experiments show a similar general trend, and the characteristic form of the curves

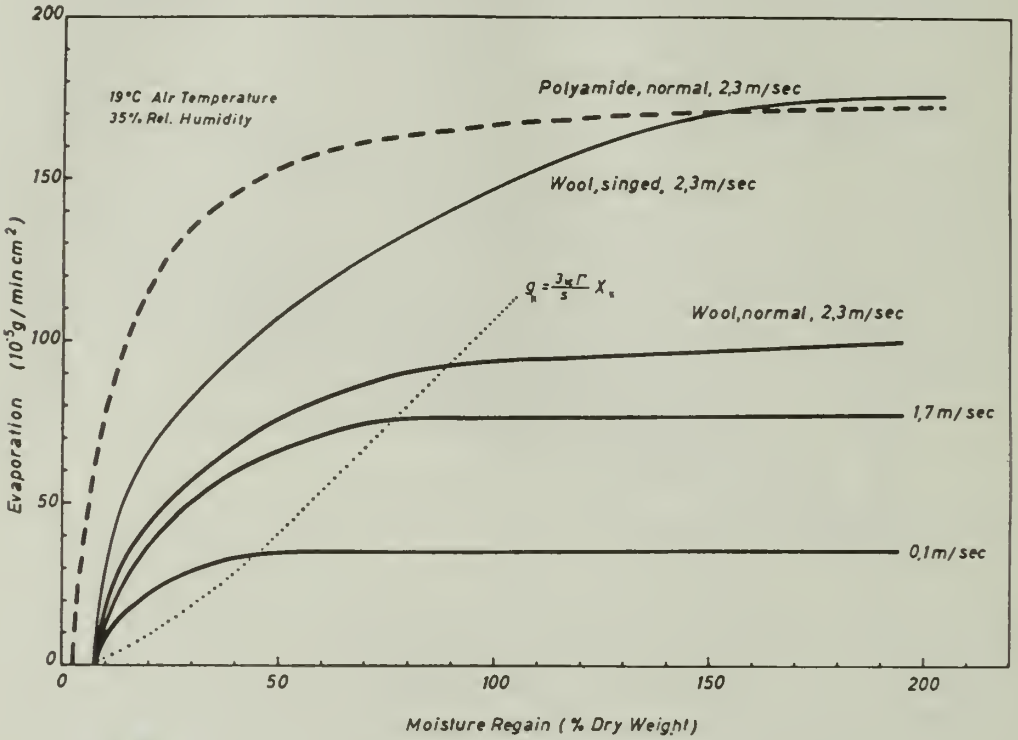


Fig. 2. Rate of evaporation of water in the drying of technologically similar fabrics made from wool and polyamide fibres suspended in free air plotted as a function of moisture regain at various wind speeds

may be explained as follows: at high moisture contents the water evaporation from the outer surface of the fabric can be immediately replenished by capillary action, so that the surface of the fabric remains wet and the rate of evaporation depends only upon outside conditions. As drying proceeds a state is eventually reached where the resultant capillary force no longer exceeds the frictional forces, so that the meniscus retreats into the fabric and an additional vapour diffusion resistance reduces the rate of evaporation.

This fall in the rate of evaporation, which theoretically can be looked upon as a transition point in the drying curve is inversely proportional to the capillary conductivity (3, 4). Earlier experiments have in fact shown that the capillary conductivity of the wool fabric under investigation is lower than that of the polyamide fabric (1) so that this transition in the drying curve should occur at a higher moisture content for the wool fabric than for the polyamide fabric, which, as the heat loss curves in Fig. 1 show, is what happens. However, if the evaporation curves of Fig. 2, for the "normal" wool fabric and the polyamide fabric are compared at a wind speed of 2.3 m/sec, it can be seen that the transition point for the wool fabric does not occur at higher moisture contents and that the evaporation rate from the two fabrics is not the same at high moisture contents. If it is now recalled from earlier work that the wool fabric has a somewhat rougher surface than the polyamide fabric (2), and that this surface layer, which is not filled with water even at high moisture contents, presents an additional diffusion resistance, then it can be understood why the evaporation from the wool fabric is lower even when the fabrics are really wet and it can be seen from Fig. 2 that this influence of the surface structure immediately disappears when the projecting fibres are removed from the wool fabric surface by careful singeing. Thus, the rougher surface of the wool fabric reduces the value of the maximum evaporation rate, in turn forcing the transition point of the curve to regions of lower moisture content (4), so that in fact this fall or transition in evaporation rate occurs at practically the same value for the two fabrics.

Moreover, the fall in the heat loss through the polyamide fabric (Fig. 1) occurs at lower moisture contents. An explanation for this observation is that in the presence of a temperature gradient, the higher capillary conductivity of the polyamide fabric (1) leads to a capillary recirculation of the water, raising the heat transport within this fabric above that within the wool fabric (1, 2, 9).

It can be deduced quite generally from these considerations that the heat loss in the drying of a wet fabric is decreased by a decrease of the capillary conductivity and by an increase in surface roughness. This effect can easily be assessed if a series of drying curves is measured for the fabric under investigation for different evaporating conditions and the transition points of the family of curves are joined to give a "transition point curve." Comparison of the measured evaporation rate of the wet fabric with the corresponding value for another fabric or for a free water surface gives an immediate measure of the influence of surface structure. If the "transition point curve" is now examined, it can be deduced from Fig. 2 that if this curve has a flat slope, not only will the effect of any fluctuation in climatic conditions be more strongly damped but also the fabric will be able to store more liquid sweat before the maximum rate of evaporation is reached. If it is remembered that the small temperature dependence of this "transition point curve" can be neglected (4), and that the effect of relative humidity can be eliminated by measuring in dry air, the "transition point curve" presents a simple and practical index characterizing the physiological performance of a moist fabric with good approximation in one single curve. As a practical demonstration, the "transition point curves" of technologically similar fabrics made from wool, cotton and polyamide fibres were constructed in Fig. 3. Although these three fabrics gave practically the same thermal insulation in a dry state, it can be seen that even at low moisture contents — and some moisture is present in any clothing — there are considerable differences between the different fibres.

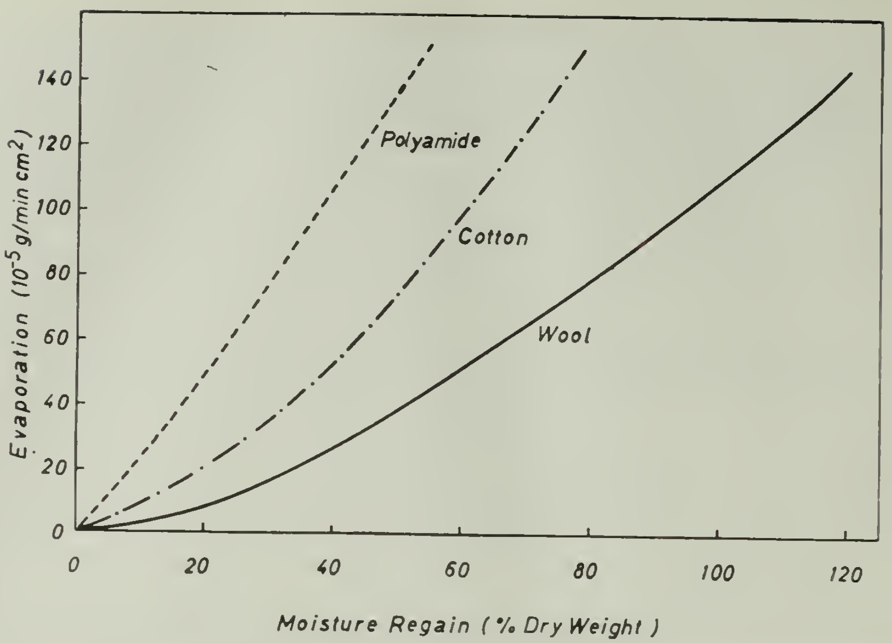


Fig. 3. "Transition point curves" of technologically similar knitted fabrics made from wool, cotton and polyamide fibres

Now, it should be recalled that the "transition point curve" can to a first approximation be described by the expression (3, 4):

$$g_K = \frac{3\varkappa\Gamma}{S} X_K$$

where $\varkappa$ = capillary conductivity;
Γ = fabric bulk density;
X_K = transition point moisture regain;
S = fabric thickness.

Thus the "transition point curve" is a definite function of fabric parameters, so that it further follows that the "transition point curve" is not only a useful practical index, but also shows how the clothing physiological performance of a fabric can be varied by means of textile parameters.

REFERENCES

1. Behmann F. W. and H. D. Meissner, Die bekleidungsphysiologische Bedeutung des Feuchteverhaltens von textilen Faserstoffen. *Melliand Textilber.* **40,** 1209 (1959).
2. Behmann F. W., Differenzierung des Wärmetransportvermögens von Textilien. *Melliand Textilber.* **41,** 468 (1960).
3. Behmann F. W., Experiments on the biologically effective insulation value of wool. *Second Quint. Wool Text. Res. Conf., Harrogate, 1960.*
4. Krischer O., Trocknung fester Stoffe als Problem der kapillaren Feuchtigkeitsbewegung und der Dampfdiffusion. *Z. VDI, Beih. Verfahrenstechn.* 104 (1938).

5. Lustig W. L. and J. S. Cammerer, Folien-Wärmestrom-Messer für technische und physiologische Untersuchungen. *Gesundh. Ing.* **76**, 254 (1955).
6. Marsh M. C., The thermal insulating properties of fabrics. *J. Text. Inst.* **22**, 245 (1931).
7. Rees W. H., The Transmission of heat through textile fabrics. *J. Text. Inst.* **32**, 149 (1941).
8. Speakman J. B. and N. H. Chamberlain, The thermal conductivity of textile materials and fabrics. *J. Text. Inst.* **21**, 29 (1930).
9. Woodcock A. H. and T. E. Dee *Wet-Cold*—I. Env. Prot. Sec. Report 170 (1950).

THE CONTROL AND FAILURE OF SWEATING IN MAN

K. J. COLLINS and J. S. WEINER
M. R. C. Unit for Research on Climate and Working Efficiency,
Department of Human Anatomy, Oxford, Great Britain

Abstract—The maintenance of high rates of sweating is an essential part of man's adaptation to prolonged heat stress. Complete or partial failure of sweating such as occurs in dehydration, "thermal fatigue" or heatstroke is therefore of serious consequence. The sites of failure in such conditions may be in the central nervous system, the neuroglandular junction or in the secretory cells or duct of the gland itself. The sweat gland exhibits a relatively high resistance to prolonged physiological stimulation; abnormal circumstances, e. g. ischaemia or desensitization will bring about a rapid failure.

Résumé—Le maintien d'une transpiration élevée est un aspect essentiel de l'adaptation humaine à une chaleur intense prolongée. Le manque complet ou partiel de la transpiration — comme dans les cas de déshydratation, de «fatigue thermique», de coup de chaleur — a par conséquent une grande importance. L'origine du défaut dans ces cas pourrait être localisée dans le système nerveux central, dans la jonction neuro-glandulaire, ou bien dans les cellules sécrétrices ou dans le conduit de la glande elle-même. La glande sudoripare présente une résistance relativement élevée à une stimulation physiologique prolongée: des circonstances anormales — comme l'ischémie et la désensibilisation — peuvent apporter un manque immédiat

Auszug—Die Aufrechterhaltung hoher Schweissabgabe ist ein wesentlicher Faktor in der menschlichen Anpassung an längere Hitzebelastung. Vollkommenes oder teilweises Versagen des Schwitzens, wie es in Dehydrierung, «Hitzeermüdung», oder Hitzschlag vorkommt, kann somit ernsthafte Folgen haben. Das Versagen kann in solchen Umständen im Zentralnervensystem, in neuroglandulären Synapsis oder in den Sekretionszellen oder dem Duktus der Drüse selbst stattfinden. Die Schweissdrüse zeigt eine relativ hohe Resistenz gegen längere physiologische Reizung auf; anormale Umstände, wie z. B. Ischämie, oder Desensibilisierung haben schnelles Versagen zur Folge.

The evaporation of sweat from the general body surface plays an essential part in maintaining thermal balance in hot environmental conditions by dissipating accumulated body heat. When the temperature of the air and the surroundings is above skin temperature there is an overall gain of heat by convection, conduction and radiation, the loss of which depends entirely on evaporative cooling. The heat load of the body is added to by metabolic heat which depends primarily on body size and physical activity, and therefore if the body temperature is not to rise rapidly during exercise, sweat rate must also increase. Generalized sweating in thermoregulation is controlled in the central nervous system by the hypothalamus which derives thermal information from warmed blood reaching the centre and from the skin through afferent nervous pathways. Hypothalamic and spinal centres discharge nervous impulses to the sweat glands by sympathetic sudomotor nerves which terminate in close connection with the gland cells at the neuroglandular junctions.

Eccrine sweat glands normally exhibit a remarkable capacity for continuous secretory activity in hot climates. During short periods of strenuous exercise in severe heat total sweat rates of up to 3 or 4. l/hr may be achieved. In prolonged heat exposure over many days the economy of thermoregulation improves as the result of acclimatization; a process which involves adjustments in the cardiovascular system and an increase in the responsiveness of the sweating mechanism. An unacclimatized man is relatively intolerant to heat, he sweats poorly, his body temperature quickly rises and he is not capable of performing heavy work. With successive exposures, sweating commences at a lower body temperature, sweat output increases and the capacity for work improves. This is not to say, however, that thermal sweating is indefatigable or that the sweat glands continue to function efficiently in extreme heat stress even in an acclimatized individual. On the contrary, partial or complete failure of sweating has frequently been observed in climatic studies both in the field and in simulated conditions in the hot room. Not surprisingly the consequences of defective sweat production in hot climates are serious and may eventually lead to hyperpyrexia and more dangerous heatstroke.

Some individuals are more prone to sweat disturbances and associated heat disorders than others. For example, people with hereditary ectodermal defects who lack an adequate number of functional sweat glands are unable to tolerate hot environments. Apart from individual susceptibility, there are other factors which may affect the normal function of the sweat glands in the heat. Although the maintenance of water and salt balance is a function largely controlled by the kidneys, dehydration and salt deficiency have both been shown to influence the chemical nature if not the output of sweat. Progressive body dehydration does not produce a consistent reduction in sweating, as Adolph (1947) observed in men exposed to desert conditions. Others (Pitts *et al.*, 1944) have found that men dehydrating in the heat sometimes sweated more slowly than men supplied with adequate water.

A more fundamental approach to the problem of heat-induced failure of the sweat glands has been made in recent years by studies on experimentally produced "sweat gland fatigue". Here it has been shown that sweat rate declines after a few hours in very hot conditions apparently independent of acclimatization, dehydration, salt-deficiency or change in the external heat stimulus (Ladell, 1945; Gerking and Robinson, 1946; Thaysen and Schwartz, 1955). These investigations all demonstrate that the decrease in sweat output is associated with sustained or rising high skin and rectal temperatures together with an increase in the salt content of the sweat. Gerking and Robinson observed that the most profound reduction in sweat rate occurred when the initial sweat rates were highest and that, for the same initial sweat rate, the decline was always much greater in humid heat than in dry heat.

Little is known about the site and therefore the causes of failure in sweat gland fatigue. Studies on the aetiology of heat illnesses and less abundant physiological investigations suggest three possible sites:

(1) Failure may occur in the central nervous control mechanism. A possible indication of this is the sudden cessation of sweating which precedes or coincides with the generalized breakdown of heat regulation in heat stroke. The clinical features of less extreme cases of heat disorder associated with hypohidrosis led Wolkin *et al.* (1944) to consider the possibility of central paralysis or even active inhibition. A similar view was put forward by Ladell (1955), who suggested that sweating diminishes when the rectal temperature exceeds a limiting value. There is, however no proof that central failure is involved in sweat gland fatigue.

(2) The defect in the sweating mechanism may otherwise be more peripherally located, for example at the neuroglandular junction. Failure at this site may be due to deficiency of transmitter substance produced at the sudomotor nerve endings or to reduced excitability of the sweat gland receptor system.

(3) Alternatively, anhidrosis may result from morphological changes in the secretory cells or duct of the sweat gland itself. A wide variety of sweat disturbances are attributable to such peripheral changes, e. g. sweat retention brought about by plugging of the sweat gland ducts (O'Brien, 1947; Shelley and Horvath, 1950; Sulzberger and Herrmann, 1954).

In recent studies (Collins *et al.*, 1959), an appraisal has been made of the function and properties of the neuroglandular junction in sweat gland control. The effects of nervous excitation may be reproduced locally by drugs which exert their effect directly at this site. Such drugs can furthermore be used to test the responsiveness of the glands in situations in which sweating fails. It was established that, continuous stimulation by repeated injections of appropriately low concentrations of sudorific drugs can maintain local sweat secretion for at least 6 hr with no marked diminution in output; an indication of the relatively high resistance of the neuroglandular junction to failure by prolonged stimulation. This property of the neuroglandular junction was confirmed in more recent experiments on the cat's pad (Collins and Weiner, unpublished) in which profuse sweating was sustained for from 3 to 4 hr by stimulation of the plantar nerves at intensities above threshold.

After 4 to 6 hr nerve stimulation in the cat, however, both the output of sweat and the response to a standard dose of sudorific drug decreased considerably. Comparable results in man have been obtained by Thaysen and Schwartz (1955) who found that the reaction to a single injection of drug diminished after 6 hr of sweating in the hot room. These experiments show that "fatigue" involves failure of the peripheral effector site.

An extreme case of neuroglandular blockage in man or cat is that which can be rapidly induced by high concentrations of drugs which desensitize the sweat receptor system to further stimulation (Collins *et al.*, 1959). Cognizance of the autoinhibitory effect of high concentrations of such drugs is important when pharmacological tests of sweat gland function are made. For example, the failure of sweating produced locally by massive doses of methacholine (Thaysen and Schwartz, 1955) is not necessarily analogous to thermal "fatigue" of the glands. We have found that the salt concentration of sweat in desensitization does not progressively increase as it does in thermal sweat gland fatigue.

That the receptor system is specially sensitive to depression is shown by experiments of a different kind in which the circulation to a limb is arrested (Collins *et al.*, 1959). From 20 to 30 min after arterial occlusion there is complete failure of thermal sweating. Activity is restored within a few minutes after the occlusion is released. During ischaemia the sweat response to drugs is impaired and it was therefore concluded that ischaemic depression of sweating is at least partly due to a loss of responsiveness of the receptor system. Under these conditions the secretory mechanism of the gland cells is also affected as shown by the changes in chemical composition of sweat secreted during arterial occlusion (van Heyningen and Weiner, 1952).

We have recently confirmed the finding of the high resistance of the neuroglandular junction to depression during thermal sweating (Collins and Weiner, unpublished). It was found that the response of sweat glands to acetylcholine did not diminish significantly in experiments lasting from 3 to 5 hr in which subjects periodically performed step-climbing exercises in environments of 46/30°C or 40/32°C. Skin temperature increased steadily to about 37°C and rectal temperature to about 39°C, but the decrement in sweat rate never amounted to more than 30 per cent of the maximum output, usually much less. However, a more rapid and complete failure in forearm sweating was produced by enclosing the limb in an impermeable envelope. In experiments on seven subjects at 40/32°C sweat output in the armbag decreased by 70—100 per cent (mean 92 per cent) of the maximum during the first 2 to 3 hr while on the general body surface the decrement was 11—27 per cent (mean 19 per cent) after 3 to 4 hr. The response to acetylcholine in the armbag was also much reduced and a normal reaction could still not be elicited 10 to 30 min after the armbag was removed in a cool environment. The problem is whether the more pronounced failure of sweating in the armbag than on the general body surface is due to the higher skin temperature, higher humidity or to both of these factors. The importance of high humidity is suggested by the results of experiments in which the opposite, unenclosed arm was heated by radiant heat lamps. The skin temperature of the irradiated arm was equal to or greater than that of the enclosed arm, but no decrease in the response to acetylcholine in the heated arm could be detected. Gerking and Robinson (1946) have shown, however, that the fall-off in sweat output from one hand enclosed in a rubber glove and cooled, was considerably less than in a gloved hand which was warmed. It appears therefore that optimum conditions for promoting sweat gland failure in localized areas of the body are provided by a combination of both high humidity and high skin temperature. Under these circumstances, part of the unevaporated sweat adhering to the skin may be reabsorbed. This is evident first from the slight swelling and maceration of the skin and also from the high osmotic pressure of sweat collected from armbags (Weiner and van Heyningen, 1951). Indeed, the suggestion was put forward by Bazett (1949) that when the body surface was covered with sweat at high skin temperature, some diffusion of water may occur inwards. It is not possible to say whether the reabsorption of sweat at high skin temperatures contributes to the failure of sweating in "sweat gland fatigue", but a comparable situation to that in the armbag may be produced in humid environments with high rates of sweating, when sweat drips unevaporated from the skin surface. It must not be concluded, however, that overactivity of the sweat glands is implicit in the phenomenon of fatigue merely because the humidity of the air in contact with the skin is increased. This was shown by armbag experiments in which sweating in a small area of the forearm was suppressed by repeatedly injecting atropine. When sweating in the armbag had ceased, the rested, atropinized glands responded well to an injection of acetylcholine while those in other parts of the arm did not.

There is evidence that during normal sweating, morphological changes occur in the cells of the gland and duct (Way and Memmesheimer, 1936). Biopsy specimens of skin taken when the sweat glands have become refractory after sustained activity in humid heat show much more pronounced cytological changes, which, in some respects, suggest damage to the glands (Dobson *et al.*, 1958). The rise in salt content of sweat in "sweat gland fatigue" is also regarded as a measure of secretory failure of the gland cells. In moderate sweating, chloride concentration is reported to increase with sweat rate, skin temperature and with duration of sweating during a single exposure to heat (Robinson and Robinson, 1954). Even during a short (2-hr) exposure, it has been suggested that the rise in chloride concentration is due to "fatigue" of the glands which are limited in capacity for osmotic work and therefore can no longer elaborate hypotonic sweat (Ladell, 1945). However, it is difficult to reconcile this with the fact that a sudden fall in skin temperature during a short exposure to heat can bring about an immediate fall in sweat chloride and a concomitant increase in osmotic work. The high salt concentration of sweat in "sweat gland fatigue" may be due to high skin temperature, reabsorption of water from unevaporated sweat as well as to exhaustion of the gland cells.

The structural changes which sometimes occur in the sweat gland duct during prolonged heat exposure are well documented (Sargent and Slutsky, 1957). Anhidrosis in prickly heat is brought about by abnormal keratinization in the skin in which sweat gland ducts become obstructed. Sulzberger and Herrmann (1954) have shown that closure of the sweat gland pores can occur in conditions of high humidity and temperature or when the skin becomes excessively hydrated. It is characteristic of experimentally produced lesions of this nature that a latent period of several days usually elapses before plugging becomes apparent. This, together with the absence of dermatological signs of sweat retention in "sweat gland fatigue", suggests that occlusion of the ducts is not the immediate cause of anhidrosis. It is possible, however, that the same factors which may eventually give rise to prickly heat produce more imperceptible defects in the peripheral sweat apparatus at some earlier stage.

Summarizing these findings, it can be affirmed that in many instances of failure in sweating the peripheral effect or organ is shown to be vulnerable. This is shown by the lack of response to stimulant drugs in "sweat gland fatigue" and the plugging of sweat gland ducts in some cases of chronic heat exposure. Failure of the central control mechanism or of the neuroglandular junction cannot easily be demonstrated. There are insufficient studies on anhidrosis to decide whether the apparent central nervous failure of heat regulation as in heat stroke is the direct result of sweat deficiency, or whether dysfunction of the central nervous system is primarily responsible for the decrease in sweating.

REFERENCES

Adolph E. F. (1947) *Physiology of Man in the Desert*. Interscience Publishers New York and London.

Bazett H. C. (1949) *Physiology of Heat Regulation and the Science of Clothing* (edited by Newburgh L. H. Saunders, Philadelphia and London.

Collins K. J., Sargent F. and Weiner J. S. (1959) Excitation and depression if eccrine sweat glands by acetylcholine, acetyl-ß methylcholine and adrenaline. *J. Physiol.* **148,** 592—614.

Collins K. J., Sargent F. and Weiner J. S. (1959) The effect of arterial occlusion on sweat gland responses in the human forearm. *J. Physiol.* **148,** 615—24.

Dobson R. L., Formisano V., Lobitz W. C. and Brophy D. (1958) Some histochemical observations on the human eccrine sweat glands—III. The effect of profuse sweating. *J. Invest. Derm.* **31,** 147—59.

Gerking S. D. and Robinson S. (1946) Decline in the rates of sweating of men working in severe heat. *Amer. J. Physiol.* **147,** 370—8.

Ladell W. S. S. (1945) Thermal sweating. *Brit. Med. Bull.* **3,** 175—9.

Ladell W. S. S. (1955) The decline in sweating with raised rectal temperature. *J. Physiol.* **129,** 8—9P.

O'Brien J. P. (1947) A study of miliaria rubra, tropical anhidrosis and anhidrotic asthenia. *Brit. J. Derm.* **59,** 125—58.

Pitts G. C., Johnson R. E. and Consolazio F. C. (1944) Work in the heat as affected by intake of water, salt and glucose. *Amer. J. Physiol.* **142,** 253—9.

Robinson S. and Robinson A. H. (1954) Chemical composition of sweat. *Physiol. Rev.* **34,** 202—20.

Sargent F. and Slutsky H. L. (1957) The natural history of the eccrine miliarias: a study in human ecology. *New Engl. J. Med.* **256,** 401—8; 451—9.

Shelley W. B. and Horvath P. N. (1950) Experimental miliaria in man. III. Production of miliaria rubra (prickly heat). *J. Invest. Derm.* **14,** 193—204.

Sulzberger M. B. and Hermann F. (1954). *The Clinical Significance of Disturbances in the Delivery of Sweat.* Thomas, Springfield, Illinois.

Thaysen J. H. and Schwartz I. L. (1955) Fatigue of the sweat glands. *J. Clin. Invest.* **34,** 1719—25.

van Heyningen R. and Weiner J. S. (1952). The effect of arterial occlusion on sweat composition. *J. Physiol.* **116,** 404—13.

Way S. C. and Memmesheimer A. (1936) The sudoriparous glands. I. The eccrine glands. *Arch. Derm. Syph., N. Y.* **34,** 797—808.

Weiner J. S. and van Heyningen R. (1951). Comparison of arm and general body sweat. *J. Physiol.* **112,** 13P.

Wolkin J., Goodman J. I. and Kelley W. E. (1944) Failure of the sweat mechanism in the desert. Thermogenic anhidrosis. *J. Amer. Med. Ass.* **124,** 478—82.

NATURAL AND ARTIFICIAL COLD ACCLIMATIZATION IN MAN

THOMAS R. A. DAVIS, M. D. and ROBERT J. T. JOY, CAPTAIN, MC
Division of Environmental Medicine, U. S. Army Medical Research Laboratory, Fort Knox, Kentucky, U. S. A.

Abstract—The effect of natural or artificial chronic cold exposure on the response of human subjects to a standardized acute exposure was used as the criterion of cold acclimatization. During the standard exposure of 12—14°C for 2 hr, shivering, oxygen consumption, rectal temperature and skin temperature were measured. Seasonal acclimatization was studied by determining the monthly response of fourteen subjects to the standard test for year. During the winter, shivering was 90 per cent less, cold-induced oxygen consumption 50 per cent less, and rectal and skin temperatures remained unchanged. The effect of a sub-arctic climate was studied on ten Kentucky soldiers: After 52 days in Alaska, shivering was 50 per cent less and oxygen consumption 25 per cent less while rectal and skin temperature responses were unchanged. The rate of change between the group in Alaska and the seasonally studied group was the same. Ten subjects were artificially acclimatized by nude exposure for a period of 8 hr daily for 30 days in a chamber at 12°C. Shivering in this group decreased 90 per cent, cold-induced oxygen consumption was unchanged, rectal temperature was depressed significantly after the tenth day but skin temperature was unchanged. Monthly retesting of the chamber acclimatized group for 11 months showed no change in their cold test response. The seasonally acclimatized group lost their winter response to the cold test. While maximally cold acclimatized, both seasonal and chamber groups did not lose their cold-acclimatization as a result of a 3-week period of heat acclimatization.

Résumé—L'effet de l'exposition au froid constant, naturel ou artificiel a été utilisé comme critère d'acclimatation ou froid en ce qui concerne la réaction des êtres humains à une exposition standardisée à l'air froid.

Pendant l'exposition à l'air froid, standard, température 12° à 14°C, durée deux heures, le frisson, la consommation en oxigène, la température rectale et la température de la peau ont été mesurés. L'acclimatation saisonnière a été étudiée en déterminant la réaction mensuelle de 14 sujets par rapport au test standard relatif à une année. Pendant l'hiver le frisson a diminué de 90%, la consommation d'oxigène induit froid a diminué de 50%, tandis que la température rectale et la température de la peau se maintenaient sans changement. L'effet du climat subarctique a été étudié sur 10 soldats du Kentucky: après avoir séjourné 52 jours dans l'Alaska, les frissons ont diminué de 50% et la consommation en oxygène de 25%, tandis que les réactions de la température rectale et de la température de la peau étaient inchangées. Le taux de variation entre le groupe d'Alaska et le groupe étudié par rapport à l'influence saisonnière était le même. Dix sujets ont été acclimatés artificiellement en exposant le corps nu dans une chambre à la température de 12°C pendant 30 jours et une durée de 8 heures par jour. Dans ce groupe le frisson a diminué de 90%, la consommation en oxygène induit froid a été inchangée, la température rectale a baissé d'une façon appréciable après le 10e jour, mais la température de la peau n'a pas changé. Les contre-essais mensuels faits pendant 11 mois sur le groupe acclimaté en chambre ne présentaient pas de changement dans leur test de réaction au froid. Le groupe acclimaté saisonnièrement perdait sa réaction d'hiver au test réaction au froid.

Bien que acclimatés au maximum au froid, les deux groupes, saisonnier et en chambre, ne perdaient pas leur acclimatation au froid, par suite d'une acclimatation au chaud pendant une période de trois semaines.

Auszug—Die Wirkung der natürlichen oder künstlichen Kälte auf die Reaktion menschlicher Wesen gegenüber starker Kälteeinwirkung von bestimmter Dauer wurde als Kriterium für die Kältegewöhnung verwendet. Im Laufe der Normaleinwirkung von 12—14°C auf die Dauer von 2 Stunden wurden Zittern, Sauerstoffverbrauch, Rektaltemperatur und Hauttemperatur gemessen. Die jahreszeitliche Gewöhnung wurde dureh die Ermittlung der monatlichen Reaktion von 14 Versuchspersonen auf den Normalversuch im Laufe eines Jahres untersucht. Im Winter waren Zittern 90% und der durch die Kälte bewirkte Sauerstoffverbrauch 50% geringer, während die Rektal- und Hauttemperatur unverändert blieb. Die Wirkung eines subarktischen Klimas wurde an 10 Soldaten in Kentucky untersucht. Nach 52 Tagen in Alaska waren Zittern 50% und Sauerstoffverbrauch 25% geringer, während Rektal- und Hauttemperatur unverändert blieben. Der Grad der Veränderung war bei der Gruppe in Alaska und der jahreszeitlich untersuchten Gruppe der gleiche. Zehn Versuchspersonen wurden durch den täglichen 8-stündigen Aufenthalt in einer Kühlkammer bei 12 C° mit nacktem Körper in einem Zeitraum von 30 Tagen künstlich akklimatisiert. Das Zittern verringerte sich bei dieser Gruppe um 90%, der Sauerstoffverbrauch blieb unverändert und die Rektaltemperatur sank nach dem zehnten Tage beträchtlich, jedoch war die Hauttemperatur unverändert. Eine monatliche Wiederholungsuntersuchung der in der Kühlkammer eingewöhnten Personen für die Dauer von 11 Monaten ergab keine Veränderung der Kältereaktion. Die jahreszeitlich akklimatisierte Gruppe verlor ihre winterliche Reaktion auf den Kälteversuch. Bei höchster Kältegewöhnung verlor weder die jahreszeitlich noch die in der Kühlkammer akklimatisierte Gruppe ihren Eingewöhnungszustand nach dreiwöchiger Gewöhnung an Wärme.

INTRODUCTION

It has long been common knowledge that man can become "accustomed to" cold weather or hot weather, or to work in unusual industrial situations, such as steel foundries or refrigeration plants. Whether this tolerance is a true physiological acclimatization or adaptation has long been a subject of investigation by physiologists. True physiological adaptation—that is, definite and persistent changes in the body allowing it to withstand and tolerate the prejudicial influences of a foreign climate—has been well established for hot environments (7, 9, 23, 32, 49, 56—58). True acclimatization to cold in man has not been as clearly demonstrated. This paper will present the results of several investigations which we believe demonstrate that a true acclimatization to cold does exist, that it can be induced either naturally or artificially, and that the degree of acclimatization can be quantitated by measuring a basic physiological response to cold, namely shivering.

Previous investigations of human cold acclimatization may be divided into four general methods of approach: the use of cold chambers to acclimatize artificially

(1, 3, 16, 18, 26, 27, 35, 36, 39, 41, 48, 56—58); the deliberate exposure of men to cold weather, under controlled or uncontrolled conditions (2, 5, 6, 11, 15, 24, 42, 47, 52); comparisons between the natives of Arctic or sub-Arctic areas and non-native "controls" (12, 13, 33, 38, 45, 46, 50, 51, 62); and attempts to define differences in the same group of subjects during different seasons of the year (8, 25, 28, 37, 44, 61). Three of these approaches have been used in the studies reported here—artificial, seasonal and cold weather acclimatization.

One of the major problems in studying human cold acclimatization has been the lack of good indices of the acclimatized state. Skin and rectal temperatures, basal and environmental metabolic rates, and "tolerance" or "comfort" have been used to define acclimatization in the great majority of investigations; in a few studies the peripheral circulation, either measured directly or inferred from skin temperature measurements, has been thought to define acclimatization. Hormonal changes, fluid balance, hematological changes, the critical temperature, changes in plasma proteins, cardiovascular responses (blood pressure and pulse), and miscellaneous changes in serum chemistry have served as indices in various reports. This array of methods of measurement demonstrates the difficulty of defining human cold acclimatization, and has in large measure contributed to the conflicting reports about cold acclimatization. The usefulness of shivering as an index of cold acclimatization in animals (17, 19, 20, 21, 30, 31, 54) and the occasional note of its loss in human cold acclimatization (5, 26, 33, 38, 51, 52) support our belief that a decrease in or extinction of shivering is an important adaptive mechanism in human cold acclimatization.

Although the majority of studies have found evidence for human cold acclimatization, there is a significant minority report which found no demonstration of this phenomenon in man, regardless of method of approach (1, 2, 16, 28, 35, 36, 44, 47, 50, 57, 58, 62). As we will discuss later, marked variability in methods of exposure and criteria for acclimatization may account for many of the failures to find evidence of cold acclimatization in man.

METHODS

All results reported in this paper were secured during a standard cold exposure test. For each given set of experiments, all subjects were exposed nude, reclining on a mesh cot, to a fixed room temperature. For the experiments described here, exposures were for 1 or 2 hr to ambient temperatures between 12°C and 14°C. Prior to cold room exposure, the subjects were fasted for 15 hr, and control measurements made for 1 hr at an ambient temperature of 28°C.

In these studies shivering was measured by integrating muscle action potentials. A grass amplifier with integration by a Philbrick model MK operational four-fold absolute electronic integrator (19) was used in some studies, and an Offner EMG integrator in others. Electrodes were placed on the thighs and upper arms. The data is reported as electrical activity of shivering per unit time. Oxygen consumption was secured by analyzing expired air with a Beckman E2 oxygen analyzer, and measuring respiratory minute volumes with a Phipps and Bird flowmeter. Basal metabolic rates were obtained during the 1-hr control period prior to cold exposure, thus allowing calculation of the cold induced increase in oxygen consumption. All values are reduced to s. t. p.

Rectal and skin temperatures were sensed by thermocouples in combination with a Brown recording potentiometer. Skin temperatures were measured in the following areas: forehead, upper arm, dorsum of the hand, pad of the index finger, upper thigh, calf, dorsum of the foot, and pad of the great toe. Rectal temperature was secured at 12.5-cm insertion, and all ambient air temperatures were measured at a height level with the recumbent subject.

Hand cooling studies were performed by inserting the hand into an insulated box with an air temperature of —15°C. Temperatures were recorded by thermocouples attached to the pads of the fingers. The experiment was terminated when finger temperature reached —1°C or when pain was unbearable. The finger cooling rate is expressed in degrees centigrade per minute.

It is not possible to compare absolute shivering data among all the groups studied, because the previous degree of cold acclimatization at the beginning of any given study could not be known. Some individuals had a very high initial shivering response, and have been presumed to have a low degree of cold acclimatization. These individuals showed the greatest absolute change in electrical activity of shivering. Other subjects had lower initial values and a smaller magnitude of absolute decrease. However, the percentage change from beginning to end of study would be similar for both subjects.

In studies restricted to one group, absolute values for shivering and O_2 consumption are given. Where two or more groups are compared, values are given as percentage changes.

Statistical analysis was performed throughout on a paired data basis, using standard methods. The Fisher t-test was used to give values for P in order to determine the level of significance. Plus and minus signs always refer to one standard deviation.

RESULTS

Experimental Cold Acclimatization

Ten subjects were exposed nude 8 hr a day for 31 days excluding Sundays in a cold room at a temperature of 11.8 ∓ 0.46°C. They performed no exercise, but spent the time quietly sitting or reclining, reading and watching television. The study was performed during the month of March when, as will be described later, seasonal cold acclimatization is maximal. Although the quantitative changes to be described are evident, not the least striking manifestation of acclimatization was the observation of the change from marked subjective discomfort of the subjects early in the study, to rather complete tolerance of the cold at the end of the study. Indeed, it was not unremarkable to find subjects sound asleep in the cold during the concluding days of exposure.

Measurements of shivering, oxygen consumption, and temperature were secured on the third, eighth, fourteenth, twenty-first and thirty-first days of exposure on each subject, for 1 hr after an initial exposure to the cold that day of 1 hr. The results are depicted in Fig. 1. Throughout the period of cold exposure heat production

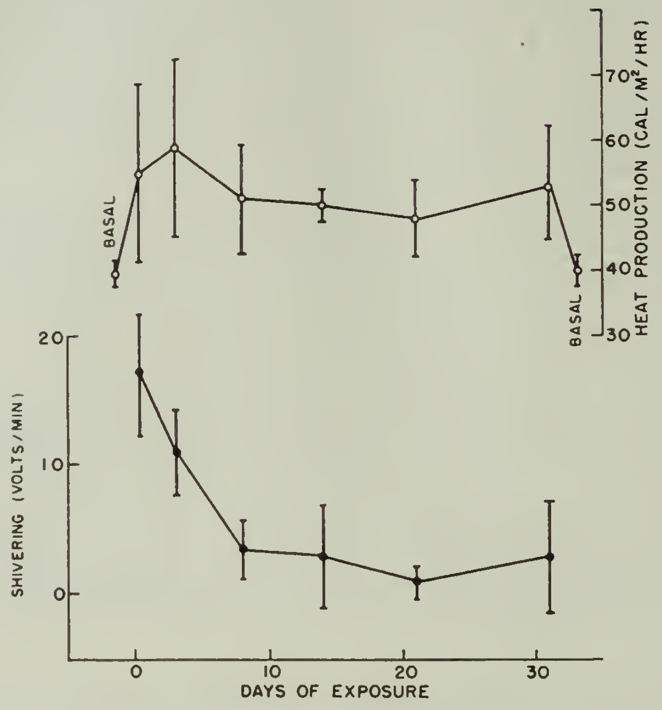


FIG. 1. Changes in heat production and electrical activity of shivering occurring in ten nude subjects exposed 8 hr daily for 31 days (except Sundays) to an ambient temperature of 11.8 °C. Results are plotted as means for the group, the vertical bars are one standard deviation

remained significantly ($P < 0.01$) elevated above basal oxygen consumption. Although there is demonstrated a trend toward gradual decrease later in the study, the differences are not significant ($P > 0.05$). Shivering activity was decreased by the eighth day of exposure ($P < 0.01$), and remained depressed for the remaining time. The large variability among subjects is evident in the large standard deviations. One subject, of ectomorphic habitus, showed the greatest amount of shivering in the early stages of exposure and was responsible for keeping group means above zero during the latter part of the study. Two subjects, one an under-ice skin diver, and the other with an unremarkable thermal history, showed the least amount of shivering in the initial exposure period, and rapidly decreased their rates of shivering to zero by the eighth day. All gradations between these extremes were encountered in the remaining subjects.

Fig. 2 shows the rectal and skin temperatures obtained. The mean rectal temperature for the group was significantly ($P < 0.01$) depressed by the fourteenth day of exposure, and remained so. Although statistically significant fluctuations of mean skin temperature occurred on the eighth and fourteenth day of acclimatization, there was no real change in either mean skin temperature or the temperature of any particular area as a result of the total period of cold exposure. The only surface

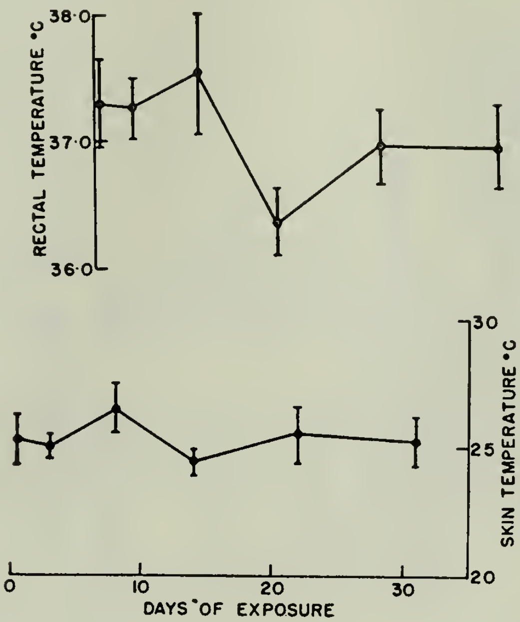


Fig. 2. Changes in rectal and skin temperature occurring in ten nude subjects exposed 8 hr daily for 31 days (except Sundays) to an ambient temperature of 11.8 °C. Results are plotted as means for the group, the vertical bars are one standard deviation

temperature which showed a significant change occurred on the thigh. This change was a decrease of 0.79°C with a P-value of less than 0.01. All other areas had P-values of greater than 0.10.

These physiologic adjustments to a prolonged period of nude cold exposure demonstrate in man findings previously elicited in rats (17, 20, 30, 31, 54, 55) chronically exposed to cold. It is our contention that this is evidence for a quantitative demonstration that a physiologic acclimatization to cold occurs in man, and that this acclimatization can be artificially induced.

Natural Cold Acclimatization

Six subjects were exposed once monthly for 1 hr to a cold room temperature of 14.1 ± 0.95°C for 6 months. This was their only deliberate cold exposure. Shivering, oxygen consumption and rectal and skin temperatures were measured as described. During this 6-month period, the subjects performed their ordinary duties as laboratory assistants, with their cold exposure being that of the ordinary individual living in Kentucky. The amount of deliberate exposure is considered insufficient to induce an appreciable artificial acclimatization.

Fig. 3 illustrates their response to the once-monthly cold exposure, and compares it to the mean monthly outdoor temperature at Fort Knox. Heat production (ex-

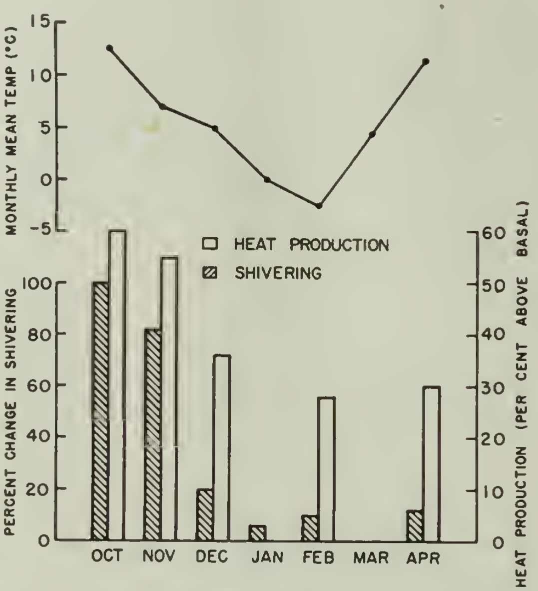


FIG. 3. The response of six subjects to seasonal cold acclimatization beginning in October. Cold exposures were made once monthly at 14.1 °C. The top curve is the mean monthly outdoor temperature at Fort Knox. Shaded bars represent shivering expressed as a percentage of the October value, and open bars heat production, expressed as percentage elevation above basal

pressed as per cent above basal) decreased from a mean of 60 per cent in October to 28 per cent in February ($P < 0.05$). Shivering after December fell to 3 to 6 per cent of the October value ($P < 0.01$). It was not possible to study the same group of subjects any longer, so another group of five subjects were studied the following year in exactly the same circumstances except that the experiment began in February. The results are shown in Fig. 4. Instrumentation failure precludes reporting the heat production data. As expected, shivering increased during the summer period ($P < 0.01$). Previous work (12, 15, 24, 52) has suggested that surface temperatures would be expected to decrease while rectal temperatures increased in the cold. Rectal temperatures did not change ($P > 0.10$) while the surface temperatures of the calf, the arm and the trunk increased ($P < 0.05$, < 0.02 and < 0.02 respectively).

These studies demonstrate, we believe, that there is a natural or seasonal cold acclimatization in a temperate climate, which is maximal in late winter, but which is not retained, being lost during the summer.

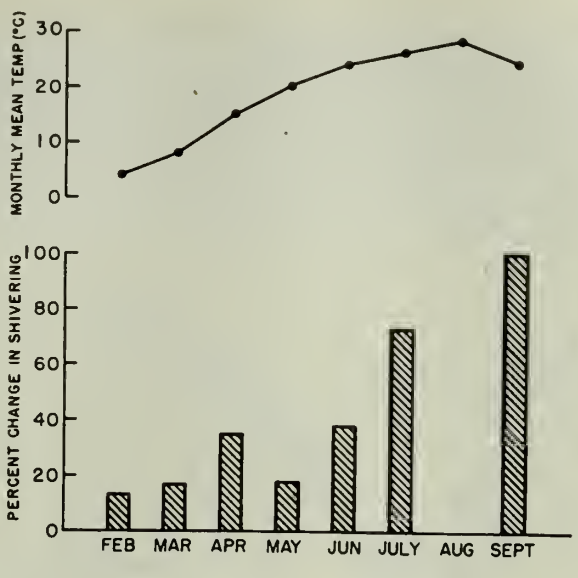


Fig. 4. The response of five subjects to seasonal cold acclimatization beginning in February. Cold exposures were made monthly at 13.7 + 0.9 °C. The top curve is the mean monthly outdoor temperature at Fort Knox. The shaded bars represent shivering, expressed as a percentage of the September value

In order to test the effect of a sub-Arctic climate upon cold acclimatization, ten subjects were tested immediately before and after a 52-day sojourn in Anchorage, Alaska in January and February, 1960. The subjects were all combat trained infantry

Table 1. Mean Daily Environmental Conditions, Cold Exposure, Physical Activity and Sleep Experienced by ten Subjects during a 52-day Period in Alaska ("Indoor" is barracks and tent temperature. Cold exposure is hours spent outdoors. Activity refers to miles of walking and skiing. Climatic conditions were recorded in the immediate vicinity of the subjects. All observations were recorded by a trained observer living with the group.)

	Barracks 25 days	Field 19 days	Barracks 8 days
Indoor temperatures (°F)	73.9	62.2	72.3
	±3.65	±8.38	±3.93
Outdoor temperatures (°F)	16.0	4.5	25.1
	±8.72	±3.73	±5.64
Wind velocity (miles/hr)	1.3	0.5	1.68
	±1.67	±0.86	±1.8
Cold Exposure (hrs/man per 24 hrs)	4.05	6.9	3.2
	±2.92	±2.70	±1.30
Activity (miles/man per 24 hr)	3.13	3.86	1.76
	±2.55	±2.44	±2.22
Sleep (hr/man per 24 hr)	7.61	7.17	6.4
	±1.01	±2.13	±1.05

soldiers from Fort Knox, and in superb physical condition. Nineteen days of their stay were spent in field conditions 200 miles north of Anchorage, living in tents and participating in a winter manoeuver. Table 1 records the climate they were exposed to, their activity, sleep, and amount of cold exposure.

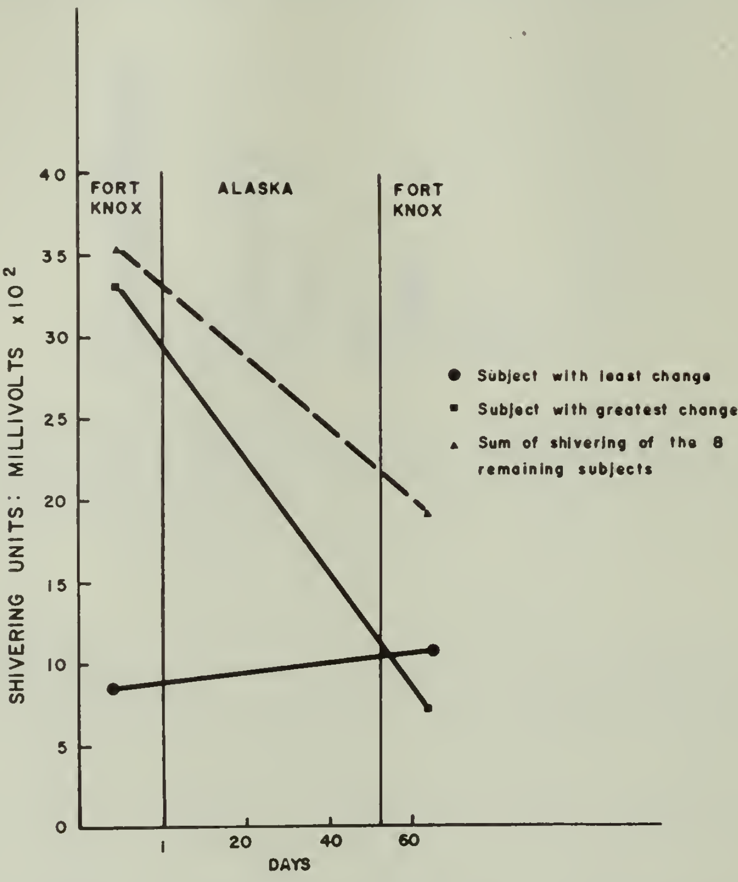


FIG. 5. The response of ten soldiers to a 52-day stay in Alaska. The lower solid line of the subject with no real change in shivering was obtained from an individual who had spent the previous 6 months in Greenland. The line representing the subject with the greatest change was obtained from a subject whose immediate previous work had been as an indoor clerical worker

The cold exposure test utilized for this group consisted of 2 hr at 12.8 ∓ 0.5°C with the previously described variables being measured. The results of shivering activity are plotted in Fig. 5. The decrease in shivering of the group was statistically significant ($P < 0.01$). Heat production (per cent above basal) was 39.2 per cent prior to Alaska and 29.7 per cent after Alaska — a non-significant change ($P < 0.05$).

A change of extremity temperature in this group of subjects was studied before and after their trip by measuring hand cooling in an insulated box at —15°C as described under Methods. Although there was a tendency towards a decreased cooling rate, there was no significant difference ($P > 0.05$).

Comparisons Between Natural and Experimental Cold Acclimatization

In addition to differences in the retention of cold acclimatization, to be discussed below, there appear to be differences in the rate of change and probably in the depth of cold acclimatization between seasonal and chamber acclimatization. Fig. 6 compares the relative changes in mean shivering of the seasonally acclimatized, the Alaskan

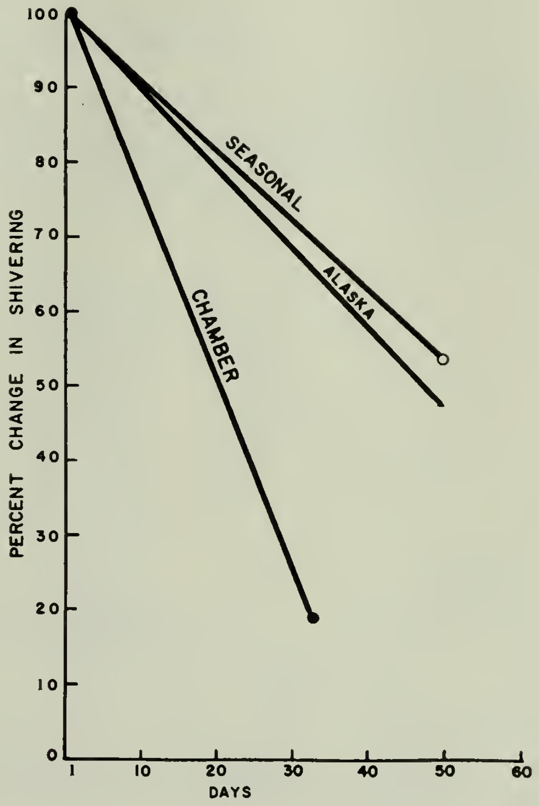


Fig. 6. Relative change in shivering, expressed as percent change from initial values, for the seasonal (Fort Knox), Alaskan, and chamber (experimental) subjects. For equivalent periods of time over the same period of the year, the rate of change and the amount of change is nearly identical for the two naturally acclimatized groups, while the chamber subjects have both a faster rate of acclimatization and a greater change from initial values

acclimatized and the chamber acclimatized subjects obtained over the same period of the year. The slope and percentage reduction of the seasonal and Alaskan groups are nearly identical. The rate of change for the chamber group and the total percentage reduction of shivering is greater than for either of the two preceding groups. This suggests that appropriately clothed individuals become acclimatized to the cold at nearly the same rate and to the same degree when compared to any pre-existing acclimatization regardless of the environmental temperature. It would appear that in order to achieve faster or greater acclimatization, subjects must be deliberately exposed in an unclothed, unprotected condition.

The Effect of Heat Acclimatization Upon Cold Acclimatization

The results in Fig. 7 are from six subjects cold acclimatized in a cold chamber at 13.5 ∓ 1.45°C for 28 days. Acclimatization and weekly testing were performed as before. The experiment began in October. Seven days following the last cold exposure, the subjects were exposed to heat acclimatization in a chamber at 40.5 ∓ 1.12°C

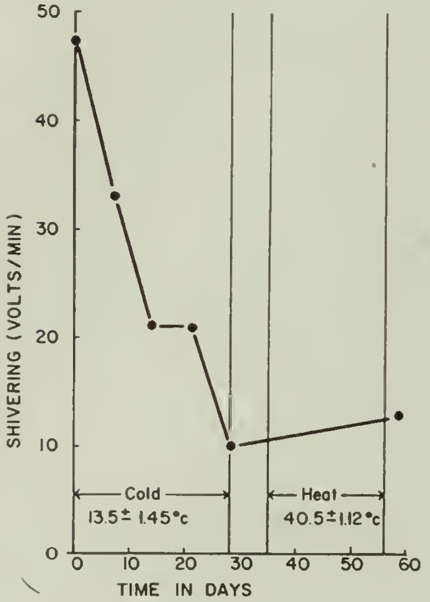


FIG. 7. The effect of heat acclimatization upon experimental cold acclimatization. Six subjects were employed, and were cold acclimatized at 13.5 °C for 28 days as described in the text

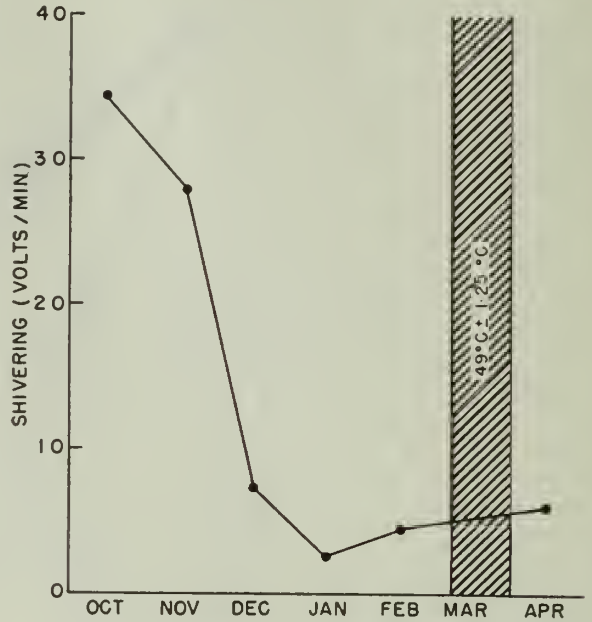


FIG. 8. The effect of heat acclimatization upon seasonal cold acclimatization. Six subjects were employed and were studied as described in the text and in Fig. 3

8 hr daily for 21 days. During the period of heat acclimatization, they were exercised on a treadmill at 3.5 miles/hr for 20 min in each hour, for a total daily distance of 9.36 miles of walking. Measurements of pulse rate, blood pressure and rectal temperature made before and after the exercise periods indicated that the criteria for acclimatization to heat had been satisfied (9, 23, 49). Following heat acclimatization, the shivering response was again measured in response to the standard cold exposure previously employed for this group. There was no significant change in shivering ($P > 0.05$).

The six subjects studied for seasonal cold acclimatization beginning in October (Fig. 8), were also heat acclimatized, in March, at a time when cold acclimatization was maximal. The same procedure of heat acclimatization was employed, except that the temperature of acclimatization was 49 ∓ 1.25 C. Again, heat acclimatization made no difference ($P > 0.05$) to the shivering response elicited by the standard cold test for this group of subjects. Heat production was also unchanged ($P > 0.10$).

These results would appear to demonstrate using cold acclimatization, conclusions drawn from heat acclimatization studies: that they are independent processes of physiological adjustment to environment, do not participate in the same processes of adaptation and may coexist simultaneously (26, 32, 56—58).

The Retention of Cold Acclimatization

The differences between seasonal and experimental cold acclimatization when rate of acclimatization and depth of acclimatization were compared, excited speculation concerning the long-term retention of artificial or experimental acclimatization.

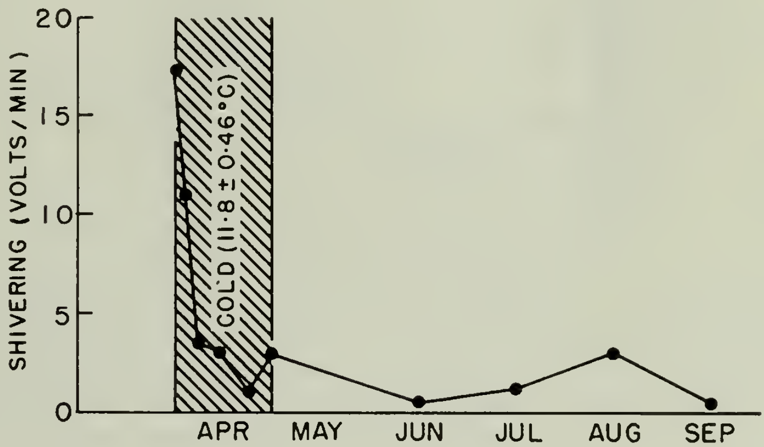


Fig. 9. The effect of chamber acclimatization upon the ability to retain cold acclimatization with a change in season. Values are means for the group

Accordingly, ten subjects were chamber acclimatized at 11.8 ∓ 0.46°C for 30 days and tested in our usual fashion. They were then studied once monthly at the test temperature for the succeeding 5 months. The study began in April, when seasonal acclimatization is near maximum. Fig. 9 shows that their cold acclimatization was unaffected by the change in season ($P > 0.05$). This should be contrasted to the marked increase in shivering shown by non-chamber acclimatized subjects as the year progressed over the same months (Fig. 4).

Parallel studies were then performed. Five subjects were chamber acclimatized in October to a temperature of 13.5 ∓ 1.45°C and tested monthly for 11 months. A group of controls were tested once monthly to the same cold stress, beginning in January. The results may be seen in Fig. 10. There is a parallel response in both groups to the cold test until June. In July, August and September, the chamber group continued to exhibit a low and unchanged level of shivering ($P > 0.10$), while the control group increased their rate of shivering remarkably ($P < 0.01$).

These results suggest that there is a real difference between artificial and natural cold acclimatization. It would appear that the ability to retain cold acclimatization is highly dependent upon the rate and degree of acclimatization, that there is in effect a "penetrance" of acclimatization, and that once this is achieved, it is little

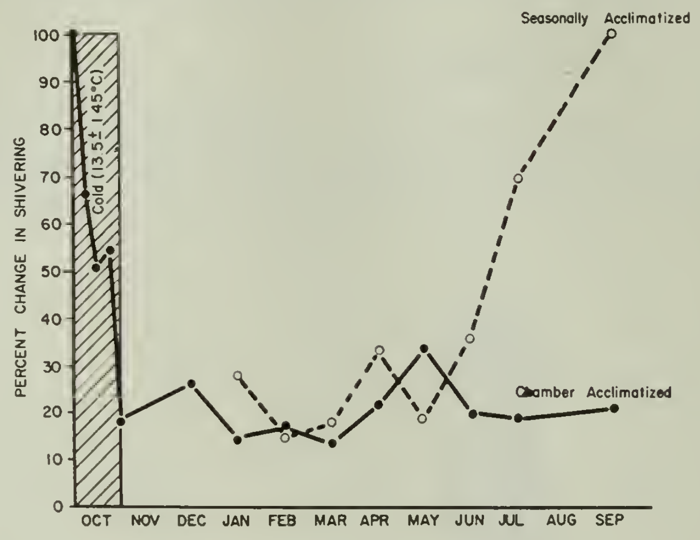


FIG. 10. The effect of chamber acclimatization upon the ability to retain cold acclimatization with a change in season, contrasted with a control group of non-acclimatized subjects followed over the same period of the year. The dotted line represents the mean values for the non-artificially acclimatized group, and the solid line the mean values for the artificially acclimatized group. Shivering is plotted as percent change from the maximum value

influenced by the environmental temperature. Natural or seasonal acclimatization, on the other hand, does not appear to have a deep "penetrance" and thus is lost when the environmental temperature rises in the summer months.

DISCUSSION

Whether measured by survival (10, 53, 55), changes in endocrine function (14, 22, 29, 34, 43), heat production (17, 31, 55), shivering (17, 19, 21, 30, 31, 54), oxygen uptake of tissue (20, 59, 60, 63) or changes in specific enzyme systems (4, 29, 40, 63), a true acclimatization to cold has been well established in animals.

The presence or absence of cold acclimatization has not been as universally accepted or demonstrated, and many investigators do not think it can occur. As a consequence of the present studies reasons for some of the differences of opinion can be perceived: the presence of clothing inhibits acclimatization; and an inadequate period of exposure will not permit adequate establishment of acclimatization. The reliability of criteria has also provided conflicting results: body temperature appears to decrease significantly only if the acclimatizing stimulus is sufficiently great (as in nude cold exposure). Peripheral temperature has not proved helpful in this series of studies. In the studies using natural exposure, and in the experimentally exposed groups no firm evidence was obtained which would suggest that a peripheral temperature change occurred as a result of cold exposure. In the seasonal study, only the trunk and lower leg temperatures increased significantly. In the chamber study only the upper leg temperatures showed a significant change which in this case was a decrease. All other areas had P-values of greater than 0.05. Our conclusions concerning the uselessness of peripheral temperature as an index of cold acclimatization are corroborated by some workers (16, 18, 27, 28, 35, 39, 41, 42, 48, 58, 62) but not by others (5, 15, 24, 26, 46, 51). Metabolism has not in these studies proved a consistently reliable index of acclimatization. In the experiments reported here, a significant change in oxygen consumption occurred only in those subjects who could be considered by the violence of their shivering response to be minimally cold acclimatized at the beginning of exposure. All subjects, of course, had an increased oxygen consumption in the cold.

Subjects who were measured in the summer had a consistently higher initial cold induced heat production than those measured in the winter. After acclimatization, heat production in both groups stabilized around 30 per cent above basal. It is proposed that the initial difference in heat production is a function of the degree of acclimatization prior to experimentation, and that the value after chronic cold exposure, represents in large measure, non-shivering heat production previously demonstrated in both unacclimatized and acclimatized animals (20, 21, 29, 60, 63).

These experiments appear to demonstrate that seasonal cold acclimatization takes place in man, but that it is not retained over the summer. On the other hand, chronic nude exposure in a cold chamber is well retained at least through one summer season. This would suggest that retention is a function of acclimatization achieved or of "penetrance" of acclimatization. The inability of heat acclimatization to affect either artificially or naturally induced cold acclimatization together with the demonstrations of others (26, 32, 56—58), that heat acclimatization is unaffected by cold exposure, indicates that both acclimatizations can coexist in an individual. The loss of seasonally acquired cold acclimatization over the summer period is considered by us to be due not only to the lack of "penetrance" but also to the absence of the adequate acclimatizing stimulus. Therefore it is postulated that heat and cold acclimatization are not mutually exclusive, the loss of one during change of seasons is due to the absence of the adequate stimulus and not to the presence of the other.

The studies of naturally occurring acclimatization at Fort Knox and in Alaska seem to demonstrate that appropriately clothed individuals acclimatize to the same extent irrespective of the ambient temperature of the environment. Since chamber acclimatization produces both a faster rate and a greater degree of acclimatization, it does not appear that the mere act of living in a cold climate even under field conditions is any guarantee that man will cold acclimatize to the full potential of his ability. It would therefore appear that the ambient temperature actually next to the skin determines the amount and rate of cold acclimatization (50).

In both animals and man the underlying change in physiology implied by the decrease or disappearance of shivering and the maintenance of homeothermy by non-shivering heat production, suggests that some important changes at the tissue and cellular level have taken place. The possible sources of non-shivering heat production are suggested by previous animal studies on liver (40, 59, 60, 63), muscle (20, 21, 29, 60), hormones (14, 22, 29, 34, 43) and enzyme systems (4, 5, 29, 40, 63). But to date evidence is insufficient to allow firm conclusions to be drawn as to the mechanisms involved.

These studies appear to demonstrate that man has a physiological adaptation to the cold, that this can be artificially induced at a faster rate and to a greater degree than naturally occurring cold acclimatization, that acclimatization in clothed individuals is similar in rate and degree regardless of ambient environmental temperature, that heat acclimatization does not affect either artificial or natural cold acclimatization, and that artificial cold acclimatization is retained through the summe months while seasonal acclimatization is not.

In conclusion, we find cold acclimatization to be a phenomenon requiring controlled conditions for its definitive and measurable occurrence. More so than heat acclimatization, it is an elusive physiological property of man, not capable of easy definition. To date shivering loss appears to be the only measurement that has any degree of precision in defining the presence or absence of acclimatization to cold. Future experimental studies in this field with humans must be conscious of the effects produced by previous thermal experience, by clothing, by exposure time, by seasonal change, and of the variability of skin and rectal temperatures and oxygen consumption as indices of acclimatization.

REFERENCES

1. ADAMS T. and E. J. HEBERLING, Human physiological responses to a standardized cold stress as modified by physical fitness. *J. Appl. Physiol.* **13**, 226 (1958).
2. ADOLPH E. F. and G. W. MOLNAR, Exchanges of heat and tolerances to cold in men exposed to outdoor weather. *Amer. J. Physiol.* **146**, 507 (1946).
3. BADER R. A. J., W. ELIOT and D. E. BASS, Hormonal and renal mechanisms of cold diuresis. *J. Appl. Physiol.* **4**, 649 (1952).
4. BAKER D. G. and E. A. SELLERS, Carbohydrate metabolism in the rat exposed to a low environmental temperature. *Amer. J. Physiol.* **174**, 459 (1953).
5. BALKE B., H. D. CREMER, K. KRAMER and H. REICHEL, Untersuchung zur Kälteanpassung. *Klin. Wschr.* **23**, 204 (1944).
6. BARLOW J. S., *Measurements of Changes in Hematocrit, Plasma Specific Gravity, and Plasma Sodium in Troops Taking Part in Arctic Winter Exercises.* Defense Research Board Canada, DRNL Tech. Paper No. 13 (1954).
7. BASS D. E., C. R. KLEEMAN, QUINN M., A. HENSCHEL and A. H. HEGNAUER, Mechanisms of acclimatization to heat in man. *Medicine* **34**, 323 (1955).
8. BAZETT H. C., F. W. SUNDERMAN, J. DOUPE and J. C. SCOTT, Climatic effects on the volume and composition of the blood in man. *Amer. J. Physiol.* **129**, 69 (1940).

9. Bean W. B. and L. W. Eichna, Performance in relation to environmental temperature. Reaction of normal young men to simulated desert environment. *Fed. Proc.* **2**, 144 (1943).
10. Blair J. R., *in Trans. First Conf. on Cold Injury* (edited by M. I. Ferrer), pp. 207—33. Josiah Macy Jr. Foundation, New York (1952)
11. Bly C. G., R. E. Johnson, R. M. Kark, C. F. Consolazio, H. L. Swain, A. Lawdani, M. A. Maloney, W. G. Figueroa and L. E. Imperiale, Survival in the cold. *U. S. Armed Forces Med. J.* **1**, 615 (1950).
12. Brown G. M., G. S. Bird, T. J. Boag, L. M. Boag, J. D. Delahaye, J. E. Green, J. D. Hatcher and J. Page, The circulation in cold acclimatization. *Circulation* **9**, 813 (1954).
13. Brown G. M., G. S. Bird, L. M. Boag, D. J. Delahaye, J. D. Hatcher and J. Page, Blood volume and the basal metabolic rate of esquimos. *Metabolism.* **3**, 247 (1954).
14. Brown-Grant K., Changes in the thyroid activity of rats exposed to cold. *J. Physiol.* **131**, 52 (1956).
15. Carlson L. D., H. L. Burns, T. H. Holmes and P. P. Webb, Adaptive changes during exposure to cold. *J. Appl. Physiol.* **5**, 672 (1953).
16. Conley C. L. and J. L. Nickerson, Effects of temperature change on the water balance in man. *Amer. J. Physiol.* **143**, 373 (1945).
17. Cottle W. H. and L. D. Carlson, Regulation of heat production in cold-adapted rats. *Proc. Soc. Exp. Biol. N. Y.* **92**, 845 (1956).
18. Daniels F., Jr., D. C. Fainer, C. L. Bonmarito and D. E. Bass, Acclimatization to cold in man. *Fed. Proc.* **10**, 32 (1951).
19. Davis T. R. A. and J. Mayer, The nature of the physiological stimulus for shivering. *Amer. J. Physiol.* **181**, 669 (1955).
20. Davis T. R. A., D. R. Johnston, F. C. Bell and B. J. Cremer, The regulation of shivering and non-shivering heat production during acclimatization of rats. *Amer. J. Physiol* **198**, 471 (1960).
21. Davis T. R. A. and J. Mayer, Demonstration and quantitative determination of the contribution of physical and chemical thermogenesis on acute exposure to cold. *Amer. J. Physiol.* **181**, 675 (1955).
22. Depocas F., The calorigenic response of cold-acclimated white rats to infused noradrenaline. *Canad. J. Biochem. Physiol.* **38**, 107 (1960).
23. Eichna L. W., W. B. Bean, W. F. Ashe and N. Nelson, Performance in relation to environmental temperature. *Bull. Johns Hopkins Hosp.*, **76**, 25 (1945).
24. Elsner R. W., *Some Acclimatizing Responses of Man to Prolonged Cold Exposure.* Arctic Aeromed. Lab. USAF, Report No. 1, Project No. 8-7951, Nov 1955 (ASTIA No. AD-95930).
25. Forbes W. H., D. B. Dill and F. G. Hall, The effect of climate upon the volumes of blood and of tissue fluid in man. *Amer J. Physiol.* **130**, 739 (1940).
26. Glaser E. M., Acclimatization to heat and cold. *J. Physiol.* **110**, 330 (1949).
27. Glickman N., R. W. Keeton, H. H. Mitchell and M. K. Fahnestock, The tolerance of man to cold as affected by dietary modifications: High versus low intake of certain water soluble vitamins. *Amer. J. Physiol.* **146**, 538 (1946).
28. Glickman N., T. Inouye, R. W. Keeton and M. K. Fahnestock, Comparison of physiological adjustments of human beings during summer and winter. *Heating, Piping.* **20**, 113, 1948.
29. Hart J. S., Metabolic alterations during chronic exposure to cold. *Fed. Proc.* **17**, 1045 (1958).
30. Hart J. S., O. Heroux and F. Depocas, Cold acclimatization and the electromyogram of unanesthetized rats. *J. Appl. Physiol.* **9**, 404 (1956).
31. Heroux O., J. S. Hart and F. Depocas, Metabolism and muscle activity of anesthetized warm and cold acclimatized rats on exposure to cold. *J. Appl. Physiol.* **9**, 399 (1956).

32. Henschel A., H. L. Taylor and A. Keys, Persistence of heat acclimatization in man. *Amer. J. Physiol.* **140,** 321 (1943).
33. Hicks C. S. and R. F. Matters, The standard metabolism of Australian aborigines. *Austr. J. Exp. Biol. Med. Sci.* **11,** 177 (1933).
34. Hsieh A. C. L. and L. D. Carlson, Role of adrenaline and noradrenaline in chemical regulation of heat production. *Amer. J. Physiol.* **190,** 243 (1957).
35. Horváth S. M., A. Freedman and H. Golden, Acclimatization to extreme cold. *Amer. J. Physiol.* **150,** 99 (1947).
36. Horváth S. M., H. Golden and J. Wager, Some observations on men sitting quietly in extreme cold. *J. Clin. Invest.* **25,** 709 (1946).
37. Houghten F. C., A. A. Rosenberg and M. B. Ferderber, Seasonal variation in reaction to hot atmospheres. *Trans. Amer. Soc. Heat. and Vent. Eng.* **46,** 185 (1940).
38. Irving L., Human adaptation to cold. *Nature Lond.* **185,** 572 (1960).
39. Keeton R. W., E. H. Lambert, N. Glickman, H. H. Mitchell, J. H. Last and M. K. Fahnestock, The tolerance of man to cold as affected by dietary modifications: Proteins versus carbohydrates and the effect of variable protective clothing. *Amer. J. Physiol.* **146,** 66 (1946).
40. Kline D., C. McPherson, E. T. Pritchard and R. J. Rossiter, Effect of exposure to a cold environment on labeling of phospholipid in rat liver slices. *Proc. Soc. Exp. Biol. N. Y.* **92,** 756 (1956).
41. Kreider M. B., P. F. Iampietro, E. R. Buskirk and D. E. Bass, Quartermaster R. and E. Comm., Natick, Mass. Tech. Report EP-117, July (1959).
42. LeBlanc J., Evidence and meaning of acclimatization to cold in man. *J. Appl. Physiol.* **9,** 395 (1956).
43. LeBlond C. P., J. Gross, W. Peacock and R. D. Evans, Metabolism of radio-iodine in the thyroids of rats exposed to high and low temperatures. *Amer. J. Physiol.* **140,** 671 (1943).
44. MacLean D. L.and R. C. Partridge, Seasonal change in the body's response to ventilative conditions. *J. Indust. Hyg.* **22,** 244 (1940).
45. Meehan J. P., Racial and individual differences in the peripheral vascular response to a cold stimulus. *Amer. J. Physiol.* **179,** 657 (1954).
46. Meehan J. P., Body heat production and surface temperature in response to a cold stimulus. *J. Appl. Physiol.* **7,** 537 (1955).
47. Miller A. J., Study of certain blood properties in healthy men transferred from a subtropic to a subarctic environment. *J. Aviat. Med.* **20,** 201 (1949).
48. Mitchel H. H., N. Glickman, E. H. Lambert, R. W. Keeton and M. K. Fahnestock, The tolerance of man to cold as affected by dietary modification: Carbohydrate versus fat and the effect of frequency of meals. *Amer. J. Physiol.* **146,** 84 (1946).
49. Robinson S., E. S. Turrell, H. S. Belding and S. M. Horvath, Rapid acclimatization to work in hot climates. *Amer. J. Physiol.* **140,** 168 (1943).
50. Scholander P. F., K. L. Anderson, J. Krog, F. V. Lorentzen, and J. Steen, Critical temperature in Lapps. *J. Appl. Physiol.* **10,** 231 (1957).
51. P. F. Scholander, H. T. Hammel, J. S. Hart, D. H. Le Messurier and J. Steen, Cold adaptation in Australian aborigines. *J. Appl. Physiol.* **13,** 211 (1958).
52. Scholander P. F., H. T. Hammel, K. L. Anderson and Y. Lyning, Metabolic acclimation to cold in man. *J. Appl. Physiol.* **12,** 1 (1958).
53. Sellers E. A., S. Reichman, N. Thomas, Acclimatization to cold: natural and artificial. *Amer. J. Physiol.* **167,** 644 (1951).
54. Sellers E. A., J. W. Scott and N. Thomas, Electrical activity of skeletal muscle of normal and acclimatized rats on exposure to cold. *Amer. J. Physiol.* **177,** 372 (1954).

55. Sellers E. A., S. Reichman, N. Thomas and S. S. You, Acclimatization to cold in rats metabolic rates. *Amer. J. Physiol.* **167**, 651 (1951).
56. Spealman C. R., M. Newton and R. L. Post, Influence of environmental temperature and posture on volume composition of blood. *Amer. J. Physiol.* **150**, 628 (1947).
57. Stein H. J., R. A. Bader, J. W. Eliot and D. E. Bass, Hormonal alterations in men exposed to heat and cold stress. *J. Clin. Endocrin.* **9**, 529 (1949).
58. Stein H. J., J. W. Eliot and R. A. Bader, Physiological reactions to cold and their effects on the retention of acclimatization to heat. *J. Appl. Physiol.* **1**, 575 (1949).
59. Weiss K. A. and W. G. Moss, Effects of subtotal hepatectomy on response of the rat to cold exposure. *J. Appl. Physiol.* **10**, 131 (1957).
60. Weiss K. A., Adaptation of rats to cold air and effects on tissue oxygen consumption. *Amer. J. Physiol.* **177**, 201 (1954).
61. Winslow C-E. A., L. D. Herrington and A. P. Gagge, The reactions of the clothed human body to variations in atmospheric humidity. *Amer. J. Physiol.* **124**, 692 (1938).
62. Wyndham C. N. and J. F. Morrison, Adjustment to cold of bushmen in the Kalahari desert. *J. Appl. Physiol.* **13**, 219 (1958).
63. You S. S. and E. A. Sellers, Increased oxygen consumption and succin-oxidase activity of liver tissue after exposure of rats to cold. *Endocrinology* **49**, 374 (1951).

THE COOLING EFFICIENCY OF SWEAT EVAPORATION

B. GIVONI and H. S. BELDING

Research engineer, in charge of Indoor Climate Research, Building Research Station, Technion, Haifa, Israel

Professor of Environmental Physiology, Graduate School of Public Health, University of Pittsburgh, Pittsburgh, U. S. A.

Abstract—A theoretical analysis is presented which defines the cooling efficiency of sweat evaporation for clothed man, and shows effects of humidity, air motion, clothing and sweat rate on efficiency.

A "sweating" cylinder was constructed and used in a laboratory study of physical factors which affect the efficiency. The experimental results with regard to effects of air motion, humidity and clothing on evaporation efficiency were in good agreement with the theoretical analysis. Evaporative efficiency was found to be a function of relative evaporation, which is the ration between the actual evaporation and the maximum evaporative capacity of the environment.

Résumé—Les auteurs présentent une analyse théorique qui définit l'efficience réfrigérante de l'évaporation par sudation pour l'homme habillé et démontre les effets de l'humidité, du mouvement de l'air, des vêtements et du taux de la sudation sur cette efficience. Un cylindre de «sudation» a été construit et a servi dans une recherche de laboratoire à étudier les facteurs physiques qui affectent l'efficience. Les résultats expérimentaux de l'étude des effets du mouvement de l'air, de l'humidité et des vêtements sur l'efficience de l'évaporation concordaient parfaitement avec l'analyse théorique. On a constaté que l'efficience de l'évaporation était une fonction de l'évaporation relative, définie par le rapport entre l'évaporation réelle et la capacité évaporatoire maximale.

Auszug—Es wird eine theoretische Analyse vorgelegt, in der die kühlende Wirkung der Schweißverdunstung bei bekleideten Menschen definiert ist, und die die Wirkungen von Feuchtigkeit, Luftbewegung, Kleidung und Schweißmenge auf die Kühlwirkung aufzeigt.

Es wurde ein «schwitzender» Zylinder konstruiert, der für die Labor-Untersuchungen der physikalischen Faktoren, die die Kühlwirkung beeinflußen, benutzt wurde. Die experimentellen Ergebnisse hinsichtlich der Auswirkungen von Luftbewegung, Feuchtigkeit und Kleidung auf die Verdunstungs-Leistung stimmten mit der theoretischen Analyse gut überein. Es wurde festgestellt, daß die Verdunstungs-Leistung eine Funktion relativer Verdunstung ist, die wiederum das Verhältnis zwischen der tatsächlichen Verdunstung und der maximalen Verdunstungs-Kapazität der jeweiligen Umgebung darstellt.

THE evaporation of sweat is the principal mechanism for achieving thermal equilibrium in hot environments and even in temperate thermal conditions when physical work is being performed. A better understanding of the factors which determine the efficiency of sweat for evaporative cooling of the skin would enable more exact evaluation of the heat strain which is imposed on man and might point to ways for reducing such strain.

THEORETICAL CONSIDERATIONS

The efficiency of evaporative cooling can be defined in two ways.

(a) *Physical Efficiency of Sweat Evaporation*

The quantity of heat removed from the skin as a result of evaporation of sweat (i. e. evaporative cooling), relative to the potential cooling capacity of the evaporation (i. e. latent heat of total sweat evaporated), or

$$I_e = \frac{\text{evaporative cooling of skin}}{\text{latent heat of total sweat } \textit{evaporated}}$$

(b) *Physiological Efficiency of Sweating*

The quantity of heat removed by evaporation (i. e. evaporative cooling), relative to the total latent heat of the sweat secreted, or

$$I_s = \frac{\text{evaporative cooling of skin}}{\text{total latent heat of sweat } \textit{secreted}}$$

In this communication we deal only with physical efficiency, I_e.

In the qualitative sense, it is known that the evaporative cooling obtained from sweat depends mainly upon: the amount of sweat secreted and evaporated, humidity and air motion, and clothing when the latter is worn. These factors determine the locus of evaporation, whether directly on the skin or at some distance, for example from the clothing.

When evaporation is readily achieved, it takes place at or near the openings of the sweat pores. In this case almost all of the latent heat of vaporization must be taken from the skin, because the possibility of gaining the heat of vaporization by conduction from the skin to the outside surface of the thin sweat layer is much greater than for gaining it through the insulative air film which lies over the skin. But with the increase in the thickness of the sweat layer, and the formation of drops upon the skin and particularly on the hairs, a greater resistance to the heat flow from the body to the evaporating surface must be presented, and some larger fraction of the heat of vaporization must be taken from the ambient air, with a corresponding reduction in the cooling obtained for the body.

If the quantity of sweat, relative to the rate of evaporation, increases, part of the sweat passes to the clothes and evaporates there. In this case the possibility of heat flow from the ambient air to the locus of evaporation may be greater than from the skin, and the efficiency for skin cooling may be expected to be further reduced.

In this paper we examine some of these ideas by providing some quantitative data which show how clothing, air movement and humidity affect evaporative cooling of an electrically heated, sweating cylinder.

DEVELOPMENT AND USE OF A "SWEATING CYLINDER"

In oder to evaluate the efficiency of sweat evaporation, a device was built by which the measurement of the quantity of heat given from a surface to the process of evaporation was possible. This amount of heat was then related to the total latent heat of vaporization, and the cooling efficiency was calculated from the equation:

$$I_e = \frac{\text{heat taken from the surface}}{\text{latent heat of vaporization}}$$

The instrument consisted of a copper cylinder with its top and bottom sealed and thermally insulated with wood stoppers, about 1 in. thick. The length of the cylinder was 50.5 cm, and its diameter 13.7 cm, with surface area of 2170 cm^2 (excluding the top and bottom).

The instrument was heated internally by means of the heat from operation of a small, variable speed, electric motor, which also drove a small fan, to ensure better distribution of the heated air. The rate of heat input was controlled to any desired level with a variable transformer. The motor was run continuously at a rate of heat input which maintained the mean surface temperature at a predetermined level. The surface temperature was kept close to air temperature to minimize the heat exchange by convection and radiation.

The wall of the cylinder was tightly wound with two layers of 4-in gauze roller bandage to form a "skin" which would readily wick moisture. Water was supplied to the "skin" through a motor-driven syringe which could be operated at different speeds to maintain different rates of water output. The water was distributed through polyethylene tubes wound around the cylinder and perforated where they faced the cylinder.

The surface temperature was measured by means of nine thermocouples, imbedded in the "skin". Another thermocouple measured ambient temperature, and two thermocouples measured the internal temperature near the top and bottom of the cylinder.

The "clothing" of the instrument was a sleeve of light-weight denim, which was adjusted loosely, but had some contact with the surface of the cylinder. As applied in this way the effective surface of the clothing was about 2220 cm^2.

The cylinder was placed on a balance, having sensitivity of 1 g. In this way changes in the weight of the system due to accumulation or loss of water could be recorded at will.

PROCEDURE

Before each experiment, the temperature and humidity of the test room, and the temperature and "sweat-rate" of the instrument were equilibrated (to constant air and "skin" temperatures). When the rate of evaporation was below or above the rate of water supply, which could be adjusted only by steps, the latter was readjusted at the end of 1 hr, in order to keep both rates as nearly in balance as possible. When this adjustment was made, the rate of evaporation changed somewhat, and the experiment was considered as two separate experiments.

During each test, the instrument was weighed, the heat input checked, and the water content of the syringe recorded every 30—60 min. The temperatures of the air, and surface and inside of the cylinder were recorded at 4-min intervals by automatic recorder.

At the end of the test, the water supply was determined from the change in the water content of the syringe. The change in the weight of the instrument, when added or subtracted from the water input (depending on whether the weight decreased or increased, respectively), gave the amount of water evaporated. The evaporated water, multiplied by the latent heat of vaporization (taken at the experimental temperature as 0.58 kcal/g), gave the heat supplied to the process of vaporization.

The mean "skin" temperature was computed from the average of the readings of the nine surface thermocouples, and the difference between the "skin" and air temperatures was calculated. The heat loss or gain by convection and radiation ($C + R$) was evaluated from "calibration curves" as will be explained later. The heat input, as indicated by the wattmeter, was corrected for ($C + R$), and in this way the total heat supply from the heated cylinder to the evaporation was determined, assuming 1 W = 0.86 kcal.

The physical efficiency of evaporation, I_e, was computed and related to the various factors under study. The effect of each one on the efficiency was evaluated, as will be discussed later.

The vapor pressure of the air was determined from wet and dry bulb thermometers. Air temperature was determined with a thermocouple near the cylinder. Air motion was measured by means of Yaglou's heated thermometer. Readings of the Globe thermometer were used to check the uniformity of the environment and no appreciable deviation of the M. R. T. from air temperature was noticed ($\pm$ 0.5° F).

CONVECTIVE AND RADIATIVE HEAT EXCHANGE

In order to take into account the heat exchange by convection and radiation, a series of "calibration" runs were performed. The heat input into the dry instrument and its heat loss, corresponding to a given difference in temperature between the mean surface and the air temperatures, was recorded. In this way, "calibration" curves for the "dry" heat exchange in still and moving air when the instrument was "nude" and "clothed" were obtained; these are summarized in Table 1. The heat input (and heat loss), per degree of temperature difference, was expressed directly in watts, and this amount was added or subtracted (depending on whether the surface temperature was below or above the air temperature, respectively) from the "gross" heat input to the wetted cylinder in order to compute the heat given to evaporation.

Some degree of error exists in this procedure, as the thermal resistance of dry clothing is greater than that of wet clothing, but as the temperature difference was kept small, the error involved is believed to be of little importance.

Table 1. Convection and Radiation (kcal/°F) *and apparent insulation (clo)*

Clothing	Air motion (ft/min)	"Dry" heat exchange (kcal/°F)	Apparent insulation (clo)
nude	50	0.95	0.71
nude	250	1.97	0.34
clothed	30	0.74	0.91
clothed	250	1.20	0.56

EFFICIENCY OF EVAPORATION FROM "NUDE" SURFACE

Fig. 1 shows the efficiency as a function of the evaporation rate from the "nude" surface, for air motion of 30, 50 and 250 ft/min.

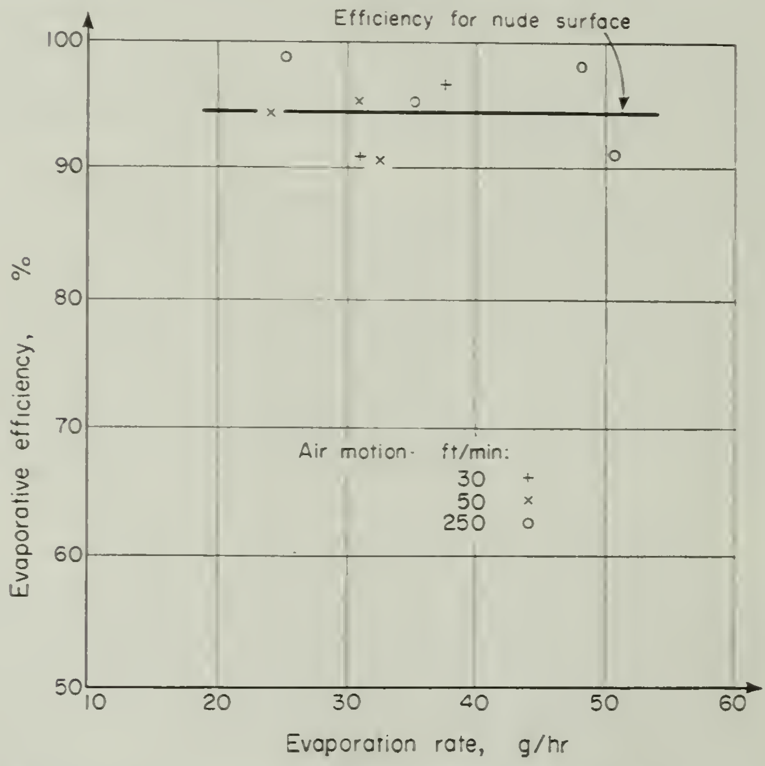


FIG. 1. Efficiency of evaporation from "nude" cylinder at various evaporation rates.

Except for one case, all the experiments yielded a result of high efficiency (above 91 per cent). Neglecting the single case with lower efficiency (which seems to be a result of some error), the mean is 95 per cent.

Within the limits of observation, there is no detectable effect of sweat rate or air motion on efficiency. This can be accounted for on the hypothesis that when the evaporation takes place on the surface, the primary resistance to heat flow is provided by the overlying film of air and lies outside the wetted layer. As a result, almost all the heat for evaporation, even when the air temperature is above the surface temperature, comes from the "skin".

THE EFFICIENCY OF EVAPORATION WHEN CLOTHED

Still Air, with High and Low Humidity

Fig. 2 shows the efficiency of evaporation for the clothed instrument, as a function of the evaporative rate, for still air, at high and low humidity. When the evaporation

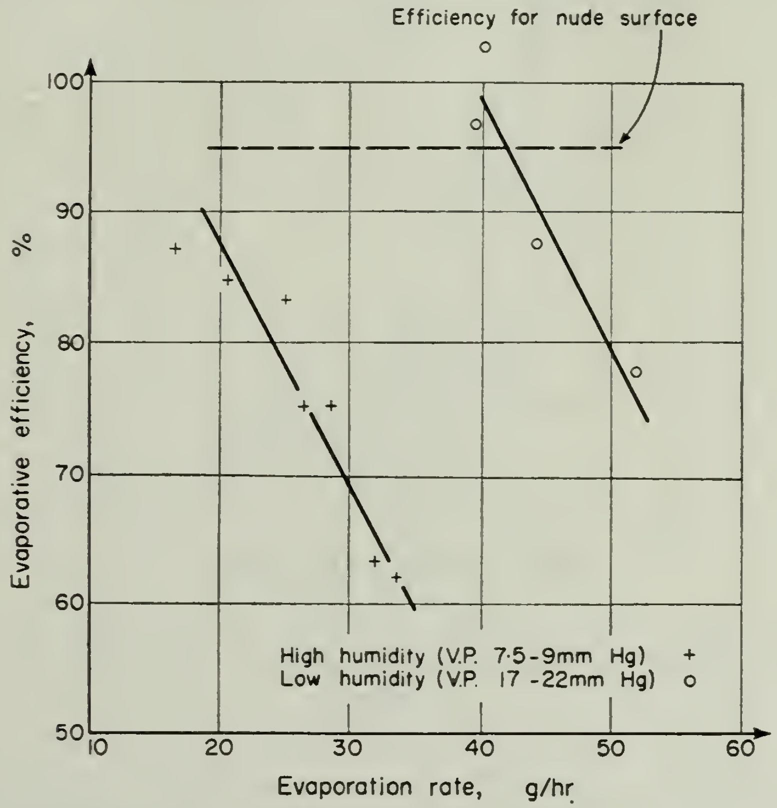


FIG. 2. Effect of humidity and evaporation rate on efficiency of evaporation from clothed cylinder at still air.

rate exceeds a certain limit, which depends upon the humidity of the air, the efficiency decreases rapidly with increasing evaporation rate.

From the same figure it can be seen that there exists a range of sweat rate in which efficiency is dependent upon the humidity of the air. The efficiency is high at low humidity, but decreases rapidly as humidity rises, until it reaches the upper limit of evaporative capacity.

Still and Moving Air, per Unit Vapor Pressure Difference between Surface and Air

Fig. 3 shows the efficiency of evaporation as a function of the evaporative rate, for air motion of 30 and 250 ft/min, when the evaporation is calculated per unit difference in vapor pressure. The first observable result from such transformation is that the difference between high and low humidity disappears. All the experiments

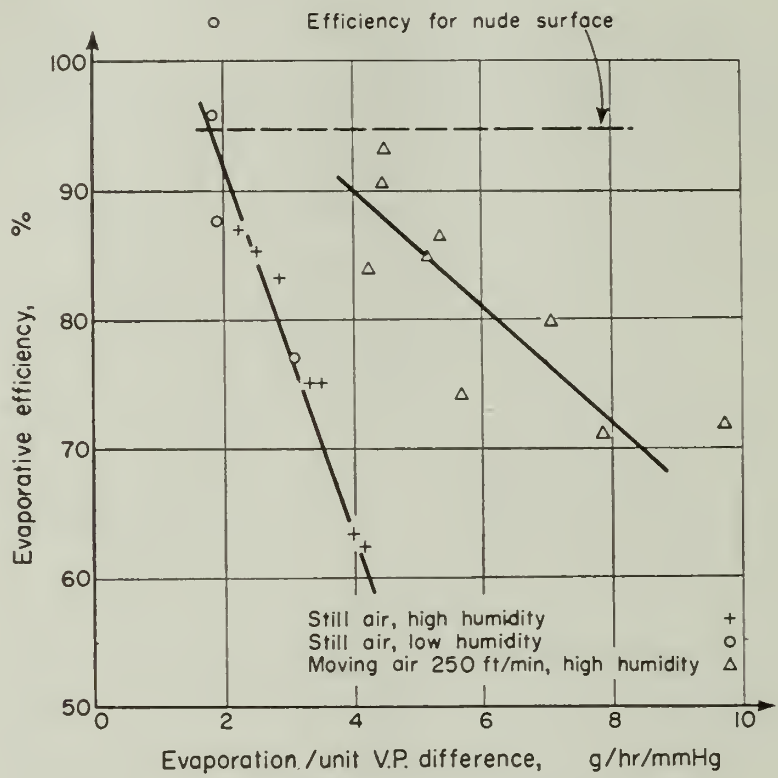


Fig. 3. Effect of air-motion and evaporation rate on the efficiency of evaporation from clothed cylinder, calculated per unit vapor pressure difference.

with still air fall on the same line, regardless of humidity. From Fig. 2 and 3 it can be seen that at a given air velocity, the factor which determines efficiency, besides the sweat rate, is the difference in vapor pressure, and that the efficiency is a linear function of the vapor pressure difference.

Fig. 3 shows also that with the same sweat rate and vapor pressure difference, air motion has great effect on the efficiency of evaporation. There is a limit in the sweat rate, at a given vapor pressure difference, above which the efficiency increases with high air motion.

The Combined Effect of Air Motion and Humidity on the Evaporative Capacity

It seems possible to reduce the relationship between the efficiency of evaporation from the clothed surface, and the various factors which affect it, into a simple and unified relationship, by looking upon the separate factors as a single factor, namely, the evaporative capacity of the environment.

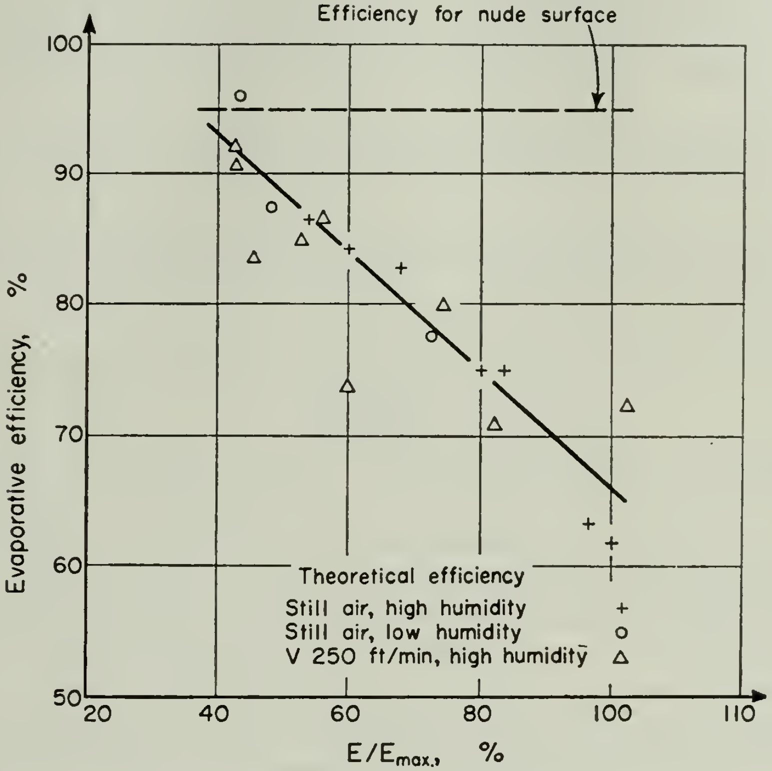


FIG. 4. Efficiency of evaporation from clothed cylinder as function of the ratio: E/E_{max}.

The evaporative capacity can be considered as a linear function of the vapor pressure difference and of some power of the air motion. Various powers are suggested in the literature, from 0.37 for the Fort Knox investigation up to 1.0 by Winslow. The experimental data of this study are not sufficient to enable an independent estimation of the form of the effect of air motion upon the evaporative capacity, but the 0.4 power gave the best agreement between the results of the experiments at 30 and 250 ft/min in the present study.

The evaporative capacity of the environment, or E_{max}, for this particular instrument when clothed was estimated to be:

$$E_{\text{max}} = 1.05(\Delta VP)\ V^{0.4}\ (\text{g/hr}/\times\ \text{mmHg}\ \ (\text{ft/min})^{0\text{-}4})$$

or, if calculated per m^2,

$$E_{\text{max}} = 4.4(\Delta VP)\ V^{0.4}\ (\text{g/hr} \times \text{m}^2 \times \text{mmHg}\ \ (\text{ft/min})^{0.4})$$

or, when expressed heat units,

$$E_{\max} = 2.55(\Delta VP)\, V^{0.4}\ (\text{kcal/hr} \times \text{m}^2 \times \text{mmHg}\ (\text{ft/min})^{0.4}).$$

It was found that efficiency of evaporation in the various conditions of this study was correlated with the percentage of the evaporative capacity, $E/E_{\max}$ represented in the rate of sweating. It seems appropriate to designate the ratio $E/E_{\max}$ as the relative evaporation or R. E. When the efficiency is expressed as a function of R. E., all the experimental results fall close to a single line regardless of the combinations of sweat rate, air motion and humidity which produced the given R. E.

Fig. 4 shows the cooling efficiency of evaporation as a function of the R. E, When R. E. was below 40 per cent (for the conditions of this particular instrument), the efficiency of evaporation was the same as in the case of the "nude" instrument. namely, near the theoretical value. When the relative evaporation exceeded 40 per cent. the efficiency started to decrease in proportion to the increase in the R. E.

AGREEMENT BETWEEN THE THEORETICAL ANALYSIS AND THE EXPERIMENTAL RESULTS

In the theoretical analysis it was argued that as long as the sweat is evaporated on the skin, the heat of vaporization is taken mainly from the body, but as the skin becomes wet, part of the sweat passes to the clothing and evaporates there, with resulting reduced cooling efficiency for the body.

The experimental results of this study not only are in good agreement with the theoretical analysis but also enable a simple explanation of these phenomena.

An hypothesis which can explain all the findings of this study can be formulated as follows. When the evaporative capacity of the air is very great relative to the rate of sweat production, the sweat is evaporated so rapidly that there is no possibility of moisture transfer into the clothing. The result is that almost all the heat of vaporization comes from the body because the heat transfer by conduction from the skin to the external surface of the thin layer of the moisture is much greater than the possible heat flow from the air.

This applies in the case of the nude skin of the surface as long as all of the sweat secreted can evaporate, regardless of the sweat rate and the environmental conditions. It may be, however, that a thick layer of sweat or formation of droplets on the skin or on the hairs in still, humid air will have enough resistance to reduce somewhat the rate of heat flow from the body and the efficiency. However, this situation was not tested in the present study.

When the body, or the instrument, is clothed, and the sweat rate relative to the evaporative capacity is high enough to produce a wet surface, part of the sweat can be absorbed by the clothing, wicked through, and evaporated on the surface of the clothing. Vaporization from the clothing removes a larger fraction of heat from the air and a correspondingly smaller fraction from the skin. The result is lower cooling efficiency when the sweat is evaporated from the clothing.

Factors which increase the evaporative capacity, relative to the actual sweat rate and evaporation, increase the rate of evaporation from the skin. When the skin remains dry, there is less possibility for the sweat to pass to the clothing and a higher proportion is evaporated on the skin, with resulting higher cooling efficiency. The effect of higher air motion or lower hamidity is the same, to increase the evaporative capacity, and so they have the same effect on efficiency. But when the skin becomes dry, any increase in air motion, or reduction in humidity cannot further improve the efficiency. This finding supports the physiological observations of the small effect of air motion at low humidity. Even at high humidity the effect of air motion on evaporation disappears when air speed is increased above a critical level. The near absence of humidity effect in the comfort zone can be explained in the same way.

LIMITATIONS OF INFERENCE FROM THE INSTRUMENT TO THE HUMAN BODY

Considerable caution is required in the application of results obtained from the instrument to problems involving the human body. Some of the differences between the instrument and man are enumerated below.

(a) The first difference is in the nature of the response to variations in the environmental conditions. The response of the human body is primarily a change in the sweat rate, whereas in the instrument the sweat rate is fixed by the operator and the effect is observed either in terms of change in heat input (or "metabolism"), or of change in internal and surface temperatures (with heat input fixed).

(b) The second difference is in the design and fit of real clothing. This partly derives from the irregularity of the human form.

(c) The third difference is in the relation between the skin and clothing. The instrument is stationary, and the relative position of the skin and the clothing is fixed. In this way the points of contact and the distance between the skin and the clothing are fixed. With the clothed human body, even at rest, there are constant changes in this respect, which increases the possibility for the sweat to pass to the clothing, and may thereby reduce the actual efficiency.

(d) The fourth difference also results from the immobility of the instrument. The "bellows" effect, by which the motion of the body and clothing promote air movement and air changes between the clothing and the skin and through the clothing, is absent.

(e) The fifth difference is the existence of limited "point sources" of water supply. This changes the pattern of water transfer from the skin to the clothing, and as a result affects efficiency.

It is obvious from this discussion that the conditions of the experiments cannot be used for numerical evaluation of the efficiency of sweat evaporation, or precise statement of the effects of the various factors which affect evaporation. This study can only demonstrate the existence of effect, the factors which influence it and the direction of action. Any actual evaluation of the magnitude of the effects has to be derived from observations on man in real clothing.

EFFECT OF THE EFFICIENCY FACTOR ON PARTITIONAL CALORIMETRY

As the existence of the phenomenon of reduced cooling efficiency has now been demonstrated, some modifications are called for in the procedure of partitional calorimetry in physiological studies.

Usually the "dry" heat exchange is computed by subtraction of two measured quantities: the metabolism and the evaporation (after correction for the heat storage, S), or

$$(C + R) = M - E + S$$

The evaporated sweat in this procedure was considered to be 100 per cent efficient in cooling the body. This procedure seems to be adequate in the case of nude subjects, but may be inaccurate in the case of clothed subjects. The actual cooling efficiency of sweat evaporation must be estimated before evaluating the evaporative heat loss.

By means of a procedure similar to that used in this study, the relationship between the evaporative capacity of the environment and the efficiency of the sweat rate and evaporation from clothed men may be established. Then the efficiency can be evaluated in each case from the ratio between the actual evaporation and the maximum evaporative capacity. The equation of thermal balance can then be rewritten as:

$$E \times I_e = M - (C - R) - S$$

At some future time it seems likely that I_e may be predictable from quantitative knowledge of its dependence on E_{max}, i. e. from knowledge of relative evaporation.

UMSTELLUNGEN IN DEN MUSKULÄREN REAKTIONEN DES MENSCHEN WÄHREND KÄLTEEINWIRKUNG

K. GOLENHOFEN
Physiologisches Institut der Universität Marburg/L., Deutschhausstrasse 2, Marburg/Lahn, Deutschland

Abstract—The increase of muscular activity in cold environments is not uniform in all parts of the muscular system. At first the peripheral muscles (forearm and calf) are more affected than the proximal ones. But during prolonged cooling, especially with the beginning of shivering, the tone in proximal muscles (quadriceps femoris) is increased accompanied by a decrease in forearm and calf. Muscular activity is thus centralized. The importance of the topography of muscular reactions during cold stress and cold acclimatization is discussed.

Résumé—Dans un milieu ambiant froid l'accroissement d'activité musculaire n'est pas uniforme dans toutes les parties du système musculaire. Au début les muscles périphériques (avant-bras et mollet) sont plus affectés que les muscles proximaux. Mais pendant un refroidissement prolongé, en particulier avec le commencement du frisson, le tonus musculaire dans les muscles quadriceps femoris s'accroît, accompagné d'une décroissance dans l'avant-bras et le mollet. L'activité musculaire est ainsi centralisée. L'importance de la topographie des réactions musculaires pendant le «stress» froid et l'acclimatation au froid est discutée.

Auszug—Die Zunahme der Muskeltätigkeit bei kalter Umgebung ist nicht für alle Teile des Muskelsystems gleich. Im Anfang werden die peripheren Muskeln (Unterarme und Waden) davon mehr betroffen als die proximalen Muskeln. Während ausgedehnter Abkühlungsperioden, besonders dann, wenn das Frösteln beginnt, wird jedoch die Spannkraft der proximalen Muskeln (quadriceps femoris) erhöht, begleitet von einer Abnahme derselben in den Unterarmen und Waden. Die Muskeltätigkeit wird dadurch zentralisiert. Es wird die Wichtigkeit der Topographie der Muskelreaktionen während deren Anspannung durch Kälteeinwirkung sowie die Kälte-Akklimatisierung besprochen.

Scholander *et al.* (1958a) haben nachgewiesen, daß die Kälteakklimatisation beim Menschen der weißen Rasse vorwiegend auf Umstellungen in der Wärmebildungs-Regulation ("metabolic acclimation") und weniger auf Veränderungen in der Regulation der Wärmeabgabe ("insulative acclimation") beruht. (Die andersartige Akklimatisation der Eingeborenen Australiens (Scholander *et al.*, 1958b) soll hier außer Betracht bleiben).

Die metabolische Akklimatisation kommt quantitativ darin zum Ausdruck, daß der Mensch lernt, auf gleiche Kältebelastungen mit stärkerer Zunahme des Energieumsatzes zu reagieren. Im Rahmen dieses thermoregulatorischen Trainings

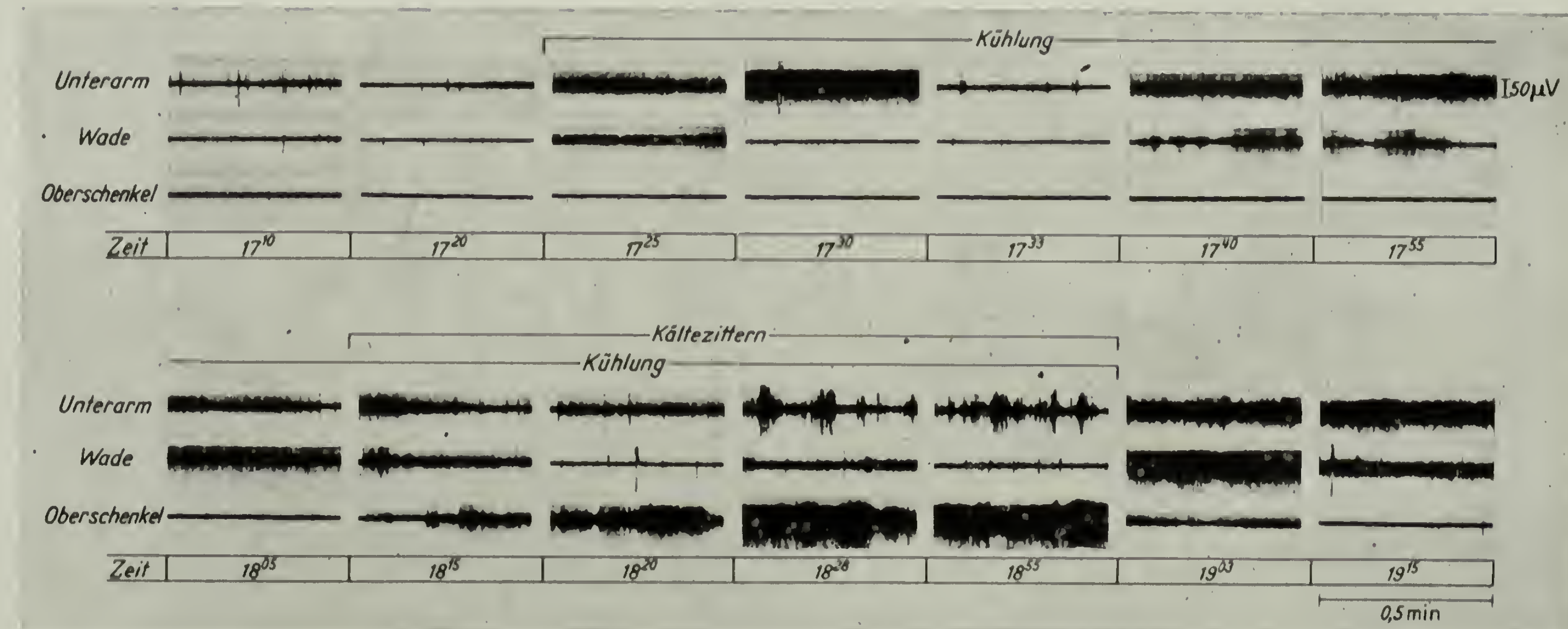


FIG. 1. «Zentralisation» der Muskelaktivität bei langer und starker Abkühlung des Menschen. Muskelaktionsströme von Unterarm, Wade und Oberschenkel. Während Kühlung war die nur mit Badehose bekleidete Versuchsperson einer Raumtemperatur von 10° C und direkter Kaltbewindung ausgesetzt (Klimakammer). (Nach Golenhofen, 1958.)

laufen aber auch gleichzeitig qualitative Umstellungen ab. So ist im Tierversuch nachgewiesen, daß mit Akklimatisation vor allem die Regulation der «Wärmebildung im engeren Sinn» (muskelaktivitätsunabhängige Wärmebildung) trainiert wird, die Tiere steigern ihren Umsatz mit geringerem Muskelzittern und insofern ökonomischer als Vergleichstiere.

Am Menschen fanden wir während Kältebelastungen bis zu mehreren Stunden qualitative Umstellungen in der Steuerung der Muskelaktivität, deren Bedeutung für die Kälteakklimatisation hier zur Diskussion gestellt werden soll.

Im Versuch der Abb. 1 wurden die Muskel-Aktionspotentiale mit Nudelelektroden in Unterarm, Wade und Oberschenkel gemessen (Einzelheiten bei Golenhofen). In der Aktivität des Unterarmes ist die typische, von Göpfert und Stufler beschriebene 3-phasische Reaktion erkennbar: einer initialen Aktivitätssteigerung (Initialphase) folgt nach vorübergehendem Abklingen (2, oder Anpassungsphase) eine erneute, anhaltende Aktivierung der Muskulatur (3, oder Auskühlungsphase). Die Abbildung zeigt aber, daß in diesem zeitlichen Ablauf nicht alle Muskelpartien einheitlich reagieren sondern vielmehr eine topographische Differenzierung besteht. Die initiale Aktivierung auf plötzliche Kühlung manifestierte sich hier vorwiegend am Unterarm und in geringerem Ausmaß an der Wade, während der Oberschenkel gar nicht ergriffen wurde, die distalen Muskelpartien waren also bevorzugt. Zu Beginn der 3 Phase bestand zunächst eine ähnliche Reaktionstopographie. Erst bei fortschreitender Kühlung, vor allem mit Einsetzen des sichtbaren Kältezitterns, wurde auch die Oberschenkelmuskulatur aktiviert, wobei der Tonus der distalen Muskelgruppen eher abnahm. Der Aktivitätsschwerpunkt verlagerte sich also mehr zum Körperkern hin, es trat eine «Zentralisation» der Muskelaktivität auf, wodurch der Wirkungsgrad in der Aufheizung des Körperkerns zweifellos erhöht wird.

Die bisherigen Befunde gestatten jedoch noch keine bindende Aussage über die Gesetzmäßigkeiten in der topographischen Differenzierung der Muskelaktivität. Wir haben darauf hingewiesen, daß Beziehungen zwischen der Qualität des Kälteerlebens (Affekt-Qualität) und der Reaktionstopographie zu bestehen scheinen.

Es wäre einerseits denkbar, daß der Kältegewöhnte die zentralisierte Muskelaktivierung bevorzugt. Andererseits fanden aber Scholander *et al.* (1958a), daß gerade der Akklimatisierte seine Extremitäten weniger auskühlen läßt. Wieweit allerdings diese periphere Aufheizung durch periphere Wärmebildung und wieweit durch gesteigerte Durchblutung erfolgt, ist noch nicht geklärt. Der letztere Weg wäre wohl ökonomischer, da Muskelzittern die Wärmeabgabe von der Haut begünstigt. Es muß aber auch daran gedacht werden, daß im Rahmen der Kälteanpassung der Nutzeffekt einer Muskelaktivierung dadurch erhöht werden könnte, daß die Muskulatur koordinierter und infolgedessen ohne so starke Zitterbewegungen angespannt wird.

Mit dem Nachweis einer Steuerung der Muskelaktivitäts-Topographie verwischen sich die Grenzen zwischen Regulation von Wärmeabgabe und Wärmebildung (physikalische und chemische Wärmeregulation): eine Verlagerung der Aktivität von der Körperschale in den Körperkern reduziert *ceteris paribus* die Wärmeabgabe.

Unter diesem Gesichtspunkt nimmt die Muskelaktivität eine gewisse Mittelstellung ein: die Steuerung ihrer Intensität wäre der chemischen, die ihrer Topographie aber der physikalischen Thermoregulation zuzurechnen.

LITERATUR

GÖPFERT H. und STUFLER R. (1952) Die Vorstadien des Kältezitterns bei geringer Abkühlung des Menschen. *Pflüg. Arch. Ges. Physiol.* **256,** 161—80.

GOLENHOFEN K. (1958) Zentralisation der Muskelaktivität bei Abkühlung des Menschen. *Pflüg. Arch. Ges. Physiol.* **266,** 665—8

GOLENHOFEN K. (1959). Die Reaktionen der menschlichen Muskulatur in Kälte und Affekt unter dem Gesichtspunkt der Thermoregulation. *Arch. physikal. Ther.* **11,** 45—58.

SCHOLANDER P. F., HAMMEL H. T., LANGE ANDERSEN K. und LOYNING Y. (1958a) Metabolic acclimation to cold in man. *J. Appl. Physiol.* **12,** 1—8.

SCHOLANDER P. F., HAMMEL H. T., HART J. S., DEMESSURIER D. H. und STEEN J. (1958b) Cold adaptation in Australian aborigines. *J. Appl. Physiol.* **13,** 211—18.

ASSESSMENT AND ALLEVIATION OF ENVIRONMENTS OF HIGH RADIANT TEMPERATURES

R. F. HELLON and G. W. CROCKFORD

Medical Research Council Unit for Research on Climatc and Working Efficiency, Department of Human Anatomy, University of Oxford, Great Britain

Abstract—An investigation is proceeding into problems of heat stress in the British steel industry. Attention is first being given to situations where the worker is surrounded, or almost surrounded, by hot surfaces. This occurs in the periodic demolition of furnaces, etc., before they are rclined or rebuilt. Observations have shown that air temperatures of up to 50° C and mean radiant temperatures of up to 200° C are not uncommon. Under these conditions the working time is limited to only about 5 min.

Suitable protection for the workers could be given if air-ventilated clothing is worn. Experiments with physical models have enabled the optimum type of material to be chosen for use in such clothing, but the final selection will have to be made on the results of *in vivo* tests in a specially built hot cubicle.

Résumé—On est en train d'étudier les problèmes concernant l'influencc de la chaleur dans les aciéries de Grande Bretagne. Avant tout on examine des situations dans lesquelles le travailleur est entouré ou presque par des surfaces très chaudes, comme dans le cas des démolitions périodiques des fournaises etc. avant un nouveau revêtement ou une reconstruction. On a observé qu'une température ambiante de 50° C et une température moyenne radiante jusqu'à 200° C ne sont pas rares. Dans ces conditions on réduit le temps de travail à cinq minutes seulement.

Les travailleurs pourraient être convenablement protégés s'ils portaient des vêtements aérés. Des essais avec des modèles physiques ont permis de choisir les meilleurs étoffes pour de tels vêtements, mais le choix définitif devra être basé sur les résultats d'épreuves *in vivo* dans une cabine construite pour ce but.

Auszug—Eine Untersuchung der Hitzebelastung in der Englischen Stahlindustrie findet momentan statt. Zunächst wird eine Situation untersucht, in der der Arbeiter von heissen Oberflächen völlig oder teilweise umgeben ist. Dies kommt in dem periodischen Herabreissen von Hochöfen usw. vor, welches stattfindet bevor diese wieder gefüttert oder wiederaufgebaut werden. Befunde zeigen, dass Lufttemperaturen bis 50° C, und mittlere Strahlungstemperaturen bis 200° C nicht ungewöhnlich sind. In diesen Umständen werden Arbeitszeiten bis auf 5 Minuten eingeschränkt.

Angemessener Schutz des Arbeiters könnte durch das Tragen ventilierter Anzüge vorgesehen werden. Durch Versuche mit physikalischen Modellen kann das bestmögliche Material für solche Anzüge gewählt werden, doch kann die entscheidende Auswahl erst auf Grund der Ergebnisse von *in vivo* Versuchen in einer besonders für diesen Zweck konstruicrten Hitzezelle gemacht werden.

There are many situations in industry where the heat given off by manufacturing processes may hinder, or even render inadequate, the heat-regulating powers of the body. This is particularly true of the steel industry and work is now being carried out to assess the severity of these particular microclimates and to provide some protection for the workers who are exposed to them. The study is still in progress so the following account must be in the nature of a progress report.

GENERAL SURVEY

A series of visits was made to steel works of varying types in Great Britain in order to inspect the situations where heat stress was said to be present. It was not possible to take any microclimatic measurements during this preliminary survey and only subjective impressions were collected. However, these, together with talks within the industry, have probably revealed most of the important situations.

It became apparent that hot jobs in steel works can be broadly divided into two groups according to the source of heat, i. e. whether the source was localized or general. The chief form of environmental heat was infra-red radiation and in many cases this was not accompanied by high air temperatures.

Group A : Omni-directional radiation

It frequently happens that a worker is completely or almost completely surrounded by hot surfaces. This occurs mainly in the course of maintenance operations such as the demolition or repair of various types of furnace. This work has to be done as quickly as possible for economic reasons, so that work must start when the furnace is only partially cooled. Heavy work has to be done by the men and the metabolic heat of this adds to the severity of the situation. Work is often only possible for five or so minutes and rest in a cool place has then to be taken. A second group of men may then take over the hot work.

Group B : Uni-directional Radiation

The other type of situation which is very common in steel works occurs when a man is subjected to radiation from one direction only. Usually this exposure is intermittent or mild, but sometimes the intensity of radiation or length of exposure make the situation undesirable or even intolerable.

Protection for workers in these two groups of situation could take various forms, but before specifying and devising this protection, it is necessary to assess the microclimates in terms of air temperature, air movement and radiant heat; humidities are generally low. Work so far has been concerned only with Group A.

TEMPERATURE SURVEY

Methods of measurement

Air temperatures were taken with Assmann psychrometers which had thermometers reading up to 140° C. Even with the polished double tubes round the thermometer bulbs, it was necessary to take readings as quickly as possible when radiation was severe. The reading was found to level off after about 2 min and then to rise again slowly as the radiation shields warmed up.

Air movements were measured with the ionization anaemometer (Welman and Lovelock, 1955) which gives an instantaneous reading of wind in all directions. On occasions the kata-thermometer with silvered bulb was also used (Bedford and Warner, 1933). For the measurement of radiation a robust and simple instrument was required which would take the least time to assess the temperature of the surroundings. The globe thermometer was therefore chosen in preference to various forms of radiometer. The original globe thermometer (Bedford and Warner, 1934) requires some 20 min. to come into equilibrium with its surroundings. In the globe thermometers used on the present survey, this time has been reduced to 6 min. This reduction is achieved by agitating the air in the globe with a small propeller and using a thermocouple in place of the usual thermometer (Hellon and Crockford, 1959).

Results

Cooling curves have been recorded from several furnaces, etc., readings being taken as soon as possible after the fuel is shut off and continuing for as long as 30 hr. Normal operating temperature is 1200—1650° C. After shut-down, the temperature drops rapidly and the roof is usually knocked in by a crane. From 3 to 4 hr later the mean radiant temperature (MRT) was found to be about 200° C and this gradually fell at a rate depending mainly on the size of the structure. Men have been observed to start work for short spells when the MRT was 160° C. In these situations the air temperature was very much lower and varied between 60° C and 20° C depending on the ambient conditions.

The worker is thus gaining heat by radiation and may or may not be losing heat by convection. The heat exchange by convection will, however, be small compared to the heat gain by radiation.

METHODS OF PROTECTION

Theoretically the best type of protection which can be given in a work place with high radiant temperatures is to screen and reflect the radiation. In the type of work which has been surveyed, portable screens are not practicable and protection has to be in the form of clothing.

Ideally the clothing should take the form of aluminized material which will reflect up to 95 per cent of the incident radiation. Unfortunately this material is unlikely to be suitable for two reasons: (1) the aluminium will soon wear off under the rough conditions of use; (2) the dust, which is always present, will coat the aluminium with an absorbing layer.

Irrespective of whether reflective layers are practicable or not, the suit will have to be supplied with air through a pipeline to allow the man to dissipate his own heat production. This air will also provide for respiratory needs and remove the heat which is conducted through the clothing.

Tests on physical models (Crockford and Hellon, unpublished) have shown that a very efficient form of insulation can be obtained by forcing air across a fabric, perpendicular to its surface. In a suit this can be done by closing the normal exits at wrists, ankles and the neck. The tests show that this arrangement would be efficient enough to allow the incident radiation to be absorbed, so that reflective layers are not necessary. For example, with an MRT of 200° C, air temperature of 50° C and air movement of 50 m/min, the surface of an absorbing non-reflective material would rise to 160° C. If an air flow across the material of 25 ft^3/m^2 per min is maintained, then the inner temperature of a layer of foamed plastic 1 cm thick and covered with a cotton material, is only 31° C. While such physical tests provide a valuable guide in the design of ventilated clothing, there are other complex problems, and the final selection of any one design must await experiments on subjects in simulated conditions.

REFERENCES

Bedford T. and Warner C. G. (1933) The influence of radiant heat and air movement on the cooling of the kata-thermometer. *J. Hyg. Camb.* **34,** 330.

Bedford T. and Warner C. G. (1934) The globe thermometer in studies of heating and ventilation. *J. Hyg. Camb.* **34,** 458.

Hellon R. F. and Crockford G. W. (1959) Improvements to the globe thermometer. *J. Appl. Physiol.* **14,** 649.

Welman W. L. and Lovelock J. E. (1955) An ionization anaemometer with omnidirectional response. *J. Inst. Hyg. Vent. Engrs.* **55,** 421.

MECANISME PHYSIOLOGIQUE DE LA TACHYCARDIE DUE A LA CHALEUR

R. LEMAIRE

Lab. de Physiologie de la Faculté de Médecine de l'Univ., Dakar, Sénégal

Abstract—An increase of temperature of the blood irrigating the cardio-accelerator centres is able by itself to produce a heart rate acceleration similar to that observed in subjects placed in hot environment.

Résumé—L'augmentation de la température du sang baignant les centres cardio-accélérateurs médullo-encéphaliques est capable à elle seule de provoquer une augmentation de la fréquence cardiaque analogue à celle que l'on constate chez les sujets placés en milieu chaud.

Auszug—Eine Erhöhung der Temperatur des Blutes, das das Herzbeschleunigungszentrum speist, allein genügt, um eine Beschleunigung der Herztätigkeit hervorzurufen, u. zw. ähnlich der, die dann eintritt, wenn Lebewesen in eine heiße Umgebung versetzt werden.

On sait que des sujets placés en milieu chaud augmentent la fréquence de leurs battements cardiaques. Le mécanisme de cette tachycardie est complexe. Il est classique cependant, d'admettre qu'une élévation discrète de la température du sang circulant, peut provoquer cette tachycardie en agissant sur les centres encéphalo-médullaires. On a soutenu d'autre part, que dans ces conditions expérimentales, les influx nerveux, nés au niveau des thermo-récepteurs périphériques, et conduits aux centres suivant les voies ascendantes de la thermicité, déterminaient une augmentation de la sensibilité de ces centres cardio-moteurs. Nous nous sommes demandés si l'élévation de température du sang, considérée comme facteur agissant sur les centres supérieurs, pouvait à elle seule, être capable de déterminer une augmentation de la fréquence cardiaque.

TECHNIQUE

Nous nous sommes adressés au chien chloralosé en utilisant une technique d'étude du fonctionnement des centres cardio-moteurs permettant d'explorer ces structures centrales, comme si elles étaient isolées (1).

L'encéphale d'un chien (B) est irrigué par un chien (A) transfuseur, préalablement hépariné, à l'aide d'un cathéter joignant la carotide droite de l'animal transfuseur (A) aux deux carotides de l'animal transfusé. Le retour veineux s'effectue par l'intermédiaire d'un autre cathéter réunissant les deux jugulaires du chien (B) à la jugulaire droite du chien (A). D'autre part, l'irrigation des centres médullaires du chien (B) est réalisée par la mise en place d'un cathéter artériel allant de la carotide gauche de l'animal transfuseur (A) à la sous-clavière gauche de l'animal trans-

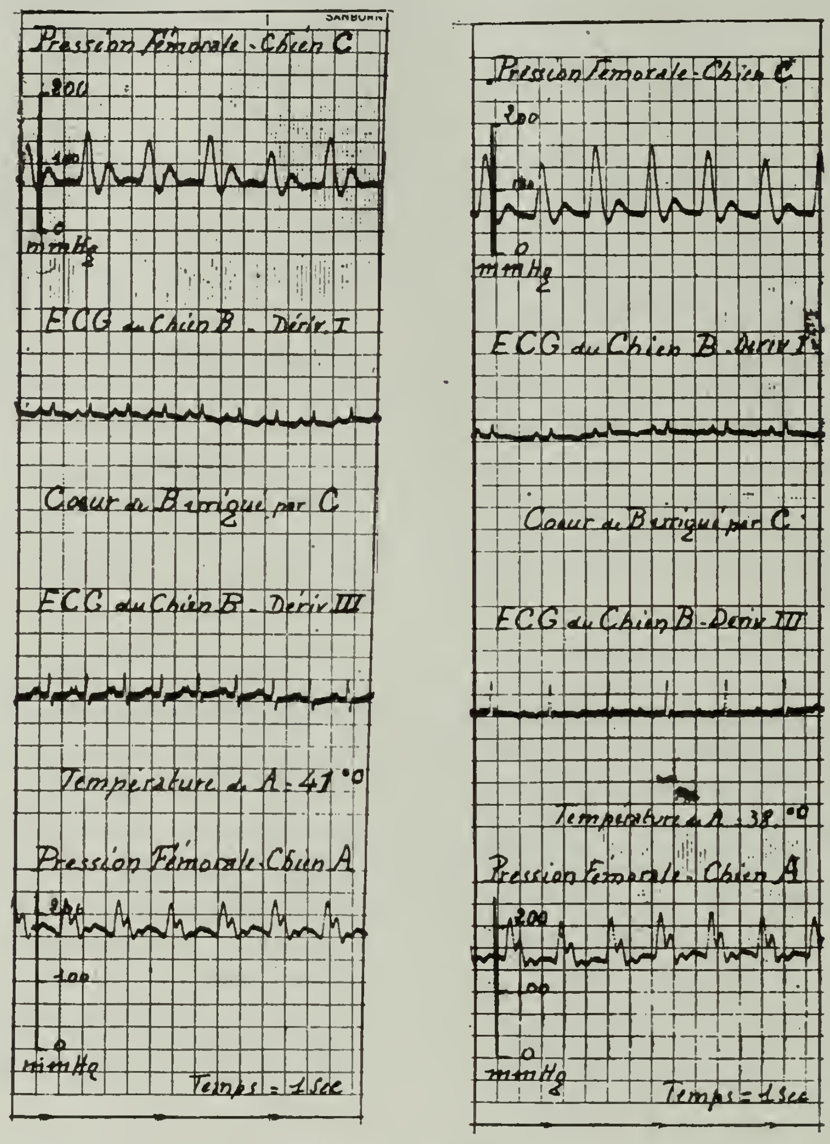


FIG. 1. Disposition des cathéters indiquant la technique du coeur et des centres irrigués de manière indépendante

fusé. Deux ligatures sont serrées l'une sur la crosse de l'aorte entre l'artère sous-clavière et le tronc commun des carotides, l'autre sur l'aorte descendante à l'endroit ou cette artère coupe le thorax, ainsi, le sang artériel du chien transfuseur (A) atteint la moelle par les artères inter-costales, branche de l'aorte descendante. Le sang veineux médullaire, drainé par les veines inter-costales qui se jettent dans le système azygos, retourne vers le chien transfuseur (A) par un cathéter enfoncé dans l'extrémité périphérique de la grande veine azygos du chien (B), l'autre extrémité du cathéter étant connectée à la veine jugulaire du chien (A).

Afin de réaliser l'exclusion circulatoire du coeur du chien (B), un troisième animal (C), également hépariné, irrigue cet organe. Le sang artériel du chien (C) est conduit au coeur du chien (B) par un cathéter dont une extrémité est introduite dans une carotide de l'animal transfuseur, tandis que l'autre passe à travers le tronc commun des carotides jusqu'à la crosse aortique du chien (B). Le sang veineux est capté au niveau de l'oreillette droite et retourne au chien (C) par un cathéter suivant le trajet de la veine cave supérieure, puis de la jugulaire pour être réuni à la veine jugulaire de l'animal transfuseur (C). La ligature de la veine cave inférieure du chien (B) complète l'exclusion circulatoire du coeur. Ainsi se trouve réalisée une préparation (Fig. 1) dans laquelle les centres encéphalo-bulbo-médullaires ont une irrigation indépendante de celle du coeur. On peut alors explorer l'activité des centres cardio-accélérateurs. Après vagotomie double, ces centres ne sont réunis à l'organe effecteur que par les nerfs sympathiques cervicaux.

Nous avons placé le chien (A) transfuseur des centres cardio-moteurs du chien (B) dans une boîte de chaleur et nous avons mesuré la température du sang circulant dans le circuit — corps du chien (A) — encéphale et moelle du chien (B).

RÉSULTAT ET CONCLUSION

Lorsque la température du chien (A) transfuseur des centres a atteint 40° C une polypnée thermique est apparue chez cet animal. Dans le même temps nous avons constaté l'apparition d'une augmentation de la fréquence cardiaque du chien (B)

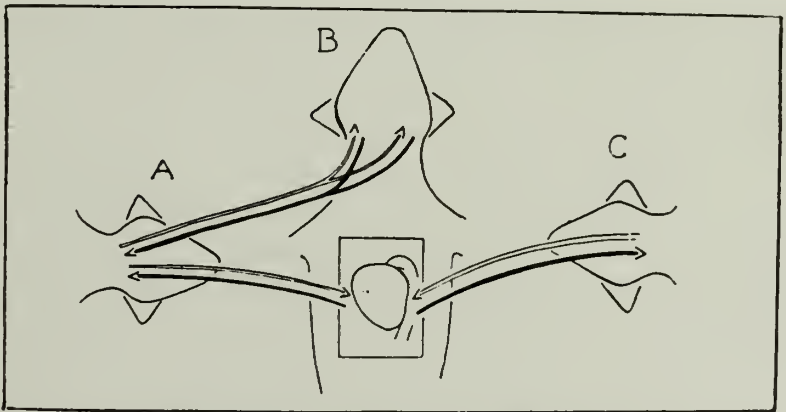


Fig. 2. Influence de l'élévation de température du sang sur les centres cardio-accélérateurs

réactif. Cette augmentation est nette (Fig. 2), elle est estimée à l'électrocardiogramme. Cette tachycardie ne peut être, étant donné les circonstances expérimentales, que la conséquence de l'augmentation de la température du sang circulant dans les centres. Il y a lieu de remarquer que, dans les conditions physiologiques, une augmentation de la température du sang circulant, de $\frac{2}{10}$ °C, est suffisante pour déclencher les mécanismes thermo-régulateurs (sudation, vaso-dilatation (2)). Dans nos expériences, il a été nécessaire d'élever davantage la température sanguine. D'autre part, dans notre préparation, le coeur continue à être irrigué avec un sang dont la température n'a pas été modifiée. La température du chien (*B*), propriétaire du coeur exploré, reste normale, l'animal n'étant pas placé en milieu chaud.

Au total, l'augmentation de la température du sang baignant les centres cardio-accélérateurs est capable à elle seule de provoquer une augmentation de la fréquence cardiaque, analogue à celle que l'on constate chez les sujets placés en milieu chaud.

BIBLIOGRAPHIE

1. R. LEMAIRE and M. BOURA, Une technique d'étude du fonctionnement des centres cardiomoteurs. *C. R. Acad. Sci., Paris* **243,** 518 (1956).
2. R. LEMAIRE, Physiologie de la sudation. *Arch. Biol. Thermo-climatique* (1956).

EFFETS DE L'HUMIDITÉ ABSOLUE SUR LA COURBE PONDERALE DU RAT BLANC

R. LEMAIRE et C. BENCENY
Lab. de Physiologie de la Faculté de Médecine de l'Univ., Dakar, Sénégal

Résumé—Des rats soumis à une tension de vapeur d'eau supérieure à 30 mm Hg présentent une chute pondérale. On observe 30% de décès. La même température (30 à 35 °C) avec une humidité absolue basse (tension de vapeur d'eau inférieure à 10 mm Hg ne détermine aucun trouble grave.

Abstract—When rats are subjected to a water vapour pressure higher than 30 mm Hg, they show a loss of weight. Thirty per cent of these animals die. With the same temperature (from 30 to 35° C) but a low humidity (water vapour pressure below 10 mm Hg) they suffer no serious trouble.

Auszug—Wenn Ratten einer Wasserdampfverdichtung von mehr als 30 mm Hg ausgesetzt werden, so zeigt sich bei Ihnen ein Verlust an Gewicht. 30% dieser Tiere sterben. Bei der gleichen Temperatur (30 bis 35 °C), jedoch einem geringeren Feuchtigkeitsgehalt (Wasserdampfverdichtung unter 10 mm Hg) nehmen die Tiere keinen ernsthaften Schaden.

De multiples travaux ont été consacrés à l'étude des différents facteurs climatiques et à l'examen de leur caractère agressif sur les êtres vivants. Température, rayonnement thermique, radiation, vélocité de l'air ont été étudiés sous différents climats ou recreés au Laboratoire, le comportement de l'homme, au repos ou exerçant une activité physique, étant observé dans ces différentes ambiances.

Il fut admis pendant de nombreuses années que, seul, le facteur température suffisait à caractériser une ambiance et son agressivité, lorsque sa valeur se situe en deçà ou au delà de celles définies pour délimiter la zone de confort thermique. Des recherches récentes ont montré que la signification isolée du facteur température est en fait très limitée et qu'une ambiance se caractérise davantage par la valeur du couple température-humidité. Rappelons que l'humidité de l'air, c'est-à-dire la quantité d'eau contenue dans une ambiance sous forme de vapeur, s'exprime de deux manières différentes:

(a) d'une manière «relative», c'est-à-dire en pourcentage de vapeur d'eau existant par comparaison avec la valeur de saturation;

(b) d'une manière «absolue», c'est-à-dire en grammes d'eau contenue dans un mètre cube d'air ou en pression de vapeur d'eau exprimée en millibars ou en millimèters de mercure.

Dans ce travail nous avons voulu plus particulièrement étudier l'action isolée du facteur humidité et dégager les effets physiologiques que ce facteur peut provoquer.

Dans ce but, nous avons, dans une première série de recherches, étudié le comportement d'animaux placés dans deux ambiances différant essentiellement par leur teneur en vapeur d'eau, les autres facteurs et en particulier la température étant les mêmes dans les deux circonstances expérimentales.

Les expériences ont été effectuées sur une population de rats blancs de race pure, de poids sensiblement identique.

La population fut répartie en trois groupes comprenant le même nombre d'animaux et exposés pendant neuf jours aux conditions climatiques suivantes:

(1) Le premier groupe fut placé dans une cage métabolique ou la température au thermomètre sec variait entre 33 et 35° C et l'humidité relative entre 95 et 100%, soit une pression de vapeur d'eau de 32 à 33 mm Hg.

(2) Le deuxième groupe fut placé dans une pièce climatisée où la température au thermomètre sec variait entre 30 et 35° C et l'humidité relative entre 35 et 40%, soit une pression de vapeur d'eau de 9 à 9,5 mm Hg.

(3) Le troisième groupe fut placé dans les conditions climatiques ambiantes, la température au thermomètre sec variant entre 22 et 24°C et l'humidité relative entre 50 et 70% soit une pression de vapeur d'eau de 13 à 14 mm Hg. Ce groupe constituait la série des animaux témoins.

Les animaux furent pesés chaque jour, leur aspect et leur comportement étant soigneusement observés.

Les rats du premier groupe exposés à une ambiance très humide subissent dans les premières 24 hr une proportion de décès s'élevant à 35%. La perte de poids des survivants s'élève en moyenne à 13% le premier jour. Par la suite les réactions sont différentes; si certains animaux continuent à perdre du poids, d'autres par contre, regagnent quelques grammes. Le fait important à noter est que, à la fin de l'expérience aucun des animaux de ce groupe n'a repris son poids initial. L'aspect des animaux et leur comportement (état de prostration total, pelage devenant terne) font penser que les rats de ce groupe ont éprouvé de grandes difficultés à supporter le facteur très agressif auquel il furent exposés.

Les rats du deuxième groupe, exposés à une ambiance faiblement humide, ont réagi différemment. Il faut tout d'abord observer que tous ont terminé l'expérience. La perte de poids ne survient que le deuxième jour et atteint à peine 5%. Les jours suivants les animaux regagnent du poids et récupèrent rapidement leur poids initial. L'aspect et le comportement des animaux sont totalement différents de ceux des rats du premier groupe, les animaux conservent toute leur vitalité. Ces observations tentent à montrer que l'agression subie par les animaux de ce groupe est moins sévère que celle à laquelle furent soumis les animaux du groupe précédent, et que la température élevée n'est pas un facteur très agressif.

Ces observations sont résumées dans le graphique établi en traçant pour chaque groupe d'animaux la courbe des moyennes de poids.

La courbe des animaux du premier groupe accuse une chute importante le premier jour. Le deuxième jour nous assistons à un gain de poids très faible, puis à une stabilisation dont la valeur est nettement inférieure à la moyenne initiale.

La courbe des animaux du deuxième groupe n'est pas du tout comparable. La perte de poids moins importante que celle des animaux du premier groupe ne se

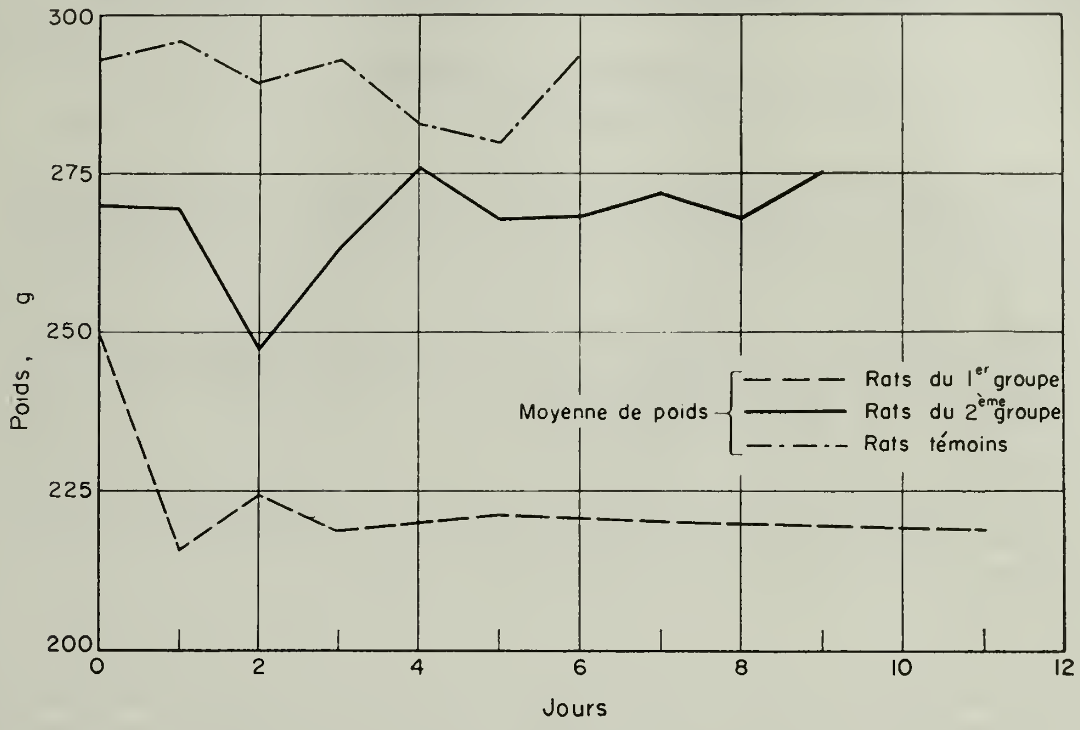


Fig. 1. Évolution de la courbe pondérale de 3 lots de 6 rats blancs. Courbe supérieure animaux témoins. Courbe moyenne animaux placés en faible humidité. Courbe inférieure animaux placés en forte humidité

produit que le deuxième jour. Cette perte est immédiatement suivie d'une reprise de poids jusqu'à récupération complète et stabilisation.

Enfin la courbe du groupe des rats témoins si elle accuse quelques fluctuations de peu d'importance ne donne cependant lieu à aucune observation particulière.

En résumé, les résultats obtenus et les observations faites sur deux séries de rats placés dans des conditions d'humidité très différentes à la même température, ne sont pas comparables. Les animaux semblent ne pas réagir d'une manière identique. Une humidité absolue élevée, (tension de vapeur d'eau supérieure à 30 mm Hg) détermine une chute pondérale prolongée, alors qu'une humidité absolue basse (tension de vapeur d'eau inférieure à 10 mm Hg) ne provoque que des perturbations transitoires.

INFLUENCE DE L'HUMIDITÉ DE L'AMBIANCE SUR LA TEMPÉRATURE CUTANÉE MOYENNE

R. LEMAIRE et C. BENCENY

Lab. de Physiologie de la Faculté de Médecine de l'Univ., Dakar, Sénégal

Abstract—In man, with a temperature of 19°C, the increase of humidity of environment (variation of from 3 to 15 mm Hg) has an effect on mean skin temperature; the more humid the temperature is the colder it is felt, and the cold becomes greater as humidity increases.

Résumé—Chez l'homme, pour une température de 19°C, l'élévation de l'humidité du milieu (variation de 3 à 15 mm Hg) influence la température cutanée moyenne. Une température sera ressentie d'autant plus froide qu'elle est plus humide; le refroidissement sera d'autant plus important que l'humidité sera plus élevée.

Auszug—Bei Menschen, die in einer Temperatur von 19°C leben, wirkt sich eine Erhöhung der Luftfeuchtigkeit (Schwankungen von 3 bis 15 mm Hg) auf die mittlere Hauttemperatur aus. Je feuchter die Luft wird, desto kälter wird sie empfunden, und die Kälte nimmt mit zunehmender Feuchtigkeit ebenfalls zu.

On sait que la température de la peau est un indicateur sûr de l'importance des échanges caloriques institués entre le milieu et les organes profonds des homéothermes, et c'est pour préciser la nature de ces échanges que de nombreuses études ont été entreprises sur les variations de la température cutanée selon les différents facteurs caractérisant le milieu extérieur. On a surtout considéré la température du milieu, on a distingué l'influence de la température de l'air ambiant mesurée au thermomètre sec de celle des rayonnements thermiques, on a étudié également l'influence du renouvellement de l'air. Toutes ces recherches ont été effectuées en admettant et en fixant une valeur moyenne pour l'humidité, le plus souvent 50%.

Il nous a paru intéressant de rechercher si, la température étant fixe, les variations de l'humidité de l'ambiance étaient capables d'influencer la température cutanée. Déjà Yaglou (1) avait constaté qu'une même température était perçue par les sujets d'autant plus chaude que l'humidité était plus élevée. Ces impressions ont été chiffrées par Zollner *et al.* (2) qui ont montré que la température cutanée augmente de manière significative lorsque la pression de vapeur d'eau varie de 5 à 40 mm Hg. La température du milieu reste fixe: elle a été choisie dans la partie supérieure de la zone de neutralité thermique (entre 27 et 33°C). Dans ces conditions, la température cutanée moyenne s'élève de 4 à 6 dixièmes de degrés quand l'humidité absolue augmente. La corrélation entre les deux phénomènes est satisfaisante.

Ce sont des observations semblables à celles de Yaglou qui nous ont amenés à entreprendre ce travail. Dans l'appréciation de températures froides, nous avons constaté qu'une même température était reconnue comme d'autant plus froide que l'humidité était plus élevée. Afin de nous assurer que ces sensations correspondaient bien à une réalité objectivée et mesurable, nous avons enregistré les variations de la température cutanée moyenne en fonction de l'humidité absolue de l'ambiance, la température restant fixe, choisie dans la partie inférieure de la zone de neutralité thermique (17—19° C).

TECHNIQUE

Nous nous sommes adressés à trois sujets en bonne santé agés de 25 ans, vêtus d'un short et de chaussures. Les températures cutanées ont été mesurées à l'aide de thermocouples, dont les variations étaient enregistrées par un potentiomètre électronique «Leeds-Northrop». Onze points ont été choisis, permettant de calculer la température cutanée moyenne. La prise de température durait 10 min. Ces mesures ont été effectuées à Dakar dans une chambre climatique, dans laquelle il est possible de faire varier indépendemment la température (entre + 10 et + 50°C) et l'humidité (entre + 10 et + 100%). La vitesse de la ventilation était inférieure à 0,25 m/sec. La température de l'ambiance était de 19° C au thermomètre sec. Les sujets ne recevaient pas de rayonnement particulier. La température des parois étant de 19° ± 0,25° C l'humidité relative a varié de 20% à 95%, l'humidité absolue a suivi une courbe parallèle (écarts allant de 3,3 à 15,1 mm Hg). Les sujets étaient au repos, dans des conditions voisines du métabolisme basal, les expériences étaient faites à la même heure pour les placer dans les mêmes conditions de dépense énergétique, un repos préalable dans la chambre climatique permettait d'adapter les sujets à l'écart de température entre l'extérieur et la chambre d'expériences (de 3 à 5° C) selon les expériences.

RÉSULTATS

Dans ces conditions expérimentales les résultats obtenus apparaissent dans Fig. 1. Chaque courbe en traits pleins représentent la température des sujets étudiés. En traits pointillés a été tracée la moyenne des trois courbes. Compte tenu des différences individuelles, cette courbe s'abaisse de 31,49° à 30,55° C lorsque l'humidité de l'ambiance augmente, la température de cette ambiance restant exactement la même. C'est aux faibles humidités que les différences sont les plus marquées. L'élévation de l'humidité ambiante abaisse donc la température cutanée moyenne.

D'autre part, choisissant 4 points de la surface cutanée, il est possible d'apprécier le refroidissement qui apparaît en fonction de l'humidité pour un même abaissement de température. Si pendant un même temps, pour une même température et pour un point donné de la peau, on compare l'abaissement de la température cutanée en ambiance d'humidité faible avec le même abaissement lorsque l'humidité est éle-

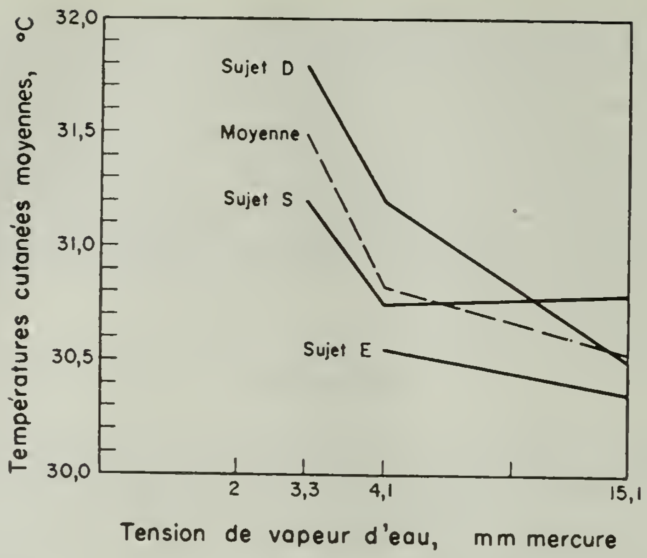


Fig. 1. Évolution de la température cutanée moyenne en fonction de la tension en vapeur d'eau d'une ambiance dont la température est restée fixe (19° C)

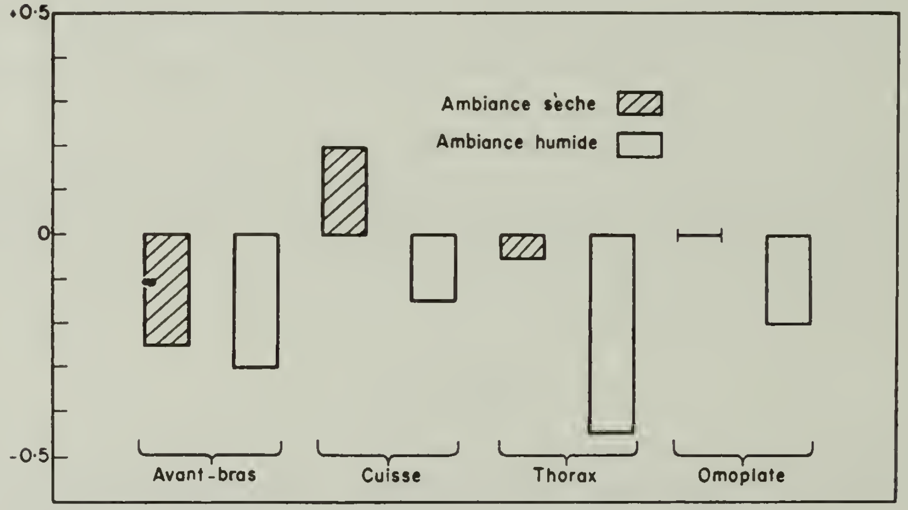


Fig. 2. Variation de la température de 4 points cutanés pendant une durée de 20 min. L'ambiance sèche correspond à une tension de vapeur d'eau de 3,3 mm Hg, l'ambiance humide à une tension de vapeur d'eau de 15 mm Hg. La température de cette ambiance reste fixée à 19° C

vée, on voit que le refroidissement est toujours plus marqué en milieu humide, sauf pour l'avant-bras ou les réactions sont voisines, le refroidissement de la cuisse, du thorax de l'omoplate sont plus importants quand l'humidité est élevée (Fig. 2).

CONCLUSION

Chez l'homme le degré d'humidité du milieu influence la température cutanée moyenne. Une température sera d'autant plus «froide» qu'elle est plus humide. D'autre part, le refroidissement sera d'autant plus important que l'humidité sera plus élevée.

BIBLIOGRAPHIE

1. C. P. Yaglou, *Physiology of Heat Regulation and Sciences of Clothing* (edited by L. H. Newburgh). Philadelphia (1949).
2. G. Zollner, R. Thauer et W. Kauffmann, *Pflüg. Arch. ges. Physiol.* **260,** 261 (1955).

ASPECTS OF THE BODY TEMPERATURE, AND HABITAT OF LARGE ANIMALS

C. P. LUCK and P. G. WRIGHT
Department of Physiology, Makerere College Medical School, Kampala, Uganda

Abstract—The hippopotamus *(Hippopotamus amphibius)* and white rhinoceros *(Ceratotherium simum)* are very similar in size and shape. They inhabit the same country and eat similar food. The habits of the hippopotamus are well defined: the days are spent in water, the nights grazing. The habits of the white rhinoceros are far less predictable; it may graze at any hour of the day and not necessarily seek either shade or water on hot days. Whereas, however, the top body temperature of the hippopotamus varies little at any time of day, that of the rhinoceros may vary 4.5° C between morning and afternoon, even on days that could hardly be considered seriously taxing, thermally speaking.

Certain ecological consequences of these behaviours will be mentioned, and also the differences in the skins of the two animals will be demonstrated and commented upon. The secretion of the "sweat" glands of the hippopotamus will be described and their possible significance discussed.

Résumé—L'hippopotame *(Hippopotamus amphibius)* et le rhinocéros blanc *(Ceratotherium simum)* sont très comparables en ce qui concerne leur taille et leur conformation. Ils habitent le même pays et se nourrissent d'une pâture semblable. Les habitudes de l'hippopotame sont bien précisées, le jour il le passe dans l'eau, la nuit il va paître. Le comportement du rhinocéros blanc est bien moins prévisible, il se peut qu'il aille paître à n'importe quelle heure de la journée et il ne recherche pas nécessairement soit de l'ombre, soit de l'eau pendant des journées torrides. Cependant tandis que la température céphalique de l'hippopotame varie peu à n'importe quel moment de la journée, celle du rhinocéros peut varier du matin à l'après-midi, et cela même pendant des journées dont la température peut, pour ainsi dire, à peine y avoir contribué.

Certaines conséquences écologiques de ces comportements seront citées, et les différences de la peau des deux animaux seront également expliquées et commentées. La sécrétion des glandes «sudoripares» de l'hippopotame sera décrite et leur signification éventuelle sera discutée.

Auszug—Das Flußpferd *(Hippopotamus amphibius)* und das weiße Rhinozeros *(Ceratotherium simum)* sind einander in Bezug auf Größe und Form sehr ähnlich. Sie leben beide in dem gleichen Land, und sie ernähren sich beide von ähnlicher Nahrung. Die Lebensgewohnheiten des Flußpferdes sind klar definiert: es verbringt die Tage im Wasser und in den Nächten grast es. Die Lebensgewohnheiten des weißen Rhinozerosses lassen sich bei weitem nicht so genau voraussagen; es kann vorkommen, daß es zu jeder beliebigen Tageszeit grast, und es ist nicht mit Bestimmtheit zu erwarten, daß es an heißen Tagen immer Schatten oder Wasser aufsucht. Während sich beim Flußpferd die höchste Körpertemperatur an den verschiedenen Tageszeiten wenig verändert, kann die Körpertemperatur des Rhinozerosses um 4.5° C zwischen Morgen und Nachmittag schwanken, und das auch an Tagen, die man in Bezug auf Wärme als nicht besonders anstrengend bezeichnen könnte.

Gewisse ökologische Folgerungen dieser Verhaltungsweise werden Erwähnung finden, und die Unterschiede in den Häuten der beiden Tiere werden ebenfalls herausgestellt und kommentiert werden. Die Sekretion der «Schweiß»-Drüsen des Flußpferdes wird beschrieben, und deren mögliche Bedeutung besprochen werden.

An inflexible deep body temperature is under certain circumstances a luxury that even the mammal may forego; this has been admirably shown by Schmidt-Nielsen and his fellow workers in their comparative physiological studies on the camel (1). This animal tolerates a considerable fluctuation in its internal temperature, and in consequence gains striking advantages in freedom of movement in hot climates.

Some elementary field studies undertaken in East Africa have provided further examples of how modifications of habitat and behaviour or modifications in physiological regulations can be possible alternative or complementary responses to climatic stresses.

These studies are being made on several of the largest land mammals; for this particular occasion we shall describe some of our findings on the hippopotamus and white rhinoceros.

Among the largest land animals, the hippopotamus *(Hippopotamus amphibius)* and white rhinoceros *(Ceratotherium simum)* are very alike in size and shape. They are both found within the same area of country, and both are grazers, living on land grasses.

Their differences in behaviour are, however, very striking. The hippopotamus is a nocturnal grazer, seldom found out of water long after dawn on an average African day; if he is so found, it is often because he has been driven from water by other hippopotamuses. On overcast, cool days, however, they may be seen about more frequently. The white rhinoceros, on the other hand, has a far wider range of behaviour; although often described, e.g. by Selous, as being active at dawn and dusk and resting in shade during the day, closer investigation (2) reveals that this behaviour is not nearly so predictable; the animals will frequently graze throughout a hot day without taking cover. Although fond of wallowing in swamps, they may ignore a wallow on a hot day and take to one on a cooler day in apparently a most arbitrary way. The white rhinoceros, therefore, seems to have a greater freedom of movement than the hippopotamus. When moreover, in search of grazing, hippopotamuses move from their primary source of water, they have to "colonize" a near area, developing a muddy patch into a wallow, ultimately large enough to contain a colony of hippopotamuses during the day, who can then graze the surrounding country during the night.

It seemed therefore interesting to take opportunities that arose from studying aspects of the anatomy and physiology of these animals. We have described elsewhere (3, 4), the findings on body temperature of these two animals, which show that the rhinoceros certainly, does not appear to suffer any inconvenience at all when the day body temperature fluctuates 4° C during the course of the day. Such a rise does not even provoke visible sweating. The hippopotamuses' temperature was always found to lie very close to 35.4° C at whatever time of day or night it was taken. It is possible that this animal's choice of habitat and its behaviour reflect a poor tolerance to a raised internal temperature. Until we have actually tried the experiment, which we hope shortly to do, we cannot of course say, but when we try to couple the animal's behaviour with any other need than a thermal one, we are hard put to it. The animal feeds entirely on land; it is a very formidable beast, having the most dangerous jaws of any land animals, so neither food nor defence seem adequate explanation for its aquatic behaviour (presumably living in water forms a valuable defence against man, but is hardly necessary against other living or extinct predators).

Let us consider certain anatomical and physiological adaptations which may be linked with these differences in behaviour.

The rhinoceros sweats on exertion, the sweat is pigmented, red (5), not viscous, flowing freely from glands around the ears, forehead and flanks. Unfortunately we know no more about it than that at the moment.

The glands producing the sweat are fairly small and occur, on the flank, 10—15 per cm². They lie bedded in the dermis, the cells show little specific affinity for basic or acid dyes, the glands being most remarkable for the very well developed myoepithelial cells (6).

The hippopotamus sweats profusely, whether at rest or not, on cool or hot days on land. The sweat as usually collected, is very viscous, red in colour and highly alkaline (pH 10.5). On standing it loses viscosity and changes to a brown colour.

Its most obvious chemical characteristics are represented in the following analysis:

sodium	18 mEq./l.
potassium	283 mEq./l.
calcium	0.5 mEq./l.
chloride	130 mEq./l.
bicarbonate	201 mEq./l.

A very small amount of an ether-soluble substance is present, which is probably a sterol.

The nature of the red pigment is unknown. Recent work has shown that several stages exist in the process of secretion, so that some variation is to be expected in different samples.

This fluid is produced by large (up to 10 mm diameter) glands situated below the dermis, and spaced about 20—30 mm apart (7). The ducts open usually near a group of scanty hairs.

Such a secretion is obviously highly specialized and certainly not well adapted for temperature regulation by recognised means. The unusually high concentration of potassium in the secretion might represent an excretory function by the skin, but one can see no particular reason for it.

A histological comparison of the skins of the rhinoceros and the hippopotamus shows interesting structural differences.

The surface of the rhinoceroses' skin is rough and pitted, the epidermis is not strikingly thick, 0.5—1.0 mm being the thickness on a section taken from the flank. The stratum lucidum merges into a stratum corneum, much as found in human skin, and constitutes half or more of the total thickness of the epidermis; it stains poorly and flakes freely on the surface.

By comparison, the skin of the hippopotamus is much smoother, the total thickness of the epidermis is somewhat less than that of the rhinoceros' s but the difference is solely at the expense of the stratum corneum. This layer is compact, thin and strongly acidophilic and arises abruptly from the underlying stratum granulosum without an easily discernible stratum lucidum. The surface of this layer shows little flaking and has usually the appearance of a distinct black or dark brown line. It is interesting that this skin is not greasy, nor has it a hairy coat as is found in most typical aquatic mammals.

It is tempting to associate the nature of the skin with that of the secretion as an adaptation to the aquatic environment, and we are investigating the possible antibacterial and detergent effects of the secretion on the skin; there are good *a priori* grounds for looking in that direction. The muddy water of the wallows is never drained and is constantly being defiled with faecal matter. There is also a suspicion in our minds that the pigmented material may be adsorbed onto the outermost layer of the stratum corneum because the pigment adsorbs very strongly on to organic material such as cotton, and also probably on to protein. Thus boiled egg white will decolorize sweat in which it is incubated, turning brown or black in the process; stratum corneum from the human foot has a similar effect.

Until, however, we know the chemical composition of the pigment it is hard to come closer to grips with the problem. From the point of view of the habitat, however, it is worthy of note that hippopotamus living in the clear water, large rivers and lakes, will have an adequate protection against the infra-red wavelengths of the solar spectrum but much less against the ultra-violet, and that a barrier surface tan may be no very modern invention after all!

Apart from the interest that attaches to the physiology of the skin and its adaptions, lie the wider problems of the biological necessity for these adaptations; further comparative studies of anatomy, physiology and behaviour in relation to the environment, involving the pigmy hippopotamus *(H. liberiensis)* on the one hand and the water buffalo *(Bos bubalis)* and related species on the other, might be very illuminating.

Inhabiting the same regions as these animals, but showing interesting differences in behaviour, is also the elephant *(E. loxodontus)*. Unfortunately technical difficulties have hitherto prevented us studying these creatures as closely as we might wish; we believe however, that we have now overcome some of these.

REFERENCES

1. K. SCHMIDT-NIELSEN, B. SCHMIDT-NIELSEN, S. A. JARNUM and T. R. HOUPT, Body temperature of the camel and its relation to their water economy. *Amer. J. Physiol.* **188**, 103—12 (1957).
2. A. BROOKS, Personal communication.
3. D. B. ALLBROOK, A. M. HARTHOORN, C. P. LUCK, and P. G. WRIGHT, Temperature regulation in the white rhinoceros. *J. Physiol.* **143**, 51—52 (1958).
4. C. P. LUCK and P. G. WRIGHT, The body temperature of the hippopotamus. *J. Physiol.* **147**, 53—4 (1959).
5. J. A. LOCK, Personal communication.
6. D. B. ALLBROOK and A. J. E. CAVE, Epidermal Structures in a Rhinoceros *(Ceratotherium simum). Nature, Lond.* **182**, 196—7 (1958).
7. S. SCHUMACHER, Mucous glands in the skin of a hippopotamus. *Denkschr. Akad. Wiss. Wien* **94**, 1—53 (1918).

THERMAL STABILITY IN THE NEWLY BORN*

R. A. McCANCE, C. B. E.
Medical Research Council and Prof. of Physiology, Department of Experimental Medicine
University of Cambridge, Great Britain

Abstract—The thermal stability of the newborn animal is usually less secure than that of its parents, even if its ambient temperature is maintained not far below the neutral zone. The reasons for this are: (1) Its smaller size and relative larger surface area. (2) The absence, in most newborn animals, of an insulating layer of subcutaneous fat. (3) The state of nutrition, which may be of immediate importance in some species. (4) The immaturity of the thermal regulating mechanisms. Of these the last is by far the most important.

Noradrenaline may be the thermogenic agent which, for a limited time after birth, puts up the oxygen consumption in response to a fall in the ambient temperature.

Most newborn animals below their thermoneutral zone reduce their oxygen consumption if the pO_2 falls in the ambient air. Since oxygen consumption initiates all heat production this means that hypoxia very often leads to hypothermia. The principles which underly the regulation of body temperature in the newborn baby are no different from those of other newborn animals. The baby differs only in matters of detail and its thermal stability should be managed by the application of well established physiological knowledge.

Résumé—La stabilité thermique de l'animal nouveau-né est en général moins constante que celle des parents, même si la température de son milieu ambiant est maintenue peu au-dessous de la zone neutre.

Les raisons en sont les suivantes:

(1) Son plus petit volume et la zone de surface relativemcnt plus grande. (2) L'absence, chez la plupart des animaux nouveaux-nés d'une couche isolée de graisse hypodermique. (3) La condition de nutrition, susceptible d'être d'une importance immédiate chez quelques espèces. (4) L'immaturité du mécanisme de régulation thermique. De tous ces facteurs le dernier est de loin le plus important.

D'ailleurs l'adrénaline peut être un agent thermogène, qui pendant un certain temps, bien limité après la naissance augmente la consommation en oxygène pour réagir contre la baisse de température du milieu ambiant. La plupart des animaux nouveaux-nés réduisent, au-dessous de leur zone thermoneutre leur consommation en oxygène, dans le cas où la pression d'oxygène diminue dans le milieu ambiant. Or comme la consommation d'oxygène amorce toute production de chaleur, cela signifie que l'anoscie conduit souvent à l'hypothermie.

* This talk is based upon one of the Leonard Parsons lectures given in Birmingham (McCance, 1959). The subject has developed very rapidly since that time and an attempt has been made to bring it up to date. Few original papers referred to in the first lecture have been quoted a second time.

Les principes fondamentaux de la régulation de la température du corps chez le bébé nouveau-né, ne se différencent pas de ceux d'autres animaux nouveaux-nés. Les particularités qu'elle présente chez le bébé se réduisent à des détails, et la stabilité thermique du bébé serait susceptible d'être traitée en se basant sur une connaissance physiologique bien établie.

Auszug—Die Wärmestabilität eines neugeborenen Tieres ist gewöhnlich weniger sicher als die seiner Eltern, selbst wenn seine Umgebungstemperatur nicht weit unter der neutralen Zone gehalten wird. Die Gründe hierfür sind: (1) die geringere Grösse und verhältnismässig grosse Körperoberfläche des Tieres. (2) Das Fehlen einer isolierenden Fettschicht unter der Haut bei den meisten neugeborenen Tieren. (3) Der Ernährungszustand, welcher bei einigen Gattungen von unmittelbarer Bedeutung sein kann. (4) Die Unreife des Wärmeausgleich-Mechanismus. Hiervon ist der letztgenannte Grund bei weitem der wesentlichste.

Bei dem wärmeerzeugenden Stoff kann es sich um Noradrenalin handeln, durch welches für eine beschränkte Zeitdauer nach der Geburt der Sauerstoffverbrauch zum Ausgleich einer Senkung der Umgebungstemperatur erhöht wird.

Die meisten neugeborenen Tiere unter der neutralen Wärmezone senken ihren Sauerstoffverbrauch, wenn der Gehalt an pO_2 in der Umgebungsluft absinkt. Da der Sauerstoffverbrauch die ganze Wärmeerzeugung einleitet, bedeutet dies, dass eine ungenügende Oxydation sehr oft zur Unterkühlung führt. Das Prinzip, nach welchem die Regelung der Körpertemperatur eines neugeborenen Tiers erfolgt, unterscheidet sich nicht von dem eines neugeborenen Kindes. Der Säugling unterscheidet sich lediglich in unbedeutenden Einzelheiten. Seine Wärmestabilität sollte durch die Anwendung fundierter physiologischer Erkenntnisse behandelt werden.

Whatever happens to an animal before birth its thermal stability is not endangered, but this is far from being the case after birth, for then the surroundings will most likely be colder unless the animal is born in a very hot part of the world such as Lucknow or Khartoum in the summer. The object of this lecture is to consider how the newborn animal reacts to this fall in its environmental temperature at birth.

GENERAL PRINCIPLES

The temperature of the deep parts of the body are maintained by a balance being struck between heat production and heat loss under all physiological circumstances. But the whole body need not be and seldom is at the same temperature. The limbs may be much colder than the central parts of the body and the skin considerably colder still. In animals with long legs, or birds which stand for long periods on ice, the temperature of the feet may be very low and even the arterial blood supplying them may have fallen to quite a low temperature before it reaches the distal parts.

The heat production of the body under standardized conditions of rest is usually described as the basal metabolism. It is regulated by the activity of the thyroid, and depends to some extent upon the environmental temperature. The remainder of the heat produced by the body is generated largely by the contractions of the skeletal muscles. Movements may be voluntary as in the normal activities which take place throughout the day, or they may be forced if the surrounding temperature is low and the body temperature is being maintained by shivering. A low environmental temperature also increases the "tone" of voluntary muscles, and this too raises the amount of heat produced above that measured under basal conditions. The third form of heat production may for the moment be termed "thermoregulatory". This is detectable after some animals have become adapted to living at a low temperature, and will be discussed later.

All heat production in the body is a result of the biological oxidations taking place inside it. Most cellular activity, voluntary or involuntary is initiated by the breakdown of adenosine triphosphate, for this is the great energy provider in biological systems. Most of the oxidation which takes place in the body is aimed primarily at replacing the stores of ATP, in the mitochondria. Heat wasted in this process goes to warm the animal, be it a poikilotherm or a homoeotherm. Since most oxidations are coupled with ATP synthesis, oxidation only becomes active when there has been a breakdown of ATP. Hence the amount of oxidation taking place in the body is dirchtly linked to the activity of the cells, and this is why shivering, unpleasant thouge it is, may be necessary to keep us warm. Only by breaking through this coupling between functional activity and heat production can one get heat production unrelated to demonstrable function. Substances are known which do this. Too much thyroid does so, and poisons like dinitrophenol. Although one has not been found as yet, a physiological uncoupler is just what is required to explain the heat production of acclimatized persons who appear to be able to produce more heat than unacclimatized persons without shivering or visible functional activity. In the past this has been attributed speculatively to increased muscular tone and possibly to some alternative pathway of glucose breakdown. We shall come back to this presently.

Heat loss takes place from the body surface by radiation, conduction, convection and evaporation, and this must be too well known to require any discussion. A certain amount of heat is also lost through the lungs, mostly due to evaporation. A trifling amount of heat is lost in the urine and faeces. Heat loss may be greatly modified by varying the peripheral blood flow and degree of insulation on the surface of the body. The variable insulations take the form of fur and feathers, or of clothes. The most important permanent insulation for many animals, such as pig and man, is the subcutaneous fat (Suzuki, 1960). Channel swimmers are mostly fat men (Pugh *et al.*, 1960; *The Times*, 1960), and comfort in cold water depends mostly upon the amount of fat in the subcutaneous tissues (Keatinge, 1960). A full-term baby has much more fat under its skin than the premature baby, and this is one of the chief reasons for its greater defence against cold. Loss of heat may be increased in dogs and some other animals by moving air in and out rapidly over the tongue. In man sweating is the most important way of raising the heat loss.

For each animal there is what is called a "critical" temperature or a critical zone of temperature. This varies with the species. It may be defined as the temperature at which the metabolic rate of the animal is at its lowest. If the environmental temperature falls below the critical temperature the heat production of the animal rises, and this helps to prevent a fall in body temperature. If the environmental temperature rises above the critical temperature the temperature of the deep parts of the body tend to go up and this automatically increases the rate of cellular metabolism. The critical temperature varies very much with age as well as from species to species, In adult man it is about 28° C in air and about 33° C in water. In many newborn animals it may be as high as 36° or 37° C. The difference between the environmental temperature and the critical temperature may be described as a measure of the necessity to produce heat to maintain the deep body temperature, or perhaps better as the thermogenic stimulus.

Most adult animals regulate their internal body temperature by adjusting their loss of heat to meet the production of heat going on inside them. Small rodents do not do this, and we shall be discussing this later. If the ambient temperature of an adult is lowered a process of adaptation begins which enables the animal to live comfortably at the new temperature. If the fall in the ambient temperature is not a large one a diminished blood flow through the skin may be sufficient to maintain the internal body temperature. If the fall is greater, muscle tone and ultimately shivering may be called into play in order to maintain the body temperature. Any of these changes may take place within a few minutes. In addition to these, other slow and mysterious changes go on over a matter of days or weeks which seem to involve both the thyroid and the suprarenal gland, and when they are complete the animal is said to be fully adapted to the new temperature. It now has a slightly higher basal metabolic rate than it had at the original temperature, even when this is measured under identical conditions, and a higher overall metabolic rate, although the animal does not appear to be shivering. It is possible that the medulla of the suprarenal is involved in this, for it has been shown that in an adapted animal adrenaline is to some extent calorigenic, even after the administration of curare. Why this is so has never been demonstrated, but should adrenaline be able to act in some way as an uncoupler the observed effects could be explained.

A deficiency of oxygen does not make much difference, if any, to the heat production of an adult man, dog, or cat. If the percentage of oxygen in the environmental air is reduced very materially no fall takes place in its heat production. A fall does take place, however, in the heat production of rodents, but only if the experiment is carried out below the critical temperature of the animal.

The size of the body is a very important matter in all questions of thermal regulation. As you know, small bodies have relatively larger surface areas than large bodies, and therefore in temperate climates small animals tend to cool more rapidly than large ones. Rubner established the great generalization that this effect of size was compensated for biologically by the heat production of animals varying directly with their surface area, not with their body weight. Small rodents such as harvest-mice, which live in an ambient temperature that sometimes falls to 0° C, weigh only about 10 g and their energy expenditure per day is of the order of 8.4 cal (Pearson, 1960). If a man weighing 70 kg produced heat at this rate he would require 60,000 cal per day.

OXYGEN CONSUMPTION AND THERMAL REGULATION OF THE NEWBORN

Few newborn animals have the thermal stability of their parents. This is not merely a matter of size, and Edwards, who lived over 100 years ago, showed that whereas adult wrens could maintain a perfectly normal body temperature at 17°C, newborn hawks, which were considerably larger, could not. No newborn baby, even if it were to weigh 4 kg could possibly maintain a normal body temperature if that of the surroundings fell to 0°C, but the harvest-mouse which weighs only from 8 to 15 g can do so quite easily. In animals which have large litters or make good nests the size of the young animals can be effectively increased if they huddle together. This also was known to Edwards, and has recently been demonstrated quantitatively in young pigs by Mount (1959a). The newborn baby constricts its peripheral vessels in response to a low ambient temperature (Brück *et al.*, 1957; 1958a, b, c; Brück, 1959a, b), but its insulation is poor, particularly if it is premature. It would, however, appear that control of heat loss seems relatively unimportant in regulating the internal body temperature of most newborn animals. In this they differ from the adults of the same species, and behave like the small rodent which controls its internal body temperature largely by modifying its heat production. It is indeed the only way in which a small rodent could live, move and have its being, because, were it to carry enough insulating material to maintain its internal temperature without a high rate of heat production, it would be so handicapped by the weight and bulk it would be unable to get about at all. The thermal regulation of the newborn, therefore, must be discussed largely in terms of heat production.

Even directly after birth most newborn animals raise their heat production materially and progressively as the environmental temperature falls below their critical temperature. This has been demonstrated in pigs, rats, monkeys and babies. In the first few hours or days of life this ability to raise the heat production materially improves. Dawes *et al.* (1960) have demonstrated this in lambs and in monkeys. Mount (1959b) has shown it in pigs and Brück *et al.* (1957) have demonstrated it in babies. This rise in heat production takes place without apparent shivering—unless the body temperature falls to very low levels (Miller, 1960) — and most people have thought without any great, if any, increase in activity, but Mestyan and Varga (1960) have recently claimed that most of the increase in heat production of the newborn baby as the ambient temperature falls is due to an increase in visible activity. An increase in the amount of heat production in the body can only be brought about effectively if the animal has been well fed and has energy reserves in the body. Baric (1953) has shown, for example, that this effect of food is critical, for a starved rat 4 days old acts as a poikilothermic animal if its ambient temperature is reduced, whereas a well fed one behaves like a homoeothermic animal within the limits over which it can maintain its body temperature. The high metabolic rate produced by subjecting the animal to a low environmental temperature is essential for keeping it warm, but a price has to be paid for this in the shape of additional food requirements. Some newborn animals like the rat, which depend largely upon their mother's warmth and the heat of the nest for their thermal stability, have a much smaller price to pay than an animal like the newborn lamb which may be born into very cold surroundings.

From what has already been said it is probably evident that the endocrine glands must be involved in maintaining prolonged thermal stability in a low environmental temperature, particularly the adrenals and the thyroid. Workers in Prague have studied the age of the rat at which these organs become operative in thermal control. The adrenals apparently begin about the third or fourth day after birth, the thyroid not until the fourteenth, and movements of fur and changes in the skin of that kind only on the eighteenth day.

It has already been pointed out that reducing the percentage of oxygen in the ambient air of adults does not reduce their oxygen consumption. It does do so, however, in newborn animals. This was first shown by Cross and his co-workers in man, but it has been confirmed up to the hilt in kittens by Hill (1959), and Moore (1959). You will notice that in this the newborn animal is behaving like the adult rodent, and there is a further point of resemblance in that hypoxia has no effect if the newborn animal is being maintained at its critical temperature. It looks as though there must be some heat regulating mechanism operative in the newborn animal which does not enter to any extent into the physiology of the adult.

Let us recapitulate for a moment before we go on to the rest of this fascinating story. The response of the newborn animal to a fall in its external temperature depends upon, firstly, the extent of the fall below the critical temperature; secondly, upon the time which has elapsed since birth; thirdly, upon whether the animal has been fed or not, and fourthly, upon the supply of oxygen. The results now to be described have been obtained largely by Dr. Moore (Baum *et al.*, 1960; Moore and Underwood, 1960a, b), some of them so recently that it is difficult to appraise their full significance as yet. It would appear from this work that the rise in oxygen consumption below the critical temperature is mediated by the action of noradrenaline. The evidence for this is as follows. *Below* the critical temperature the oxygen consumption goes up progressively as already described, and injected noradrenaline increases the rise but less so as the environmental temperature falls. Hypoxia reduced the increase of oxygen consumption, if severe to its level at the critical temperature. Hexamethonium, which is a ganglion blocking agent, and therefore may be presumed to knock out the production of endogenous noradrenaline, reduces the oxygen consumption to its level at the critical temperature. *At* the critical temperature, the oxygen consumption is at its lowest. Hypoxia has no effect upon it and hexamethonium has no effect upon it, but injected noradrenaline has more effect than at any lower ambient temperature. How does the noradrenaline work? Nobody knows at present, but there is some evidence that its action is intracellular. Like to picture the noradrenaline as uncoupling oxidation in some way from the hitherto recognized cellular functions, but this may just be wistful thinking on my part.

The full-term baby has all the characteristics of other newborn animals, and differs only in particulars. Much work was done many years ago on the basal metabolic rate of premature and full-term babies and it was established that their basal metabolic rates, although higher per kg of body weight than those of adults, were lower per square metre of body surface. This evidence in itself shows that the newborn baby is more vulnerable to a fall in the ambient temperature than an adult, but the external temperature was not carefully controlled in these experiments and they should probably be repeated at the critical temperature of the newborn baby to get at the real basal metabolic rate.

The temperature of newborn babies usually falls several degrees within an hour or two of birth (McClure and Caton, 1956; Smith, 1959) and, even if the surrounding temperature is as high as 80° and the baby clothed, it may take several hours, many hours indeed, for the temperature to rise to what is regarded as normal for an adult. Premature babies may continue for days with body temperatures round about 94°F, which is only 35°C, and do quite well. This is often spoken of as the tolerance of a newborn animal to a fall in its body temperature below the adult normal, and some have advocated rearing premature babies at these body temperatures on the grounds that it reduces their general metabolism and consequently the strain on the vital organs. The question of whether it really does reduce the metabolic rate is not, for me at all events, yet settled. In a poikilotherm, of course, there is no problem. The body temperature, and the metabolic rate fall with the external temperature, but in an animal striving to maintain its temperature at around 37°C, — and this is what a newborn baby can be regarded as doing — the fall in the ambient temperature leads to a fall in the peripheral skin temperature and this, by reflexes, puts up the metabolic rate in the adaptive organs and helps to maintain the deep core body temperature. If, however, this goes on falling, a further, and perhaps intense rise, takes place in the metabolic rate, particularly in the adaptive organs. If this is still insufficient to maintain the deep body temperature the latter fulls further still, and at a certain point the fall in the deep body temperature will reduce the metabolic rate of the cells for the reason it does so in a poikilothermic animal. By this time, however, the fall may have been great, and such low body temperatures may not be physiological. The detailed studies of Silverman have in fact shown that premature babies reared at a slightly lower environmental temperature than others have a poorer survival rate. It is beginning to look as though this so-called "tolerance" of the newborn animal to a fall in its deep body temperature is not so desirable as some have been led to suppose.

If a newborn baby is unable to maintain a reasonably normal body temperature owing to cold surroundings it will ultimately die, but even towards the end, when its body temperature is very low, it may look quite pink and well. It has probably been refusing food for many hours and may have a very low blood sugar and bradycardia. These babies may have hypoglycaemic convulsions and the cause of death may be respiratory failure of pulmonary haemorrhage. The whole syndrome can be reproduced in newborn pigs and analysed in much greater detail. If one group of pigs is kept at a temperature of 12°C and the other at one of 25°C, the ones kept at the high temperature maintain a normal body temperature for 24 hr without any difficulty, even if they are not fed. The ones kept at 12°C, however, can only maintain their body temperature within reasonably normal limits for about 8 hr, after which time the temperature begins to fall, and it falls progressively faster, so that by about 24 hr it is as low as 20° to 23°C. If the bodies of these animals are then analysed and compared with the composition of the bodies of newborn animals it can easily be demonstrated that the animals kept in the cold have metabolized much more of their glycogen and tissue protein than the animals kept warm. Their bodies in consequence are more watery and they often have oedema. The animals kept at 12°C also have extremely low blood sugars, and when they are warmed they may have convulsions. The conclusions are clear: The first move in treating a baby with a very subnormal body temperature should be to administer glucose.

It may be wise at this point to recapitulate the causes of hypothermia in the newly born (Gelineo, 1959). They are, firstly, exposure to an overwhelmingly low ambient temperature. Just what this is depends upon the species of animal and its degree of development at birth. The premature baby, for example, is much more vulnerable than a full-term one. Secondly, exposure for too long to a reasonable ambient temperature, in which the animal would have survived quite well for a short period of time and maintained a normal body temperature. The effect of food comes in here. Newborn pigs can be reared satisfactorily at 12°C if they are well fed from the time of birth. Thirdly, a reduced supply of oxygen. I need not go over these effects again, except to remind you that anaerobic metabolism is very wasteful of glycogen and even if maintained, produces very little heat, and a progressively severe acidosis. The relationship between anoxaemia, hypothermia and survival is a very interesting and important one. The clear case is that of the poikilothermic animal. If its oxygen supply is cut off it survives a much shorter period of time at 30°C than it does, say, at 20°C. As already stated, hypoxia in adult rodents leads to hypothermia and it has been shown that if their body temperatures are maintained they die more quicky than they do if they are allowed to cool down spontaneously. Even if newborn animals which are born in a very advanced state of development, such as guinea-pigs, are quickly cooled when their oxygen supply is cut off, they live considerably longer. A low body temperature during anoxaemia is beneficial because it reduces the breakdown of glycogen, most importantly perhaps in cardiac muscle (Dawes *et al.*, 1959), and hence delays the production of lactic acid and the resulting acidosis, and the rise of serum potassium which is induced by it. It is not suggested for a moment that a fall in the deep body temperature due to anoxaemia is in itself a good thing, only that it is for a time the lesser of two evils. To put it another way, anoxaemia is less quickly lethal when the temperature of the body is low than it is when it is high.

Finally, treatment. This can be tabulated very simply on physiological grounds, Firstly, give glucose for further anaerobic metabolism should it be necessary, and also because it is beneficial in hypothermia *per se* as already described. Secondly, give sodium bicarbonate to correct the acidosis produced by the lactic acid and to help by so doing to reduce the high serum potassium which may in many instances be the cause of death. The benefits of these two actions have been demonstrated in the treatment of anoxic human infants. Thirdly, do everything possible to re-establish oxygenation of the newborn baby or animal, and when its respiration is re-established, or it has become fully oxygenated, warm it up. It may not even be necessary to apply much heat in a very warm environment and this manoeuvre should certainly be left until the last.

REFERENCES

Baric J. (1953) La consommation d'oxigène du rat nouveau-né au cours du jeûne. *Bull. l'Acad. Serb. Sci. (Sci. Nat. Nouv. Ser.)* **12,** 71—6.

Baum H., Moore R. E. and Underwood M. C. (1960) Stimulation of heat production in newborn cats and adult rats by adrenaline and noradrenaline. *Proc. Physiol. Soc.* 29—30th July (1960).

Brück K. (1959a) Besonderheiten thermoregulatorischer Vorgänge bei infantilen Individuen. *Pflüg. Arch. ges. Physiol.* **270,** 54—5.

Brück K. (1959b) Die Temperaturregelung in den ersten Lebenstagen. *Die Physiologische Entwicklung des Kindes* pp. 41—53. Springer-Verlag, Berlin.

Brück K., Brück M. and Lemtis H. (1957) Hautdurchblutung und Thermoregulation bei neugeborenen Kindern. *Pflüg. Arch. ges. Physiol.* **265,** 55—65.

Brück K., Brück M. and Lemtis H. (1958a) Wärmeleitfähigkeit und Durchblutung verschiedener Stellen der Körperoberfläche bei reifen und unreifen Neugeborenen. *Pflüg. Arch. ges. Physiol.* **266,** 518—27.

Brück K., Brück M. and Lemtis H. (1958b) Thermoregulatorische Veränderungen des Energiestoffwechsels bei reifen Neugeborenen. *Pflüg. Arch. ges. Physiol.* **267,** 382—91.

Brück K., Brück M. and Lemtis H. (1958c) Hautdurchblutung und Thermoregulation bei reifen und unreifen Neugeborenen. *Arch. Gynaek.* **190,** 512—19.

Dawes G. S., Jacobson H. N., Mott J. C. and Shelley H. J. (1960) Some observations on foetal and newborn Rhesus monkeys. *J. Physiol.* **152,** 271—98.

Dawes G. S. Mott J. C. and Shelley H. J. (1959) The importance of cardiac glycogen for the maintenance of life in foetal lambs and new-born animals during anoxia. *J. Physiol.* **146,** 516—38.

Gelineo C. (1959) The development of homeothermy by mammals. *Usp. Sovrem. biol.* **47,** 108—20.

Hill J. R. (1959) The oxygen consumption of new-born and adult mammals. Its dependence on the oxygen tension in the inspired air and on the environmental temperature. *J. Physiol.* **149,** 346—73.

Keatinge W. R. (1960) The effects of subcutaneous fat and of previous exposure to cold on the body temperature, peripheral blood flow and metabolic rate of men in cold water. *J. Physiol.* **153,** 166—79.

McCance R. A. (1959) The maintenance of stability in the newly born. *Arch. Dis. Childh.* **34,** 361—70 and 459—70.

McClure J. H. and Caton W. L. (1955) Newborn temperature—1. Temperatures of term normal infants. *J. Pediat.* **47,** 583—7.

Mestyan Gy. and Varga F. (1960) Chemical thermoregulation of full-term and premature newborn infants. *J. Pediat.* **56,** 623—9.

Miller J. A. (1960) Heat regulation. *Transactions of the 4th Conference of the Josiah Macy Foundation on The Physiology of Prematurity,* p. 18.

Moore R. E. (1959) Oxygen consumption and body temperature in newborn kittens subjected to hypoxia and reoxygenation. *J. Physiol.* **149,** 500—18.

Moore R. E. and Underwood M. C. (1960a) Possible role of noradrenaline in control of heat production in the newborn mammal. *Lancet* **1,** 1277—8.

Moore R. E. and Underwood M. C. (1960b) The calorigenic action of noradrenaline in the newborn kitten: its inhibition by hypoxia. *J. Physiol.* **152,** 52.

Mount L. E. (1959a) The effect on rate of heat production of grouping newborn pigs together. *J. Physiol.* **147,** 24—55.

Mount L. E. (1959b) The metabolic rate of the newborn pig in relation to environmental temperature and to age. *J. Physiol.* **147,** 333—45.

Pearson O. P. (1960) The oxygen consumption and bioenergetics of harvest mice. *Physiol. Zool.* **33,** 79—86.

Pugh L. G. C. E., Edholm O. G., Fox R. H., Wolff H. S., Hervey G. R., Hammond W. H. Tanner J. M. and Whitehouse R. H. (1960) A physiological study of Channel Swimming. *Clin. Sci.* **19,** 257—74.

Smith C. A. (1959) *The Physiology of the Newborn Infant,* 3rd ed. C. C. Thomas, Springfield, Illinois.

Suzuki S. (1960) Basal metabolism in the Japanese population. *World Rev. Nutr.* **1,** 103—24.

The Times, 5th August, 1960. Clinical view of Channel swimming — Insulation against the cold.

DIE FRIGORIGRAPHIE IN DER TIERHALTUNG

H. PECHERT

Forschungsstelle für Tierhaltung Knau der Deutschen Akademie der Landwirtschaftswissenschaften zu Berlin, 15 Knau/Thür., Kr. Pöszneck, Deutschland (D. D. R.)

Abstract—Advances in the research on animal behaviour in Germany are reported. The foremost task is designing suitable methods of measuring and producing the microclimate under working conditions which would facilitate the calculation of the "climatic efficiency zone" limits especially cattle in the cold zone. Cathathermometry and frigorigraphy are thought to be suitable methods because they integrate the dry-cooling effect and correlate it with surface temperature, i.e. skin temperature which is the most important thermoregulator. The author is of the opinion that the term "comfort" is also accounted for provided that homeothermy is determined only by physical thermoregulation. On the basis of results obtained with frigorigraphy it is thought possible to characterize the climate in three dimensions (space climate) as long as the usual components of the climate are not omitted. As expected, winter temperatures of the skin showed great variation. There were signs that thermoregulation outside the normal limits starts only at below-zero temperatures and this point should be covered by the largest difference between the measured temperature of the skin and the control, at the same time paying attention to chemical thermoregulation beyond the limits of economy. Other important rules to be observed are respiration experiments in natural conditions, such as in the shelters or winter quarters assigned to the animals.

Résumé—L'auteur fait un exposé du développement des recherches sur l'entretien des bestiaux en Allemagne. Au premier plan de ces problèmes actuels se place l'application des procédés des mesures et des méthodes de représentation convenables du microclimat, dans les conditions d'exploitation qui permettent de déterminer les valeurs limites de «la zone de rendement du climat», en particulier de la partie froide, chez les bovins. Outre la catathermométrie la «frigorigraphie» semble être un procédé approprié, puisqu'il fait intervenir intégralement l'effet du pouvoir refrigérant et comme mesure de référence la température superficielle, la température cutanée étant normalement le régulateur le plus important. A notre avis cela permet d'introduire également dans les mesures la notion de confort dont on s'aperçoit lorsque l'homéothermie est maintenue essentiellement par des procédés physiques de régulation thermique. L'auteur se basant sur les résultats des travaux voit dans la «frigorigraphie» une possibilité de caractériser le climat dans ses finesses à condition de tenir compte en même temps des facteurs climatologiques habituels.

Des comparaisons faites avec des mesures de temperature cutanée ont donné en hiver, comme il fallait s'y attendre, une différence très notable par rapport au point d'indifférence. Il semble d'après certains indices que le bovin commence sa régulation thermique au-dessus de la température superficielle limite uniquement à partir des températures négatives. A notre avis le point fixe réel sera déterminé par la différence maximale entre la température cutanée mesurée et le corps d'épreuve, en tenant compte de l'enjeu d'une régulation thermique chimique dépassant le taux économique. L'auteur estime qu'en plus des mesures de la température cutanée, des essais de respiration dans des conditions d'exploitation sont susceptibles de faciliter les travaux de recherche relatifs à l'entretien des animaux dans l'utilisation des abris.

Auszug—Es wird über die Entwicklung der Haltungsforschung bei Tieren in Deutschland berichtet. Im Vordergrund derzeitiger Aufgaben steht die Anwendung geeigneter Meßverfahren und Darstellungsmethoden des Kleinklimas unter betriebsmäßigen Bedingungen, die es gestatten, die Grenzwerte der »Klimaleistungszone« vor allem im kalten Bereich bei Rindern zu erarbeiten. Hierzu wird neben der Katathermometrie die Frigorigraphie als passendes Verfahren angesehen, da es integrierend den trockenen Abkühlungseffekt erfaßt und als Bezugsmaß die Oberflächentemperatur, sinngemäß das wichtigste Regulativ, die Hauttemperatur, heranzieht. Damit wird u. E. auch der Begriff der Behaglichkeit meßtechnisch erfaßt, der dann gewahrt ist, wenn die Homoiothermie hauptsächlich nur mit Maßnahmen der physikalischen Wärmeregulation erhalten wird. Wir sehen auf Grund unserer Arbeitsergebnisse in der Frigorigraphie eine Möglichkeit, das Raumklima in seinen Feinheiten zu charakterisieren, wobei allerdings die Erfassung der üblichen Klimakomponenten nicht entfallen darf. Vergleiche mit tatsächlich gemessenen Hauttemperaturen zeigten erwartungsgemäß im Winter eine sehr große Differenz zum Indifferenzpunkt. Es ergaben sich Anzeichen dafür, daß erst im Minusbereich das Rind mit der Wärmeregulation über seine Grenzflächentemperatur beginnt. Der wirkliche Fixpunkt wird sich u. E. aus der größten Differenz zwischen der gemessenen Hauttemperatur und dem Probekörper unter Beachtung des Einsatzes einer über das wirtschaftliche Maß hinausgehenden chemischen Wärmeregulation ergeben. Respirationsversuche unter praktischen Verhältnissen sind daher neben der Messung der Hauttemperatur u. E. weitere wichtige Maßnahmen bei der Haltungsforschung in Tierunterkünften der Praxis.

Die Haltungsforschung für Rinder und Schweine ist in Deutschland im Laufe von ca. 100 Jahren verschiedene Wege gegangen. Nachdem sie ihre ersten Impulse aus der Hygiene erhielt, begann im Jahre 1880 eine Periode des Luftchemikers, die Mitte der 1920er Jahre ihren Höhepunkt erreichte. Seitdem liegen hygienische Grenzwerte für die verschiedensten Gasanteile im Stallraum fest.

Da man im weiteren Verlauf die Bedeutung des Stallklimas für das Wohlergehen und die Leistungen der Tiere immer mehr erkannte, wurden dessen ureigenste Elemente, Lufttemperatur und Luftfeuchtigkeit, stärker beachtet. Ein Grund hierfür mag das teilweise sehr ungünstige Stallklima gewesen sein, das aus Überforderungen an den Temperaturstand in den verschiedensten Unterkünften resultierte und in keinem gesunden Verhältnis zur Bauausführung wie zu den eigentlichen Bedürfnissen der verschiedensten Tierarten und Nutzungsformen stand. Fragen der Belichtung kamen hinzu. Selbstverständlich spielte das Moment der Be- und Entlüftung eine wesentliche Rolle.

Unter Beachtung der oben genannten Gesichtspunkte setzte sich dann ab etwa 1949 die Bedeutung der Abhärtung für die Jungtieraufzucht und die Tierhaltung im allgemeinen immer mehr durch. Sie fand ihren Niederschlag besonders im Offenstallsystem bei Rindern, das als Kaltstallhaltung bekannt ist und einschneidende Änderungen im Verlauf des Stallklimas, besonders im Winter, zur Folge hatte.

Eben dieser Tatsache schreibt man aus Erkenntnissen der Konstitutionsforschung und der Klimaheilkunde günstige abhärtende Wirkung auf den Organismus zu, die laut Pfleiderer und Schittenhelm darin liegen, daß sie zur größeren Stabilität des organischen Betriebes, zur Lockerung und Verbesserung der Regulationen führt, Abwehrreaktionen stärkt und den Rückgang von Überempfindlichkeitsreaktionen bedingt.

Maßgebend erscheint hier die Frage der Klimadosierung, die wiederum nach Bianca die Kenntnis der genauen Beschaffenheit des Offenstallklimas, aber auch des Stall- oder Weideklimas, zur Voraussetzung hat. Hier gilt es u. E., durch geeignete Meßverfahren unter betriebsmäßigen Bedingungen die integrierende Wirkung einzelner Faktoren darzustellen. Dies um so mehr, als einerseits in Deutschland z. Zt. nur ein Klimalabor in Betrieb ist, andererseits die Forderung Bianca's nach Vergleichen bei verschiedenen Versuchsanstellern einheitliche Verfahren in der Meßtechnik zur Voraussetzung hat.

Von den bekannten Verfahren übernahmen wir die *Katathermometrie*, die in Deutschland besonders in der technischen Bauhygiene Bedeutung gewonnen hat und den *Frigorigraphen* nach Büttner und Pfleiderer. Letzterer schien uns geeignet, da er als Bezugsmaß für die Summe der Abkühlungswirkung aus Lufttemperatur, Luftbewegung, Einstrahlung von Sonne und Himmel und infraroter Abstrahlung eine Ausgleichsgröße nimmt, die auf der Oberflächen- und nicht auf der Kerntemperatur basiert, und die sich aus der Kompensierung zwischen Gesamtwärmezufuhr und -abgabe auf die Oberflächeneinheit ergibt. Weitere Vorteile sehen wir darin, daß die Gerätekonstanten denen des menschlichen Wärmehaushaltes angepaßt sind, so daß wohl kein absoluter, aber doch relativer Vergleich bei Versuchen in der Tierhaltung möglich erscheint.

Mit diesem Verfahren wäre wohl auch meßtechnisch ein Postulat erfüllt, nach dem der Behaglichkeitsbereich dann gewahrt ist, wenn das Tier seine Homoiothermie hauptsächlich nur mit den physikalischen Hilfsmitteln der Wärmeregulierung, also wesentlich mit über die Hauttemperatur reguliert und aufrecht erhält. Dabei entspricht die Differenz zwischen Haut- und Oberflächentemperatur des Probekörpers vom Indifferenzpunkt bei Überwärmung einer zunehmenden Inanspruchnahme der perspiratorischen Regulation, der Fall in Richtung des kälteren Bereiches einer Belastung des Organismus mit der chemischen Wärmeregulation (Pfleiderer).

Wir glauben, auf dieser Basis unter betriebsmäßigen praktischen Bedingungen einen Beitrag zur Erarbeitung der Grenzwerte der Klimaleistungszone bei laufender Kontrolle der Hauttemperatur und mit Hilfe der Respirationsanordnung nach Douglas und Haldane in dem uns interessierenden kalten Bereich zu leisten. Selbstverständlich werden die üblichen Klimaelemente weiter mitregistriert, und weitere physiologische Untersuchungen werden sich anschließen.

Es wäre an dieser Stelle vielleicht einzufügen, daß mit den Worten »Klimaleistungszone« und »Klimaleistungskunde« kein anderes Ziel verfolgt wird, als es die angelsächsischen und amerikanischen Forscher mit dem wohl fundierten Begriff der »Behaglichkeitszone« oder der »Thermoneutralität« festgelegt haben. Der

Tabelle 1. Monatliche ∅ Raum- und Frigorigraphen-

	Dezember 1957			Januar 1958			Februar 1958		
	0700 T °C	1400 T °C	2100 T °C	0700 T °C	1400 T °C	2100 T °C	0700 T °C	1400 T °C	2100 T °C
massiver Kuhstall	+5,3	+6,4	+6,6	+5,0	+7,4	+ 7,8	+7,6	+8,2	+8,9
Offenstall	—0,6	+1,3	+0,3	—0,8	+1,4	—0,04	+1,3	+3,2	+1,6
t M.St.: O.St.	+5,9	+5,1	+6,3	+5,8	+6,0	+ 7,8	+6,3	+5,0	+7,3
	Ft °C	*Ft* °C	*Ft* °C	*Ft* °C	*Ft* °C	*Ft* °C	*Ft* °C	*Ft* °C	*Ft* °C
massiver Kuhstall	+16,4	+17,4	+17,5	+16,3	+18,3	+18,7	+18,6	+19,0	+19,7
Ft M.St.: O.St.	+ 6,8	+ 6,4	+ 7,3	+ 7,9	+ 7,4	+ 8,8	+ 7,8	+ 6,9	+ 8,0
t : *Ft* massiver Kuhstall	11,1	11,0	10,9	11,3	10,9	10,9	11,0	10,8	10,8
t : *Ft* Offenstall	10,2	9,7	9,9	9,2	9,5	9,9	9,5	8,9	10,1
t : *Ft* M.St.: O.St.	+ 0,9	+ 1,3	+ 1,0	+ 2,1	+ 1,4	+ 1,0	+ 1,5	+ 1,9	+ 0,7

Ausdruck wurde einmal zur Abgrenzung der Arbeit in der Tierhaltung von denen anderer bioklimatischer Forschungsrichtungen geprägt, da unsere Arbeiten das Ziel verfolgen, die Leistungen direkter und indirekter Art des gesunden landwirtschaftlichen Nutztieres durch beste Umweltgestaltung zu erhalten, zu stärken und zu fördern, z. a. machte sich die Ausschaltung des menschlichen Vorurteils und des menschlichen Vorbehaltes nötig, die mit der Behaglichkeit verbunden sind und die sich in Deutschland in Fragen der Stallklimatisierung negativ ausgewirkt haben.

Als Standorte der Frigorigraphen wurden der Mittellangstand eines Warmstalles und das Standende eines Offenstalles (jeweils in Gebäudemitte) gewählt. 2 Drahtkäfige schützen die Geräte vor den Kühen. Die Meßhöhe mit ca. 1,0 m entspricht dem Mittel zwischen dem liegenden und stehenden Tier.

Jede Meßstelle setzt sich aus einem elektrischen Widerstandsthermometer und einem Probekörper zusammen.

Die Frigorigraphentemperatur (*FT*) ist stets größer als die Lufttemperatur. Die Differenz zu dieser wird mit Übertemperatur (*ÜT*) bezeichnet. Sie beträgt bei Luftruhe und ohne Einstrahlung nach Büttner und Pfleiderer ca. 12 bis 13° C. Einstrahlung erhöht sie, Wind und Abstrahlung vermindern den Wert.

Die Frigorigraphentemperaturen können im Sommer oder im Winter bis auf +50° und —20° C ansteigen oder absinken, liegen dann allerdings weit außerhalb des Indifferenzbereiches. Die *ÜT* des hier eingesetzten Gerätes wurde mit 11,4° C eingeeicht. Der Verlauf des Kleinklimas kann nach dieser Methode folgendermaßen dargestellt werden.

Raum- und Frigorigraphentemperatur kongruieren stark, das Amplitudengefälle der *ÜT* zur *RT* erscheint dabei nur in Einzelfällen abgeschwächt. Die Ausgleichsgröße liegt im Offenstall teilweise nur knapp über der Lufttemperatur des Warmstalles. Es kann der Fall eintreten, daß die *FT* des Offenstalles die *RT* des Massivstalles unterschreitet. Umgekehrte Bedingungen treten im Winter zur Zeit der Stallarbeit ein.

temperatur vom massiven Kuh- und Offenstall

	März 1958			April 1958			Mai 1958		
	0700 T °C	1400 T °C	2100 T °C	0700 T °C	1400 T °C	2100 T °C	0700 T °C	1400 T °C	2100 T °C
massiver Kuhstall	+5,0	+7,8	+8,5	+9,1	+11,2	+12,2	+14,0	+17,3	+16,3
Offenstall	—2,1	+1,7	+0,2	+3,1	+ 8,1	+ 5,8	+11,6	+17,7	+14,4
t M.St.: O.St.	+7,1	+6,1	+8,3	+6,0	+ 3,1	+ 6,4	+ 2,4	— 0,4	+ 1,9
	Ft °C	Ft °C	Ft °C	Ft °C	Ft °C	Ft °C	Ft °C	Ft °C	Ft °C
massiver Kuhstall	+16,0	+18,6	+19,6	+20,2	+21,6	+23,0	+23,8	+26,0	+26,1
Ft M.St.: O.St.	+ 8,3	+ 7,0	+ 9,0	+ 7,0	+ 4.2	+ 6,9	+ 2,9	+ 0,2	+ 2 1
t : Ft massiver Kuhstall	11,0	10,8	11,1	11,1	10,4	10,8	9,8	8,7	9,8
t : Ft Offenstall	9,8	9,9	10,4	10,1	9,3	10,3	9,3	8,1	9,6
t : Ft M.St.: O.St.	+ 1,2	+ 0,9	+ 1,2	+ 1,0	+ 1,1	+ 0,5	+ 0,5	+ 0,6	+ 0,2

Bemerkungen:
T °C — Raumtemperatur.
Ft °C — Frigorigraphentemperatur.
t °C — Temperaturdifferenz.

Der Einfluß der Windbewegung wird im Offenstall an Hand der Frigorigraphenwerte besonders deutlich. Dem fast geradlinigen Verlauf der Raumtemperatur steht eine solche in der Zeiteinheit sehr oft wechselnde, dabei aber schwach variierende *FT* gegenüber. So wechselte z. B. die Amplitude am 9.2.1958 über 24 Stunden pro Stunde im Offenstall im Durchschnitt 12, im Massivstall hingegen nur 5mal (Schwankung 15 bis 8° C, 10 bis 1° C), während die mittlere Temperaturschwankung im Offenstall mit 1,72° C, im Massivstall mit 1,6° C bei einem größten Wert von 3° C und 4° C festgestellt wurde. Die Auswertung zeigt weiter sehr deutlich, daß der Wind trotz steigender Temperaturen die allgemeine Gesetzmäßigkeit des Parallelverlaufes durchbrechen kann.

Eingangs findet sich die Feststellung, daß aus der Eichung im Raum eine *ÜT* von 11,4° C resultiert. Es wurde darauf verwiesen, daß die Einstrahlung, die Windbewegung und die Abstrahlung ein Steigen oder Absinken um diesen Normalwert nach sich ziehen. Tabelle 1 spiegelt die Verhältnisse in den Monaten Dezember 1957 bis Mitte Mai 1958 im Offen- und Massivstall wider.

Die Ausgleichstemperatur liegt im Massivstall im ⌀ bei 10.67° C, im Offenstall im Mittel bei 9,69° C. Die größte Annäherung wird im Warmstall mit 11,3° C bei der im ⌀ niedrigsten Stalltemperatur von +5° C erreicht. Die *ÜT* fällt im Mai auf den niedrigsten Wert ab, bedingt durch die uneingeschränkte Querlüftung.

Insgesamt läßt sich sagen, daß im Massivstall die Bilanz der Gesamtwärmeabgabe wie der Gesamtwärmezufuhr, bezogen auf den Probekörper, nur unwesentlich gestört wird. Im übertragenen Sinne wäre es so zu formulieren, daß nach Einstellung des Tieres auf die Umgebungstemperatur keine weiteren größeren Belastungen auftreten.

Tabelle 2. Raum- und Frigorigraphentemperatur dekadenweise errechnet

Dekade	Mass. Stall 0700		Off. Stall 0700		Mass. Stall 1400		Off. Stall. 1400		Mass. Stall 2100		Off. Stall 2100	
	T°C	Ft °C	T°C	Ft °C	T°C	Ft °C	T°C	Ft °C	T°C	Ft °C	T°C	Ft °C
1. 12. — 10. 12. 57	+ 6,7	+17,8	+1,2	+10,7	+ 6,7	+17,3	+ 2,8	+11,0	+ 7,8	+18,9	+ 1,8	+11,2
11. 12. — 20. 12. 57	+ 4,8	+16,2	—1,3	+ 9,5	+ 5,9	+17,2	— 0,4	+10,1	+ 5,9	+17,1	— 1,6	+ 9,2
21. 12. — 30. 12. 57	+ 4,4	+15,4	—1,1	+ 9,1	+ 6,8	+17,7	+ 1,8	+11,8	+ 6,2	+16,6	+ 0,7	+10,4
31. 12. — 9. 1. 58	+ 5,0	+15,8	+1,1	+ 9,3	+ 6,8	+17,7	+ 1,4	+ 9,5	+ 7,2	+17,6	+ 1,0	+ 9,8
10. 1. — 19. 1. 58	+ 6,7	+18,0	+1,6	+10,8	+ 8,5	+18,9	+ 2,3	+12,3	+ 8,5	+19,3	+ 1,9	+11,9
20. 1. — 29. 1. 58	+ 3,4	+15,0	—3,9	+ 5,8	+ 6,7	+17,9	+ 0,5	+10,4	+ 7,2	+18,3	— 3,0	+ 7,6
30. 1. — 8. 2. 58	+ 5,9	+17,5	—0,4	+ 7,9	+ 7,5	+18,6	+ 2,1	+11,1	+ 8,5	+19,6	+ 1,7	+11,0
9. 2. — 18. 2. 58	+10,7	+21,5	+5,7	+14,9	+11,3	+22,0	+ 8,3	+16,7	+11,5	+22,2	+ 5,6	+15,1
19. 2. — 28. 2. 58	+ 5,8	+16,7	—2,1	+ 8,3	+ 6,2	+17,0	— 0,7	+ 9,2	+ 7,0	+17,0	— 2,4	+ 9,0
1. 3. — 10. 3. 58	+ 4,9	+15,9	—0,9	+ 8,9	+ 7,6	+18,3	+ 1,9	+11,5	+ 8,8	+19,9	+ 1,0	+11,1
11. 3. — 20. 3. 58	+ 4,0	+14,7	—3,9	+ 5,9	+ 6,8	+17,3	— 0,6	+ 9,3	+ 7,0	+18,3	— 1,9	+ 8,6
21. 3. — 30. 3. 58	+ 6,1	+17,4	—1,2	+ 9,1	+ 9,2	+20,2	+ 4,1	+14,2	+10,2	+21,0	+ 1,6	+12,3
31. 3. — 9. 4. 58	+ 7,0	+18,2	+0,5	+11,0	+ 9,4	+20,2	+ 5,9	+16,1	+10,6	+21,7	+ 3,4	+14,1
10. 4. — 19. 4. 58	+ 8,4	+19,8	+2,1	+12,4	+10,5	+21,1	+ 6,4	+16,4	+11,6	+22,5	+ 5,0	+15,5
20. 4. — 29. 4. 58	+11,2	+22,1	+5,8	+15,3	+12,7	+28,5	+10,7	+18,4	+13,2	+23,6	+ 7,7	+17,3
30. 4. — 9. 5. 58	+12,6	+22,7	+9,7	+19,4	+16,5	+25,6	+16,7	+25,1	+15,9	+25,9	+13,8	+23,4

Bemerkungen: T °C — Raumtemperatur.
Ft °C — Frigorigraphentemperatur.

Ähnliches gilt für den Offenstall. Hier liegt die Ausgleichstemperatur auf Grund des Windeinfalles und der veränderten Strahlungsbedingungen zwar um 1,8° C niedriger als der Testwert, die Schwankung von +0,8 und —1,5° C zu 9,69°. *ÜT* unterstreicht jedoch das fast gleichbleibende Gefälle ohne plötzlich auftretende über- oder unterschwellige Reize. Wesentlich für dieses Ergebnis sind die richtige Bauausführung und die Stellung der Unterkunft im Gelände, auf die immer hinzuweisen ist.

Der weiteren Diskussion der Meßwerte dient die Tabelle 2, in der die dekadenmäßige Erfassung die Beschreibung eng begrenzter Zeiträume mit den möglichen Extremwerten erlaubt. Eliminiert man hier alle Werte unter ±0° C, so errechnet sich durchschnittlich für den Offenstall eine *ÜT* von sogar 10,1° C. Dies besagt zwar keinesfalls, daß sich absolut die Bedingungen gebessert haben, unterstreicht aber, daß außer dem natürlichen Gefälle zwischen Oberflächen- und Lufttemperatur keine weiteren Faktoren Einfluß genommen haben. Noch deutlicher repräsentieren das Ergebnis Tage im Dezember 1957 und Januar 1958, als bei Raumtemperaturen

Tabelle 3. Hauttemperatur von Milchkühen im Massiv- und Offenstall Knau

Stall	*RT* °C	Hauttemperatur °C			
		Schulter Haarkleid	Schulter geschoren	Kreuz Haarkleid	Kreuz geschoren
Mass. Kuhstall	+2,0	29,8 (32,6—26,0)	28,5 (31,0—24,0)	29,0 (32,8—23,4)	27,3 (31,6—22,2)
Mass. Kuhstall	+5,0	28,2 (31,0—22,9)	27,1 (29,3—21,7)	27,2 (32,7—24,4)	26,5 (30,5—23,0)
Mass. Kuhstall	+8,0	30,7 (34,2—25,1)	30,7 (36,0—25,2)	31,5 (34,7—24,1)	30,4 (34,5—21,1)
Mass. Kuhstall	+10,0	30,3 (33,8—27,3)	29,7 (32,7—26,2)	30,2 (33,7—27,4)	30,1 (34,5—26,1)
Offenstall	—20,0	22,1 (24,4—20,6)	20,9(1) (22,3—<18)	18,2(2) (18,3—<18)	—(3) —
Offenstall	—12,0	24,6 (28,6—22,3)	22,1(4) (25,8—<18)	24,2(5) (31,7—<18)	21,2(6) (28,6—<18)
Offenstall	—11,0	24,2 (28,2—22,1)	22,7 (24,3—20,0)	21,5(7) (27,4—<18)	20,5(8) (23,9—<18)
Offenstall	+3,0	31,1 (32,8—29,1)	30,2 (31,9—27,9)	32,0 (34,7—25,8)	30,8 (33,6—24,1)
Offenstall	+4,0	28,8 (31,2—25,9)	25,6 (28,4—24,3)	28,9 (31,2—24,6)	25,8 (29,5—21,1)
Offenstall	+6,0	28,8 (32,1—26,0)	24,8 (28,1—22,2)	29,2 (32,1—25,8)	26,2 (28,8—22,3)

Bemerkungen: (1) — 5 Meßwerte unter 18° C
(2) — 7 Meßwerte unter 18° C.
(3) — 9 Meßwerte unter 18° C.
(4) — 2 Meßwerte unter 18° C.
(5) — 4 Meßwerte unter 18° C.
(6) — 4 Meßwerte unter 18° C.
(7) — 2 Meßwerte unter 18° C.
(8) — 2 Meßwerte unter 18° C.

im Offenstall von —10,2° C und —10° C Abkühlungstemperaturen von 1,5 und 6° C gemessen wurden, die damit den Testwert um 0,1 bzw. um 4,5° C überschreiten und eine Einstrahlung andeuten.

Zum Vergleich der erhaltenen Oberflächentemperaturen des Probekörpers werden in Tabelle 3 die Ergebnisse von Hauttemperaturmessungen an Kühen dargestellt. Als Meßpunkte wählten wir wie Zorn die Schulter und das Kreuz. Die Temperatur wurde auf dem Haarkleid und nebenan auf einer etwa 1 cm^2 umfassenden geschorenen Hautstelle gemessen.

Gestattet man vorerst die Gegenüberstellung der Raumtemperatur von +5° C im Massivstall und von +4° C bzw. +6° C im Offenstall unter Beachtung der Fehler-

Tabelle 4. Frigorigraphen- und Hauttemperatur im Offenstall

RT °C	*FT* °C	Schulter Haarkleid *t* °C	Schulter geschoren *t* °C	Kreuz Haarkleid *t* °C	Kreuz geschoren *t* °C
+ 3,0	12,2	31,1	30,2	32,0	30,8
	14,3— 9,0	32,8—29,1	31,9—27,9	34,7—25,8	33,6—24,1
+ 4,0	13,5	28,8	25,6	28,9	25,8
	15,0—11,0	31,2—25,9	28,4—24,3	31,2—24,6	29,1—21,1
+ 6,0	15,9	28,8	24,8	29,2	26,2
	17,2—13,0	32,1—26,0	28,1—22,2	32,1—25,8	28,8—22,3
—11,0	(3,7)	24,2	22,7	21,5	20,5
(—10,0)	(6,0— 1,0)	28,2—22,1	24,3—20,0	27,4—<18	23,9—<18
—12,0	(5,1)	24,6	22,1	24,2	21,2
(— 8,0)	(7,5—2,5)	28,6—22,3	25,8—<18	31,7—<18	28,6—<18
—20,0	—	22,1	20,9	18,2	—
		24,4—20,6	22,3—<18	18,3—<18	
	Differenz *RT* : *FT*	Differenz *FT* : *HT*			
+ 3,0	9,2	18,9	18,0	19,8	18.6
	11,3— 6,0	18,5—20,1	17,6—18,9	20,4—16,8	19,3—15,1
+ 4,0	9,5	15,3	12,1	15,4	12,3
	11,0— 7,0	16,2—14,9	13,4—13,3	16,2—13,6	14,1—10,1
+ 6,0	9,9	12,9	8,9	13,3	10,3
	11,2— 7,0	14,9—13,0	10,9— 7,9	14,9—12,8	11,6— 9,3
—11,0	13,7	20,5	20,7	17,8	16,8
(—10,0)	16,0—11,0	22,2—21,1	18,3—19,0	21,4— ?	17,9— ?
—12,0	—	20,9	18,4	20,5	17,5
(—10,0)		22.6—21.3	19,8— ?	25,7— ?	22,6— ?
—20,0	—	18,4	17,2	14,5	?
(—10,0)		18,4—19,6	16,3— ?	12,3— ?	?

Bemerkungen: *RT* — Raumtemperatur.
FT — Frigorigraphentemperatur.
HT — Hauttemperatur.

grenze von $\pm 1{,}5°$ C der benutzten Thermographen, dann scheint sich zumindest in der Schwankungsbreite um den Mittelwert eine gewisse Tragheit oder besser gesagt eine geringere Empfindlichkeit gegen Temperaturen dieses Bereiches bei den Offenstalltieren abzuzeichnen. Sie reagieren wahrscheinlich nach Zeiten in der Zone unter $\pm 0°$ C nicht so sensibel wie es den Massivstalltieren bei den herausgenommenen Einzelwerten von $+2°$ C bis $+10°$ C eigen ist. Mit Raumtemperaturen von —11° bis —20° C sinkt dann die Hauttemperatur ab, wobei die Rückenpartien empfindlicher reagieren als die Stellen an der Schulter (vergleiche Verhältnisse der Anzahl der Meßwerte unter 18° und Schwankungen). In welchem Umfange die Hauttemperatur weiter unter 18° C absinkt, können erst weitere Versuche klären. Die Meßwerte der Frigorigraphen-Oberflächentemperatur und der Hauttemperatur stimmen auf alle Fälle keineswegs überein. Die Tabellen 4 und 5 bringen es mit Differenzen von fast stets über 100% zum Ausdruck.

Tabelle 5. Frigorigraphen- und Hauttemperatur im massiven Kuhstall

RT °C	*FT* °C	Schulter		Kreuz	
		Haarkleid *t* °C	geschoren *t* °C	Haarkleid *t* °C	geschoren *t* °C
+ 2,0	13,1	29,8	28,5	29,0	27,3
	15,9—12,0	32,6—26,0	31,0—24,0	32,8—23,4	31,6—22,2
+ 5,0	16,2	28,2	27,1	27,2	26,5
	17,3—11,9	31,0—22,9	29,3—21,7	32,7—24,4	30,5—23,0
+ 8,0	19,2	30,7	30,7	31,5	30,4
	21,0—18,1	34,2—25,1	36,0—25,2	34,7—24,1	34,5—21,1
+10,0	21,2	30,3	29,7	30,2	30,1
	22,0—20,3	33,5—27,3	32,7—26,2	33,7—27,4	34,5—26,1
	Differenz *RT* : *FT*	Differenz *FT* : *HT*			
+ 2,0	11,1	16,7	15,4	15,9	14,2
	13,9—10,0	16,7—14,0	15,1—12,0	16,9—11,4	15,7—10,2
+ 5,0	11,2	12,0	10,9	11,0	10,3
	12,3— 6,9	13,7—11,0	12,0— 9,8	15,4—12,5	13,2—11,1
+ 8,0	11,2	11,5	11,5	12,3	11,2
	13,0—10,1	13,2— 7,0	15,0— 7,1	13,7— 6,0	13,5— 3,1
+10,0	11,2	9,1	6,5	9,0	8,9
	12,0—10,3	11,8— 7,0	10,7— 5,9	11,7— 7,1	12,5— 5,8

Bemerkungen: *RT* — Raumtemperatur.
FT — Frigorigraphentemperatur.
HT — Hauttemperatur.

Da weiter die Frigorigraphenwerte mit der Hauttemperatur des Menschen nur im mittleren Temperaturbereich gut übereinstimmen, ist die Abkühlungstemperatur z. Zt. lediglich als relatives Maß zu werten (Pirlet).

Unter Zugrundelegung des Relativmaßes kann man dazu geneigt sein (vergleiche Tabelle 5, Differenz 11 : 10, Kreuz, Haarkleid und nackt), dem Rind ein wirksames Abwehrvermögen über die Veränderung der Grenzflächentemperatur im Minusbereich zuzuschreiben. Zorn nahm das gleichfalls bei der Deutung seiner Versuche an, obwohl damals noch keine Differenzwerte zu Probekörpern vorlagen, die eine echte Auslegung zuließen. Andererseits wären die Angaben z. Zt. so zu verstehen, daß die Kühe bis $\pm 0°$ C überhaupt keiner Regulation ihres Wärmehaushaltes über die Haut bedürfen, da die Grenzflächentemperaturen ein relatives Gleichmaß im Bereich von ± 0 bis $+10°$ C in beiden Haltungsformen aufweisen (vergleiche Tabelle 3).

Ansonsten zeigt sich in den beiden letzten Übersichten, daß mit zunehmender Lufttemperatur die Differenz zwischen der Ausgleichsgröße und der gemessenen Hauttemperatur kleiner wird, also zur Annäherung zum Indifferenzpunkt führt. Wann Übereinstimmung eintritt, müssen weitere Untersuchungen zeigen. Aus dem Verhältnis der größten Abweichungen vom Indifferenzpunkt werden sich wahrscheinlich in Verbindung mit Respirationsversuchen Anzeichen für die notwendige Umstellung des Rindes auf weniger zutreffende Umweltbedingungen zeigen (Grenzpunkte der Leistungszone).

Insgesamt kann gesagt werden, daß mit der Frigorigraphie in Verbindung mit anderen Größen eine treffliche Charakterisierung des Kleinklimas in Unterkünften möglich ist. Vergleiche mit Hauttemperaturen bei Kühen sind allerdings z. Zt. nur relativ zu sehen.

Auf Grund der bisherigen Ergebnisse wäre mit Vorsicht festzustellen, daß:

(1) Kühe bis zu $\pm 0°$ C Stalltemperatur einer zusätzlichen Wärmeregulation über die Grenzfläche der Haut wahrscheinlich nicht bedürfen.

(2) Sich im Minusbereich Anzeichen dafür ergeben, daß das Rind über die Haut das Wärmegefälle zur Umwelt zu verringern sucht.

(3) Mit steigenden Lufttemperaturen die Differenzen zwischen den Probekörpern und den tatsächlichen Hauttemperaturen geringer werden.

THE EFFECTS OF HEAT ON HUMAN PERFORMANCE

K. A. PROVINS and C. R. BELL

Medical Research Council Unit for Research on Climate and Working Efficiency, Department of Human Anatomy, University of Oxford, Great Britain

Abstract—Previous work on the effects of heat on sensori-motor performance is critically examined in terms of the three major variables: (1) the thermal environment, (2) the task, and (3) the subject.

There is a good measure of agreement between the range of climates subjectively assessed as comfortable and that in which no deterioration in performance has been found. But the hypothesis is proposed that the effect of climate stress on performance is also dependent on the relative difficulty of the task for the subject and the "effort" he expends in accomplishing his performance. Further experiments controlling these factors are needed.

Résumé—Les auteurs examinent des travaux précédents sur les effets de la chaleur sur le rendement sensori-moteur en relation aux trois variables les plus importantes: (1) l'ambiance thermique, (2) la tâche, et (3) le sujet.

Il y a une correspondance considérablement exacte entre les espèces de climat jugées subjectivement confortables et celles où on ne trouve point de détérioration dans le rendement. Mais on suggère l'hypothèse que l'influence du climat sur le rendement dépend aussi de la difficulté de la tâche relativement au sujet, et de l'effort qu'il doit exercer pour l'accomplir. Il sera nécessaire d'élargir la recherche sur ces trois coefficients du rendement.

Auszug—Frühere Arbeiten über den Einfluss der Hitze auf die Verrichtung von sensorimotor Aufgaben werden mit Rücksicht auf die folgenden drei Hauptvarianten kritisch untersucht: (1) die thermale Umgebung, (2) die Aufgabe, und (3) die Versuchsperson.

Die Übereinstimmung über den Bereich, in welchem das Klima subjektiv als behaglich empfunden wird, und über die klimatischen Bereiche, in denen keine Leistungsverschlechterung stattfindet, ist gut. Die Hypothese wird jedoch vorgeschlagen, dass der Einfluss der Klimabelastung auf die Leistung auch von der relativen Schwierigkeit der Aufgabe für die Versuchsperson abhängt, und von der »Anstrengung«, die die Versuchsperson anwenden muss, um die Aufgabe zu verrichten. Weitere Versuche sind nötig um diese Faktoren zu kontrollieren.

INTRODUCTION

The measurement of the effects of high atmospheric temperatures on human performance is complicated by the multiplicity of actual or potential variables present in any given situation. For "climate" is rarely the unique environmental influence upon the experimental subject; such factors as the general noise level, lighting arrangement, presence or absence of other subjects and time of day or length of exposure may have an appreciable influence on the subjects' behaviour. Furthermore, "climate" itself consists of several elements, different combinations of which may affect the subjects' performance in different ways.

The various environmental factors affecting the thermoregulatory processes of the body are well known and many attempts have been made to find an adequate means of assessing the severity of a given climate by combining these different elements in some overall heat stress index. The severity of the heat stress changes according to the amount of physical work which is undertaken due to the increased heat load imposed on the body by the higher rate of metabolism. Useful discussion of the relative merits of the best known heat stress indices in relation to heavy manual work is contained in the papers by Bedford and Tredre (1955) and Lind (1960).

In any investigation of the effects of heat on human performance, it is of course necessary to assess both the work output and the cost to the subject of doing the work. The efficiency of a man, like that of a machine, is dependent on the amount of effort applied to the task as well as on the work done or performance level reached. In experimental studies of heavy work it is customary to fix the performance level by controlling the rate at which subjects work and to assess the applied effort by measuring their energy expenditure during the task, using a record of body temperature as an index of heat balance. In light work however, involving purely mental tasks or sensory—motor skill there is at present no adequate measure of applied effort, although the level of performance achieved again provides a valid indication of work output. Consequently, while a change in performance level with heat exposure is acceptable evidence for a climatic effect on the subject, the absence of a performance decrement on sedentary work with heat exposure is no indication that heat has not produced an effect. For the maintained quality or quantity of work output may only have been possible at an increased cost to the subject in terms of effort put into the task. Most of the studies of light work where the traditional physiological methods of measuring the effort applied are inappropriate, have been carried out by psychologists and it is this field of research which is reviewed in the present paper.

It would of course, be unwise to assume that the effects of heat are likely to be similar on all types of light task. Some jobs make much greater demands on attention than others while some require considerable manipulative skill, so that consideration of the precise nature of the task employed in each environmental study is very necessary (Provins, 1958; Provins and Clarke, 1960). Furthermore, interaction between the type of job and the subject tested on it must also be expected. Thus a task requiring fine manipulative ability does not pose the same problems for a laboratory technician as it does for a naval rating.

It is impossible to investigate climatic effects on human performance without the subjects exerting their own particular individual influences in the experimental situation, but it is not always evident in the literature that investigators have recognized the "performer" as a relevant variable in their experimental design. The level of performance achieved on tasks which are susceptible to the influences of the subjects' personality, his motivation and his emotional state at the time of testing can only be related to the climatic conditions as they affect that particular subject at that particular time. Even tasks which appear to be comparatively free from such personal factors may be markedly influenced by the subjects' general intellectual level, his special abilities, training or experience.

Thus, in any study of the effects of heat on human performance, the three basic variables are (a) the thermal environment, (b) the task, and (c) the subject, and for convenience the following discussion has been subdivided accordingly.

THE THERMAL ENVIRONMENT

Two main aspects of the study of thermal environments important to psychologists are, firstly, the assessment of climatic conditions, and secondly, the effects of different climatic conditions on behaviour.

Of the different ways of expressing the main environmental variables in terms of a single index of thermal stress, the effective temperature scale (Houghten and Yaglou, 1923a, 1924) is probably the most extensively used, particularly in connexion with sedentary work. The scale is based on the subjective assessments of three observers who judged the equivalence of different combinations of air temperature and humidity by passing back and forth between two adjacent climatic chambers and on further comparisons involving different amounts of air movement. Unfortunately, there appears to be no data available on the reliability of the observers' judgements nor has any other laboratory conducted a comfirmatory study, although Houghten and Yaglou claim a general concordance of opinion between their three subjects of plus or minus half a Fahrenheit degree on the wet or dry bulb scale. In view of the disagreement between the effective temperature measurement and other indices of thermal stress concerning the equivalence of certain climatic conditions particularly at high environmental temperatures (Lind and Hellon, 1957), a further study of the validity of the effective temperature scale is clearly overdue.

Using the effective temperature index to assess different climatic conditions, what is the effect of various degrees of thermal stress on human performance?

In discussing the selective nature of perception in attending to certain environmental stimuli and neglecting others, Broadbent (1953) suggested that the discomfort of extreme temperatures may produce the same sort of "fatigue" effect from discomfort which has been shown with loud noise. More precisely, Broadbent (1957) has proposed that . . . "the limited capacity of the human perceptual system makes it necessary for some incoming sensory information to be filtered out before reaching the main analyzing centres of the brain. Normally, irrelevant features of the surroundings are ignored and task stimuli control response. But after prolonged work in noise, the auditory stimulation may interfere with the task stimulation and so produce the effect we have called an internal blink" (i. e. an intermittent, involuntary shifting of attention to the distracting stimulus). If uncomfortable climatic conditions are likely to have a similar effect on performance, then it is necessary to ascertain first of all which environmental temperatures have been judged to be uncomfortably warm.

Closely following the studies on effective temperature, Houghten and Yaglou (1923b) attempted to define the climatic conditions which were acceptable to most people as comfortable for sedentary work. In this investigation subjects of both sexes, different ages and wearing various types of clothing were asked to record their opinions of a range of climatic conditions. The results suggest that the point at which half of the unacclimatized American subjects began to feel "too warm" was approximately 70°F (E. T.). However, in a study of (mostly young) men stripped to the waist, Yaglou (1927) found that half of his subjects said they were too warm at a temperature of approximately 77°F (E.T.), while at 83°F (E.T.) all subjects considered the conditions too warm. Clearly, this evidence shows that clothing and age may have an appreciable effect on what is found to be thermally acceptable.

In an investigation of environmental comfort in summer conditions on people of both sexes (and a fairly wide age range) wearing customary American warm weather clothing, Yaglou and Drinker (1928) showed that about half their subjects found the conditions too warm when the temperature exceeded approximately 75°F (E.T.) and all subjects considered the environment too warm at 79°F (E.T.). Compared with the 1923 study, these results suggest that acclimatization to summer conditions can also exert an appreciable influence on the acceptable limits for thermal comfort.

It is therefore interesting to find that in an investigation of the opinions of 2000 women and girls working in British factories, Bedford (1936) showed that beyond about 68°F (E.T.) most of his subjects considered the environmental conditions too warm for comfort. As the author himself suggests, it seems likely that the difference between this upper limit and those defined in the American studies is in part due to (a) the generally lower indoor air temperatures to which British people are accustomed (at least during winter), and (b) the warmer indoor clothing usually worn in Britain.

THE TASK

In considering the effect of heat on human performance, therefore, no well defined temperature limit can be expected beyond which deterioration is inevitable. It seems more likely that such factors as acclimatization, clothing and age will combine with other influences to modify any heat effects and produce a varying level at which performance decrement may be expected.

Perhaps the most important variable influencing the assessment of an environmental effect on performance is the amount of effort the subject puts into the task. This concept of effort is not nearly so clear or well defined as the physiological measure of energy expenditure, but it is nevertheless just as important. The effort a subject applies to his work is undoubtedly due to the degree to which he is motivated, but it is also likely to be influenced by his familiarity with the task and its difficulty relative to his ability.

It is therefore of particular interest to find that those tasks which have shown an effect of heat on performance have been, (a) those which usually show a deterioration with prolonged work anyway, and (b) those which are paced at a rate of work close to the subject's maximum capacity.

An example of (a) is Mackworth's clock test. This is a task of visual vigilance in which a few signals requiring a simple response are presented at random time intervals during a regular sequence of signals requiring no response at all. The typical finding is that the number of appropriate responses falls off after the first half hour. In other words vigilance or alertness is reduced over time. On Broadbent's discomfort hypothesis, the subjects' attention is more and more frequently shifted to environmental influences not related to the critical task stimuli and as the latter are only very brief, the probability of their being detected becomes less and less as time goes on. Consequently if the subject is exposed to environmental conditions which are distinctly uncomfortable, the same result may be expected but should be rather more pronounced. Mackworth's (1950) and Pepler's (1958) studies on this particular task at high environmental temperatures show precisely this effect.

In the second type of task (b), the signals requiring action are given at a high rate of presentation so that the subject has very little opportunity to pause between responses. If he does take a brief rest or allow his attention to stray from the source of critical stimuli then he is likely to miss or be late in perceiving an important stimulus and either fail to respond or to do so inadequately. Again, therefore, if the environmental conditions are uncomfortable, according to Broadbent's hypothesis, the subject will tend to be more often distracted from the central task and show a deterioration in performance. A good example of this type of situation is found in the investigation of Wireless Telegraphy Operators by Mackworth (1946) who tested skilled telegraphists on high speed morse code reception in five different climatic conditions. He found that the average number of mistakes per man per hour increased with effective temperature over the range of conditions examined and that in each climate performance deteriorated with time.

THE SUBJECT

Perhaps the most interesting aspect of Mackworth's (1946) study of W. T. operators, is the variation in the effect of heat on performance according to the ability of the subject. He found that not only were the most skilled operators less affected by heat than the others, but that they were less affected by time or even by a combination of the two. In other words, the nearer the subjects were working to their maximum capacity under ordinary conditions, the greater the effect of the experimental variable on their performance. Thus, the more highly skilled subjects showed little effect of heat or time on their performance, presumably because they could compensate for the increased stress by "drawing on their reserves" as it were, or putting an increased effort into maintaining their level of performance.

A further aspect of the subject's behaviour which is likely to have an appreciable bearing on his performance is the degree of motivation of the subject. In an investigation of the importance of this factor in adverse environmental conditions, Mackworth (1947) showed that while high incentives considerably raised the overall level of performance in a physical effort task, hot climates produced a significant deterioration at the same effective temperature in each case. However, it is worth noting that the absolute amount of deterioration due to heat was very much greater for the high than for the low incentive conditions. This suggests again that when subjects are working close to their maximum capacity, the effect of adverse working conditions will be marked, but when subjects are working well within their capabilities, little or no effect may be detected.

GENERAL DISCUSSION

In view of the considerable variation in the upper limit for environmental comfort depending upon the clothing, age and acclimatization of subjects, it is worthwhile noting that in nearly all investigations of the effects of heat on performance, the subjects have been fit young men stripped to the waist, either naturally or artificially acclimatized to hot conditions.

If subjects live or work in warm climates for long periods of time they not only become habituated to the conditions and experience less discomfort than when first exposed to the heat, they also undergo a physiological acclimatization (Hellon, *et. al.*, 1956). Their bodily responses become modified in order to maintain a heat balance at the higher environmental temperatures and there is a concomitant improvement in the subjects' diminished ability to perform muscular work. It therefore seems likely that there is also a recovery in the subjects' ability to perform more purely mental tasks and light skilled work but so far there is no experimental evidence on this point.

Attempts have been made to relate performance on various tasks in different climatic conditions to some physiological index of heat balance of the body such as the rectal temperature. This seems to be a reasonable association to assume yet so far no significant correlation has been shown. For example, in his investigation of performance by wireless telegraphists in five different climatic conditions, Mackworth (1946) found no significant association between rectal temperature and the incidence of W. T. errors. But it must be remembered that in this particular investigation there were appreciable differences in skill between subjects and that the high temperatures had a much smaller effect on the skilled operators. It therefore seems likely, as Mackworth suggests, that the effect of these differences in ability completely swamped any association between body temperature and performance.

Other attempts to relate these two variables have not met with any greater success (e.g. Carpenter, 1946; Pepler, 1958). On the other hand, the relationship between body temperature and environmental temperature has been shown many times (e.g. Yaglou, 1926), and it is interesting to note that the point on the effective temperature scale at which the body (i.e. rectal) temperature begins to rise is approximately the same as the point at which performance has been found to deteriorate significantly, that is, between about 85° and 90°F.

If a direct relationship could be found between performance and some physiological index of heat balance of the body, it would have considerable practical value in helping to predict human achievement in any given conditions as it would automatically take into account the influence of both clothing and acclimatization. Clearly, further research in this direction is highly desirable.

REFERENCES

BEDFORD T. (1936) *The Warmth Factor in Comfort at Work ; a Physiological* Study of Heating and Ventilation. Medical Research Council Industrial Research Board, Report No. 76.

BEDFORD T. and TREDRE B. E. (1955) Heat stress in industry. *Trans. Inst. Mining Engrs.* **115,** 210—40.

BROADBENT D. E. (1953) Neglect of the surroundings in relation to fatigue decrements in output. In *Symposium on Fatigue* (edited by FLOYD W. F. and WELFORD A. T. (Lewis), London.

BROADBENT D. E. (1957) Effects of noise on behaviour. In *Handbook of Noise Control* (edited by HARRIS C. M.), ch. 10. McGraw-Hill, New York.

CARPENTER A. (1946) *The Effect of Room Temperature on the Performance of the Resistance Box Test ; a Performance Test of Intelligence.* Medical Research Council Applied Psychology Unit, Report No. A.P.U. 50.

HELLON R. F., JONES R. M., MACPHERSON R. K. and WEINER J. S. (1956) Natural and artificial acclimatization to hot environments. *J. Physiol.* **132,** 559—76.

HOUGHTEN F. C. and YAGLOU C. P. (1923a) Determining equal comfort lines. *J. Amer. Soc. Htg. Vent. Engrs.* **29,** 165—76.

HOUGHTEN F. C. and YAGLOU C. P. (1923b) Determination of the comfort zone. *J. Amer. Soc. Htg. Vent. Engrs.* **29,** 515—36.

HOUGHTEN F. C. and YAGLOU C. P. (1924) Cooling effect on human beings produced by various air velocities. *J. Amer. Soc. Htg. Vent. Engrs.* **30,** 169—84.

LIND A. R. (1960) The effect of heat on the industrial worker. *Ann. Occup. Hyg.* **2,** pt. 3.

LIND A. R. and HELLON R. F. (1957) Assessment of physiological severity of hot climates. *J. Appl. Physiol.* **11,** 35—40.

MACKWORTH N. H. (1946) Effects of heat on wireless telegraphy operators hearing and recording morse messages. *Brit. J. Indust. Med.* **3,** 143—58.

MACKWORTH N. H. (1947) High incentives versus hot and humid atmospheres in a physical effort task. *Brit. J. Psychol.* **38,** 90—102.

MACKWORTH N. H. (1950) *Researches on the Measurement of Human Performance.* Medical Research Council Special Report Series, Report No. 268. (HMSO.) London.

PEPLER R. D. (1958) Warmth and performance: an investigation in the tropics. *Ergonomics* **2,** 63—88.

PROVINS K. A. (1958) Environmental conditions and driving efficiency: a review. *Ergonomics* **2,** 97—107.

PROVINS K. A. and CLARKE R. S. J. (1960) The effect of cold on manual performance. *J. Occup. Med.* **2,** 169—76.

YAGLOU C. P. (1926) The thermal index of atmospheric conditions and its application to sedentary and to industrial life. *J. Industr. Hyg.* **8,** 5—19.

YAGLOU C. P. (1927) The comfort zone for men at rest and stripped to the waist. *J. Industr. Hyg.* **9,** 251—63.

YAGLOU C. P. and DRINKER P. (1928) The summer comfort zone: climate and clothing. *J. Industr. Hyg.* **10,** 350—63.

VARIATION, OVER A PERIOD OF A YEAR, IN RESTING PULSE RATE AND ORAL TEMPERATURE IN YOUNG MEN

(A STUDY OF SEASONAL VARIATION IN A TEMPERATE CLIMATE) A PRELIMINARY REPORT WITH A REVIEW OF THE LITERATURE

E. T. RENBOURN

Statistical assistance by J. Greenland

Director Clothing and Equipment Physiological Research Establishment,
Directorate of Physiol. and Biol. Research, War Office.
Farnborough, Hants, Great Britain

Abstract—Over a period of a year, resting oral temperature (at 2½, 5, 7½ and 10 min of recording) and pulse rate was recorded, under standardized conditions, on mornings of various months in groups of healthy young men (1175 soldiers). Data were also available for pulse rate over 7 months of the previous year (total subjects for pulse rates 1976).

A variation of 36—132 beats per min was found in the complete data, with a variation of oral temperature of from 94.0° F to 100.4° F at 5 min and from 95.0° F to 100.6° F at the 10-min. recording. On a warm day in England the incidence of "raised" temperature was 6.8 per cent for 99° F and over, and 1.2 per cent for 99.5° F and above at 5 min, with 20.5 and 2.3 per cent, respectively, for a 10-min recording. If comparable and accurate results are to come from long term studies of oral body temperature, it is suggested that 10-min is the minimum recording time to be accepted for oral temperatures.

Higher oral temperatures and faster pulse rates occur on warmer mornings of the year. The evidence is stronger in the former case. The results are consistent with the hypothesis that the raised body temperature and pulse rate described for the tropics are but an exaggeration of what occurs in the summer of a temperate climate.

Errors of body temperature measurement and the physiological, psychological and meteorological conditions modifying pulse rate and body temperature are critically analysed. Reference is made to factors giving rise to spurious seasonal variation. An outline is given of the historical background and the earlier literature dealing with seasonal variation of body temperature and pulse rate in the tropics and in temperate zones.

Résumé—Au cours d'une période d'une année la température buccale au repos (enregistrement de 2, 5½ et 10 minutes) et la fréquence du pouls ont été enregistrées, dans des conditions standardisées, le matin, pendant plusieurs mois, chez un groupe de jeunes gens bien portants (1175 soldats). Ces données furent également valables en ce qui concerne la fréquence du pouls enregistrée au cours de 7 mois de l'année précédente (au total 1976 sujets dont la fréquence du pouls a été enregistrée).

Une variation de 36 à 132 pulsations par minute a été trouvée pour l'ensemble, avec une variation de la température buccale de 94,0° F a 100,4° F d'après l'enregistrement de 5 minutes et de 95,0° F à 100,6° F d'après l'enregistrement de 10 minutes. Par une journée chaude en Angleterre la fréquence d'apparition de la température «élevée» était de 6,8% pour 99° F ou une valeur très approchée, et de 1,2% pour 99,5° F et au-dessus d'après l'enregistrement de 5 minutes et respectivement de 20,5% et de 2,3% d'après l'enregistrement de 10 minutes. S'il s'agit de résultats comparables et précis d'études à long terme sur la température buccale, on signale que le temps minimum d'enregistrement acceptable pour les températures buccales est de 10 minutes.

Pendant les matinées chaudes de l'année les températures buccales deviennent plus fortes et la fréquence du pouls plus rapide. L'évidence est plus marquée dans le premier cas. Les résultats sont compatibles avec l'hypothèse que l'accroissement de la température du corps et de la fréquence du pouls observé sous les tropiques n'est qu'une amplification de ce qui se produit pendant l'été dans un climat tempéré.

Les erreurs de mesure de la température du corps et les conditions physiologiques, psychologiques et météorologiques modifiant la fréquence du pouls et de la température du corps sont analysées dans un esprit critique. L'auteur signale les facteurs qui provoquent une fausse variation saisonnière. A ce sujet il donne un aperçu historique et sur la litérature du début traitant la variation saisonnière de la température du corps et de la fréquence du pouls sous les tropiques et dans les zones tempérées.

Auszug—Während eines Jahres wurden die Mund-Temperatur bei Ruhe (Aufzeichnungs-Zeiträume: $2\frac{1}{2}$, 5, $7\frac{1}{2}$ und 10 Minuten) und der Pulsschlag unter standardisierten Bedingungen aufgezeichnet, u. zw. am Morgen verschiedener Monate bei Gruppen von gesunden jungen Männern (1175 Soldaten). Es waren ebenfalls Unterlagen vorhanden über die Pulsgeschwindigkeiten für einen Zeitraum von sieben Monaten des vorhergehenden Jahres (Gesamtzahl der Personen, deren Pulsschlag aufgezeichnet worden war: 1976).

Die zusammengefassten Daten ergaben Schwankungen von 36—132 Pulsschlägen pro Minute, und Abweichungen der Mund-Temperatur von 94,0° F bis 100,4° F bei fünfminütiger, und 95,0° F bis 100,6° F bei zehnminütiger Aufzeichnungszeit. An einem warmen Tag in England betrug die Häufigkeit einer »erhöhten« Temperatur 6,8% bei Temperaturen von 99° F und darüber, und 1,2% bei Temperaturen von 99,5° F und darüber bei fünfminütiger Aufzeichnungszeit; bei zehnminütiger Aufzeichnungszeit betrugen die entsprechenden Werte 20,5% bezw. 2,3%. Falls Wert gelegt wird auf vergleichbare und genaue Ergebnisse von Untersuchungen der oralen Körpertemperatur, die sich über einen langen Zeitraum erstrecken, so wird vorgeschlagen, daß als Aufzeichnungszeit für orale Temperaturen mindestens 10 Minuten angenommen wird.

Eine höhere Mund-Temperatur sowie schnellere Puls-Geschwindigkeiten kommen an wärmeren Morgenden vor. Die Beweisunterlagen sind für den ersteren Fall stärker. Die erzielten Ergebnisse stimmen mit der Hypothese überein, daß die in Bezug auf die Tropen angeführte erhöhte Körpertemperatur sowie die grössere Pulsgeschwindigkeit nur eine Steigerung dessen sind, was im Sommer auch in einer gemäßigten Zone auftritt.

Vorkommende Fehler bei der Messung der Körpertemperatur sowie die physiologischen, psychologischen und meteorologischen Bedingungen, die den Pulsschlag und die Körpertemperatur modifizieren, werden kritisch analysiert. Es wird auf Faktoren hingewiesen, die Anlaß zu unechten periodischen Schwankungen geben. Es wird ein Überblick gegeben über die historische Entwicklung sowie die frühe Literatur, welche die periodischen Schwankungen der Körpertemperatur und der Pulsgeschwindigkeit in den Tropen wie auch in den gemäßigten Zonen behandelt.

INTRODUCTION

From the time of the ancient Greeks, man has been preoccupied with the effects of weather and climate. Since it was believed that the balance of the four bodily humours varied with the individual, with age, sex, the passions and the climate, the heat of the body correspondingly varied. In hot weather, so it was said, bile (hot and dry) became greater in quantity thus increasing animal heat and the dryness of the body. According to some authorities, the 'innate heat' of the body was of celestial origin and hence could not be modified by the bodily functions.

Up to the beginning of the seventeenth century heat was measured by the hand alone and hence gave a measure of surface temperature only. The humoral theory dominated medical thought well into the nineteenth century, and even a century ago it was widely held that in a hot climate bile was not only increased in quantity but in some way deranged.

During the eighteenth century a number of clinicians began to use the thermometer as a measure of body heat. Boerhaave taught that the heat of the external air was rarely above that of the body. In any case, he added, the body temperature could rise but little, for above 100° of Fahrenheit's thermometer the blood coagulated like the white of an egg. It is hence not surprising that it was widely accepted that normal body temperature varied but little under various climatic conditions. Thus, writing in 1749, Senac noted: ". . . pourtant, la variété de température selon les climats ne fait pas varier celle de notre corps" (57). George Martine (32) referring to the experiments of Fahrenheit and Hales, was concerned with the error associated with the use of a thermometer for, said he, "I suspect that at least in some of them, there was not sufficient time allowed to warm up the bulb of their thermometers". Anton de Haen (21) of Vienna regularly used the thermometer at the bedside. He was also suspicious of the results of other physicians for, he insisted, they did not appear to know that the mercury in a thermometer maintained in the armpit could continue to rise for a half hour or even more. As a consequence he kept the instrument in position for seven and a half minutes and added to the reading, for good measure, another two or three degrees. His experience led him to believe that body temperature was higher in the summer than in the winter months. De Sauvages (56) went further and recorded that in winter the body temperature was 28° and in summer 30° R. About this time a number of observers (8, 16, 28) were recording normal body temperature in various tropical areas. Rush, in his Medical Observations of 1798, quoted a Dr. Adair who had found the body temperature in the tropics to be three or four degrees higher in newcomers than in the natives or those accustomed to the climate. Commenting on the matter, Currie (12) finding that Dr. Chisholm of Demarary had denied Adair's statement, insisted that medical men were not then sufficiently accurate in their thermometric observations. John Hunter had been concerned with the effect of breathing on cooling a thermometer in the mouth; but, enjoined Currie, "if it be under the tongue with the mouth close, the effect of respiration may be disregarded, as I have found from many hundred experiments".

The most important early observations on body temperature in various climates are those of Davy (13a, b, c). He found that in men (and sheep) the body temperature was somewhat higher in the summer than the winter of England. As for the tropics, the oral temperature was higher in both whites and indiginous people. Edwards (15), in 1824, had noted that the temperature of birds was higher in the summer time.

Following Davy a series of observers (5, 10, 17, 24, 29, 31, 35, 37, 46, 54) wrote on normal resting body temperature in the tropics. In general, it was said that the level was above that of temperate climates. Others, however (3, 18, 62), denied that climate had any effect on body temperature as measured in the axilla. Apart from the work of Davy and Edwards, there is little recorded observation on body temperature changes during the seasons in Europe. However, Bosanquet (4), in 1895, from records of rectal temperatures taken of himself four times daily, found the highest readings during the winter and early spring months. More recent work on body temperature in the tropics is that of Radsma *et al.* (45), Mason (33), Renbourn and Bonsall (51), Cullumbine (11), and Porter and Gibson (44). These observers find, under tropical conditions, a measurable increase of the accepted normal resting body temperature in both acclimatized residents and indiginous people. On the other hand, it has been stated that with exposure to heat in a climatic chamber, the resting body temperature is unaffected once acclimatization has been achieved (6). The early literature shows controversy as to a racial difference in body temperature, but it is somewhat doubtful whether this exists in healthy individuals (49). Cursory examination of the available data shows but little recent reference to the presence of a seasonal variation in body temperature in non-tropical zones. In a small number of subjects, Gustafson and Benedict (20) found no evidence for seasonal variation in basal temperatures in a temperate climate. Kleitman and Ramsaroop (26) in a study of two individuals found higher non-basal oral temperatures in the summer months.

From early periods, data (albeit inaccurate, uncontrolled or inappropriately analysed) have been available on the variation of resting body temperature over the period of a year in a temperate climate or in the tropics. There is, however, much less information on resting pulse rate. The earlier work had suggested a rise in the latter with exposure to heat — particularly in hot rooms. In 1870, Rattray (46) carried out work on the variation of physiological functions in the tropics. He found the average morning resting pulse rate to be five beats per minute slower in the tropics than in a temperate climate. This was due, so he said, to the diminished respiratory function then believed characteristic of tropical exposure. Parkes (39), Jousset (24), Plehn (43), Castellani and Chalmers (7), Napier (36), and others noted, on the other hand, an increase in resting pulse rate of newcomers to the tropics with a return to temperate levels with acclimatization.

In 1861 Smith (60) noted a faster mean pulse during an English summer, bat Coste (9), 30 years later, published an opposite finding. The latter agrees with work of Nicolai (38), and Paul (40). On the other hand, Völker (63) and Grollman (19) noted, under basal conditions, an absence of seasonal change in the pulse rate. Kleitman and Ramsaroop (26) gave evidence for seasonal variation in non-basal pulse rates in two subjects with maxima in the summer months.

It has been assumed by the writer that changes in body temperature and pulse rates found in the tropics are, to some extent, an exaggeration of what occurs during the summer months in a temperate climate. The present paper presents data which may throw light on the matter.

METHOD

Previous work has shown that under warm room conditions (68°F), temperature equilibration of a clinical thermometer under the tongue is not fully complete in 5 min (27). Examination of groups of young men during winter months demonstrated that with 5-min recordings, oral temperatures of 95°F and less could occasionally occur on cold mornings. In order to assess the validity of such readings, preliminary laboratory experiments were carried out on the problem of equilibration time of sublingual temperature readings under various conditions. The results, derived from twelve men, were briefly as follows:

(a) Within 5 min of recording, an ice cold thermometer gives the same mean reading as one conditioned at 80°F.
(b) Comparison of a clinical thermometer with a thermocouple at the same place under the tongue, shows that the former reads true oral temperature at 5 min or less.
(c) After preliminary rest of half an hour in a cold (32°F) or a warm (80°F) conditioned room with the mouth continuously closed, the sublingual equilibration time was found to be up to 15 min in some individuals. The mean difference between 10—5 min recordings was appreciably larger in the cold than under warm conditions.
(d) It was concluded that although a clinical thermometer records true mouth temperature within 5 min, a period of not less than a 10-min equilibration is required to give trustworthy data for oral temperature.

Over a period of a year, oral temperatures (checked NPL thermometers) and pulse rates (½-min reading by stop watch) were taken on one morning (11.30 a. m. to 12.15 a. m.) each month from groups (about 100 men) of young healthy soldiers of age, with few exceptions, 18—21 years. No food or drink had been taken for at least an hour. Men had previously been on some duty, and reported, in the open, at the time stated, outside a large well ventilated room where they remained standing and chatting for about a quarter of an hour. Subjects were then brought into the room in groups of 50, and given a simple brief explanation of the purpose of the visit. In order to minimize apprehension in the subjects, an informal manner was maintained by the observers. A group of fifty men was subdivided into groups of ten, each of which had two experienced observers, one for taking pulse rate and the other for oral temperature measurement. Men remained upright during the whole procedure. The following data were obtained: age, height, weight, military "fitness" index (Pulheem), nature of duty before reporting, inoculation if any during the preceding 2 weeks, and exposure to "stress" (examination, military charge, etc.) during the previous 2 days. In order to obtain readings that would be valid yet correspond to the usual clinical or physiological procedure, sublingual temperatures were obtained in the following way. The mercury in the thermometers was shaken to well below the 95°F level and readings taken to the nearest 0.1° level. A technique was devised whereby, using a stop watch, sublingual readings could be taken consecutively from ten men at exactly 2½, 5, 7½ and 10 min (with 12½- and 15-min readings in the colder months). In order to eliminate the "retreating" mercury phenomenon sometimes seen with clinical thermometers, these were read whilst in the mouth and the bulbs quickly replaced at the original site. The mouth was kept continuously closed during the whole period of recording. Readings of the same clinical thermometers by a group of experienced observors showed a random error of s. d. ± 0.12°F.

All unusually slow (below 60 per min) and fast (over 100 per min) pulses were checked by an independent observèr and all oral temperature readings over 99.5°F repeated with another thermometer. These repeat temperature readings usually showed pretty complete equilibration in 5 min. Temperatures below the lowest marked point on the clinical thermometer were read by extrapolation. Periodic wet and dry bulb temperature readings were taken outdoors and indoors during the period of examination.

RESULTS

Oral Temperature

Only the more relevant data are dealt with in this preliminary report. These are outlined in Table 1.

Variance analyses (between and with mornings) were carried out for 5- and 10-min. oral temperatures and for mean pulse rates for the mornings of the various months. More detailed scrutiny of the means was then done by further F-tests any by Tukey's method. Although analyses for the various equilibration times (2½—15 min) are not presented here, an example of the results for a warm and cold morning is given in Table 2.

A clinical thermometer is a maximum recording instrument and, hence, not suitable for measuring the continuous, small but rapid random temperature changes (as measured with thermocouples) which usually occur in the mouth or rectum (53). This, together with the slow diurnal change of temperature (usually rising or falling before noon), makes it somewhat difficult to assess the equilibration time as given in Table 2. However, where periods of equilibration of 5 min or less are used(as done commonly in clinical or even physiological studies), the mean reading in cold weather may appreciably underestimate (2.4°F at 2½ and 1.6°F at 5 min) the true oral temperature. It is worth noting that the reading at 15 min (Table 2) is close to 99.0°F — an unexpected high mean for even a warm morning in England. In the present study it was not possible to give more than 15 min for temperature recording, because the

Table 1. Mean Oral Temperature °F and Pulse Rate

Month Date	March 20. 3. 58.	May 1. 5. 58.	May 29. 5. 58	July 4. 7. 58	August 14. 8. 58	October 2. 10. 58
Environment						
Outside temp. °F/rel. hum. %	37 54	64 53	56 88	65 77	66 80	57 80
Room temp. °F/rel. hum. %	50 44	66 65	62 76	69 62	67 63	63 70
5 min oral temp. °F						
mean	96.94	98.40	98.11	98.29	98.31	97.87
s. d.	±1.220	±0.576	±0.652	±0.578	±0.583	±0.814
10 min oral temp. °F						
mean	97.78	98.71	98.57	98.69	98.69	98.40
s. d.	±0.975	±0.504	±0.502	±0.391	±0.501	±0.643
Pulse rate/min.						
mean	76.2	78.4	83.9	81.6	80.3	80.5
s. d.	±11.17	±12.90	±11.67	±11.78	±12.49	±10.93
Number of men (n)	100	100	100	100	100	100

large groups of men (recruits on a tight training programme) were available during a morning for only a short period of time. If results over a period of a year are to be strictly comparable, it is clear that an exact equilibration period must, in any case, be used as a routine.

Table 2. Mean Oral Temperature at Various Equilibration Times for a Cold and Warm Morning

Equilibration time (min)	Oral temperature (°F) 26. 1. 59 Cold $n = 99$ Reading	26. 1. 59 Cold Difference time—time	14. 5. 59 Warm $n = 100$ Reading	14. 5. 59 Warm Difference time—time	Difference hot—cold
2½	95.49	0.80	97.93	0.47	2.44
5	96.29	0.71	98.40	0.22	2.11
7½	97.00	0.40	98.62	0.40	1.62
10	97.40	0.29	98.76	0.07	1.36
12½	97.69	0.20	98.83	0.06	1.14
15	97.89		98.89		1.00

per Minute over Period of One Year (1175 Men)

Month Date	November 13. 11. 58	December 11.12.58	January 26. 1. 59	February 26. 2. 59	April 16. 4. 59	May 14. 5. 59
Environment						
Outside temp. °F/rel. hum. %	45 84	43 80	35 85	53 73	52 97	66 34
Room temp. °F/rel. hum. %	56 65	48 65	53 52	55 63	57 90	70 44
5. min. oral temp. °F						
mean	97.65	97.51	96.29	97.66	97.86	98.40
s. d.	±0.905	±0.951	±1.278	±1.030	±0.760	±0.621
10 min. oral temp. °F						
mean	98.42	98.24	97.40	98.27	98.51	98.76
s. d.	±0.606	±0.694	±1.132	±0.891	±0.573	±0.502
Pulse rate/min.						
mean	82.6	79.4	74.0	78.2	79.1	82.1
s. d.	±11.49	±11.39	±13.36	±12.01	±9.02	±11.71
Number of men (n)	100	100	99	77	99	100

Mean morning temperatures for 5- and 10-min recordings, with significant differences where present, are given in Tables 3 and 4. Although there is insufficient evidence for hard and fast conclusions, it would appear (particularly for the 10-min readings) that warm mornings of late spring and summer months give higher means than the winter months.

The grand means, and maximum and minimum temperature readings for the whole year are worthy of examination. At 5- and 10-min. readings the means are: 97.78°F ±0.031 (s. d. = ±1.056) and 98.38°F ±0.023 (s. d. = ±0.783), respectively. An analysis of the distribution of low temperatures (97.9°F and below) for the 10-min recordings are as follows:

% frequency: 97.9°F and below = 20.16 per cent, mainly on colder mornings.
96.9°F and below = 4.86 per cent, mainly on colder mornings.
95.9°F and below = 1.26 per cent, only on coldest mornings.
94.9°F and below = 0.42 per cent, only on January morning.

Preliminary examination of the distribution of the 10-min oral temperature readings of 99°F and over showed results as in Table 5. It is clear that the main incidence of raised oral temperature is found on warm mornings corresponding in general to the warmer months of the year. For the whole period of study, the incidence of tempera-

Table 3. Mean 5-Min Oral Temperature over 1 Year

Date	1. 5. 58	14. 5. 59	14. 8. 58	4. 7. 58	29. 5. 58	2. 10. 58	16. 4. 59	26. 2. 59	13. 11. 58	11. 12. 58	20. 3. 58	26. 1. 59
mean (°F)	98.40	98.40	98.31	98.29	98.11	97.87	97.86	97.66	97.65	97.51	96.94	96.29
c. e. mean. (variance analysis)	0,086						0,087	0,098	0,086			0,087
significance					> $P < 5\%$					> $P < 0.1\%$	> $P < 0.1\%$	

Table 4. Mean 10-Min Oral Temperature over 1 Year

Date	14. 5. 59	1. 5. 58	14. 8. 58	4. 7. 58	29. 5. 58	16. 4. 59	13. 11. 58	2. 10. 58	26. 2. 59	11. 12. 58	20. 3. 58	26. 1. 59
mean (°F)	98,76	98,71	98,69	98,69	98,57	98,51	98,42	98,40	98,27	98,24	97,78	97,40
s. e. mean (variance analysis)	0,068					0,068	0,068		0,077	0.068		0.068
significance						> $P < 5\%$	> $P < 5\%$	> $P < 5\%$	> $P < 5\%$	> $P < 0.1\%$	> $P < 0.1\%$	

Table 5. % Frequency of 10-Min *Oral Temperature over* 99° F *during* 1 *Year*

	1958								1959			
	March	May	May	July	Aug.	Oct.	Nov.	Dec.	Jan.	Feb.	April	May
% > 99.0	4	26	21	26	36	16	20	17	3	17	27	33
% > 99.5	1	6	3	3	4	3	0	2	0	1	0	8
Max.	99.8	100.6	99.6	99.7	99.9	99.8	99.4	99.6	99.4	101.6	99.4	100.3

tures 99°F and over is 20.3 per cent, with 2.6 per cent for 99.5°F and over. It may be noted that at 5-min temperature recording the incidence of the latter is 1.2 per cent.

Pulse Rate

The results from variance analysis and separate examinations of the means are given in Table 6. Because of the marked mean difference found on two days of the same month, viz. May, 1958, it is again difficult to draw hard and fast conclusions. However, it would appear that the lowest pulse rates are found on the coldest mornings of January and March. On the whole the result is somewhat similar to that found for oral temperatures but much less marked. Uncontrollable variables may play a part in the results. This will be taken up later. There is, of course, no equilibration error in the pulse rate as in the case of oral temperature. Taking the year as a whole the percentage frequency distribution of pulse rates are as given in Table 7. This demonstrates that a "slow" (60 per min and below) and a "fast" pulse (90 per min and over) may be found in normal young men (standing posture) in about 3.5 per cent and 21 per cent of cases, respectively, with a "normal" pulse rate of 70—89 per min in 59.8 per cent of cases. Our total mean pulse rate for the year is 79.11 $\pm$ 0.348, s. d. = $\pm$ 11.945, with a range of 48—132 per min. If data from the previous year (period of 7 months, 801 men) are included, the range becomes 36—132 per min. Such a variation is much wider than generally accepted. A pulse of 60 per min and below was always checked by other observers. No clinical abnormalities were found in such cases, but further clinical investigations were not possible. Some of the men knew that their pulse rate was slow, but none was an athlete in the strict sense of the word. Checking an unusual reading is by no means a fully valid procedure, for it was clear that any "special treatment" — re-examination of body temperature or pulse rate — may itself produce apprehension in some men.

Full meteorological analysis is not presented here, but Table 8 gives correlations between mean oral temperature and pulse rates with corresponding morning indoor and outdoor air temperature (dry bulb) over the period of study.

As the total number of pairs of values is small, it is not valid to compare the indoor and outdoor correlations. However, it does appear that correlation of pulse

Table 6. Means Pulse Rates during 1 Year

Date	29.5.58	13.11.58	14.5.59	4.7.58	2.10.58	14.8.58	11.12.58	16.4.59	1.5.58	26.2.59	20.3.58	26.1.59
mean	83.9	82.6	82.1	81.6	80.5	80.3	79.4	79.1	78.4	78.2	76.2	74.0
s. e. mean (variance analysis)	0.849							0.853	0.849	0.951	0.849	0.853
significance	> $P < 5\%$	> $P < 5\%$								> $P < 5\%$	> $P < 5\%$	

Table 7. % Frequency of Pulse Rates during 1 Year

120 and over	110 and over	100 and over	90 and over	89 and below	69 and below	59 and below	49 and below
0.25%	0.91%	5.66%	21.36%	78.64%	18.82%	3.42%	0.17%

Table 8. Correlation Coefficients between Indoor and Outdoor Temperature with Mean Oral Temperature and Pulse Rate

	Indoor temperature			Outdoor temperature		
	5-min oral temperature	10-min oral temperature	Pulse rate	5-min oral temperature	10-min oral temperature	Pulse rate
r	0.800	0.767	0.537	0.935	0.903	0.587
Sig.	$P < 5\%$	$P < 5\%$	Not sig.	$P < 5\%$	$P < 5\%$	Not sig.

rate with ambient temperature is not statistically significant. In the case of body temperature a fair sized and significant coefficient is present which may be larger for external temperature.

DISCUSSION

From the time of Hippocrates a keen interest has been taken into the effect of weather and climate on man in health and disease but, in spite of a long existing and voluminous literature, it cannot yet be said that a great deal of critical data are yet available on the matter. Biometeorolcgical change can be considered as an aspect of biological time variation (diurnal, day-to-day and seasonal, etc.). For this reason control of experiment is of vital importance if valid data are to be forthcoming. Since the state of posture, activity and nutrition (hot and cold food or drinks, etc.) are known to affect oral temperature and pulse rate, standardization of procedure is prerequisite. The errors of method of measurement (viz. equilibration time of thermometer, error of readings, etc.) are not to be forgotten, mean differences of comparable data should be analysed by suitable statistical procedures. Since a diurnal variation of body temperature and of pulse rate (2, 25) is known to exist, the same time of the day must be used in long-term studies. Sex and age are to be remembered. In children the emotional stress due to being examined in a group for the first time, increases the pulse but particularly the oral temperature (50). This phenomenon (to which acclimatization occurs with repeated examination) is, apparently, much less marked in adults, but undoubtedly occurs in nervous individuals or in psychoneurotics (50). The matter is to be remembered in the light of our maximal readings.

Complete data are rarely available for long-term studies except in the case of the individual or small groups and, even in the latter, statistical "missing plots" are inevitable. Since there is a marked inter-individual variation in pulse rate and body temperature (47) as in other characteristics, results from the few may not be applicable to the general population.

It is tacitly assumed that the pulse rate taken at the wrist and the temperature taken in the mouth are valid measures of the heart rate and "body" heat. Whilst for normal individuals this is undoubtedly true for the pulse rate, it is often assumed, particularly by the physiologist, that the oral is but a poor replica of the "general" or "internal" body temperature as measured in the rectum (23). However, if mouth temperature has not been disturbed by food, drinks or cold air, etc., and once temperature equilibration in the mouth has been reached, the resting sublingual temperature curve follows that of the rectum (both measured with thermocouples) pretty faithfully (53). Because of the complexities of body heat balance, it is doubtful whether any single measurement of body temperature (even that of the rectum) has any absolute value as a measure of general "body temperature" (53). In any case, oral temperature recording has become the clinical standard in many countries, and there are, furthermore, practical difficulties associated with the use of rectal recording in large groups of subjects particularly where time is limited.

More than two centuries ago Martine and de Haen suspected that equilibration errors were present with temperature recording. This was mentioned by Currie (12), Davy (13), Pembrey and Nicol (41); and the problem has been investigated more recently by Shelley and Horvath (58), McDwyer (30) and by Lewis and Renbourn (27). The present data show that in bioclimatological studies a minimum of 10 min recording should be allowed and that times should be accurately measured. The higher standard deviations of the 5-min than the 10-min recordings (Table 1) are probably related to the systematic underestimation of oral temperatures in the former case. Such an error can produce a spuriously low oral temperature on cold mornings. As a consequence, an apparent "seasonal" variation may result with higher figures in the warmer periods of the year. The long period of temperature equilibration found in this study is related to the time required for a new state of thermal balance in passing from the outside environment to a warmer room, but it is doubtful whether the activity itself (walking a few yards) plays any part (50).

There are abundant data in the recent literature on the effects of acute exposure in hot or cold climatic chambers on body temperature and pulse rate, particularly after exertion. The present work concerns, on the other hand, less available information on individuals at rest and presumably fully acclimatized to the realities of outside weather conditions. Although it is generally assumed that air temperature is an important single meteorological factor modifying body heat balance, humidity becomes of importance at air temperatures over about 75° F. It has been accepted for centuries that damp cold has a peculiar and deleterious effect on man. Recent work nevertheless suggests that the "cold damp" phenomenon is due to complex meteorological factors but is unlikely to be due to any specific thermal properties of damp air itself (52). Wind, rain and solar radiation, etc., are not always considered in simple studies such as the present one, but they may be more potent than air temperature itself in impressing the mind as well as modifying the thermal balance of the body. Barometric, electrical and other phenomena are factors in the storm fronts which, according to Petersen (42), Mills (34) and others, modify the physiological and psychological state of the body. With acclimatization to heat (and to some extent to cold), an imprint of the physiological response may remain for some time after removal from the environment of exposure. The body temperature and pulse rate may hence be affected not only by the weather at the time of examination, but also by that of the day or week or so before. This has not been determined for the data presented here. In certain parts of Europe, and proverbially in England, climate is dominated by the day-to-day vagaries of weather. In England a fair correlation may exist between outdoor and indoor temperature and humidity (Table 1), but with air conditioning, as practised in some countries, the indoor winter conditions (70° to 80°F dry bulb) may correspond to what some would call warm outdoor summer conditions. Indoor environments during the winter (and even summer) may thus sometimes bear little relationship to those outside. Since many individuals spend much of the 24 hr indoors, a change in body temperature and pulse rate over the year may reflect the indoor rather than the meteorological changes. Furthermore, examinations are usually done indoors. For this reason we have another possible source for a spurious "seasonal" variation and, perhaps, an explanation of the contradictory findings in the literature. Women expose a fair amount of skin to the ambient air and wear light and loose clothing. Men wear heavier clothing and expose, in general, the head, neck and hands only. Another factor modifying heat balance of the body may thus be the air movement, temperature and humidity within the clothing microclimate — a "climate" which will vary during the year and also from person to person. Physiological factors and the state of mind can modify both body temperature and pulse rate, but these various functions cannot be fully controlled even from day to day. It may be for these many reasons that we have found but an imperfect correlation between body temperature and pulse rate and the outdoor and indoor temperature. Nevertheless, a sizeable correlation is present for both outdoor and indoor air temperature and oral temperature (but not pulse rate).

Because of the complexity of interacting meteorological variables, and the ease in drawing invalid conclusions from physiological or clinical studies, the suggestion of de Rudder (55), that single meteorological factors be first considered, is worthy of much merit. Until this is done, the great volume of valuable work carried out by bioclimatologists may be viewed with reserve by clinicians, physiologists and others.

Accepted beliefs die hard even in the presence of repeated challenge. This is true for concepts of physiological normality (48). Since it is still assumed that the normal pulse rate and oral temperature are 70—90 per min and 97—99°F, respectively, figures above and below these are sometimes accepted as the abnormal. It is perhaps for this reason that, in studies of healthy individuals, data have been discarded if they do not fit in with accepted ideas of the normal range of values. Thus, Coste, in a classical study, took his own resting pulse rates every evening for 5 years. It is, however, fairly clear that he discarded pulse rates over 79 per min. This may, perhaps, explain a still further spurious "seasonal" variation with slower pulse rates during the summer (as described by Coste, Nicolai and Paul). In the present study, subjects were examined on one occasion only, and hence the presence of subclinical disease cannot be completely eliminated. In the winter months there was always a sprinkling of slight colds and catarrhs, but with no obvious correlation between these and the measurements taken or between them and a history of recent innoculations. The maximum oral temperature (morning and afternoon) in a large group of young men in the tropics was found to be 100.6°F (Renbourn and Bonsall). Although we have not discarded any figures in the present data, we would, nevertheless, regard with suspicion a morning temperature of say 100.6°F and above, at any time of the year, as possibly being outside the normal range of values. The mean evening temperature can, however, be 0.5°F above this.

The grand mean morning oral temperature in our data was 97.78° F for a 5-min, and 98.38°F for the 10-min recording. Whiting (64), in a study of 500 normal criminals (mean age 43 years and times of year unspecified), found a mean oral temperature of 98.38°F. Since a period of 3 min was used for temperature recording, the mean would correspond more closely to our 5-min figure. Heath (22), for a group of young men (with time of recording and period of the year unspecified) gave a mean oral temperature, for morning and afternoon, of 98.4°F (range 97—100°F). It is obvious that unless the conditions of experiment are identical, these various figures are not strictly comparable. Our data show, in general, that warm mornings (of warm months) show higher oral temperatures than cold ones. This corresponds to the results of Kleitman and Ramsaroop with two subjects. Unfortunately as our data are derived from one year only, and since we do not have monthly or weekly mean temperatures to present, our results cannot strictly throw light on seasonal variation. Nevertheless, it would appear that the original hypothesis put forward has some basis — that the pulse and body temperature findings in the tropics are but an exaggeration of what may be found in the summer period of a temperate climate. Our data demonstrate mean difference between a cold and warm morning of 2.4°F at 2½-min, 2.1°F at 5-min, and of 1.1°F at the 10-min recording. A mean difference of 1.0°F is still present at the 15-min recording.

Since the time of Wunderlich (67), oral temperatures less than 97°F have been regarded as subnormal, and figures of 96°F and below viewed as "collapse temperatures". The same is still put forward in many clinical and physiological textbooks (61, 65). A low body temperature may, however, be present in certain forms of endocrinal hypofunction and in some hypothalamic disorders. The present study shows that over the period of a year, the frequency of "low" morning temperatures with a 10-min recording was: 97.9°F and below, 20.16 per cent; 96.9°F and below, 4.8 per cent; 95.9°F and below, 1.2 per cent; with 94.9°F and below, 0.4 per cent. At a 2½-min recording the lowest reading was 93.6°F. Since it has been shown that even with an ice cold thermometer true oral temperature is being read at 5 min, the 10-min recording can be safely accepted as indicative of the level of resting "body temperatures" at the particular time of the morning. It is not generally realized that oral temperatures of 95°F and even lower may, under certain conditions, lie within the normal range of values. However, as early as 1845 the *London Medical Gazette* (14) noted that normal oral temperature could be found as low as 95.5°F. Albutt (1), in 1873 gave his own mouth temperature at 5.30 a. m. as 95.5°F "before rising from bed". A recent authority (66) demonstrates oral temperature curves of normal individuals with a level as low as 95°F at 4.30 a. m. However, it was tacitly assumed that an oral equilibration time of 3 min is sufficient for all ambient conditions.

On the arbitrarily and generally accepted assumption that an oral temperature of 99°F is the upper limit of normality, the 5-min morning readings for the whole year give a frequency of 6.8 per cent for 99°F and over, with 1.2 per cent for 99.5°F and above. With a 10-min reading, the corresponding frequencies become 20.3 per cent and 2.6 per cent. Oral temperatures of 99.5°F or over are, however, very unusual in the mornings of winter months.

A matter of some biological importance is the interpretation of a raised body temperature in the tropics (and of the warm periods of a temperate climate). Since this phenomenon occurs in both indiginous people (presumably fully acclimatized) as well as in residents, the phenomenon can hardly be regarded as heat "retention" arising from a disturbance of thermal balance. Tropical hyperthermia appears to be well marked in some desert animals (59), and the phenomenon may possibly represent a "purposeful" rise in the deep body "thermostat" level in order to lose heat efficiently and, perhaps, to conserve water in animals that sweat. Many more data are, however, required on this point. If figures of oral temperatures of 101°F and over are disregarded, the absolute yearly range of morning oral temperatures in our data is from 94°F to 100.4°F for 5 min and from 95°F to 100.6°F for the 10-min recording. For those who still assume that the normal body temperature in warm blooded animals is maintained within very "narrow limits", this interindividual variation of some 5—6°F in man is a matter worthy of consideration. A diurnal variation of 3°F or more may occur in some individuals within the course of 24 hr (Renbourn and Bonsall).

The grand mean pulse rate in our data is 79.7 beats per min. Whiting (64) gave a corresponding figure of 74.2, but that of Heath (81.46) is more appropriate since it represents results from young men in the standing posture. Times of the year have not, however, been considered in these two studies. In general, our results show that the pulse rate is significantly higher on warm than cold mornings. The results are thus similar to those of body temperature but with less clear evidence for "seasonal" variation. The highest and lowest mean pulses are 83,9 (May) and 74.0 (June) per minute, giving a mean difference of about 10 beats per min. Our data correspond to those of Kleitman and Ramsaroop but contradict the findings of Nicolai and of Paul. The pulse rate variation in the 12 months of study is 48—132, and if data from the previous year (7 months, 801 men) are included this becomes 36—132 per min. Heath found a rather narrower range (54—122) in a smaller group of men. The frequency distribution of "slow" pulses in our data is: 69 per min and below, 18.8 per cent; 59 and below, 3.4 per cent; 49 and below, 0.17 per cent. Although such slow pulse rates are to be regarded as lying within the normal limits, they are nevertheless infrequent. In the case of "raised" pulse rates the results were: 90 per min and over, 21.3 per cent; 100 and over, 5.6 per cent; 110 and over, 0.9 per cent; 120 and over, 0.25 per cent. It seems very likely that nervousness is the most important cause of a resting pulse of about 90 per min in normal adults. Earlier work has shown that the resting pulse rate is more variable than the post-work pulse rate (47). The relative variability of pulse rate as measured by the coefficient of variation (about 15 per cent) is clearly much higher than for oral temperature (about 1 per cent).

Comparison of individual pulse rates with corresponding oral temperature showed a surprisingly good positive correlation, but dissociation does occasionally occur. A fair sized and significant correlation between the two variables is present for the data presented here ($r = 0.280$ sig., $P < 0.1$ per cent).

ACKNOWLEDGMENTS

We are indebted to the numerous observers for painstaking help, to Aldershot Military H. Q. for permission to use the subjects and to Major A. O. Greef for supervision of the general arrangements. Mr. J. Draper was responsible for the earlier statistical analyses and investigation of thermometer equilibration times.

REFERENCES

1. Albutt T. C., The effect of exercise on body temperature. *J. Anat., Lond.* **7**, 106—19 (1873).
2. Boas E. and E. T. Goldschmidt, *The Heart Rate.* Springfield (1932).
3. Boileau J. P., The temperature of the human body. *Lancet* **1**, 413—14 (1878).
4. Bosanquet W. C., Notes on pulse rate and body temperature. *Lancet* **1**, 672 (1895).
5. Brown Séquard E., Recherches sur l'influence des changements de climat sur la chaleur animale. *J. Physiol. Path gén.* **2**, 549—53 (1859).
6. Burton A. L., J. Scott, B. McClone and H. C. Bazett, Slow adaptation in the heat exchanges of man to changed climatic conditions *Amer. J. Physiol.* **129**, 84—101 (1940).
7. Castellani A. and A. J. Chalmers, *Manual of Tropical Medicine*, 2nd ed. London (1913).
8. Cleghorn G., *Observations on Epidemical Diseases of Minorca, etc.* London (1751).
9. Coste F. H. P., Five years pulse curves. *Nature Lond.* **44**, 35—7 (1891).
10. Crombie A., The daily range of normal temperature in India. *Ind. Ann. Med. Sci.* **16**, 550—606 (1874).
11. Cullumbine H., Oral, rectal and axillary temperatures of adult Ceylonese. *Ceylon J. Med. Sci.* **6**, 88—90 (1949).
12. Currie J., *Medical Reports on the Effects of Water etc.*, 2nd ed. vol. I, London (1805).
13a Davy J., An account of some experiments on animal heat. *Philos. Trans.* **104**, pt. 2, 590—603 (1814).
13b Davy J. Miscellaneous observations on animal heat. *Philos. Trans.* **134**, 57—64 (1844).
13c Davy J., On the temperature of man within the Tropics. *Philos. Trans* **140**, 437—66 (1850).
14. Editorial, Temperature of the human body. *Lon. Med. Gaz.* **1**, 114 (1845).
15. Edwards W. F., *Sur L'Influence des Agens Physiques sur la Vie.* Paris (1824).
16. Ellis H., An account of heat and weather in Georgia. *Philos. Trans.* **50**, pt. 2, 754—6 (1758).
17. Eydoux C. T. and L. F. A. Souleyet, Sur la temperature de l'homme et des oiseaux. *C. R. Acad. Sci*, Paris, **6**, 456 (1838).
18. Furnell M. C., The temperature of the human body in hot climates. *Lancet* **2**, 110 (1878).
19. Grollman A., Physiological variation in cardiac output of man. *Amer. J. Physiol.* **93**, 537—43 (1930).
20. Gustafson F. L. and F. G. Benedict, The seasonal variation in basal metabolism. *Amer. J. Physiol.* **86**, 43—58 (1928).
21. Haen A. de, *Ratio Medendi in Nosocomio Practico.* Vienna (1758—67).
22. Heath C. W., *What People Are. A Study of Normal Young Men.* Cambridge (1945).
23. Horvath S. M., M. H. Menduke and G. M. Piersol, Oral and rectal temperatures of men. *J. Amer. Med. Ass.* **144**, 1562—5 (1950).
24. Jousset A., *De L'Acclimatement et de l'Acclimatation, Paris* (1884).
25. Kleitman N., Biological rhythms and cycles. *Physiol. Rev.* **29**, 1—30 (1949).
26. Kleitman N. and A. Ramsaroop, Periodicity in body temperature and heart rate. *Endocrinology* **43**, 1—20 (1948).
27. Lewis B. D. and E. T. Renbourn, Clinical thermometry. Regional differences and times for equilibration. *J. Physiol.* **127**, 57p (1955).
28. Lining J., Concerning the weather in S. Carolina. *Philos. Trans.* **45**, 336—44 (1748).
29. Livingstone D., *Travels and Research in South Africa.* London (1857).

30. McDwyer A. D., Temperature recording. *Brit. Med. J.* **1**, 157 (1949).
31. Martin R., *The Influence of Tropical Climates on European Constitutions.* London (1861).
32. Martine G., *Essays Medical and Physiological.* London (1740).
33. Mason E. O., On the effect of change of residence from temperate to tropical climate on basal metabolism, weight, pulse rate . . . and mouth temperature. *Amer. J. Trop. Med.* **20**, 669—86 (1940).
34. Mills C. A., *Climate makes the Man.* New York (1942).
35. Montegazza M., De la température des urines aux différentes heures du jour et sous différentes climats. *Pr. Méd.* **15**, 14—19 (1863).
36. Napier L. E., *The Principles of Practice of Tropical Medicine.* New York (1946).
37. Neuhauss R., Untersuchungen über Körpertemperatur, Puls und Urinabsonderung auf einer Reise um die Erde. *Virchows Arch.* **134**, 365—79 (1893).
38. Nicolai, Quoted by H. von Paul.
39. Parkes E. A., *A Manual of Practical Hygiene for Use in the Medical Services of the Army.* London (1861).
40. Paul H. von, Der Jahreszeitliche Gang der Kreislaufgrössen. *Arch. Kreislaufforsch.* **9**, 164—87 (1941).
41. Pembrey M. S. and B. A. Nicol, Observations on deep and surface temperatures of the human body. *J. Physiol.* **23**, 386—406 (1898—9).
42. Peterson W. F., *The Patient and the Weather.* Ann Arbor (1936).
43. Plehn F., *Die Kamerun-Küste. Klimatologie, Physiologie und Pathologie in den Tropen.* Berlin (1898).
44. Porter H. H. G. and M. M. H. Gibson, Observations on normal temperatures in Singapore schoolgirls. *Med. J. Malaya* **5**, 213—19 (1951).
45. Radsma W., J. T. Meyman and C. G. A. Masterbrook, Metingen van Bloeddruk en Polsfrequentie bij Blanken in Tropische en in Koelere Luchtstreken. *Nederlandsch Tydschr. v. Geneeskunde.* **82**, 4679—91 (1938).
46. Rattray A., On some of the more important physiological changes induced in human economy by changes of climate etc. *Proc. Roy. Soc.* **18**, 513—29 (1870).
47. Reid A. M., E. T. Renbourn and J. Draper, Comparative physiological trial of . . . load carrying equipment. *J. Roy. Army Med. Corps* **101**, 137—52 (1955).
48. Renbourn E. T., Normality in relation to human reactions. *Proc. 9th International Congress Industrial Medicine, Bristol* (1949).
49. Renbourn E. T., Racial differences in blood constituents. *Brit. Med. J.* **2**, 1163—4 (1954).
50. Renbourn E. T., Body temperature and pulse rate in boys and young men prior to sporting events. A study of emotional hyperthermia, etc. *J. Psychosom. Res.* **4**, 149—75 (1960).
51. Renbourn E. T. and F. F. Bonsall, Observations on normal body temperature in North India. *Brit. Med. J.* **1**, 909—14 (1946).
52. Renbourn E. T., A. M. Reid, D. R. Gilling and J. Draper, A contribution to the physiology of damp cold. An aspect of temperate climate—2. *Int. J. Bioclim. Biometeorol.* 3, pt. IV., Sect. A, 1—19 (1959).
53. Renbourn E. T. and P. F. Taylor, Unpublished Ministry of Supply Report (1956).
54. Reynaud A. A. M, Sur la Température Humaine, considerée sous le Rapport des Ages . . . des Races et des Climats. Thèse de Paris (1829).
55. Rudder B. de, *Wetter und Jahreszeit als Krankheitsfaktoren.* Berlin (1931).
56. Sauvages F. B. de, *Oeuvres Diverses.* Paris (1771).
57. Senac J. B., *Traité de la Structure du Coeur, etc.* Paris (1749).
58. Shelley H. B. and Horvàth S. M., Oral and rectal temperatures in a hot environment. *Bull. U. S. Army Med. Dpt.* **5**, 459—461 (1946).
59. Schmidt-Nielsen K., Ò. Schmidt-Nielsen, S. A. Jarnum and T. R. Haupt, Body temperature of the camel in relation to water economy. *Amer. J. Hyg.* **188**, 103—12 (1957).

60. Smith E., *Health and Disease as Influenced by the Daily, Seasonal and other Cyclical Changes in the Human Systems*, p. 162. London (1861).
61. Sunderman F. W. and F. Boerner, *Normal Values in Clinical Medicine*. London (1950).
62. Thornley J. G., The temperature of the human body in the Tropics. *Lancet* **1**, 554 (1878).
63. Völker H., Ueber die Tagesperiodischen Schwankungen der Lebensvorgänge des Menschen. *Pflüg. Arch. ges. Physiol.* **215**, 43—77 (1927).
64. Whiting M. H., On the association of temperature, pulse, and respiration with physique and intelligence in criminals. *Biometrika* **11**, 1—37 (1915—17).
65. Wiggers C. J., *Physiology in Health and Disease*. London (1949).
66. Wright S., Notes on experiments illustrating normal temperature regulation in young men. *Brit. Med. J.* **1**, 610—13 (1949).
67. Wunderlich C. A., On the use of temperature in disease. *A Manual of Medical Thermometry*. London (1871).

THE INFLUENCE OF CLOTHING ON THE COOLING POWER—(MAINLY ITS SOLAR COMPONENTS) MEASURED BY MEANS OF CYLINDRICAL FRIGORIMETERS

N. ROBINSON and D. RECHNITZER
Department of Physics, Institute of Technology, Haifa, Israel

Abstract—Generally, spherical frigorimeters are used for determination of cooling power. To liken the shape of frigorimeter to that of human body, we built and need frigorimeters of cylindrical shape. A spherical and a cylindrical frigorimeter were freely exposed and cooling power measurements carried out in order to obtain numerical coefficient of transition.

The influence of dry and wet clothing on the cooling power was determined under various conditions and in that way the quality of different textiles (concerning the cooling power) in various climatic conditions tested. Also the influence of the amount of evaporated liquid (wet clothing) on the cooling power was measured for different textiles.

Résumé—Pour la détermination du pouvoir réfrigérant on emploie d'une manière générale les frigorimètres sphériques. Afin d'adapter la forme du frigorimètre à celle du corps humain, nous avons construit et utilisé des frigorimètres de forme cylindrique. Un frigorimètre sphérique et un frigorimètre cylindrique ont été exposés librement et les mesures ont été faites de façon à obtenir des coefficients numériques de transposition.

L'influence des vêtements secs et humides sur le pouvoir réfrigérant a été déterminée dans diverses conditions et c'est ainsi que la qualité des différents textiles (en ce qui concerne le pouvoir réfrigérant) a été testée dans des conditions climatiques différentes. De plus l'influence de la quantité de liquide évaporé (vêtements humides) sur le pouvoir réfrigérant a été mesurée pour différents textiles.

Auszug—Für die Bestimmung der Kühlleistung werden im allgemeinen kugelförmige Kältemesser (Frigorimeter) verwendet.

Um die Form des Kältemessers der des menschlichen Körpers anzugleichen, wurden von uns Frigorimeter von zylindrischer Form gebaut und angewandt. Es wurden ein kugelförmiger und ein zylindrischer Kältemesser der Temperatur unbehindert ausgesetzt, und Kühlleistungs-Messungen durchgeführt zum Zwecke der Erlangung eines numerischen Übergangs-Koeffizienten.

Der Einfluß sowohl trockener als auch nasser Kleidung auf die Kühlleistung wurde unter verschiedenen Bedingungen festgestellt, und dabei wurden auch die Eigenschaften der verschiedenen Textilien (hinsichtlich der Kühlleistung) unter verschiedenartigen Bedingungen überprüft. Der Einfluß der Flüssigkeits-Verdunstungsmenge (bei nasser Kleidung) auf die Kühlleistung wurde bei verschiedenen Textilien gemessen.

One of the main factors affecting the senses of man in his environment are the climatic conditions. The meteorological elements that are usually measured are not sufficient to determine how a climate is actually experienced by the human body.

A practical approach to this problem was made by using a quantity known as "cooling power" (C. P.). Cooling power is defined as the heat loss (or heat gain) from 1 cm^2 of area of a body and measured in mcal/sec. The instrument used for this measurement is the frigorimeter — a metal sphere equipped with an electrical heating element and an automatic device to switch it on and off when the temperature of the sphere has reached the required temperature. For a spherical frigorimeter when freely exposed and dry the cooling power is given by:

$$\text{C. P.} = Q + \frac{1000 \cdot S \cdot \pi \cdot r^2}{60} + \frac{1000}{60} D\, 2\pi r^2 - a_1(T_F - T_A) - a_2\,\sigma(T_F{}^4 - T_S{}^4) \quad (1)$$

where Q is the electrical energy supplied to the frigorimeter in order to maintain the temperature at the intended level;

S is the direct solar radiation in (cal/cm^2 per min);

D is the diffuse sky radiation in (cal/cm^2 per min);

T_F is the absolute temperature of the frigorimeter;

T_A is the absolute temperature of the air;

T_S is the absolute temperature of the surroundings.

For a freely exposed body and a cloudless sky the T_S is the temperature of the upper layer of the atmosphere (which is very low) and for an overcast sky the T_S is approximately the temperature of the clouds. The first three terms in equation (1) are heat gains, the rest are heat losses. The $a_1(T_F—T_A)$ is the heat loss by natural and forced convection. For low wind velocities (up to 5 m/sec):

$$a_1 = a + b.v$$

a linear function of the wind velocity v.

The coefficient a_2 is the absorption coefficient of the frigorimeter, σ is the Stefan—Boltzmann constant.

When the C.P. $<$ 0 we speak about cooling power and when C.P. $>$ 0 it is called "heating power". It may be seen that the C.P. value in equation (1) contains all possibilities for heat exchange as long as the frigorimeter is dry. For a frigorimeter evaporating all the humidity supplied to it, a third term of losses must be added — the latent heat of evaporation.

In spite of its symmetry and simplicity for computation, the spherical frigorimeter poses some difficulties when intended for specific purposes, as for instance measurements where the comparison with the silhouette of the human body is required.

An interesting proposal was put to the authors several months ago: would there be a way of checking the properties of a certain number of different textiles as to how they affect the persons who wear them, from the climatological point of view? A pair of frigorimeters of cylindrical form (nearest to the human torso) was built based on the main properties of the spherical frigorimeters (volume, power supply, etc.). The cylindrical form makes it easy to wrap the frigorimeter in a material. For such a frigorimeter:

$$\text{C.P.} = Q + \frac{1000}{60} S \cos h \cdot 2\pi r H + \frac{1000}{60} D\, 2\pi r H - \alpha_1'(T_F - T_A) - \alpha_2 \sigma (T_F{}^4 - T_S{}^4)$$

where h = sun altitude;
H = the height of the cylinder;
r = the radius of the cylinder.

As the wind function α_1' of the cylindrical frigorimeter has not yet been determined by the authors, a relative cooling power, $(\text{C.P.})_r$, was used — the relation between the C.P. of an "undressed" cylindrical frigorimeter and another dressed in the fabric being tested. The frigorimeters are identical and both of them are exposed in the same way, at the same temperature of 36.5°C. Several measurements were carried out under different circumstances.

A comparison of values obtained after both the dressed and undressed frigorimeters were exposed for several hours to the following conditions: sun in still air or in wind; weak wind only; strong wind; heated air circulation without exposure to the sun; humid air circulation, etc., has shown clearly the influences of the above-mentioned conditions on the C.P.

Fabrics soaked in artificial sweat were also checked for their influence on the C.P. when the frigorimeters were wrapped in them. All these experiments have given certain readings which indicate the influence of specific conditions as well as the influence of the composition and the texture of the fabric. In order to prove the results for different materials, checks were made in the following way: the readings were obtained by comparing the results after a dressed and an undressed frigorimeter were exposed to similar conditions, and the percentage of energy invested was computed in order to maintain the same temperature in both frigorimeters. When the computation showed that one fabric caused the frigorimeter to draw twice as much energy as the other fabric (when both frigorimeters were compared to an undressed one), both fabrics were wrapped round identical frigorimeters and exposed to the same conditions as in the previous test. The reading showed for the first fabric an expenditure of energy twice as great as for the second.

In order to determine the influence of sweat on the C.P., the velocity of suction of artificial sweat, the maximum amount of sweat absorbed by 1 cm^2 of the fabric and the velocity of evaporation under different temperatures and wind velocities were measured.

The data received for all elements enable one to conclude which fabric is convenient and suitable for specific climatic conditions, e. g. for a place with much sunshine, high temperature, low humidity and high wind velocities, a bright textile transparent to air, of good suction velocity, high sweat absorption capacity and quick evaporation is suitable.

It is not the intention of the authors to claim the achievement of a foolproof method for determining the influence of various climatic outside conditions on the senses of the human being. They only desire to present this paper as a step towards this ultimate goal.

SLEEP AND WAKEFULNESS IN THE ARCTIC UNDER AN IRREGULAR REGIME

HELEN E. ROSS B. A.

187, Bermondsey Street, London S. E. I.

Abstract—This study aims to show the effects of irregular and interrupted sleep periods on the distribution and total amount of sleep taken, and the pattern of compensation for shortage or excess of sleep. The total amount of sleep was about the same in Oxford as in the Arctic.

Résumé—L'intention de cette étude est à montrer les effets des durées de sommeil irrégulières et interrompues sur la distribution et la somme totale de sommeil prise, et le dessin de compensation ou pour la brièveté ou pour l'excès de sommeil.

Äuszug—Die Untersuchung geht darauf hinaus, die Wirkung von unregelmässigem und unterbrochenen Schlaf auf die Verteilung und Gesamtmenge des Schlafes darzustellen, sowie die Form eines Ausgleichs für den Mangel oder Überfluss an Schlaf. Die Gesamtschlafzeit war in Oxford wie auch in der Arktik ungefähr dieselbe.

Studies have been previously made on the sleep habits of members of the British North Greenland Expedition of 1952—1954 (1) and of the London School of Economics Mountaineering Club Himalaya Expedition of 1956 (2). It was shown that Arctic conditions had no effect on the total number of hours slept per day, though there were great changes in the sleep/wakefulness patterns of individuals. In the Himalayas, the average number of hours slept per day while living between 10,000 and 20,000 ft was greater than the average below that level, but the sleep/wakefulness patterns were only slightly changed.

On both these expeditions members were allowed to establish fairly regular, if unusual, sleep patterns. The present study aims to show the effects of irregular and interrupted sleep periods on the amount and distribution of sleep taken.

METHODS

The sleep was studied of six members of an ornithological expedition while camping in July in the extreme northeast of Norway, near the borders of Russia and Finland. Three of the subjects were men and three women, and their ages ranged from 20 to 23 years. Each subject was issued with a printed sleep card which he filled in daily. The cards were supplied by the Medical Research Council and were similar to those described by Lewis and Masterton (1) except that they lasted for a week instead of a month. A thin line was drawn across all hours spent in sleep, and interruptions were marked by a break in the line at the appropriate time, or by a V-shaped mark if very short. The causes of interruptions were noted on the backs of the cards. Sleep was reckoned from the time that a subject lay down, unless he suffered major interruptions almost immediately. Short naps were marked in the same way as longer sleep periods.

Subjects were not all at the base camp at the same time, so that, although in most cases records were kept for longer periods, the present results refer to a 3-weeks' period in July when they were together under comparable conditions. A 3-weeks' control period while studying at Oxford was obtained for each subject, and in most cases also a 3-weeks' control period while travelling in other parts of Scandinavia under more permissive sleep conditions than at camp.

Sleep/wakefulness diagrams were prepared, following the method of Kleitmann and Engelmann (3), with the bottom of the rectangle representing the fraction of the 3-weeks' period spent in sleep (Fig. 1). The shaded portion of the rectangle shows at a glance the total fraction of the period slept, and the times of sleep.

RESULTS

Total sleep

The mean sleep of all subjects was 7.8 hr per night at camp and 7.6 hr during the control period at Oxford, so that camp conditions did not affect the total sleep taken. There was considerable variation between individual means (Table 1), but the difference between the camp and control periods was not statistically significant for any individual (except for male 1, whose Oxford mean should be discounted, as he was taking sleeping tablets under medical advice).

Table 1 Average Hours of Sleep per Day during Three Weeks' Periods

Subject	Camp	Scandinavia	Oxford
Female 1	8.68	—	7.92
Female 2	8.62	—	8.12
Female 3	8.43	8.33	8.17
Male 1	6.69	7.31	(8.16)
Male 2	7.76	7.93	7.41
Male 3	7.09	7.00	7.29

The average sleep for the women at camp was 8.56 hr, and for the men 7.01 hr. The difference (1.55 hr) was significant at the 2 per cent level of confidence. At Oxford the average sleep for the women was 8.07 hr, and for the men 7.65 hr. The difference (0.42 hr) was not significant, and would probably not have been so even if male 1 had been sleeping less.

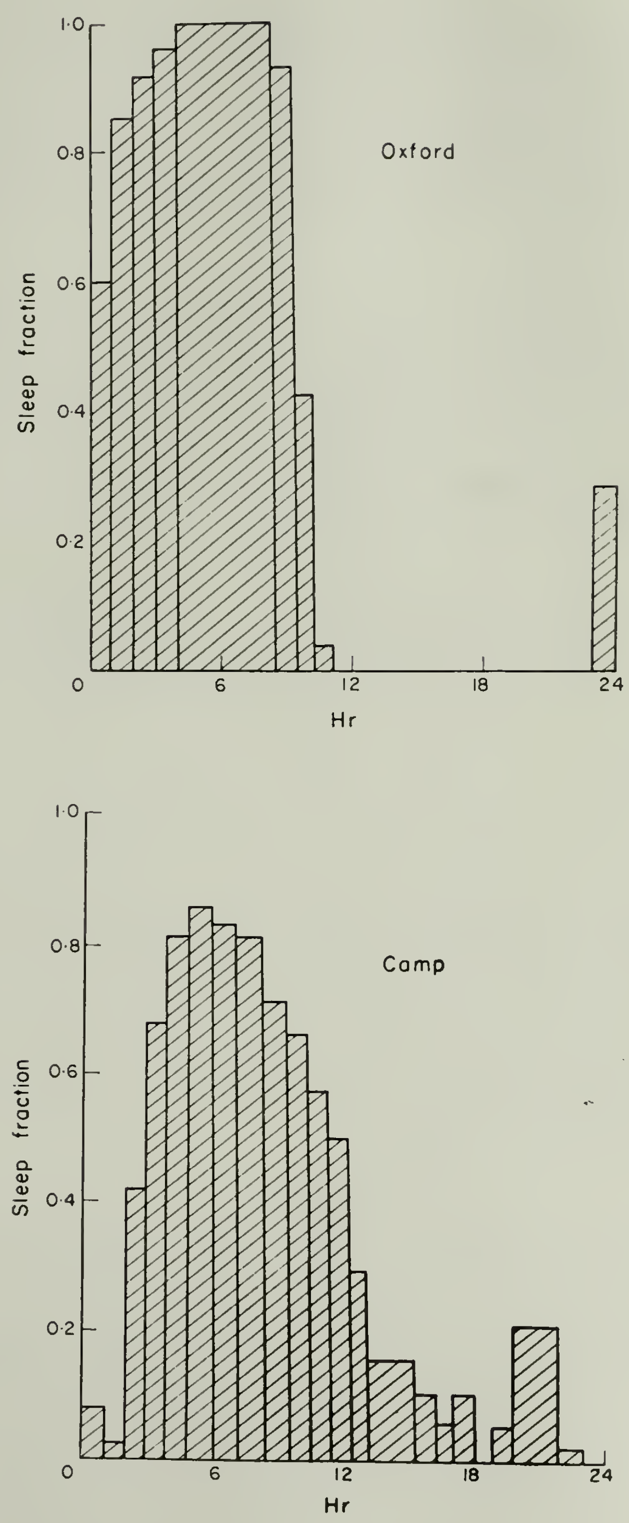

Oxford
Sleep fraction
1·0
0·8
0·6
0·4
0·2
0
6
12
18
24
Hr
Camp
Sleep fraction
1·0
0·8
0·6
0·4
0·2
0
6
12
18
24
Hr

FIG. 1.

Sleep Distribution

The sleep/wakefulness diagrams (Fig. 1) show the change in sleeping hours for a typical individual at camp and at Oxford. The total shaded area remains about the same, but at Oxford all sleep is taken between the hours of 11.0 p. m. and 11.0 a. m., whereas at camp sleep is taken at almost any hour, though more between 2.0 a. m. and 12.0 midday. There were similar changes for all subjects.

Compensation for Short Sleep

A short sleep was defined as one of at least an hour less than the mean for the individual concerned. Similarly a long sleep was at least an hour more than the mean. A sleep period of up to 3 hr and following the main period by at least 1 hr was defined as a "nap". The findings agreed with those of Lewis and Masterton (1) and Williams (2), that there was no correlation between interrupted nights and the taking of naps, though naps usually only occurred after short sleeps.

Table 2 Percentages of Long and Short Nights Followed by Long or Short Nights

Nights	Percentage followed by at least			
	1 Long	1 Short	2 Long	2 Short
Short	68%	31%	22%	0%
Long	37%	52%	6%	1%

Table 2 is the combined results of 5 weeks' sleep for four subjects and 4 weeks' sleep for two subjects, to show the relation between short and long nights. (The patterns for all subjects were similar). Forty per cent of all nights were short, whereas only 34 per cent were long. Short sleeps were more often followed by long sleeps than long by short. Long sleeps usually followed short sleeps within 3 days, and appeared to be caused by them, whereas short sleeps were due to compulsory interruptions rather than previous long sleeps.

DISCUSSION

Sleep was interrupted and irregular mainly because the ornithological work often entailed watches round the clock, or at least during the "night". There was continuous daylight during the camp period, though for an hour or two around midnight the light grew slightly dimmer and the sun went behind the hills. The temperature could vary between freezing point at night and 80° F. during the day, and this was a common cause of interrupted sleep. Subjects frequently went to bed at about 3.0 a. m. with all their clothes on, only to be woken up by the heat at 7.0 a. m. when the sun struck their tents. They would then remove most of their clothes and sleep in the heat till midday. Discomforts due to cold, heat, full bladders and hard ground were the most frequent causes of the constant minor interruptions that most sub-

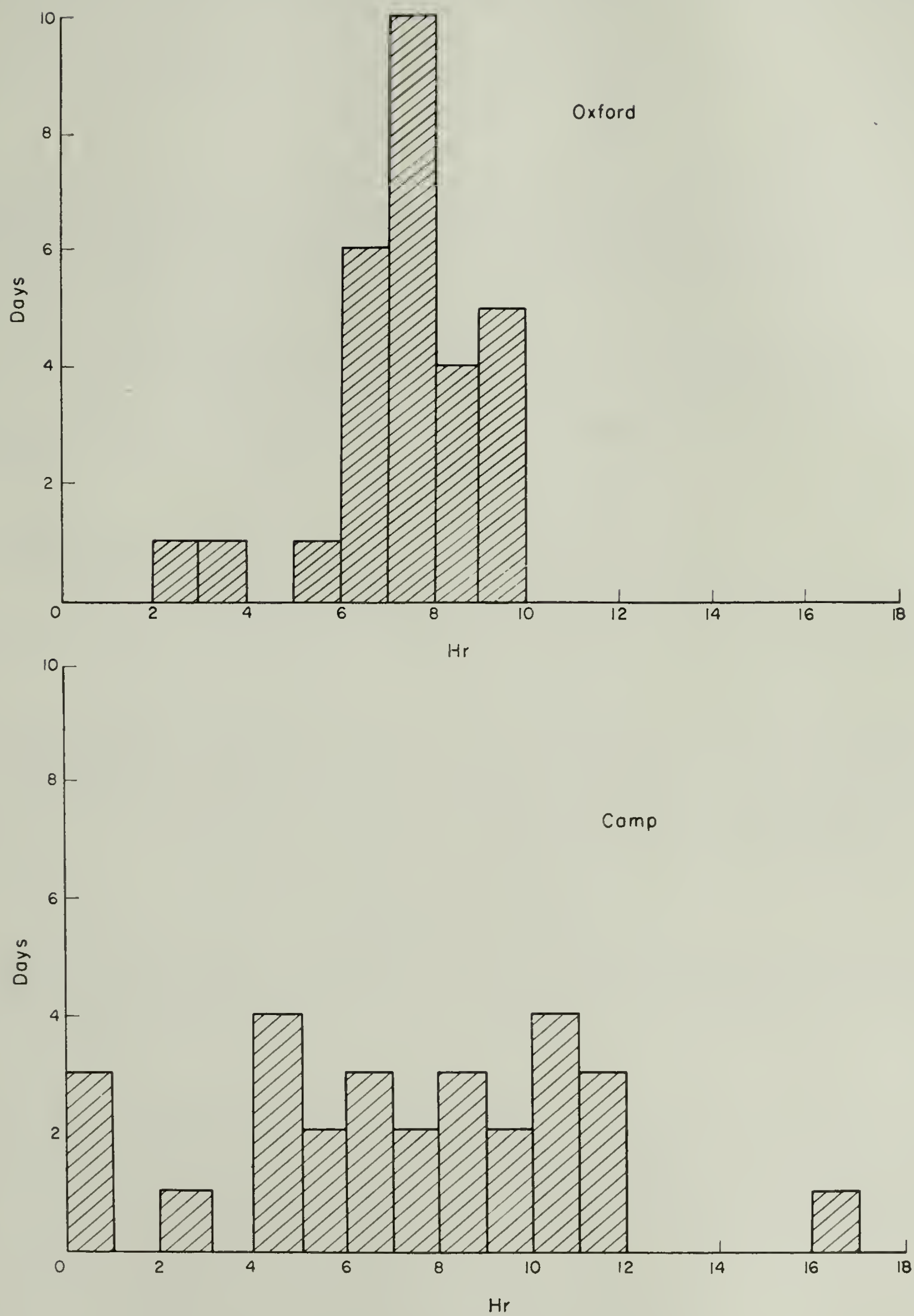


FIG. 2.

jects experienced during their sleep periods. Major interruptions were usually caused by bird watching sessions at fixed hours, or the necessity to meet the villagers at certain times, or reach the shops before they closed. The subjects' sleeping habits were therefore a compromise between the demands of the scientific work, the social and sleeping habits of the village community around them, the necessity to eat their meals together, and the exigencies of the weather.

Contrary to the findings of Lewis and Masterton (1), there appeared to be a fair amount of activity past midnight among the villagers in July. They said that they slept less during the summer than the winter, but there was no direct evidence about their winter sleeping habits. The activity observed was mainly among the young people, and the older people may have retired at their usual hour. The fact that the women slept longer than the men at camp was probably due to the fact that they did less of the night bird watching, and were inclined to stay in bed until the men had started cooking breakfast. They slept less at Oxford than they did at camp, but this may have been because they found Oxford life less physically tiring.

SUMMARY

The sleep habits of three men and three women were studied during a 3-weeks' period in Arctic Norway and a similar control period at Oxford.

The total amount of sleep taken was approximately the same under both conditions; but in the Arctic the sleep was taken at irregular hours and in variable amounts, because of the difficulty of obtaining uninterrupted sleep periods.

A sleep of less than average length was usually followed by a long sleep within the next 3 days, while a long sleep was not so often followed by a short sleep.

The women slept significantly longer than the men while in the Arctic, but it was not clear whether this was a physical need or due to laziness.

ACKNOWLEDGEMENTS

This study formed part of the work of the Oxford Finnmark Expedition 1959, and I should like to thank its members for their cooperation. My thanks are also due to Dr. K. A. Provins and Dr. H. E. Lewis for their suggestions and help.

REFERENCES

1. H. E. Lewis and J. P. Masterton, *Lancet* **1**, 1262—6 (1957).
2. E. S. Williams, *Brit. Med. J.* **1**, 197—8 (1959).
3. N. Kleitman and T. G. Engelmann, *J. Appl. Physiol.* **6**, 269 (1953).

A COMPARISON OF THE CUMULATIVE DISCOMFORT INDEX (CUM. D.I.) AND CUMULATIVE EFFECTIVE TEMPERATURE (CUM. E.T.), AS OBTAINED BY METEOROLOGICAL DATA

E. SOHAR, M. D., J. TENNENBAUM*, M. Sc. and N. ROBINSON
*Climatic Research Unit, Tel-Hashomer Hospital, Tel-Hashomer, Israel
Prof. N. Robinson: Solar Physics Lab., Inst. of Technology, Haifa, Israel

Abstract—During a 24-days' march traversing several regions differing in climatic conditions, in August 1959, two methods for the comparison of the heat load on separate days were investigated. The Cum. E.T. which was based on the sum of E.T. degrees for each hour of the day and night, and Cum. D.I. based on the sum of D.I. values (modification of the method of Thom) for each hour of the day and night.

Both methods were found equally suitable, but the Cum. D.I. method has the advantage of simples measurement and calculation, as compared with the Cum. E.T. method which necessitates the use of more instruments, tables and calculations.

Résumé—Deux méthodes pour la comparaison de la quantité de chaleur en des jours distincts ont été examinées en août 1959, au cours de 24 jours de marche à travers diverses régions présentant des conditions climatiques différentes. (1) la sommation E.T. basée sur les degrés E.T. cumulés (Température Equivalente) pour chaque heure de la journée et de la nuit et (2) la sommation D.I. basée sur les valeurs cumulées de D.I. (Indice de «Disconfort») (Modification de la méthode de Thom) pour chaque heure de la journée et de la nuit.

Les deux méthodes convenaient aussi bien l'une que l'autre, toutefois la méthode sommation. D.I. présente l'avantage de mesures et de calculs simples, par rapport à la méthode sommation E.T. qui nécessite davantage de calculs et des instruments et des tables plus nombreux.

Auszug—Während eines Marsches von 24 Tagen, der im August 1959 stattfand, und bei dem mehrere klimatisch voneinander verschiedene Regionen durchquert wurden, wurden zwei Methoden für den Vergleich der Hitzebelastung an verschiedenen Tagen untersucht. Die «Cum. E.T.» gründete sich auf die Summe von E.T.-Graden für jede Stunde des Tages und der Nacht; und die «Cum D.I.»-Methode gründete sich auf die Summe der D.I.-Werte für jede Stunde des Tages und der Nacht (Modifizierung der Methode von Thom).

Beide Methoden wurden als gleichermaßen geeignet befunden. Die «Cum. D.I.»-Methode hat jedoch, verglichen mit der «Cum. E.T.»-Methode, den Vorteil der einfachsten Art der Messung und der Berechnung; die letztgenannte Methode macht die Benutzung von mehr Instrumenten, Tabellen und Berechnungen erforderlich.

THE experiment reported was designed so as to find a method of comparing the heat load on separate days with the aid of simple meteorological measurements.

METHODS

During a 24-day march traversing the length of Israel, in August 1959, dry and wet bulb temperatures and wind velocity were measured each hour of the day and night. From these data the effective temperature (1—4) was worked out for each hour of the day according to the tables of the American Society of Heating and Ventilating Engineers. Simultaneously the discomfort index (D.I.) was worked out according to a modification of the method described by Thom (5). Thom found that changes in the sum of the dry and wet bulb temperatures follow a similar pattern as changes in the effective temperature under the same conditions. The difference between the two methods is, that the discomfort index does not necessitate the measuring of the wind velocity, which is necessary for the estimation of the effective temperature.

In an attempt to express the discomfort index in numbers which approach the degrees of (Fahrenheit) temperature which are usually associated with the feeling of discomfort due to heat Thom reached the following formula:

$$\text{D.I.} = (td + tw) \times 0.4 + 15$$

$$\text{where } td = \text{dry bulb temperature } (^\circ\text{F});$$

$$tw = \text{wet bulb temperature } (^\circ\text{F})\,.$$

According to this formula the dry and wet bulb temperatures are equally important in respect to man's feeling of discomfort in heat.

In an attempt to simplify the method and consider the fact that temperature in Israel is measured in °C, Thom's formula was modified this:

$$\text{D.I.} = td + tw$$

(where the temperatures are measured in °C).

Discomfort due to heat begins when the temperature exceeds 24 °C and the relative humidity is 100 per cent, i. e. when both dry bulb and wet bulb tempera-

FIG. 1. Hourly effective temperature (E.T.) (in °C) for the establishment of the cumulative effective temperature (Cum. E.T.), on 4 August 1959 near the Gulf of Eilat. (Horizontal line denotes 24°C E.T., above which discomfort due to heat commences.)

tures are 24 °C. We therefore chose a D.I. of 48 as the beginning of heat discomfort, this value being parallel to 24 °C on the effective temperature scale.

In order to obtain a comparison of various days the number of degrees of E.T. exceeding 24° C for each hour of the day and night were obtained (Fig. 1) and the

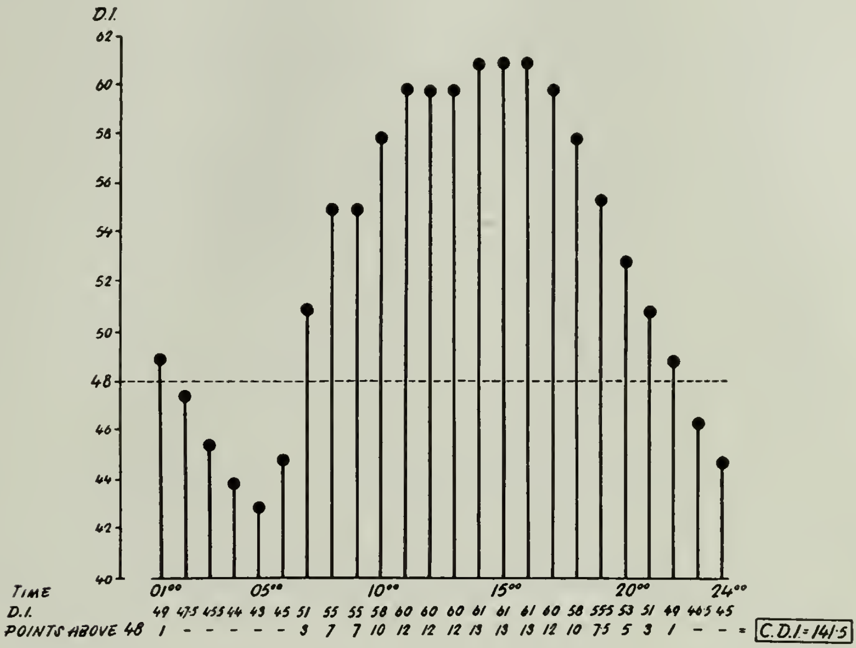


FIG. 2. Hourly discomfort index (D.I.) for the establishment of the cumulative discomfort index (Cum. D.I.), on 4 August 1959, near the Gulf of Eilat. (Horizontal line denotes D.I. of 48, above which discomfort due to heat commences.)

sum of all these was designated the cumulative effective temperature (Cum. E.T.). Similarly the sum of all D.I. values above 48 for each hour was designated the cumulative discomfort index (Cum. D.I.) (Fig. 2).

RESULTS

The measurements were carried out on twenty-four consecutive days in various regions of the country differing widely in their climatic conditions. The march began at the Gulf of Eilat, passed through a dry mountain desert, then along the coast with its high relative humidity, and ended in the Jordan Valley.

Fig. 3 shows the maximum and minimum temperature and maximum and minimum relative humidity for each day of the march. It clearly demonstrates the wide variation of climatic conditions during the experiment.

The daily Cum. E.T. and Cum. D.I. values for the 24 days are listed in Table 1 and represented graphically in Fig. 4. The good correlation between these two methods is noticeable.

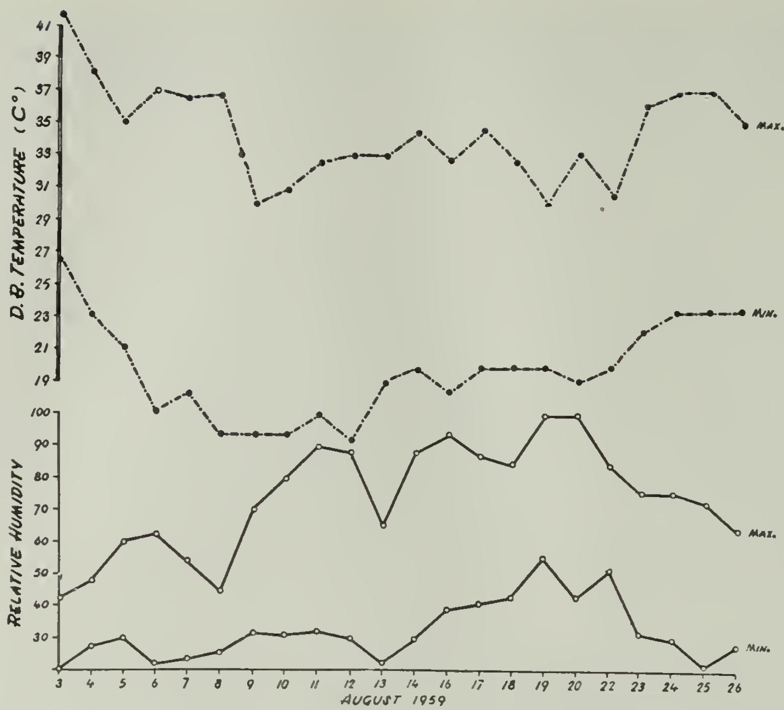


FIG. 3. Daily maximum and minimum dry-bulb temperature (°C) and relative humidity, August 1959

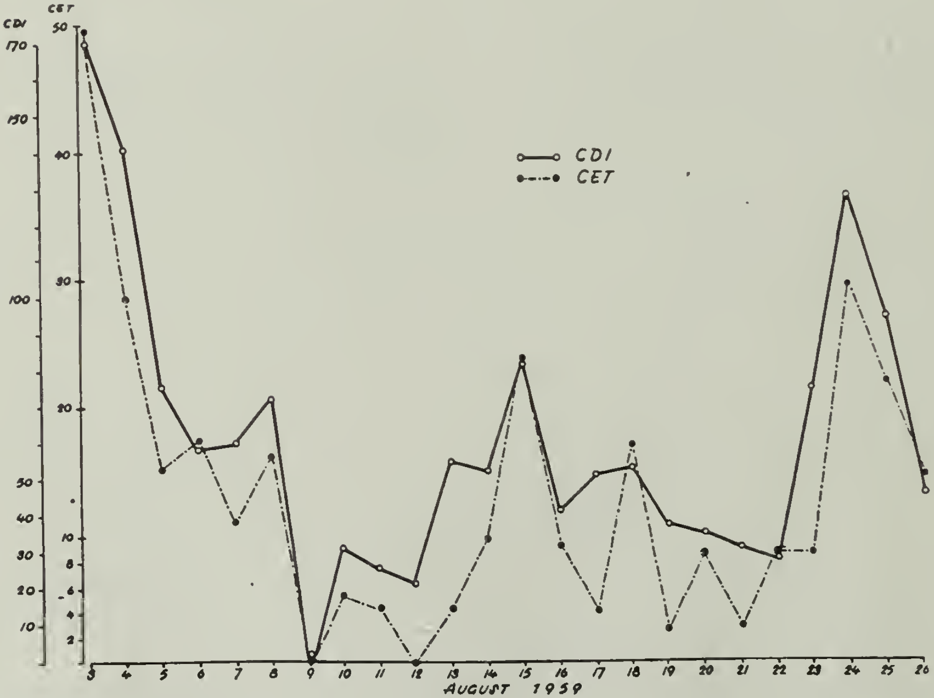


FIG. 4. Cumulative effective temperature (Cum. E.T.) and cumulative discomfort index (Cum. D.I.), August 1959

DISCUSSION

The good correlation between the two methods is somewhat puzzling if we consider the fact that the wind provides a certain amount of cooling, and while it is taken into account in the estimation of the E.T. it is completely ignored in the measurement of the D.I.

Table 1. Daily Cumulative Effective Temperature (Cum E.T.) and Cumulative Discomfort Index (Cum. D. I.), August 1959

Date	Cum. E.T.	Cum. D.I.
(Aug. 1959)		
3	49	170
4	30	141
5	15.5	76.2
6	17.6	59.2
7	11.6	60
8	16.3	72
9	—	0.7
10	5.7	31
11	4.7	26.5
12	—	21.3
13	4.7	55.3
14	10	52
15	24.6	81.5
16	9.6	41.5
17	4.1	50.2
18	17.3	52.3
19	2.7	38.0
20	8.6	36.3
21	3.0	30.6
22	8.9	29.3
23	8.6	76
24	31.3	129.5
25	22.3	90.4
26	14.6	47.5

In Israel the prevailing wind during day-time is a light wind coming from the direction of the sea. The temperature of this wind is below the skin temperature, and it causes a rise of the relative humidity. At the same time, however, it decreases the dry bulb temperature and through this affects the D.I.

In one region in the country (the Gulf of Eilat) during August there is a dry wind which is hotter than the skin temperature. This wind of course will not decrease the D.I., but on the other hand it is doubtful whether such a wind has only a cooling effect or whether it also adds to the temperature of a body exposed to it by means of conduction.

The good correlation between these two methods (in the conditions prevailing in Israel in the summer) makes it possible to use both methods for the determination of the daily heat load. The obvious advantage of the Cum. D.I. method is that it is simple and rapid and can be measured in the field with the aid of a relatively inexpensive instrument — the sling psychrometer — whereas the E.T. necessitates the use of at least an additional instrument, not to mention tables and calculations.

REFERENCES

1. F. C. HOUGHTEN and C. P. YAGLOU, Determining lines of equal comfort. *Trans Amer. Soc. Heat. Vent. Engrs.* **29,** 163 (1923).
2. F. C. HOUGHTEN and C. P. YAGLOU, Cooling effect on human beings produced by various air velocities. *Trans. Amer. Soc. Heat. Vent. Engrs,* **30,** 193 (1924).
3. C. P. YAGLOU and W. E. MILLER, Effective Temperature with Clothing. *Trans Amer. Soc. Heat. Vent. Engn.* **31,** 89 (1925).
4. *Heating, Ventilating and Air-Conditioning Guide* (1956).
5. E. C. THOM, The discomfort index. *Weatherwise* 12, 57 (1959).
6. Th. BEDFORD, *Basic principles of Ventilation and Heating* p. 325. H. K. Lewis London (1948)

ESTIMATION OF DAILY WATER INTAKE (TO REPLACE WATER LOSS) FROM THE CUMULATIVE DISCOMFORT INDEX (CUM. D. I.)

E. SOHAR, M. D., J. TENNENBAUM, M. Sc.* and D. YASKI
*Climatic Research Unit, Tel-Hashomer Hospital, Tel-Hashomer, Israel

Abstract—An equation and nomogram have been described which make it possible to estimate in advance the average fluid requirements of men in different hot climatic conditions, doing moderately hard work during a varying number of hours per day.

Résumé—Une équation et une abaque ont permis d'évaluer d'avance le besoin moyen en liquide pour l'homme, travaillant passablement dur pendant un nombre variable par jour, dans différentes conditions climatiques torrides.

Auszug—Es sind eine Gleichung sowie ein Nomogramm beschrieben worden, die es ermöglichen, den durchschnittlichen Flüssigkeitsbedarf von Menschen, die mäßig schwere Arbeit während einer wechselnden Anzahl von Stunden unter verschiedenen heißen klimatischen Bedingungen verrichten, im voraus zu schätzen.

During an experimental march traversing the length of Israel in August 1959, the effective temperature (E.T.) scale (1) was compared with the discomfort index (D.I.) (2). The formula for the discomfort index was a modification of the method of Thom (2), and was defined as the sum of the dry bulb temperature and the wet bulb temperature in °C. The cumulative discomfort index (i.e. the sum of D.I. points above 48 for every hour of the day and night (3)) was used as a means of comparing the heat load on separate days.

A good correlation was found between the cumulative discomfort index (Cum. D.I.) and the total daily output of sweat, and also between the Cum. D.I. during the hours of effort (Cum. D.I.-effort) and the amount of sweat secreted during the same time. This led to the conclusion that the cumulative discomfort index has a real physiological significance (4).

The next step was a search for a formula which would make it possible to estimate in advance the amount of fluids necessary at a given Cum. D.I. and a known effort.

METHODS

The formula for the calculation of the amount of sweat secreted is described elsewhere (4) as is the method for obtaining the Cum. D.I. and the Cum. D.I.-effort (3).

Measurement of oxygen uptake showed that the energy expenditure during the march period was 300 per cent of that during the intervals.

The daily water loss is the sum of the daily amount of urine and of sweat. Column D in the calculation sheet of the Appendix gives the daily water loss per each day of the march. A regression plane was fitted with "water loss" as the dependent variable and the following as independent variables:

Cum. D.I. during the marching period (Cum. D.I.$_m$).

Cum. D.I. during the period of rest (Cum. D.I.$_r$) and distance covered.

The water loss values were arithmetic means for nineteen participants; all three regression coefficients were t-tested and found significant. The detailed calculations are given in the Appendix.

RESULTS

The following equations were obtained from measurements of the daily water loss of soldiers marching with a load of 15 kg at an average rate of 4.5 km per hr under conditions of varying Cum. D.I.:

$$D = 0.022 \text{ Cum. D.I.}_m + 0.027 \text{ Cum. D.I.}_r + 0.122K + 3.584$$

or

$$D = 0.022 \text{ Cum. D.I.}_m + 0.027 \text{ Cum. D.I.}_r + 0.549T + 3.584$$

where D = daily water loss;

K = number of kilometres covered;

and T = duration of effort in hours.

3.584 = daily water loss when Cum. D.I. = 0 and there is no effort apart from the effort of a Sunday routine.

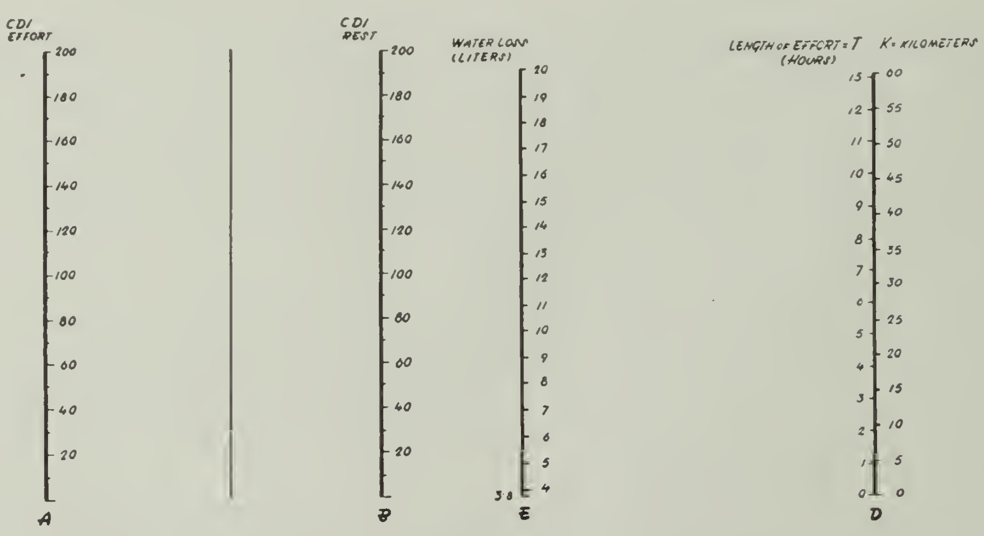


FIG. 1. Nomogram for the calculation of required daily water intake (to replace daily water loss). Explanation, see text

These equations gave rise to the nomogram in Fig. 1. The use of the nomogram is as follows: A line is drawn between Cum. D.I.$_m$ and the corresponding Cum. D.I.$_r$ (Cum. D.I.$_r$ = Cum. D.I. — Cum. D.I.$_m$). This line intersects the auxiliary line C, and a second line is drawn from the point of intersection to the number of kilometres to be covered, or to the number of hours of marching (according to which of them is stated). This line will intersect line E at a point which indicates the number of litres of fluid necessary for the stated effort on a given day.

DISCUSSION

Meteorological measurements which have been made in Israel over a period of many years, make it possible to estimate in advance the expected Cum. D.I. each month during the summer for different regions in the country.

It is therefore possible to use the equation and the nomogram described above, in order to calculate with a reasonable amount of accuracy the expected fluid requirements of men marching with a load in different climatic conditions at various times of the year.

The standard effort in the experiment which gave rise to the equation and the nomogram was marching at a rate of 4.5 km per hr with a load of 15 kg. Oxygen consumption studies indicate that the caloric expenditure during this effort is 300 per cent of the expenditure while at rest. This is roughly equivalent to moderately hard work in industry and in agriculture.

Further experiments are needed in order to modify the above equations that they may be used for various degrees of effort.

APPENDIX

Least Squares Regression of Daily Water Losses on Climatic Conditions and Effort

(1) The following units will be used:

- M, 0.3 × Cum. D.I. for period of effort; Cum. D.I.$_m$ the corresponding Cum. D. I.
- R, 0.3 × Cum. D.I. for rest period; Cum. D.I.$_r$ The corresponding Cum. D.I.
- K, number of kilometres travelled daily.
- T, length, in hours of effort period.
- D.I.$_m$, average discomfort index for effort period.
- D.I.$_r$, average discomfort index for rest period.
- D, average water loss in litres for a group of nineteen individuals.
- D^x Calculated water loss in litres.

(2) SPD and C matrices were derived:

	M	R	K	D
SPD =	916.60	420.32	542.22	171.38
		1244.45	519.79	79.45
			2141.48	254.95
				58.71

100 × C =	0.199	—0.098	—0.074
		0.138	0.058
			0.080

26*

(3) Therefore:

$$D^x = 0.022 \text{ Cum. D.I.}_m + 0.027 \text{ Cum. D.I.}_r + 0.122K + 3.584$$
$$= 0.022 \text{ Cum. D.I.}_m + 0.027 \text{ Cum. D.I.}_r + 0.549T + 3.584$$
$$= (0.022 \text{ D.I.}_m—0.027 \text{ D.I.}_r + 0.55)\, T + 0.65 \text{ D.I.}_r$$

Because of the existence of:

$$\text{Cum. D.I.}_m = \text{D.I.}_m \times T \quad \text{Cum. D.I.}_r = \text{D.I.}_r\,(24—T) \quad R = 4.5T$$

(4) All regression coefficients were t-tested according to the following values obtained:

$$t_m = 2.6 \qquad t_r = 3.8 \qquad t_k = 6.0 \qquad f = 19$$

The three coefficients are therefore significantly different from zero with a one-sided $P < 0.01$.

(5) In no case is the relative deviation $\frac{\text{observed—expected}}{\text{expected}}$, larger then 17 per cent.

(6) Nomograms and the calculation sheet are given. All calculations are based on Hald (5).

CALCULATION SHEET

$\frac{0-e}{e}$ %	D^x	D	R	M	K	date
7	11.1	11.9	26.2	24.8	27	3.8
—9	10.4	9.5	29.4	12.1	27	4.8
0	9.0	9.0	18.2	4.7	28	5
1	8.5	8.6	17.0	0.8	27	6
13	9.2	10.4	10.2	7.8	34	7
5	5.5	5.8	21.6	0.0	0	8
—1	7.5	7.4	4.8	0.2	28	9
—7	7.5	7.0	4.5	4.8	26	10
—17	7.5	8.8	7.2	0.8	26	11
—7	7.6	7.1	6.1	0.3	28	12
5	8.4	8.8	11.6	5.0	28	13
—7	9.0	8.4	8.2	7.4	34	14
5	5.8	6.1	24.5	0.0	0	15
—6	7.8	7.3	6.9	5.6	26	16
—8	8.3	7.6	11.9	3.2	28	17
—4	8.3	8.0	6.5	9.2	28	18
—1	7.8	7.7	5.6	5.8	27	19
6	7.8	8.3	4.4	4.8	28	21
—11	4.4	3.9	8.8	0.0	0	22
—2	8.9	8.7	14.2	8.6	28	23
—4	10.2	9.8	19.5	19.4	28	24
—2	9.1	8.9	12.2	15.0	27	25.8
6	8.2	8.7	7.2	7.1	28	26.8

$\frac{1}{n}S$	8.16	12.47	6.41	24.39
S	187.7	286.7	174.4	561
SS	1590.51	4818.23	1857.24	15,825
$\frac{1}{n}S^2$	1531.80	3573.78	944.64	13,683.52
SS_D	58.71	1244.45	912.60	2141.48

	SP	$\frac{1}{n}S \times S$	SPD
KM	4137.50	3595.28	542.22
KR	6473.20	6992.99	—519.79
KD	4833.20	4578.25	254.95
MR	2257.69	1837.37	420.32
MD	1374.29	1202.91	171.38
RD	2419.17	2339.72	79.45

$$D^x = 0.07371M + 0.09001R + 0.12224K + 3.58367$$

$$SSD_4 = 58.7100$$

$$\Sigma\, bi\, SPDxiy = 50.9488$$

$$SSD_4/_x = 7.7612$$

$$f = 23-4 = 19$$

$$S^2 = \frac{7.7612}{19} = 0.4085$$

$$S = 0.639$$

$$Sb_M = 0.0285$$

$$Sb_R = 0.0237$$

$$Sb_k = 0.0181$$

$$t_M = 2.585$$

$$t_R = 3.798$$

$$t_K = 6.754$$

REFERENCES

1. *Heating, Ventilating and Air Conditioning Guide* (1956).
2. E. C. Thom, The discomfort index. *Weatherwise* **12,** 57 (1959).
3. E. Sohar, J. Tennenbaum and N. Robinson, A comparison of the cumulative Discomfort Index and Cumulative Effective Temperature as obtained by meteorological data, This volume, p. 395-400.
4. J. Tennenbaum and E. Sohar, The significance of the cumulative discomfort index as a measure of daily heat load, proved by physiological tests. In press.
5. Hald, *Statistical Theory with Engineering Applications* ch. 20. John Wiley (1952).

A DEVICE FOR MEASURING EVAPORATION FROM ANIMAL AND HUMAN SKIN

J. TENNENBAUM, M.Sc. and R. VOLCANI, Ph.D.*
Agricultural Research Station, Beit-Dagan, Israel

Abstract—An apparatus was devised for the continuous measurement of evaporation from the skin. Environmental air is passed through the sealed tube without altering the pressure and humidity of the air. The sealed tube permits the character and the rate of flow of the air that comes into contact with the skin to be controlled. Moisture is adsorbed on silica gel contained in a test-tube that can be removed for weighing. Time and surface area measured can be adjusted according to need. The rate of skin evaporation is determined by substracting the amount of the moisture derived from the skin and the environment from that of the moisture obtained from the environment alone (per unit of time).

Résumé—Un appareil a été mis au point en vue de mesurer de façon continue l'évaporation par la peau. L'air ambient dont ni la pression ni l'humidité n'ont été altérées est envoyé dans l'appareil qui enclot hermétiquement une section de peau. Cet appareil hermétique permet de contrôler les caractéristiques et la vitesse de circulation de l'air qui aient de contact de la peau. L'humidité est adsorbée par un silicogel contenu dans un tube à essai que l'on peut enlever pour le peser. Le temps de passage de l'air et la superficie mesurée peuvent être ajustés selon les besoins. On détermine le faux d'évaporation cutanée par différence entre l'humidité qui provient uniquement du milieu ambient et la quantité d'eau qui dérive de la peau (par unité de temps).

Auszug—Es wurde ein Apparat zur fortlaufenden Messung der Haut-Verdunstung konstruiert. Luft aus der Umgebung wird ohne Veränderung des Druckes und der Feuchtigkeit durch einen der Haut anliegenden Behälter geleitet. Der Behälter ermöglicht die Kontrolle der Art und Grösse des Luftstroms, der mit der Haut in Berührung kommt. Die Feuchtigkeit wird auf ein Silicongel adsorbiert, dass sich in einem Reagenzglass befindet, welches zum Zwecke der Wägung entfernt werden kann. Messzeit und Grösse der gemessenen Oberfläche können je nach den Umständen nach Belieben angepasst werden. Das Aussmass der Hautverdunstung wird bestimmt durch den Abzug der Feuchtigkeitsmenge, die von Haut und Umgebung stammt, von der Feuchtigkeitsmenge, die nur in der Umgebung vorhanden ist (per Zeiteinheit).

THE methods used to measure evaporation rate of the skin surface of animals (1--6) appear imperfect. The major drawbacks resulting from the application of these methods are due to alteration of the surrounding environmental conditions to which the test animal is subjected. The major factors that are changed over the evaporating surface are: atmospheric humidity, atmospheric pressure and the rate and character of air movement. These changes may alter the rate of evaporation. The inconvenience of applying the existing device under field conditions is an additional drawback. Much labour and time are required to obtain results; this hinders the collection of sufficient data under rapidly changing weather conditions. In 1956, in the first stage of a research study designed to measure the rate of evaporation from animal skin, a device was built to this effect. This device was based on the following principles: The air from the environment to which the animal is subjected is passed

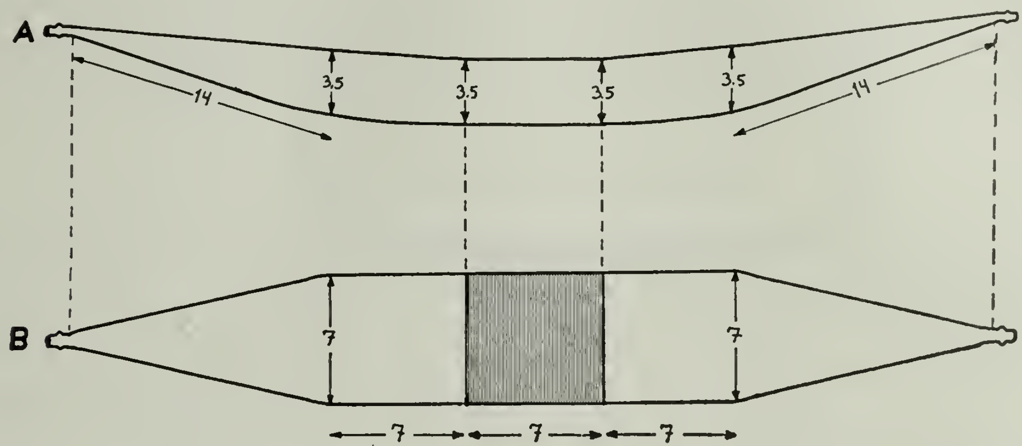


Fig. 1. The seal. (A) View from side. (B) View from below. Hatched area represents opening which is applied to skin. Measurements are in centimetres

over a measured area of skin surface; the rate of air flow is fixed and its character is defined. The standardization of the conditions of measurement permits the comparison of results obtained at different times, in different regions and under different conditions of measurement, without the use of coefficients and calculations which are liable to complicate the results.

The major components of this device are: (1) a seal to cover the skin surface under study; (2) an efficient hygroscopic material to remove humidity from the passing air; and (3) a system which closes the passage and enables the measurement of the air flow.

THE SEAL

For field work the seal is made of a sheet-metal pipe with a uniform rectangular cross-section in its centre (Fig. 2). In the bottom a square which covers the area under study is cut out. The rectangular shape of the cross-section of the seal increases the ratio of the area under study to the amount of air passing over it. It thereby relatively increases the amount of water evaporated from the skin of the animal vs. the amount of moisture present in the air drawn from the environment. The length of the seal is seven times the length of the area under study. This feature of the seal ensures an efficient flow which prevents the formation of air pockets in which the rate of flow and the humidity of the air may change. Under these conditions the air flow becomes laminar. The perfect seal is convex; thus its opening can be applied to any part of the animal body, be it convex, plane or concave. One can design seals of different dimensions shape and materials to match the size of the area under study, and with due consideration for the amount of water evapo-

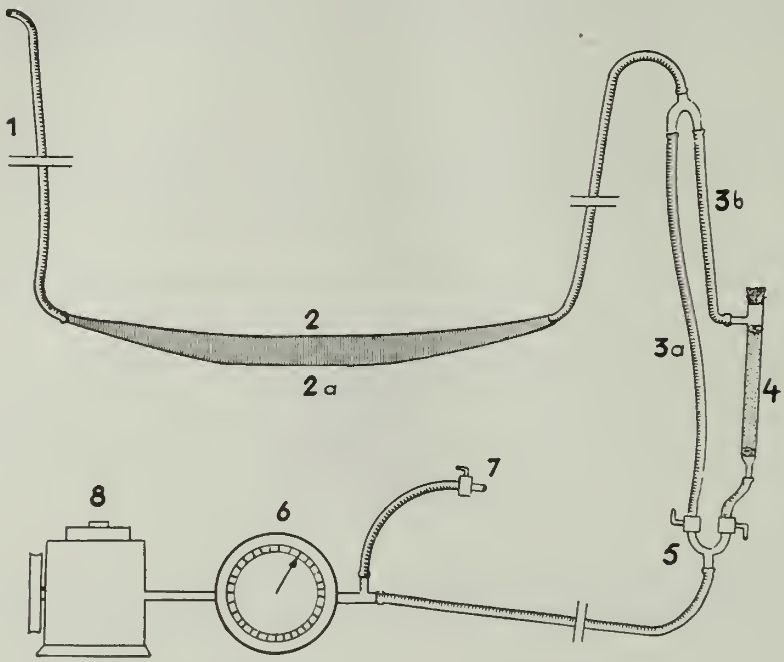


Fig. 2. Scheme of the device. (1) Rubber tube (diameter = 1 cm) for drawing air from environment. (2) Seal (see Fig. 1). (2a) area of application to skin. (3a) Rubber tube. (3b) Rubber tube. (4) Desiccant tube in which desiccant material (silicon gel) is held between two pieces of gauze. (5) Stopcock which directs flow alternatively through (3a) for preliminary equilibration or through (3b) and (4) for the measurement. (6) Gasometer. (7) Stopcock to regulate rate of air flow. (8) Vacuum pump

rated vs. the humidity of the air current. The rate of flow is important in this method since too slow an air current may cause the air to become oversaturated, and thus humidity evaporated from the body may not be efficiently removed. On the other hand, a rapid air current is liable to favour evaporation especially when the supply of water to the area under study is unlimited. An advantage of this device is that the rate of air flow can be controlled and its effect on evaporation can be studied. Accordingly, a proper rate of flow can be found for any type of experiment. The speed of the air current over the area under study can be calculated from the following formula:

$$V = \frac{K}{st}$$

where V = speed; s = area of the cross-section; t = time; K = volume of air. It was found from experience that the following standard values are suitable for work on animals: $S = 24\frac{1}{2}$ cm²; t = 180 sec, $K = 10$ l.; the speed of the air current was 1.45 m/sec. According to Reynolds' formula and in experiments carried out on these instruments with smoke, it was found, that under the above conditions air flow was laminar.

THE DEVICE

The device and its function are presented in Fig. 2. The components are: a source of vacuum (the vacuum pump of a mechanical milker will serve the purpose), a gasometer, a desiccant, and a system of pipes for the transport of air and for the regulation of its flow.

THE METHOD OF MEASUREMENT

The air flow is kept at an even rate for the desired length of time. The resistance to air flow is not the same in each desiccant tube, because the material is crystalline and may be variably arranged in space. Therefore, the air flow is regulated by a stopcock at the vacuum pump (Fig. 2[7]) and thus a uniform rate of flow may be assured during the measurements.

After applying the seal to the animal body (by lightly pressing it on the skin) some 2.5—5 l. of air from the environment is drawn through the system to equalize the humidity in the entire system apart from the desiccant tube. Following this step the air flow is redirected at the stopcock (Fig. 2[5]) to pass the desiccant tube. The water vapour from the air and from the skin is picked up by the desiccant and is determined to the nearest milligram by the difference in the weight of the desiccant before and after the measurement. In order to estimate the water vapour evaporated off the skin, a second measurement under identical conditions and using the same volume of air is carried out, without applying the seal to the animal's skin. The difference in water absorbed in the first and the second measurement represents the amount evaporation from the skin. When the differences between the subjects under comparison are large, a brief measurement is sufficient; conversely, when differences between the individuals are small, measurements of longer duration are necessary. In our work standard measurements of 3-min duration and a volume of 10 l. air were found to be most suitable. For increased precision, five repeated measurements were taken.

THE DESICCANT

In our experience, the most convenient desiccant was silica gel; this is an inert, crystalline substance, and is suitable under field conditions. It has a high adsorbing capacity (up to 2 g water per test tube) which does not diminish until complete saturation. Under standard conditions (see above) it can be used up to ten times and can be restored at its adsorbing capacity at 160°C after being dried for 3—4 hr.

THE EFFICIENCY OF THE DEVICE

Experiments performed with the above device on surfaces of inanimate objects and of animals, in order to determine its precision and efficiency, have shown that the repeatability of the results is very high in the entire range of relative humidity investigated, i.e. 20—100 per cent. A great precision was also demonstrated in estimating the evaporation from continuous water surface, from porous surfaces and from leaf surfaces. It appears that the device is suitable for miscellaneous measurements of evaporation, and that its operation is more convenient than that of other devices.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to Dr. A. Berman of the Faculty of Agriculture for his advice.

REFERENCES

1. A. Berman, Influenee of some factors on the relative evaporation rate from the skin of cattle. *Nature, Lond.* **179,** 1256 (1957).
2. K. A. Ferguson and D. F. Dowling, The function of cattle sweat glands. *Aust. J. Agric. Res.* **6,** 4, 640 (1955).
3. R. E. McDowell, D. H. K. Lee and M. H. Forman, The measurement of water evaporation from limited areas of a normal body surface. *J. Anim. Sci.* **13,** 2, 405—17 (1954).
4. Neuman, Cohn and Burch, A quantitative method for the measurement of the rate of water loss from small areas. *Amer. J. Physiol.* **132,** 748 (1941).
5. E. A. Pinson, Evaporation from human skin with sweat glands inactivated. *Amer. J. Physiol.* **137,** 492—504 (1942).
6. R. Volcani and H. Shindler, Some physiological reactions of dairy cows under different localities and seasons in Israel. *Refua Vet* **11,** 3, 130—9 (1954).
7. C. C. Taneya, Sweating in cattle—II. Cutaneous evaporative loss measured from limited areas and its relationship with skin, rectal and air temperatures. *J. Agric. Sci.* **52,** 1, 50—62 (1959).

BASAL METABOLIC RATE OF "TROPICAL" MAN IN A POLAR CLIMATE

OVE WILSON (SWEDEN)
Norsk Polarinstitutt, Oslo, Norway,
and Department of Hygiene University of Lund, Sweden

Abstract—Naked man in his mode of heat regulation can be regarded as a tropical or subtropical creature with a narrow zone of adaptability, and the difference in the BMR determined in the tropics and in a temperate zone for the same individuals does not seem to exceed 10 per cent. In the climatic extremes he raises his calorific output in situations of stress but does not adapt by further changing his BMR. Some native people, however, appear to have the ability to endure a moderate cold stress without increasing their heat production above normal basal values. The metabolic determinations made by the author on the Norwegian—British—Swedish Expedition during 2 years of continuous exposure to the Antarctic climate show that there is no difference in the mean level of the BMR of white man whether he lives in a temperate or a polar climate. Other studies in cold regions support this view. Evidence of acclimatization of man to cold will not be found in the basal metabolic rate.

However, the author's investigations show that the polar climate in its extreme form, as it is encountered by man in the Antarctic, can impose certain seasonal variations in the BMR. This periodicity in BMR is probably not a direct effect of climate on metabolism, but is related to it by reason of the typical activity pattern which ensues in the Antarctic climate. In agreement are the seasonal changes in BMR in the Arctic reported by Russian workers. The preliminary results of Lewis and Masterton in North Greenland, on the other hand, do not indicate a consistent seasonal variation.

In changing from a temperate to a tropical climate, the BMR may vary within a narrow range of about 10 per cent, decreasing in the hot environment, but not all persons will show such a change. The seasonal variation found by the author in a polar climate is almost of the same order as the change in the tropics. It may be that the alterations in BMR caused by a change to a tropical climate are due to similar influences, which, however, do not exhibit the same seasonal incidence, because of the uniformity of the climate the year around.

This implies that the basal metabolism of white man is essentially the same in all climates, but varies within a narrow range, not as a direct result of climate itself or its mean temperature, but depending upon changes in the type of activity, food, exposure, muscle tone and other factors, which are imposed by a difference in climate and regimen.

Résumé—L'homme dans son mode de régulation thermique peut être considéré comme un être tropical ou subtropical avec une zone étroite de faculté d'adaptation et un taux de Métabolisme Basal («BMR») différent qui, déterminé pour les mêmes personnes sous les tropiques et dans les regions tempérérées, ne semble pas dépasser 10%. Dans des conditions climatiques extrêmes il relève son débit calorifique dans des situations de «stress», mais l'adaptation n'entraîne pas un changement du BMR. Quelques indigènes cependant semblent être capables d'endurer un «stress» froid, modéré, sans augmenter

la production de chaleur au-dessus des valeurs basales normales. Les déterminations métaboliques faites par l'auteur pendant l'expédition norvégienne—britannique—suédoise, durant deux ans d'exposition continue au climat antarctique, montrent qu'il n'y a pas de différence du taux moyen du BMR chez l'homme blanc, soit qu'il vive dans un climat tempéré ou dans un climat polaire. D'autres études faites dans les régions froides confirment cette opinion. Dans l'acclimatation de l'être humain au froid le taux de métabolisme basal ne peut pas être un facteur determinant.

Cependant les investigations de l'auteur montrent que le climat polaire sous sa forme extrême, tel qu'il est affronté par l'homme dans l'Antarctique peut imposer une certaine variation saisonnière du BMR. Cette périodicité du BMR n'est probablement pas un effet direct du climat sur le métabolisme, il s'agit plutôt d'une relation due à l'activité spécifique du type qui en résulte dans le climat antarctique. Ces variations saisonnières du BMR ont été constatées également dans l'Arctique par les Russes. Par contre les résultats préliminaires de Lewis et de Masterton obtenus dans le Nord du Groënland n'indiquent pas une variation saisonnière appréciable.

Chez les personnes qui viennent de la région tempérée pour vivre sous un climat tropical le BMR est susceptible de varier dans une zone étroite de 10%, décroissant dans le milieu ambiant torride, toutefois toutes les personnes ne sont pas sujettes à ce genre de variations. La variation saisonnière trouvée par l'auteur dans le climat polaire est presque du même ordre que la variation du BMR constatée sous les tropiques. Il se peut que le changement du BMR, causé par un déplacement dans un climat tropical, soit dû à des influences analogues, toutefois elles ne présentent pas la même répercussion saisonnière, étant donné l'uniformité du climat dans le courant de l'année. Cela fait supposer que le métabolisme de l'homme blanc est essentiellement le même sous tous les climats, néanmoins susceptible de varier dans une zone étroite, moins en fonction du climat lui même ou de sa température moyenne, qu'en relation avec le genre d'activité, d'alimentation, d'exposition, avec le tonus musculaire et d'autres facteurs qui interviennent par suite de la différence de climat et de régime.

Auszug—In seiner Art und Weise der Wärmeregulierung, kann ein nackter Mensch als ein tropisches oder subtropisches Geschöpf mit einem begrenzten Anpassungsfähigkeitsbereich betrachtet werden, und die Differenz im Grundumsatz, die bei denselben Menschen in den Tropen und in einer gemäßigten Zone festgestellt wurde, scheint 10% nicht zu übersteigen. Unter extremen klimatischen Verhältnissen erhöht der Mensch in Situationen der Anspannung seine Kalorienabgabe, es tritt jedoch keine weitere Anpassung durch zusätzliche Änderung des Grundumsatzes ein. Einige der eingeborenen Völker haben jedoch anscheinend die Fähigkeit, einen mäßigen Kälteeinfluß ohne Erhöhung ihrer Wärmeerzeugung über die normalen Grundwerte aushalten zu können. Die Grundumsatzbestimmungen, die durch den Verfasser anläßlich der norwegisch—britisch—schwedischen Expedition durchgeführt wurden, und bei der die Teilnehmer zwei Jahre lang ununterbrochen dem antarktischen Klima ausgesetzt waren, zeigen, daß keine Differenzen im Grundumsatzspiegel des weißen Mannes bestehen, gleichgültig, ob er in einer gemäßigten oder einer polaren Klimazone lebt. Diese Ansicht wird durch andere in kalten Regionen durchgeführte Untersuchungen unterstützt. Ein Nachweis über die Kälte-Akklimatisation kann im Grundumsatzwert nicht gefunden werden.

Die vom Verfasser durchgeführten Forschungen zeigen jedoch, daß das polare Klima, wie es in der Antarktis in seiner extremen Form angetroffen wird, periodische Schwankungen des Grundumsatzwertes herbeiführen kann. Diese Periodizität des Grundumsatzes ist wahrscheinlich nicht eine direkte Auswirkung des Klimas auf den Grundumsatz, sondern steht mit dem Grundumsatzwert in Verbindung mit dem typischen Tätigkeits-Symptom, das eine Folge des antarktischen Klimas ist. Die durch russische Arbeiter in der Arktis berichteten periodischen Schwankungen des Grundumsatzwertes stimmen mit dieser Auffassung ebenfalls überein. Die von Lewis und Masterton in Nord-Grönland erzielten vorläufigen Forschungsergebnisse weisen andererseits jedoch nicht auf eine klimabedingte periodische Schwankung hin.

Beim Wechsel von einem gemäßigten in ein tropisches Klima können Schwankungen im Grundumsatzwert auftreten, u. zw. innerhalb eines begrenzten Bereiches von ungefähr 10%. Diese Schwankungen nehmen in der warmen Umgebung ab, und sie treten auch nicht bei allen Menschen auf. Die durch den Verfasser in einer polaren Klimazone festgestellten Schwankungen sind fast von derselben Größenordnung, wie die in den Tropen festgestellten. Es mag sein, daß die durch einen Wechsel in eine tropische Klimazone verursachten Veränderungen des Grundumsatzwertes auf ähnliche Einflüsse zurückzuführen sind, die jedoch auf Grund der Gleichmäßigkeit des Klimas während des ganzen Jahres nicht gleichermaßen periodisch bedingt vorkommen.

Aus vorstehendem kann gefolgert werden, daß der Grundumsatz des weißen Mannes unter allen klimatischen Verhältnissen im wesentlichen gleich bleibt, jedoch innerhalb eines begrenzten Bereiches schwankt. Diese Schwankungen sind nicht in direkter Linie auf das Klima selbst oder dessen mittlere Temperaturwerte zurückzuführen, sondern sie hängen ab von Veränderungen in der Art der Betätigung, der Nahrung, der Art und Weise, in der der Mensch dem Klima ausgesetzt ist, der Muskelspannkraft sowie anderen Faktoren, die durch den Klima-Unterschied und die veränderte Lebensweise bedingt sind.

INTRODUCTION

There is little doubt that physiological acclimatization to cold occurs in animals (6). Whether it also occurs in man is the subject of lively controversy. While it has been established that the albino rat and the rabbit raise their basal metabolism, measured at thermal neutrality, as a result of experimental adaption to a cold environment (6, 51), no definite changes have been shown to occur in the basal metabolic rate (BMR) of man (51). Krog *et al.* (25) are of the opinion that the metabolic response to cold in the albino rat does not follow the pattern of animals naturally living in a cold climate. Treichler and Mitchell (49) consider the increase in basal metabolism at thermal neutrality in the acclimatized rat to be a direct dietary effect due to an elevation in the plane of nutrition produced by cold exposure. It should be noted that in animal experimentation no effort is usually made to adjust the protein level of the ration on a caloric intake basis.

Many tropical animals increase their metabolism as temperature falls below 25°C and show signs of suffering from cold below 20°C. Their insulation is small and capable of little variation. The insulation of the larger Arctic mammals, however, like the fox and dog is sufficient to enable them to maintain normal body temperature in experiments down to —30°C and below without having to increase basal metabolic heat production.

The work of Scholander *et al.* (44) less suggests that naked man is a tropical animal in his mode of heat conservation. The critical temperature for the naked man has been found to be 26—28°C (6, 15), which places him among the more temperature-sensitive of the tropical animals. This is also the case with native people adapted to a cold climate. The critical temperature of naked Lapps has thus been found to be about 27°C (45). The effect of increased insulation was demonstrated by Erikson *et al.* (15), who found a critical temperature of 14°C in a man dressed in winter sports clothing. In the Lapp dressed in winter fur clothing the critical temperature was found to be at least as low as —10°C (45).

BMR OF WHITE MAN IN A TROPICAL CLIMATE

If man is a tropical animal, the lowest BMR should be recorded in the tropics. This seems to be the case, as most investigators have found a lower BMR for normal white individuals living in hot countries than in temperature regions (51). In comparing observations made in different groups of subjects (often few in number) in temperate and hot countries, much confusion of interpretation is presented by diverging standards and techniques. These difficulties are avoided if the same individuals are studied as they move from one climate to another. Unfortunately few such investigations have been carried out, but only these will be considered here. They are presented in Table 1.

In a recent study of the BMR of one person (Japanese) was measured with intervals during a ship voyage from Japan to the Antarctic and back again (54). The BMR was found to be lower in the tropical zone and higher in the moderately cold Antarctic region (summer, mean temp. approx. 0°C). The difference was about 16 per cent.

Two sharply marked types of behavior were found by Mason (31, 32). On moving to a hot climate eight of her subjects showed no significant change in BMR, while thirteen subjects showed a distinct fall averaging 9 per cent. This fall took place promptly and the BMR remained low, but on returning to a temperate climate the low BMR rose at once to its former level. It is interesting to note that the oxygen consumption of the group that did not change metabolic rate with change of climate was on an average 7 per cent below that of the other group in the temperate climate, but only 2 per cent higher in the tropics.

It may be concluded that while some individuals do not alter their BMR in moving from one climate to another, a large proportion do change it by lowering their BMR from 5 to 10 per cent in a tropical environment. Perhaps the metabolism of the first group is slower to react, but will later slowly decrease during the sojourn in the hot country, as indicated by the observations of MacGregor and Loh (28), who found a progressive and statistically significant fall in the hot climate (see Table 1). The evidence, however, is not conclusive.

BMR IN A TEMPERATE OR COOL CLIMATE

Galvão (17) gives evidence that in a warm climate metabolism depends on the weight of active tissue, while in a cool climate the additional heat required for maintaining body temperature brings metabolism into a closer relationship with surface area as the unit of reference. He found the BMR of lean American men in a temperate environment to be about 7 per cent above that of the same weight range group of white lean men in the tropics.

Table 1. Studies of Changes in BMR of Subjects Moving from a Temperate to a Tropical Climate, or Reverse

Investigator	Subjects*	Temperate region	Hot region	Change in mean BMR when moving to a hot or to a temperate climate (% change in kcal/m²/hr)
Eijkman (14)	1 ♂	Holland	Batavia	Same in Batavia (1895) as in Holland (1897)
Knipping (24)	14 ♂	North Europe	Colombo and Indonesia	No consistent change in the tropics (3 subjects increased >3%, 3 subjects decreased >3%,
Williams and Benedict (50)	3 ♂ ♀	Boston	Yucatan	2% increase from Boston to Yucatan
	4 ♂ ♀			7% decrease from Yucatan to Boston**
Martin (30)	1 ♂	London and Australia	tropics	12% fall in passing the tropics, then return to previous level (daily measurements were made during the journey)
Mason (33)	1 ♀	North U.S.—Honolulu	tropics—Madras	10% fall on arriving in the tropics (daily measurements were made during the journey)
Mason (31, 32)	21 ♀	England and North U.S.	Madras	9% lower in India (13 subjects)
				No difference in India (8 subjects)
Mason (31)	3 ♀	England and North U.S.	Madras	5% increase in the temperate climate (Indian women)
Investigator	**Subjects**		**Hot region**	**Changes in BMR during a sojourn in a hot climate**
Fleming (16)	1 ♂		Manila	3% decrease during 6 months' tropical sojourn
MacGregor and Loh (28)	9 ♂		Singapore	7% decrease during 6 months' tropical sojourn
	16 ♂			4% decrease during 8 months' tropical sojourn
	2 ♂			12% decrease during 2 years' tropical sojourn
Knipping (24)	18 ♂		Colombo and Indonesia	Lower levels in the subjects with a longer residence in the tropics (data must be regarded as meagre)
Camis (11)	178 ♂		Somalia-land	Increasing percentage of high rates with length of sojourn in the hot climate (1 day to 18 months)

* All subjects white except otherwise stated (31).

** Note that one subject showed a fall of 22 per cent in his BMR determined in Boston before and then after the hot sojourn. The fall in his BMR during the sojourn in Yucatan was 4.5 per cen.t

Man adapts to cool climates by artificially increasing his insulation by wearing clothes and resorting to heated shelters. However, it seems that under extreme conditions naked man can adapt to low temperatures far below the critical without increasing the basal heat production above normal for Europeans. A series of investigations on the resting metabolism of naked Central Australian aborigines in their natural environment have been made. The studies of Hicks *et al.* (20) disclosed no essential departure from the normal (averaging 0.6 per cent and 4.4 per cent Aub—DuBois standard), even in the cold of early morning. Recent investigations (46, 19) have confirmed these results. The natives slept during the cold nights with a low, normal, resting metabolism (37.0 kcal/m^2 per hr) and with considerable body cooling, loosing stored heat. The naked Australian aborigine appears to have an inborn ability to tolerate a greater body cooling before balancing heat loss by increased heat production, and this ability is increased in the Central Australian native by prolonged exposure to cold.

BMR IN A COLD CLIMATE

Metabolism of Lapps and Arctic Indians

A similar metabolic and thermal study has been made of nomadic Lapps in the Norwegian sub-Arctic (2). They rested naked during the night in single-blanket sleeping bags, subjected to a graded cold stress. The Lapps slept with a normal, resting metabolism and also showed a greater tolerance for loosing stored heat from the body core, in contrast to the unadapted white controls, who markedly increased their resting metabolism.

In a parallel study of Arctic Athabaskan Indians in Alaska (23) the natives did not show the same degree of tolerance for loosing stored heat. They increased their resting metabolism in the cold to the same extent as the unadapted white controls. The BMR of Alaskan Indians do not seem to differ significantly from normal (41, 23).

BMR of Eskimos

The high BMR (12—33 per cent above Aub—DuBois standard) found by most investigators (5a, 51) in Eskimos has been regarded as an adaption to the cold. But the Eskimo (39, 41), like the American in the Arctic (6), lives largely in a subtropical microclimate, as do the nomadic Lapps of northern Scandinavia (45). Rodahl (39) maintains that the high, elevated BMR of the Eskimo is not due to a racial influence nor to the cold climate, and he has demonstrated that it is the direct result of a high protein dietary and also of apprehension. When these two factors were eliminated, the BMR was almost exactly the same as in the white controls. Brown *et al.* (5a), on the other hand, are of the opinion that the high BMR in Eskimos is not simply the result of a high protein diet. They conclude from relationships in their study that heightened thyroid activity has a role in the increased BMR, which they consider a feature of cold acclimatization (5b). They are supported by Gottschalk and Riggs (18), who found values above normal in serum protein-bound iodine (PBI) in the same group of Eskimos. However, Rodahl (41) in a series of 131 I studies found no evidence of increased thyroid stimulation in Eskimos, Indians and white men during cold exposure in Alaska. 131 I and PBI values were well within normal range in all groups. Gottschalk and Riggs (18) also found no significant difference in PBI in white men studied in a temperate climate and later in the winter in the sub-Arctic. There seems to be no seasonal difference in thyroid activity of white man in a cold climate (41).

Reference Standard

In a comparative study of BMR there is always the problem of reference standard, and the choice of unit for reference is often criticized. For practical reasons the Aub and DuBois standard (12) has been chosen for this study, because in most of the polar investigations this reference standard has been used, and usually it is not possible to recalculate the data given. However, in the majority of the other cases, where different units of reference have been used, it has been possible to apply the Aub—DuBois standard. One objection to this standard is that it regards the BMR to be constant between the ages of 20 and 40, while it has been shown to gradually decrease between these ages (38).

BMR of White Man in a Polar Climate

Judging from determinations made in Arctic regions (Table 2 and 3) the BMR for white men residing in a polar climate seems to be around —5 per cent to —10 per cent Aub—DuBois standard, which is the same as found in temperate regions for relaxed subjects repeatedly examined (13, 38). Ames and Goldthwait (1) found a somewhat higher average, which, however was the same as previously found in a temperate climate for the same subjects.

It must be emphasized, however, that residence in a cold climate is not the same as cold exposure. When white man moves to polar regions he takes his own warm microclimate with him, which in the case of the American white man means a subtropical climate with indoor temperatures around 25—30°C in the day-time (6) and 24°C at night (40). This is in sharp contrast to European polar bases where considerably lower temperatures have been recorded with averages around 15°C in the day-time and well below 10°C at night (26, 37, 43, 52). This implies that Europeans in polar regions live continuously in a definitely colder environment than Americans and Canadians do. The cold exposure experienced by some of the latter groups stationed in the Arctic can even be regarded as negligible (40).

In agreement with the normal low values found in Arctic regions are the author's findings in the Antarctic (52). The mean BMR measured each month during the winter periods was —5 per cent Aub—DuBois standard in 1950 and —6 per cent in 1951 for eleven men (Tables 2 and 4), although these men were continuously subject to a greater degree of cold stress than in most Arctic studies.

Table 2. Studies of BMR of White Men in Polar Regions (see also Table 3)

Investigator	Men	Cold region	Month (season)	BMR*	Remarks
Arctic					
Rodahl (39)	7	Alaska	Nov. 1950	+0.7%	Untrained personnel, first test
	14	Alaska	Jan. 1951, 1952	—0.6%	Untrained personnel, first test
	5	Alaska	Oct. 1950	—5,8%	Trained personnel, first test
Rodahl *et al.* (42)	10	Alaska	Jan. 1952	—8.8%	Untrained personnel, second test. These men had spent over 17 months in Alaska
Bollerud *et al.* (4)	17	Alaska	Jan. 1950	—9.6%	Corrected figure from original report
Buskirk *et al.* (8)	8	Churchill, Canada	Jan. 1955	—8.7%	Repeated tests. Recalculated from original data in earlier report (7)
Lewis and Masterton (26)	29	North Greenland	All seasons 1952—1954	—5.3%	Mean value of 349 determinations, adjusted to mean age of 29 years (38), was 37.4 kcal/m² per hr (corresponding value in Britain was 38.7)
Antarctic					
Lockhart (27)	?	Little America III	Winter	10—15% below	below normal BMR for temperate climates Details have been impossible to procure
Butson (9, 10)	8	Graham Land	Sept. 1947	+6%	First test for 6 subjects. Method inaccurate, see text
Wilson (52)	11	Dronning	Apr.—Sept. 1950	—5.0%	Two of the subjects were not the same ones during both
	11	Maud Land	July—Dec. 1951	—6.0%	years. Monthly tests. See Table 4

* Mean basal metabolic rate. All values (except for Lockhart) are given in Aub—DuBois standard (12). Results originally presented in other units of reference have been recalculated.

Table 3. Studies of BMR of White Men Measured in a Polar Region as well as in a Temperate Climate

Investigator	Men	Cold region	Month (season)	BMR* in cold climate	BMR* in temperate climate	Temperate region	Remarks
Arctic (Summer)							
Peroni (36)	7	Barents Sea and Greenland Sea	4 months in summer 1929	2.5% fall	Base line	Italy 1929	Six subjects decreased. Air temperatures averaged —4°C
Marmet and Grandjean (29)	3	Baffin Island, Canada	May—Aug. 1953	Initial peaks, then below base values	Base line	Zürich and Montreal 1953	Tests made in the field in tents. Initial air temperatures were low. See text.
(Winter)							
Ames and Goldthwait (1)	10	Churchill, Canada	Nov. 1947—March 1948	+3.3%	+3.5%	Massachusetts 1947	Recalculated from different ref. stand. Cold exposure during bivouac periods
Pecora (35)	21	Alaska	Winter 1948	—9.0%	—7.6%	Texas 1947	Seven subjects decreased ≥ 5% in Alaska. Three subjects increased ≥ 5% in Alaska
Gottschalk and Riggs (18)	6	Churchill, Canada	Jan.—March 1948	—2.9%	—3.5%	Kentucky 1947 and 1948	Recalculated from original report (34) Cold exposure during bivouac period
Lewis and Masterton (26)	6	North Greenland	Sept.—Feb. 1953	—4.8%	—2.5%	England 1953	First year party. Calculated from preliminary data not yet published
	9		Sept.—Feb. 1953	—3.3%			
			Sept.—Feb. 1954	—10.4%	—2.0%	England 1954	Two year party
	4		Sept.—Feb. 1954	—5.1%	—4.8%	England 1954	Second year party
Antarctic							
Butson (10)	1	Graham Land	Sept. 1947	+7%	+8%	Falkland Is. (Dec.) 1946	Only 2 subjects measured in both climates. Single tests. Method not accurate
	1			+10%	—3%		
Wilson (52)	9	Dronning Maud Land	July—Sept. 1950	—6.3%		Scandinavia,	See Table 4. Later controls (1956) in temperate climate have shown mean BMR essentially unchanged
			July—Sept. 1951	—6.0%	—5.4%	England 1952—1953	

* Mean basal metabolic rate. All values (except for Peroni and Marmet and Grandjean) are given in Aub—DuBois standard (12). Results originally presented on other units of reference have been recalculated.

Table 4. Variation in BMR during 2 Years at Maudheim (1950—1951) and after Return (Mean Monthly Values, Aub and DuBois Standard (12))

Subject number	April 1950	May	June	July	Aug.	Sept.	Mean 1950	July 1951	Aug.	Sept.	Oct.	Dec.	Mean 1951	Mean 1950—51	at home 1952—53
1	—12.7	—8.6	—8.6	—11.5	—15.8	—11.9	—11.5	—11.6	—13.8	—13.4	—	—	—12.9	—12.0	—12.0
2	+15.2	+7.8	+12.5	+3.6	—0.7	+2.0	+6.7	+0.3	+2.7	+13.4	—	—	+5.5	+6.3	+9.7
3	+2.4	+0.2	—4.7	+0.7	—2.7	+0.4	—0.6	±0.0	—7.2	+2.7	—3.6	—	—2.0	—1.2	+0.5
4	+4.5	+12.7	+4.2	—4.3	—6.1	—3.2	+1.3	—8.2	—2.5	+1.3	—7.8	—	—4.3	—0.9	+0.2
5	—4.7	—7.0	—12.0	—13.8	—8.5	—3.3	—8.2	—6.3	—12.6	—5.2	—9.7	—	—8.5	—8.3	—11.5
6	—7.8	—8.0	—3.8	—5.3	—9.0	—2.7	—6.1	+4.1	+8.0	—7.1	—	—5.7	—0.2	—3.7	—5.1
7	—26.0	—4.6	—16.4	—16.6	—17.3	—9.2	—15.0	—20.3	—26.5	—17.9	—14.9	—17.2	—19.4	—17.0	—16.7
8	—9.1	+2.6	—10.2	—21.0	—11.1	—4.7	—8.9	—6.8	—12.0	—9.8	+2.3	—12.7	—7.8	—8.4	—8.7
9	+1.7	+4.8	—4.7	+3.6	—4.9	+3.2	+0.6	—11.1	+0.2	—1.2	+6.7	+4.9	—0.1	+0.3	—4.8
Mean (9 subj.)	—4.1	±0.0	—4.9	—7.2	—8.5	—3.3	—4.6	—6.7	—7.1	—4.1			—5.5	—5.0	—5.4
10	—0.3	+10.8	—8.7	—9.7	—8.5	—10.2	—4.4								
11	—2.3	—3.7	—4.5	—11.7	—15.2	—12.9	—8.4								
14								—7.9	—7.4	—4.5	—	—9.4	—7.3		
15								—5.6	—9.5	—10.6	—	—	—8.6		
Mean (11 subj.)	—3.6	+0.6	—5.2	—7.8	—9.1	—4.8	—5.0	—6.7	—7.3	—4.8			—6.0		

In addition to these findings there is also some information from the Antarctic presenting equivocal evidence. Lockhard (27) gives a general statement that at Little America III basal metabolism was from 10 to 15 per cent below normal. No experimental data have been presented, however. On the other hand, Butson (9, 10) found an average BMR of +6 per cent in eight men at Marguerite Bay in Graham Land. However, he has freely admitted that these determinations were not accurate and may be impaired by a considerable error because of inadequate number of controls and difficulties in technique under adverse circumstances. The recordings were made with a home-made apparatus and only one curve on each subject could be secured. For the majority this was the first test. No attempt to determine the error of the recording apparatus was made. These diverging reports are thus not contradictory, and might even be explained by the influence of different seasons (52) at the time of the determinations.

BMR in Changing from Temperate to Polar Environments

In a number of studies the BMR of the same individuals has been measured in a temperate or subtropical climate as well as in an Arctic or sub-Arctic region. No appreciable difference has been found (Table 3).

The investigations of Peroni (36) and Marmet and Grandjean (29) were made during summer expeditions, and the changes were reported in relation to base line values determined in a temperate climate. While the base line of Marmet and Grandjean (29) was determined at room temperature (from +9 to +19°C), their determinations in the field were made at tent bivouac temperatures ranging from —7.5° to +14°C. During the first 4 weeks in the Arctic the BMR showed two peaks of increased metabolism, after which the BMR stayed below base line. The raised values found during the first weeks are no doubt a result of low tent temperatures at night and during the tests. After-effect of increased muscular activity (52) during the day may also have contributed in part to the increases. The marked initial rise of 43 per cent above basal coincided with the coldest outdoor period (—23°C), which no doubt was accompanied by low tent temperatures. Even if adequately clothed and protected man at rest raises his metabolic rate in direct response to ambient low temperature (21, 22). In one study (21) the mean increase when sitting quietly at —29°C was 30 per cent over control values at +25°C.

Lewis and Masterton (26) studied the BMR of twenty-nine men during the British North Greenland Expedition 1952—54. The results have not yet been published. Preliminary data show no increase in BMR in the polar climate. On the contrary, lower mean rates were recorded in Greenland than in Britain. Mean winter values for the polar period and BMR in a temperate climate for strictly comparable groups are shown in Table 3.

So far only one comparable study has been made in the Antarctic. During the Norwegian—British—Swedish Expedition 1949—1952 to Dronning Maud Land the author (52) measured the BMR of fifteen men each month during the winter periods (Table 4). Nine men were studied during both years and at home. Mean rates for corresponding winter periods in the Antarctic (—6.3 per cent in 1950 and —6.0 per cent in 1951) were not significantly different from the BMR found in a temperate climate (—5.4 per cent Aub—DuBois standard) for the same nine men (Table 3).

Butson (10) recorded the BMR of two persons at Port Stanley, Falkland Islands, in December and later at Marguerite Bay, Graham Land, in September and observed a rise of 13 per cent (Aub—DuBois) in one subject and no change in the other. As previously mentioned no definite conclusions can be drawn from these findings, which are not seriously contradictory.

All investigations thus give evidence that there is no change in BMR, measured at relatively comfortable environmental temperatures, when moving from a temperate or subtropical zone to a very cold climate and staying there. Man does not acclimatize to a polar climate by raising his BMR over the temperate level. A large increase in the BMR would be an ineffective and expensive adjustment to the great temperature gradients that occur. A 10—50 per cent elevation of heat production in man would relieve only 1—5 per cent of the Arctic cold stress. Man takes his microclimate with him and adapts by increasing his artificial insulation and shelter.

SEASONAL VARIATIONS IN BMR IN POLAR REGIONS

Although the mean level of BMR is not influenced by acclimatization to cold, there is evidence of seasonal changes in BMR in a polar climate. The author found a significant seasonal trend in the mean monthly BMR of 11 men in the Antarctic (Table 4) with peaks in the autumn (+0.6 per cent Aub—DuBois standard) and in the spring (—4.8 per cent) and a fall during the polar winter (—9.1 per cent). The differences were found to be statistically significant. This periodicity in BMR was attributed to the fact that outdoor activity, cold exposure, and other factors affecting the BMR have a distinct seasonal occurrence due to the specific nature of the Antarctic climate (52). During the activity periods higher metabolic rates were induced by increased stress and cold exposure combined with hard muscular work. Under these circumstances one night's rest was probably not sufficient to allow metabolism to return from the increased rates during day to previous basal values, which resulted in a slight elevation in the BMR. A similar lag in the return to basal levels after cold exposure was observed in a study by Horvath *et al.* (22). During the sedentary polar winter, on the other hand, cold exposures were short and less frequent and considerably less muscular work was performed. As moderate exercise does not influence BMR (8), the winter level decreased when after effects of activity diminished.

Such seasonal variations in BMR have also been reported by Russian workers in the Arctic. Sinadskij (47) claims to have observed a 13 per cent rise above normal in BMR during the polar summer in people living in the Arctic. During the polar winter a 23 per cent decrease below normal was observed along with a general retardation in bodily activity and a decreased calorie intake. In this case perhaps it is justified to speak of a dormant tendency of the body towards hibernation. No doubt very special conditions must prevail to impose such marked changes. Man cannot hibernate in the true sense, but an inclination towards partial hibernation is exhibited by some of the natives of northern Asia. With them it is the custom in the winter for the whole family to sleep hour upon hour, day after day, huddled around the stove, only waking to eat morsels of food and to stoke the fire (3).

An increase in BMR during the Arctic spring—summer period has been reported by Bajĉenko (53). He made his observations on a group of men wintering in the Arctic (Os. Dikson, Kara Sea) from June 1935 to September 1936. His data showed that the BMR began to rise with the onset of full polar day (end of April and beginning of May). The highest level was reached towards the beginning of August. A similar increase in BMR during the Arctic spring—summer period with a fall during the winter was reported (48) for Russian subjects living in the Murmansk area. However, this was true only in the case of individuals spending their first year north of the Arctic circle, and the seasonal differences in BMR for this group were not greater than 5 per cent (Harris—Benedict). Persons with longer residence showed considerably less seasonal change in BMR, which on average was below —10 per cent (Harris—Benedict). The seasonal variations in BMR were attributed to changes in environmental factors such as ultra-violet radiation, light, muscular activity, etc.

It has been suggested (4) that diverging results of BMR investigations in Eskimos, conducted during different parts of the year, may indicate a seasonal variation in the BMR. A seasonal trend in the BMR of Eskimos was observed by Brown *et al.* (5a). In view of the marked influence of diet on the Eskimo BMR (39) it is not unreasonable to expect such a seasonal variation, especially in groups living in remote areas, where they subsist primarily on their native diet. Activity and diet can vary considerably during the different seasons.

ACKNOWLEDGEMENTS

I should like to express my thanks to Dr. A. R. C. Butson, Hamilton, Canada, for his kindness in making available to me his unpublished figures for BMR in the Antarctic; to Dr. H. E. Lewis and Dr. J. P. Masterton, at the Medical Research Council Laboratories, for communicating preliminary data on BMR; and to Prof. P. F. Scholander and Dr. H. E. Lewis for valuable criticism of the text.

REFERENCES

1. Ames A. and D. A. Goldthwait, *Influence of Cold Climate on Basal Metabolism.* U.S. Army Quartermaster Climatic Res. Lab. Environmental Protection Series, Report No. 136, Lawrence, Mass (1948).
2. Andersen K. L., Y. Løyning, J. D. Nelms, O. Wilson, R. H. Fox and A. Bolstad, Metabolic and thermal response to a moderate cold exposure in nomadic Lapps. *J. Appl. Physiol.* **15,** 649 (1960).
3. Bertram C., *Arctic and Antarctic ; the Technique of Polar Travel,* p. 16. W. Heffer, Cambridge (1939).

4. Bollerud J., J. Edwards and R. A. Blakely, *A Survey of the Basal Metabolism of Eskimos.* Arctic Aeromedical Lab. Project No. 21-01-020. Ladd Air Force Base, Alaska (1950).

5a. Brown G. M., G. S. Bird, L. M. Boag, D. J. Delahaye, J. E. Green, J. D. Hatcher, and J. Page, Blood volume and basal metabolic rate of Eskimos. *Metabolism* **3**, 247 (1954).

5b. Brown, G. M., G. S. Bird, T. J. Boag, L. M. Boag, J. D. Delahaye, J. E. Green, J. D. Hatcher and Page J., The circulation in cold acclimatization. *Circulation* **9**, 813 (1954).

6. Burton A. C. and O. G. Edholm, *Man in a Cold Environment.* Monographs of the Physiological Society, No. 2. Edward Arnold, London (1955).

7. Buskirk E. R. *et al., Caloric Intake and Energy Expenditure in a Sub-Arctic Environment.* U.S. Army Quartermaster Res. & Dev. Center. Environmental Protection Res. Div. Tech. Rep. EP-33. Natick, Mass. (1956).

8. Buskirk E. R., P. F. Iampietro and B. E. Welch, Variations in resting metabolism with changes in food, exercise and climate. *Metabolism* **6**, 144 (1957).

9. Butson A. R. C., Acclimatization to cold in the Antarctic. *Nature, Lond.* **163**, 132 (1949).

10. Butson A. R. C., *Report on Cold Weather Acclimatization Research.* Submitted to the Colonial Office, England (1949); and personal communication (1954).

11. Camis M., Metabolismo basale ed alimentazione in Somalia. Primo contributo alla fisiologia tropicale in Africa orientale. *Reale Accad. d'Italia. Centro studi per l'Africa Orientale Italiana,* vol. 1, Roma (1936); cited in *Nutr. Abstr. Rev.* **7**, 105 (1937), and in *Ber. ges. Physiol.* **100**, 239 (1937).

12. DuBois E. F., *Basal Metabolism in Health and Disease,* 3rd ed., p. 151. Lea & Febiger, Philadelphia and Ballière, Tindall & Cox, London (1936).

13. DuBois E. F., Energy metabolism. *Annu. Rev. Physiol.* **16**, 125 (1954).

14. Eijkman C., Le métabolisme de l'homme tropical. *J. Physiol. Path. gén.* **19**, 33 (1921).

15. Erikson H., J. Krog, L. K. Andersen and P. F. Scholander, The critical temperature in naked man. *Acta Physiol. Scand.* **37**, 35 (1956).

16. Fleming W. D., The basal metabolism of a normal young man as affected by a tropical residence of one year. *Amer. J. Trop. Med.* **5**, 283 (1925).

17. Galvão P. E., Human heat production in relation to body weight and body surface. *J. Appl. Physiol.* **1**, 385 and 395 (1948); **3**, 21 (1950).

18. Gottschalk C. W. and D. S. Riggs, Protein-bound iodine in the serum of soldiers and of Eskimos in the Arctic. *J. Clin. Endocrin.* **12**, 235 (1952).

19. Hammel H. T., R. W. Elsner, D. H. LeMessurier, H. T. Andersen and F. A. Milan, Thermal and metabolic responses of the Australian aborigine exposed to moderate cold in summer. *J. Appl. Physiol.* **14**, 605 (1959).

20. Hicks C. S., H. O. Moore and C. Eldridge, The respiratory exchange of the Australian aborigine. *Aust. J. Exp. Biol. Med. Sci.* **12**, 79 (1934).

21. Horvath S. M., H. Golden and H. Wager, Some observations on men sitting quietly in extreme cold., *J. Clin. Invest.* **25**, 709 (1946).

22. Horvath S. M., A. Friedman and H. Golden, Acclimatization to extreme cold. *Amer. J. Physiol.* **150**, 99 (1947), abstract in *Fed. Proc.* **6**, 133 (1947).

23. Irving L., K. L. Andersen, A. Bolstad, R. W. Elsner, J. A. Hildes, Y. Løyning, J. D. Nelms, L. J. Peyton and R. D. Whaley, Metabolism and Temperature of Arctic Indian men during a cold night. *J. Appl. Physiol.* **15**, 635 (1960).

24. Knipping H. W., Ein Beitrag zur Tropenphysiologie. Untersuchungen des Gaswechsels, der Blutregeneration, des Blutdruckes, der Atemmechanik, des Wärmehaushaltes, in den Tropen und der meteorologischen Faktoren des Tropenklimas *Z. Biol.* **78**, 259 (1923).

25. Krog H., M. Monson and L. Irving, Influence of cold upon the metabolism and body temperature of wild rats, albino rats and albino rats conditioned to cold. *J. Appl. Physiol.* **7**, 349 (1955).

26. Lewis H. E. and J. P. Masterton, Unpublished data from the British North Greenland Expedition 1952—54; personal communication (1959).
27. Lockhart E. E., Acclimatization in the Antarctic. *Science* **94**, 550 (1941).
28. MacGregor R. G. S. and G. L. Loh, The influence of a tropical environment upon basal metabolism, pulse rate and blood pressure in Europeans. *J. Physiol.* **99**, 496 (1941).
29. Marmet J. and E. Grandjean, Untersuchungen über das Verhalten des Ruhestoffwechsels während langdauernder Kälteexposition in der Arktis. *Helv. Physiol. Acta* **13**, 173 (1955); abstract in *Int. Abstr. Biol. Sci.* **4**, 491 (1956).
30. Martin C. J., Thermal adjustment of man and animals to external conditions. *Lancet* **219**, 617 (1930).
31. Mason E. D., The basal metabolism of European women in South India and the effect of change of climate on European and South Indian women. *J. Nutr.* **8**, 695 (1934).
32. Mason E. D., Effect of change of residence from temperate to tropical climate on the basal metabolism, weight, pulse rate, blood pressure and mouth temperature of 21 English and American women. *Amer. J. Trop. Med.*, **20**, 669 (1940).
33. Mason E. D., Daily measurements of basal metabolism, body temperature and pulse rate during a journey to the tropics. *Indian J. Med.* Res. **32**, 27 (1944).
34. Molnar G. W., R. J. Blair, C. W. Gottschalk, W. M. Layton, L. E. Osgood, W. J. Zimmerman and C. A. Johnson, *Energy Expenditure and Endurance of Men in an Arctic Bivouac.* U.S. Army Med. Dept. Field. Res. Lab. Project 6-64-12-02-(13). Ft. Knox, Kentucky (1950).
35. Pecora J. S., *Basal Metabolic Rate Studies in Relationship to Cold Acclimatization.* Arctic Aeromedical Lab. Project No. 21-01-003, Section IX. Ladd Air Force Base, Alaska (1948).
36. Peroni A., Ricerche sul metabolismo basale e sul valore energetico degli alimenti nelle regioni arctiche. *Boll. Soc. Ital. Biol. Sper.* **5**, 225 (1930).
37. Roberts J. M., The Falkland Islands Dependencies Survey. *Brit. Med. J.* **2**, 863 (1949).
38. Robertson J. D. and D. D. Reid, Standards for the basal metabolism of normal people in Britain. *Lancet* **262**, 940 (1952).
39. Rodahl, K., *Basal Metabolism of the Eskimo.* Arctic Aeromedical Lab. Project Rep. 22-1301-0001, Part 2. Ladd Air Force Base, Alaska (1952); J. Nutr. **48**, 359 (1952); abstract in *Fed. Proc.* **11**, 130 (1952).
40. Rodahl K., Nutritional requirements in cold climates. *J. Nutr.* **53**, 575 (1954).
41. Rodahl K., *Human Acclimatization to Cold.* Arctic Aeromedical Lab. Tech. Rep. 57—21. Ladd Air Force Base, Alaska (1957); Cold injury. *Trans. Fifth Conf.* (edited by M. I. Ferrer) p. 177. Josiah Macy, Jr. Foundation, New York (1958).
42. Rodahl K., C. R. Shaw and H. F. Drury, *Arctic Survival Rations.* Arctic Aeromedical Lab. Project Rep. 22-1101-0002, No. 1. Ladd Air Force Base, Alaska (1952).
43. Sapin-Jaloustre J., Contribution à l'étude de l'acclimatation de l'homme et des vertébrés supérieurs dans l'Antarctique et plus spécialement en Terre Adélie. *Biol. méd., Paris* **44**, 15 and 133 (1955).
44. Scholander P. F., R. Hock, V. Walters, F. Johnson and L. Irving, Heat regulation in some arctic and tropical mammals and birds. *Biol. Bull.* **99**, 237 (1950).
45. Scholander P. F., K. L. Andersen, J. Krog, F. V. Lorentzen and J. Steen, Critical temperature in Lapps. *J. Appl. Physiol.* **10**, 231 (1957).
46. Scholander P. F., H. T. Hammel, J. S. Hart, D. H. LeMessurier and J. Steen, Cold adaptation in Australian aborigines. *J. Appl. Physiol.* **13**, 211 (1958).
47. Sinadskij N., Ochrana zdorov'ja v Arktike (Hygiene in the Arctic. Advice to young people in polar regions). *Sovetskaja Arktika*, No. 8. (August), 82 (1939).
48. Slonim A. D., R. P. Olyanskaya and S. O. Ruttenburg, Opyty izučenija dinamiki fiziologičeskich funkcij čeloveka v uslovijach zapoljar'ja (Studies of the dynamics of physiological functions in man under Arctic conditions). In *Opyt izučenija periodičeskich izmenenij*

fiziologičeskich funkcij v organisme (Research on periodic changes in physiological function in the organism), pp. 207—22. (edited by BYKOV K. M.). Akademija Medicinskich Nauk SSSR, Moskva (1949); cited in, Effects of cold on man. An annoted bibliography, 1938—1951. *Physiol. Rev.* **39**, suppl. no. 3, 141 (1959).

49. TREICHLER R. and H. H. MITCHELL, The influence of plane of nutrition and of environmental temperature on the relationship between basal metabolism and endogenous nitrogen metabolism subsequently determined. *J. Nutr.* **22**, 333 (1941).

50. WILLIAMS G. D. and F. G. BENEDICT, The basal metabolism of Mayas in Yucatan. *Amer. J. Physiol.* **85**, 634 (1928).

51. WILSON O., Adaption of the basal metabolic rate of man to climate — a review. *Metabolism* **5**, 531 (1956).

52. WILSON O., Basal metabolic rate in the Antarctic. *Metabolism* **5**, 543 (1956).

53. BAJČENKO I. P., Sezonne izmenenija osnovnogo obmena i dychanija v Arktike (Seasonal changes in basal metabolism and respiration in the Arctic) (1936); cited in Ref. (48).

54. OGATA M., Report on physiological results of the Japanese Antarctic Research Expedition I, 1956—57. *Antarctic Record, Tokyo,* No. 6, 346 (1959).

BODY TEMPERATURES OF HEAT-ACCLIMATIZED SUBJECTS IN THE EQUATORIAL TROPICS

G. C. WHITTOW

Department of Physiology, The Hannah Dairy Research Institute, Kirkhill, Ayr, Scotland, Great Britain. Formerly Dept. of Physiology, Univ. of Malaya, Singapore

Abstract—The mean skin temperature of eleven Asian subjects, at rest in an equatorial climate, was higher than that of people in a temperate climate. The skin temperature of the habitually unclothed forearms of the heat-acclimatized subjects was also higher than the skin temperature of the clothed forearms of men in a temperate climate. The skin temperature of the lower limbs of the tropical subjects decreased from the thigh towards the foot; the skin temperature of the upper limbs increased distalwards so that the hand was warmer than the upper arm.

Résumé—La température moyenne de la peau d'ouze sujets asiatiques au repos dans un climat équatorial, fut supérieure à celle des personnes d'un climat tempéré. La température des avant-bras, habituellement découverts chez les sujets acclimatés à la chaleur, fut également supérieure à celle de la peau des avant-bras couverts, des hommes d'un climat tempéré. La température de la peau des membres inférieurs des sujets tropicaux diminua de la cuisse vers le pied. La température de la peau des membres supérieurs augmenta avec l'éloignement de telle sorte que la main fut plus chaude que le bras.

Auszug—Die mittlere Hauttemperatur ruhender Versuchspersonen war höher bei 11 Asiaten als bei Personen in einem gemässigten Klima. Die Hauttemperatur des normalerweise unbekleideten Unterarms von wärme-akklimatisierten Personen war höher als die Hauttemperatur des bekleideten Unterarms von Personen in einem gemässigten Klima. Die Hauttemperatur der Beine von tropischen Versuchspersonen nahm vom Oberschenkel zum Fusse ab; die Hauttemperatur der Arme nahm in distaler Richtung zu, sodass die Hand wärmer war als der Oberarm.

I. INTRODUCTION

It has been suggested that the physiological mechanisms of temperature regulation in man are adjusted to a tropical climate (4), but very little is known about the physiology of tropical man, whereas a great deal of work has been done on people who live in temperate climates. In recent years, a renewed interest in the physiology of temperature regulation in the indigenous peoples of the tropics has stemmed from the knowledge that such people offer special opportunities for studying the effects, on man, of localized and general body cooling (15), and of acclimatization to cold (11). By virtue of their having lived in a hot climate all their lives, the inhabitants of the tropics are also naturally acclimatized to heat (9).

The purpose of the present communication is to present data on the surface and deep-body temperatures of people in a state of thermal balance in an equatorial climate. It forms part of a study of the means by which tropical men regulate their body temperatures.

II. METHODS AND PROCEDURE

Measurements were made on eleven male subjects, all of whom had been born in Singapore and had lived there all their lives. Four of the subjects were Tamil Indians by race, and the other seven were Chinese; their mean age was 21.8 years (s. d. = $\pm$ 1.1) and their mean body weight and surface area were 56.5 kg. (s. d. = = $\pm$ 5.9) and 1.655 m^2 (s. d. = $\pm$ 0.101), respectively. The subjects wore only a thin pair of cotton shorts during the whole experimental period. Their normal clothing consisted of a short-sleeved, open-necked shirt, thin cotton trousers, shoes or sandals and thin socks. Each subject lay on his back on a stretcher of open-weave cane for 90 min before any measurements were made. During this time the sublingual thermometer was placed *in situ* and the lips sealed with adhesive tape. The preliminary rest period ensured that the subjects were in thermal equilibrium with their environment (7) before measurements were made.

Experiments were carried out in a sound-proof climatic room at the ambient temperature of Singapore. Singapore is at sea level, and lies 1° north of the equator. Its climate is uniformly warm and humid throughout the year; diurnal variations of temperature and humidity are extremely small and seasonal variations are almost entirely absent. The mean dry bulb temperature during the experiments was 29.6°C (s. d. = $\pm$ 0.9°C) and the mean wet bulb temperature, 26.1°C. (s.d. = $\pm$ 1.0°C). The mean globe thermometer temperature was 29.6°C (s. d. = $\pm$ 0.9°C) and the wind velocity was approximately 5 ft/min.

Sublingual temperatures were measured potentiometrically, using a bare, welded 40 s.w.g. copper-constantan thermocouple and a Cambridge Vernier potentiometer. The system was capable of measuring temperature changes of 0.02°C. Surface temperatures were similarly measured by means of a single, roving 40 s.w.g. thermocouple contained in a Y-shaped holder (6). It was sensitive to a temperature change of 0.03°C. All body temperatures were measured in duplicate and if the two measurements of sublingual temperature differed by more than 0.02°C the measurements were repeated to give consistent readings within these limits. Readings of skin temperature were made in the same sequence in all subjects and were repeated to give consecutive values that did not differ by more than 0.1°C.

III. RESULTS

Skin temperatures were measured at the points shown in Fig. 1 and the mean temperatures recorded for each part of the body surface in the eleven subjects are shown in Table 1. The warmest area of skin was the forehead and the coolest was the plantar surface of the foot, but the difference between the mean temperatures of these two sites amounted to only 2.58°C. The greatest variation in skin temperature amongst the eleven subjects was observed on the plantar surface of the foot and the least variation was recorded from the forehead.

Fig. 2 shows the temperature gradients along the upper and lower extremities. It can be seen that whereas along the leg the temperature decreased from the thigh to the plantar surface of the foot, the temperature of the hand exceeded that of both

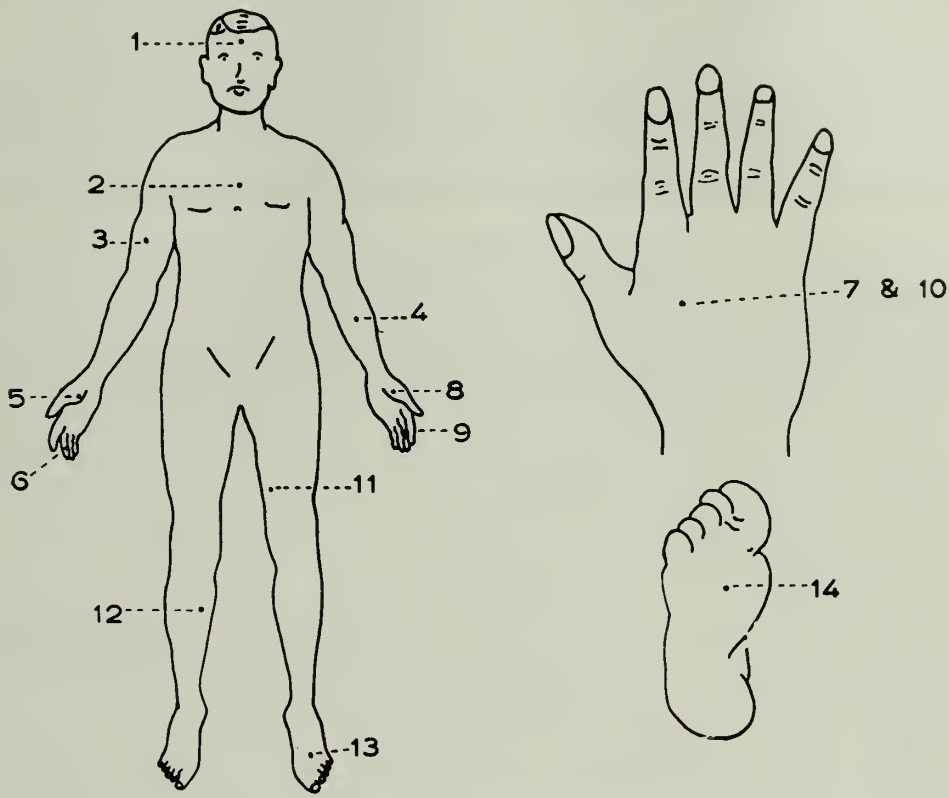


Fig. 1. Sites at which skin-temperature measurements were made

the upper arm and the forearm and there was in fact a small temperature gradient along the upper limb from the finger to the upper arm (Fig. 2). Temperatures were measured at three different sites on each hand, in order to find out if there were any marked differences of temperature between the two sides of the body. The average temperature of the right hand was 35.26°C and that of the left hand was 35.32°C and this small difference between them was not statistically significant ($t = 0.554$; $0.6 > P > 0.5$).

It can be seen from Table 1 that the average temperature of the skin in the eleven subjects was 34.60°C and that the difference between this temperature and the mean sublingual temperature was 2.32°C. Thus, the temperature gradient between the deep tissues and the surface of the body was of the same order as that between the warmest and coolest parts of the skin.

None of the subjects reported that he felt any particular thermal sensation during the experimental period and there was no visible sweating.

Table 1. *Mean Temperatures Recorded from each of the*
(All temperatures are given in °C.

Sub-lingual temp. ± s. d.	Mean temp. of sites 1, 2, 3, 4, 7, 9, 11, 12, 13, and 14 for eleven subjects ± s. d.	Skin temp. ± s. d.						
		1	2	3	4	5	6	7
36.92 ±0.25	34.60 ±1.22	35.95 ±0.32	34.88 ±0.42	34.33 ±0.54	34.88 ±0.41	35.44 ±0.40	35.40 ±0.32	34.94 ±0.50

IV. DISCUSSION

It has been shown that, as in people examined in a temperate climate (12), the warmest part of the body surface of heat-acclimatized subjects was the forehead and the coolest part was the foot. At the ambient temperatures of Singapore, however, the

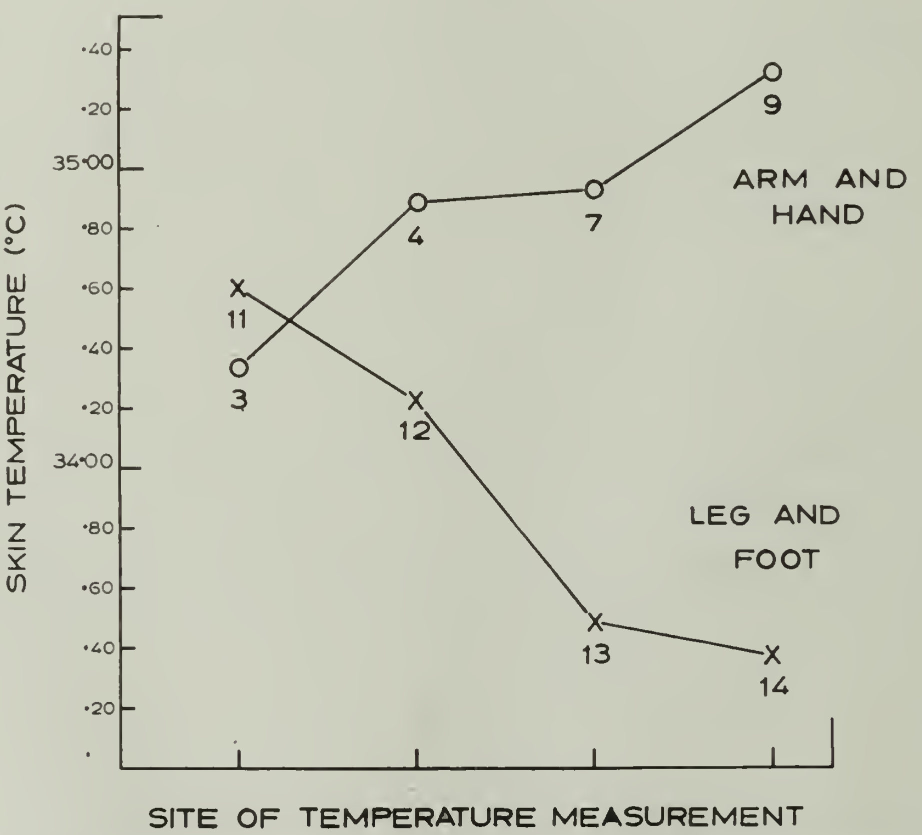


Fig. 2. Mean temperature gradients in the upper and lower extremity of eleven heat-acclimatized subjects. The numerals refer to the points on the skin from which temperature measurements were made. (See Fig. 1.)

Areas shown in Fig. 1., for the Eleven Subjects
s. d. — standard deviation.)

Sub-lingual temp. ± s. d.	Mean temp. of sites 1, 2, 3, 4, 7, 9, 11, 12, 13, and 14 for eleven subjects ± s. d.	Skin temp. ± s. d.						
		8	9	10	11	12	13	14
36.92 ±0.25	34.60 ±1.22	35.57 ±0.39	35.31 ±0.45	35.10 ±0.33	34.60 ±0.87	34.22 ±0.85	33.48 ±1.78	33.37 ±2.09

temperature difference between these two points amounted to only 2.58°C, whereas at room temperatures of 16—22°C in a temperate country, the difference has been reported to be 5—10°C (2, 5, 8). This implies that the mean skin temperature of tropical men was higher than that of temperate-climate men and comparison of Table 1 with data presented by Hellon and Lind (10) and by others (5, 8), lends support to this suggestion. The skin temperatures of the clothed subject in Singapore might be expected to be higher, but in view of the light nature of their normal clothes not very much higher, than those reported here. It is interesting to note also, that the mean skin temperature of the subjects taking part in the present investigation was slightly lower than the temperature of Caucasian subjects tested in Singapore (9).

A feature of the skin-temperature data of the Singapore subjects was the presence of a small, incremental temperature gradient distalwards along the upper limb and of a slightly greater decremental temperature gradient along the lower limb from the thigh to the foot. This suggests that any increased need for heat dissipation from the body, brought about by either an increased environmental temperature or an increased heat production, would result in a greater increase of the lower-limb temperature than of the temperature of the upper limb. That the temperature of the feet of heat-acclimatized subjects in Singapore does increase when the environmental temperature is raised has already been shown by Whittow (13, 14), who exposed young, male subjects to room temperatures of 37.6°C and 42.7°C (dry bulb). At these environmental temperatures the skin temperature of the foot increased to a level approximately 4°C higher than its temperature at the ambient temperatures of Singapore, and the temperature difference between the forehead and foot was then largely eliminated. The similarity between the temperatures of the two hands suggests a striking bilateral symmetry of skin temperature, a phenomenon which has been observed also in temperate-zone man (12).

The skin temperature of the forearm, which was normally unclothed in the Singapore subjects, was higher than that of the clothed forearms of people examined at a room temperature of 18.5°C in England (1) and of 20°C in North America (3). The subcutaneous temperature of the clothed forearm in the English subjects was also lower than the forearm-skin temperature of the heat-acclimatized subjects. In addition, the sublingual temperatures of the heat-acclimatized subjects were higher than the corresponding temperatures of the English subjects, and these findings are consistent with the view that in spite of wearing less clothes, people in an equatorial climate sustain higher body temperatures than do people who are comfortably warm in a temperate country.

It seems important to emphasize that these conclusions apply only to non-sweating, resting subjects. Activity or the outbreak of sweating would be expected to increase or decrease the body temperatures and might also alter the disposition of the temperature gradients along the skin surface.

CONCLUSION

The contribution of this investigation to our understanding of the mechanism of temperature regulation in equatorial man seems to be twofold. In the first place, the non-sweating, resting individual appears to have achieved thermal balance at a higher overall body temperature than has his counterpart in a cool climate. Secondly, the presence of a temperature gradient along the lower limb suggests that further vasomotor regulation of body temperature might occur, before the sweating mechanism is called into play, by increasing the temperature of, and dissipation of heat from, the feet.

ACKNOWLEDGEMENTS

It is a pleasure to record my gratitude to the medical students who acted as my experimental subjects and to Mr. Chan Ban Kiat who gave me technical assistance in all experiments.

REFERENCES

1. Barcoft H. and O. G. Edholm, Temperature and blood flow in the human forearm. *J. Physiol.* **104**, 366—76 (1946).
2. Bedford T., Skin temperature in relation to the warmth of the environment. *J. Hyg., Camb.* **35**, 307—17 (1935).
3. Brown G. M., J. D. Hatcher and J. Page, Temperature and blood flow in the forearm of the Eskimo. *J. Appl. Physiol.* **5**, 410—20 (1953).
4. Burton A. C. and O. G. Edholm, *Man in a Cold Environment,* p. 105. Edward Arnold, London (1955).
5. Freeman H. and R. F. Nickerson, Skin and body temperatures of normal individuals under cold conditions. *J. Nutr.* **15**, 597—606 (1938).
6. Glaser E. M., The effects of cooling and of various means of warming on the skin and body temperature of men. *J. Physiol.* **109**, 366—79 (1949).
7. Glaser E. M. and P. S. B. Newling, The control of body temperature in thermal balance. *J. Physiol.* **137**, 1—11 (1957).
8. Hardy J. D. and E. F. DuBois, Basal metabolism, radiation, convection and vaporization at temperatures of 22 to 35° C. *J. Nutr.* **15**, 477—97 (1938).
9. Hellon R. F., R. M. Jones, R. K. Macpherson and J. S. Weiner, Natural and artificial acclimatization to hot environments. *J. Physiol.* **132**, 559—76 (1956).

10. Hellon R. F. and A. R. Lind, Observations on the activity of sweat glands with special reference to the influence of ageing. *J. Physiol.* **133,** 132—44 (1956).
11. Macpherson R. K., Acclimatization status of temperate-zone man. *Nature, Lond.* 182, 1240—1 (1958).
12. Richards R. L., *The Peripheral Circulation in Health and Disease*, pp. 29—35. E. & S. Livingstone, Edinburgh (1946).
13. Whittow G. C., Circulatory and subjective responses to localized cooling of people living in a warm environment. Ph. D. Thesis, University of Malaya (1956).
14. Whittow G. C., Some factors affecting the magnitude of the pressor, cardio-accelerator and pain response to cold of heat-acclimatized subjects. *Clin. Sci.* **17,** 339—48 (1958).
15. Whittow G. C., Physiological responses to the moist tropics. Introduction and the circulatory system. *Proceedings of the Centenary and Bicentenary Congress, Singapore,* 1958, pp. 242—244 (edited by R. D. Purchon). University of Malaya, Singapore (1960), distributed by Oxford University Press, London.

MISCELLANEOUS BIOCLIMATOLOGICAL PAPERS SUBMITTED TO THE CONGRESS

GENERAL BIOCLIMATOLOGY

ÉTUDE BIOCLIMATOLOGIQUE DU SÉNÉGAL ET DE LA MAURITANIE

J. P. NICOLAS*

*Dept. de Géographie, Institut Français d'Afrique noire, Dakar, Sénégal

Abstract—Taking as a basis his formerly published papers, the author looks for a meaningful graphical and numerical expression to distinguish the different climates of Mauretania and Segenal. Taking the four main groups: cold-dry, cold-humid, hot-dry and hot-humid, J. P. Nicolas combines them to show the degree of physiological effort supported by the organism in its adaptive fight. The association of the climatic elements takes into account their evolution in time and their frequency. The salubrity of a climate can in no case be understood through the immediate psycho-physiological comfort. A well developed climatographical analysis can alone give the optimal conditions, given that the typological and individual human variations as well as the way of life interfere with purely climatological facts. This paper may be considered as a valuable basis leading to a widespread original regional cartography.

Résumé—Se basant sur ses travaux d'analyse climatique antérieurement publiés, l'auteur s'efforce de rechercher une expression graphique et chiffrée parlante afin de différencier les divers climats de Mauritanie et du Sénégal. Reprenant les quatre ensembles froid-sec, chaud-sec, chaud-humide et froid-humide, J. P. Nicolas les combine afin de faire ressortir le degré d'effort physiologique supporté par l'organisme dans sa lutte adaptative. Les associations des éléments climatiques tiennent compte de leur évolution dans le temps et de leur fréquence. Le degré de salubrité ne saurait pour un climat donné en aucun cas être assimilé au degré de bien être psychologique instantané. Seule une analyse climatographique poussée permet de définir les conditions optima en sachant bien que la variabilité typologique individuelle humaine et celle du genre de vie viennent interférer avec les états purement climatologiques. Le travail présenté peut servir de base à une étude plus étendue menant à une cartographie régionale originale.

Auszug—Der Verfasser stützt sich auf frühere Untersuchungen über die klimatischen Verhältnisse und sucht eine anschauliche, sprechende Formel zur Kennzeichnung der klimatischen Lage in Mauretanien und Senegal zu geben. Zu diesem Zweck übernimmt J. P. Nicolas die vier Grundbezeichnungen kalt-trocken, warm-trocken, warm-feucht und kalt-feucht und verbindet sie, um dadurch die physiologische Kraftanstrengung zu kennzeichnen, die der Organismus zur Anpassung an die wechselnden Verhältnisse aufbringen muss. Bei dieser Zusammenfassung der klimatischen Merkmale werden ihre zeitlichen Veränderungen und Häufigkeit berücksichtigt. In keinem Falle dürfe man den für die Gesundheit zuträglichen Grad eines bestimmten Klimas dem eigenen Wohlbefinden gleichstellen. Nur mit Hilfe eingehender klimatologischer Untersuchungen könne man die bestmöglichen Voraussetzungen bestimmen. Hierbei komme es aber auf die individuelle körperliche Verfassung sowie auf die Lebensweise unter bestimmten klimatischen Verhältnissen an. Die vorgelegte Arbeit lässt sich als Grundlage für eine ausführliche Untersuchung zur Erstellung einer kartographischen regionalen Darstellung verwenden.

Quoique le climat soit un terme bien défini au point de vue météorologique et que son utilisation soit courante en géographie et en écologie, il n'en reste pas moins qu'il représente un concept ambigu. Si l'on peut définir physiquement le climat comme étant l'expression synthétique d'un certain nombre d'éléments simples en un lieu donné et durant un laps de temps déterminé nous devons être très prudents quant à l'utilisation de ce terme lorsqu'il s'agit d'un être vivant. Du point de vue biologique nous ne rencontrons que des réactions entre un organisme vivant et un état atmosphérique se traduisant essentiellement par des échanges énergétiques variés. La connaissance des éléments du climat se fait par l'intermédiaire d'appareils physiques qui nous sont totalement extérieurs, et nous ne pouvons prendre conscience des échanges que par l'information de nos sens et des procèsses physiologiques qu'il détermine. Aussi pouvons nous dire que le «climat» n'est que l'impression laissée par un état atmosphérique et par la succession de ses variations sur un être vivant. Cette impression se traduit par le développement des fonctions vitales, varie d'un individu à l'autre, et ceci d'une manière d'autant plus sensible que l'organisation de l'être vivant est plus complexe. Cette variation que l'on peut tenir pour négligeable à l'intérieur d'une même espèce dans le règne animal inférieur et dans le règne végétal dans son ensemble, devient majeure pour les espèces à très haute concentration nerveuse et à régulation endocrinienne fortement organisée, telle que celle de l'homme.

Le «climat» est diversement apprécié par l'homme selon sa typologie, sa race, son sexe. C'est pourquoi je me suis toujours efforcé dans mes travaux à rechercher des critères d'appréciation relativement indépendants de ces facteurs.

Trois travaux antérieurs (1) ont tenté de mettre au point une méthode d'analyse fine du climat en relation avec les besoins biologiques et psychiques humains. Tous trois supposent une connaissance étendue des données statistiques climatiques et reposent sur des calculs simples mais longs. Les deux indices saisonniers que j'ai développés pour les stations sénégalo-mauritaniennes permettent de chiffrer une appréciation psychologique du «climat». Les nombres expressifs sont calculés en fonction de l'impression laissée par la saison. Les «Climats africains en biogéographie humaine» proposent une conception physiologique des rapports entre l'homme et l'état de l'atmosphère. Ce sont là deux points de vue distincts, mais complémentaires. Il nous est aparu qu'une appréciation simplifiée pourrait être utile lorsqu'il s'agit de procéder à une étude extensive ou relativement superficielle d'une région étendue.

Sans modifier notre point de vue, c'est-à-dire en appliquant les mêmes points de départ et les mêmes principes que précédemment, j'ai recherché un mode d'expression calculée et graphique parlant, susceptibles de nous éclairer sur la salubrité des stations dont les statistiques sont réduites à trois observations journalières du vent, de la température et de la tension de vapeur. Nous basant sur les travaux de Leroy (2), nous avons choisi pour point critique d'humidité absolue 16 mbar, et pour la température 18 °C. Ces deux valeurs constituant un état atmosphérique optimum auquel nous associons la vitesse de 4 m/sec pour le vent afin que l'indice de Hill (3) soit de 20 unités c'est à dire à la limite des modes «relaxant» et «tonique.» Nous prendrons donc pour base de travail les trois caractéristiques suivantes: 18 °C, 16 mbar, 4 m/sec. A partir de cet état se distinguent les ensembles chauds /humides; chauds/secs; frais/humide et frais/sec, chaque pouvant être ventilé ou non.

BASES DE TRAVAIL

Le critère thermique étant donc de 18 °C nous nous situons à la limite des groupes hygrothermopsyque et éolothermopsyque. Le critère de tension de vapeur de 16 mbar limite les ensembles sains des ensembles fatigants. L'idéal climatique est donc caractérisé par une combinaison de ces deux éléments, quoique'à notre sens elle représente un état légèrement trop humide. Toutefois en région intertropicale ou les tensions de vapeur sont élevées nous avons cru bon de prendre ce seuil de préférence à 11,7 mbar qui serait plus acceptable pour les régions tempérées. Les écarts autour de cet état entrainent le déclanchement d'efforts physiologiques soit de rétention ou de déperdition de vapeur d'eau, soit de thermogénèse ou de thermolyse chez l'homme vêtu. Nous n'avons pas recherché la neutralité thermique pour le corps nu, cette neutralité ne correspondant pas à un optimum d'activité physique et intellectuelle.

L'EXPRESSION GRAPHIQUE

Le mode graphique utilisé dans un travail précédent et destiné à l'étude détaillée d'une station sous forme de grille, peut être avantageusement remplacé ici par une triple courbe en coordonnées cartésiennes. Afin d'avoir entre les courbes de température et d'humidité absolue une surface d'autant plus grande que l'on s'écarte de l'optimum, nous portons les températures en ordonnée de valeur croissante de bas en haut et les tensions de vapeur en sens inverse, croissantes vers le bas. La surface obtenue entre les deux courbes sera donc d'autant plus grande que la salubrité sera faible. La courbe de vitesse du vent vient se superposer mais les ordonnées sont portées en échelle logarythmique allant de 1 à 10 m/sec; l'importance de ce facteur n'étant pas une fonction linéaire.

Lorsque la courbe des températures est au-dessus de la ligne de neutralité idéale et la courbe d'humidité au-dessous nous obtenons la figuration d'un état chaud et *humide*, l'inverse détermine le froid *sec*. Les deux courbes au-dessus de la neutralité déterminent le chaud sec, l'inverse le froid humide. Ces quatre états de l'atmosphère peuvent servir à determiner les caractéristiques de l'état annuel de l'atmosphère d'une station. La figure est suffisamment caractéristique. Nous affecterons les quatre combinaisons d'un symbole:

(A) froid sec: $—T$, $—U$;
(B) chaud sec: $+T$, $—U$;
(C) chaud humide: $+T$, $+U$;
(D) froid humide: $—T$, $+U$.

Chaque combinaison peut être ventilée ou non selon que la courbe de vitesse du vent franchit ou non la ligne des 4 m/sec. Cette limite corresponds nous l'avons vus à un indice de Hill pour 18 °C/16 mbar de 20.

Comme nous avons défini un état neutre à la limite de l'éolothermopsyque et de l'hygrothermopsyque nous obtenons huit combinaisons possibles, chacune s'écartant par un ou plusieurs caractères de la neutralité.

EXPRESSION CHIFFRÉE

Toute valeur de température ou d'humidité est comparée aux valeurs de base. Les excédents sont positifs, les déficits négatifs. Ainsi par simple soustraction nous obtenons mensuellement pour chacune des trois heures de la journée (06,12 et 18,00 heures) un nombre double (T,U) positif ou négatif caractéristique à la fois du type d'effort physiologique demandé à l'organisme et de son intensité. La somme algébrique de ces trois doubles nombres exprime cet effort pour chaque mois en tenant sensiblement compte des valeurs extrêmales. Attendu que le vent n'agit qu'en fonction de la racine carrée de sa vitesse nous n'avons pas voulu l'introduire dans le calcul algébrique. Nous évaluerons le caractère de ventilation par un nombre à part qui est la somme algébrique du déficit/surplus de vitesse autour de la valeur critique de 4 m/sec. Toutefois lorsque nous aurons affaire à une station hyperventilée dont la température dépasse 36°C nous considérerons que l'effet physiologique de ce vent est nuisible et l'on ajoutera son surplus au lieu de le soustraire. En effet au-dessus de 36°C le vent ne fait qu'accroître la rétention et l'absorbtion de chaleur par le corps.

EXPRESSION GÉOGRAPHIQUE

Pour chaque station nous disposons donc des éléments suivants:

(1) Valeur des combinaisons A, B, C, D pouvant être cartographiées séparément.

(2) De la valeur totale des combinaisons B et C c'est-à-dire des états atmosphériques faisant appel à la thermolyse et au jeu de la régulation de la vapeur d'eau.

(3) De la valeur algébrique de la ventilation.

A partir de ces éléments nous pouvons calculer et cartographier le rapport B/C exprimant le type dominant d'effort physiologique. Lorsque ce rapport est supérieur à «1», l'effort dominant est celui de la thermolyse en mileu humide; inversement lors que le rapport devient inférieur à «1», l'effort dominant est celui de la rétention de l'eau en milieu sec.

RÉPARTITION GÉOGRAPHIQUE DES ENSEMBLES

Ensemble A : Froid Sec

Ces états atmosphériques n'existent qu'en fin de nuit lors du minimum thermique de 6 à 7 hr. Étant en région tropicale leur importance est réduite dans toutes les stations et ne preprend une valeur un tant soit peu significative que dans les

Tableau 1. Tableau des ensembles

Ensemble *A*		Ensemble *B*		Ensemble *C*	
Tididjka	57,7	Ziguinchor	0	Ft. Gourand	27,7
Atar	36,2	Dakar	9,0	Tididjka	162,8
Fort Gouraud	35,7	Pt. Etienne	41,7	Atar	172,4
Nouakchott	32,7	St. Louis	55,2	Pt. Etienne	174,5
Boutilimit	28,9	Thiès	116,8	Boutilimit	235,7
Rosso	25,5	Kolda	151,1	Matam	244,2
Akjoujt	21,4	Akjoujt	160,6	Néma	257,2
Port Etienne	21,4	Diourbel	165,7	Rosso	315,1
Podor	23,8	Nouakchott	167,4	Podor	328,7
Diourbel	21,3	Kaolack	185,5	Nouakchott	331,1
Kaolack	18,5	Linguère	256,2	Akjoujt	370,9
Linguère	16,8	Rosso	267,9	Linguère	376,7
Matam	14,1	Tambacounda	269,2	Tambacounda	394,2
Thiès	13,0	Podor	279,1	Thiès	409,2
Tambacounda	11,8	Matam	302,3	Diourbel	416,6
Saint Louis	9,0	Atar	323,7	Kolda	447,8
Kolda	7,0	Boutilimit	360,4	Kaolack	431,1
Ziguinchor	1,1	Tididjka	378,3	St. Louis	452,3
Dakar	0	Néma	409,7	Dakar	466,7
Néma	0	Ft. Gouraud	454,2	Ziguinchor	512,9

Tableau 2. Somme et Rapport des Eléments B et C

Station	$B + C$	B/C
Pt. Etienne	216,2	0,24
Ft. Gouraud	481,9	16,5
Atar	496,1	1,87
Nouakchott	498,5	0,50
Ziguinchor	512,9	0
Saint Louis	508,5	0,12
Thiès	526,0	0,28
Akjoujt	531,5	0,43
Tididjka	541,1	2,32
Matam	546,5	1,23
Dakar	576,0	0,19
Diourbel	580,0	0,39
Rosso	583,0	0,85
Boutilimit	596,1	1,53
Kolda	598,9	0,34
Podor	607,8	0,85
Kaolack	616,6	0,43
Linguère	632,9	0,67
Tambacounda	663,4	0,68
Néma	667,1	1,59

climats subsahariens ou sahariens (Tididjka, Atar, Fort Gouraud). Leur apparition dans les régions plus méridionales est cependant à noter et sert à définir des incursions sahariennes dans le domaine de frange. Notons que Dakar et Néma ne possèdent pas cet ensemble. Dakar parce que beaucoup trop océanique, où cet ensemble est remplacé par le *D* qui n'apparait qu'ici. Néma est trop chaud pour laisser apparaître cette combinaison. Les deux stations sont donc opposées de ce point de vue.

L'essai de cartographie, qui ne peut être évidemment qu'un essai attendu le caractère trop lache du réseau d'observations, montre assez bien l'influence combinée de la continentalité et de la latitude sur la présence de l'ensemble froid sec.

Ensemble B: Chaud Sec

C'est l'expression classique du climat saharien et les nombres obtenus montrent que cet ensemble est essentiellement soumis à l'influence de la continentalité. Les stations côtières sont représentées par des nombres très faibles: Ziguinchor, 0, Dakar, 9, Saint Louis, 55, Port Etienne, 41,7, alors que Fort Gouraud accuse le nombre de 454,2 et Néma 409,7.

Tableau 3

Station	Médiane de l'effort	Angle de la courbe	Ventilation
Port Etienne	VIII—IX	32°30′	+156,0
Fort Gouraud	VIII—IX	30°00′	+118,3
Tididjka	VIII—IX	37°00′	—41,0
Atar	VII—VIII	48°00′	+10,9
Boutilimit	VII—VIII	47°30′	+34,8
Nouakchott	VII—VIII	51°30′	+11,0
Rosso	VI—VII	55°30′	—8,0
Podor	VII—VIII	56°00′	—20,9
Néma	VII	58°00′	+31,8
Akjoujt	VII	57°30′	+47,8
St. Louis	VII—VIII	58°30′	+17,4
Thiès	VII—VIII	57°30′	+3,4
Dakar	VII—VIII	60°00′	+68,5
Matam	VIII	55°30′	—55,5
Diourbel	VI—VII	60°00′	—74,5
Kaolack	VII—VIII	60°30′	—22,9
Linguère	VI—VIII	59°30′	—60,6
Tambacounda	VI—VIII	62°00′	—50,7
Kolda	VI—VII	64°00′	—90,4
Ziguinchor	V—VI	66°00′	+0,9

Le promontoire ouest africain influe les courbes par se continentalité. La salubrité est d'autant plus faible que le nombre est grand et inversement. Du point de vue de la chaleur sèche excédant le seuil que nous avons adopté, les stations sont donc d'autant plus malsaines ou pénibles que nous nous éloignons vers l'Est.

Ensemble C: Chaud Humide

Inversement l'ensemble *C* montre géographiquement une répartition liée à la latitude avec une très forte influence marine au Sénégal. Le minimum se situe donc à Fort Gouraud, le maximum à Ziguinchor comme on devait s'y attendre. Toute la zone côtière est influencée par la masse océanique qui introduit une humidité d'autant plus pénible à supporter que la température est élevée. La région située au delà de la ligne des 300 qui s'étend sur toute la Mauritanie occidentale est remarquable par le fait que l'influence de mousson ressentie au Sénégal est prolongée vers le nord par l'influence océanique des vents de Nord Ouest.

La combinaison des Ensembles B et C

Les deux ensembles *B* et *C* traduisent donc l'effort supporté par l'organisme pour lutter contre la chaleur et contre la déperdition de l'eau, ou au contraire pour assurer au corps une bonne évacuation de cette eau jouant un rôle capital dans le refroidissement de la peau sous forme de sueur. Si nous additionnons ces deux valeurs pour chaque station le nombre obtenu sera caractéristique de l'effort physiologique total annuel. La station idéale devrait avoir zéro pour total.

Ainsi que nous devions nous y attendre la station la moins malsaine est Port Etienne (216), la plus malsaine Néma (667). Entre les deux nous trouvons dans la bande des 400—500: Fort Gouraud, Atar Nouakchott. Dans la bande des 500—600: Ziguinchor, Saint Louis, Thiès, Akjoujt, Tididjka, Matam, Dakar, Diourbel, Rosso, Boutilimit, Kolda. Dans la bande des 600—700: Podor, Kaolak, Linguère, Tamba et Néma. La carte montre la nette influence de la latitude jusque Nouakchott, puis une influence marine et équatoriale dans l'Ouest Sénégalais. Enfin une vaste zone intérieure l'étend sur l'est du Sénégal et le sud Mauritanien où chaleur et humidité s'associent pour demander à l'organisme humain un très grand effort.

Le rapport entre les deux valeurs exprimant les états *B* et *C* nous renseigne donc sur le mode d'effort physiologique demandé. Les valeurs supérieures à ,,1" traduisent un effort de rétention d'eau plus faible que celui de régulation thermique; ce sont des climats relativement favorables aux enfants dont le système nerveux n'est pas encore bien organisé et pour lesquels la loi de surface/poids est un grand handicap en régions sèches. Nous trouvons donc que les stations suivantes sont fatigantes pour les enfants en bas âge: Fort Gouraud, Atar, Tididjka, Matam, Boutilimit, Néma. Viennent ensuite par ordre croissant de salubrité du seul point de vue de l'équilibre hydrique: Rosso et Podor (0,85) Linguère (0,67) Tambacounda (0,68). Dakar avec 0,19, Saint Louis 0,12, et Port Etienne sont sains. Notons que Ziguinchor a un rapport égal à zero mais ceci est contrebalancé par une humidité excessive.

Cette classification valable pour les enfants en bas âge ne l'est plus pour les adultes dont l'activité exige une thermorégulation aisée et le rapport étudié perd sa valeur absolue.

EXPRESSION CUMULÉE

La série de graphiques (Fig. 6) rend compte du facteur temps et de l'évolution des complexes au cours de l'année. Cette dernière commence climatiquement au premier décembre. Les courbes peuvent être analysées d'après leur position par rapport à la ligne de neutralité, d'après leur forme et leur pente générale. Les stations où une partie de l'année permet un relâchement de l'effort montrent une courbe recoupant la neutralité vers le bas, au contraire celles où l'effort est continu se situent entièrement au-dessus. Par ailleurs les courbes sont plus ou moins arquées selon la vitesse de variation d'un mois à l'autre du complexe thermohygrométrique. Plus la courbe est tendue, plus la vitesse est grande et traduit un effort intense d'adaptation à des conditions mouvantes, mais cet effort se trouve réparti au cours de l'année d'une manière assez régulière. Par ailleurs les courbes arquées peuvent comporter des sections particulièrement noscives où la salubrité diminue brusquement. Chaque courbe peut de plus être étudiée d'après l'angle que fait leur corde avec l'axe des abeisses. Plus l'angle est grand et plus l'effort est grand et continu. Enfin la médiane de l'effort annuel se situe pour toutes les stations au même moment dans l'année.

En général plus la courbe est redressée et tendue, plus la médiane est précoce.

CLASSIFICATION DES STATIONS

De toutes les stations étudiées c'est Port Etienne qui évidemment vient en tête en fait se salubrité. Déjà nous avions trouvé pour les indices saisonniers une situation privilégiée (SS: 55, SH: 0). Le complexe froid humide y apparaît, la ventilation y est particulièrement bonne et les deux complexes B et C bien équilibrés. Comme pour toutes les stations littorales; e'est l'effort de réaction au complexe C qui l'emporte ($B/C = 0{,}24$). C'est-à-peine si l'on peut parler ici d'une station tropicale. Plus au nord mais dans une position plus continentale Fort Gouraud a une courbe encore plus inclinée, mais l'équilibre entre les deux ensembles est totalement différent. C'est une station saine mais dangereuse pour les enfants ou les sujets dont le système sympathique supporte mal les valeurs maximales. Si les nuits sont fraîches le milieu de la journée et de la soirée sont très chauds et relativement humides en saison des pluies. De mai à aôut nous rencontrons le complexe endothermique avec risque de coup de chaleur même au repos. Le gros avantage de Fort Gouraud est sa sècheresse qui permet à la fois de supporter la grosse chaleur et de profiter de la ventilation pour des températures inférieures à 36°C.

Il n'en est pas de même de Tididjka où la température est moindre mais l'humidité beaucoup plus forte et la ventilation faible. Nous y avons un rapport B/C égal à 2,32 contre 16,5 à Fort Gouraud par suite d'une invasion humide au cours de la saison des pluies. C'est une station pénible en haute saison où la relaxation nocturne n'est possible que pendant une courte période de l'année, situation agravée par le fait d'une ventilation déficiente tout au cours de l'année et de la journée (ventilation —41 contre +118 à Fort Gouraud). Cependant nous y observons dans les moyennes l'apparition du complexe endothermique entre avril et juin toujours en fin d'après-midi. Ce même complexe apparaît à Atar d'avril à juillet également en fin d'après-midi. Si les hautes saisons sont sensiblement analogues pour les deux stations il n'en est pas de même des saisons sèches, beaucoup plus arides à Tididjka qu'à Atar ce qui explique que le nombre caractéristique passe de 240,7 pour la première station à 348,9 pour la seconde. Le rapport B/C est respectivement de 2,32 et de 1,87.

Boutilimit qui vient ensuite à une amplitude d'humidité plus forte qu'Atar alors que les températures maximales y sont plus faibles, bien que le complexe endothermique apparaîsse encore. La période de relaxation nocturne est réduite à trois mois d'hiver. Le nombre caractéristique est de 306,7 avec une ventilation supérieure à celle d'Atar. Notons qu'entre Tididjka et Atar/Boutilimit la courbe cumulée s'est redressée passant de 37 à 48 °C d'inclination ce qui entraîne un changement total dans le déroulement de l'année biologique. Le rapport B/C est de 1,53 à Boutilimit.

Vient ensuite Nouakchott où l'angle poursuit son mouvement de redressent (51,30 °C), et le nombre caractéristique passe à 358,0. Le rapport B/C s'inverse et devient inférieur à «1». Nous sommes en région maritime et nous approchons du Sénégal, tandisque la ventilation n'excède que de 11 la neutralité. Il n'est plus question de complexe endothermique, mais les tensions de vapeur approchent du type malsain (31,2 mbar).

Notons que jusqu'alors dans toutes les stations observées la période de la journée la plus malsaine est la fin de l'après midi. Avec Rosso nous sommes sur le fleuve Sénégal, le nombre caractéristique passe à 405,4, le complexe B augmentant de 100 unités par rapport à Nouakchott. C'est donc l'humidité chaude qui intervient pour rendre cette station plus malsaine et sous-ventilée (—8). Le rapport B/C est encore inférieur à un (0,85). Ce n'est que l'association température humidité qui intervient car les valeurs séparées sont plus faibles qu'à Nouakchott pour la tension de vapeur, mais plus fortes pour les températures. Il n'est pas douteux que le fleuve soit l'agent principal de ce type de climat, amenant un amoindrissement de l'amplitude journalière et réduisant la période de relaxation.

Podor présente une très grande similitude avec Rosso (nombre: 403,7, angle de courbe 55,30° contre 56° à Rosso) mais la ventilation est encore plus mauvaise (—20,9) ce qui accroit l'effort physiologique en haute saison. Les rapports B/C sont identiques (—0,85). Il peut sembler bizarre de voir apparaître Néma réputé pour son climat malsain et désagréable; mais il s'avère que les courbes sont à 18,00 heures, avec un décalage dans le temps, semblables à celle de Podor en ce qui concerne l'humidité. A 12,00 heures les températures y sont plus élevées avec une tension de vapeur identique; par contre le matin un maximum de saison sèche en Avril vient raccourcir la période de relaxation, qui subsiste à Podor encore à cette époque. La ventilation positive de saison sèche devient insuffisante en haute saison entre 06,00 et 12,00 heures, mais reste toute l'année négative à 18,00 heures. En résumé c'est un climat très pénible parce que l'année s'y déroule sans répit où le complexe endothermique se manifeste durant une grande partie de l'année (mars à juin) au cours de la journée, alors qu'il n'existe qu'à 18,00 heures de mars à mai à Podor. L'angle de la courbe continue a augmenter (58°) mais la ventilation est finalement positive pour l'année entière ((+ 31,8) et le rapport B/C égal à 1,59).

A Akjoujt le complexe endothermique en fin d'après-midi apparait d'avril à août à midi. Le nombre est de 440,2 avec un angle de courbe de 57,30° analogue à celui de Néma. Si les températures de pointe sont plus fortes, la ventilation est meilleure (+47,8) et fort heureusement pas trop intense au moment de l'endothermie. Le rapport B/C est inférieur à un, indiquant une légère influence océanique (0,43).

Vient ensuite Saint Louis (463,2) avec un angle de courbe de 58,30°. Nous n'avons plus ici à faire à des hautes températures mais à de fortes humidités atteignant la limite entre les états fatigants et malsains en haute saison. Bien que Saint Louis soit agréable, bien qu'on y envoie en haute saison les européens de l'intérieur de la Mauritanie, son humidité en fait une station peu recommandée. Certes il n'est plus question de déshydratation pour les enfants en bas âge, mais l'effort physiologique y est cependant intense, la ventilation est positive (+17,4) mais sans excès. Les nuits de saison sèche permettent une bonne relaxation mais il convient d'être prudent quant à la haute saison.

Afin de respecter un ordre géographique, et pour clore cet échantillonnage de stations nous terminerons brièvement sur Thiès dont le nombre est de 435,1 et l'angle de 57,30°. La température il y est remarquablement constante entre 12,00 et 18,00 heures au course de l'année et l'humidité évolue très régulièrement. La ventilation est positive avec +3,4 et le rapport B/C est de 0,28. Il s'agit là d'une station typiquement sénégalaise.

Nous ne nous étendrons pas plus longtemps sur les caractéristiques des stations cet article étant essentiellement destiné à montrer les avantages de la méthode et quels renseignements nous sommes susceptibles d'en tirer pour une meilleure connaissance des conditions climatiques règnantes dans l'ouest africain sénégalo-mauritanien du point de vue de l'homme.

Basée sur un nombre relativement restreint d'éléments climatiques et de données statistiques, ne faisant appel qu'à des calculs simples et à des représentations graphiques aisées, nous estimons que ce procédé est susceptible d'être appliqué à une prospection extensive des régions tropicales et l'auteur procède actuellement à une étude d'ensemble.

BIBLIOGRAPHIE

1. J. P. Nicolas, Essais sur deux nouveaux indices climatiques saisonniers pour la zone intertropicale. *Bull. I.F.A.N. Dakar* **18,** No. 3, sér. A, 653—664 (1956). Les climats africains en biogéographie humaine. *Ibid.* **20,** No. $^1/_2$, sér. B, 7—67 (1958); *Bioclimatologie Humaine de Saint Louis du Sénégal (Essai de Méthodologie Bioclimatologique).* Mémoire I.F.A.N. Dakar No. 57 (1959).
2. Leroy, *L'indice Climatique Pulmonaire.* Doc. I.F.A.N. Dakar Mincroft.
3. D. H. Ash et L. Hill, *The Katathermometer. Studies of Body heat and Efficiency,* London (1923).

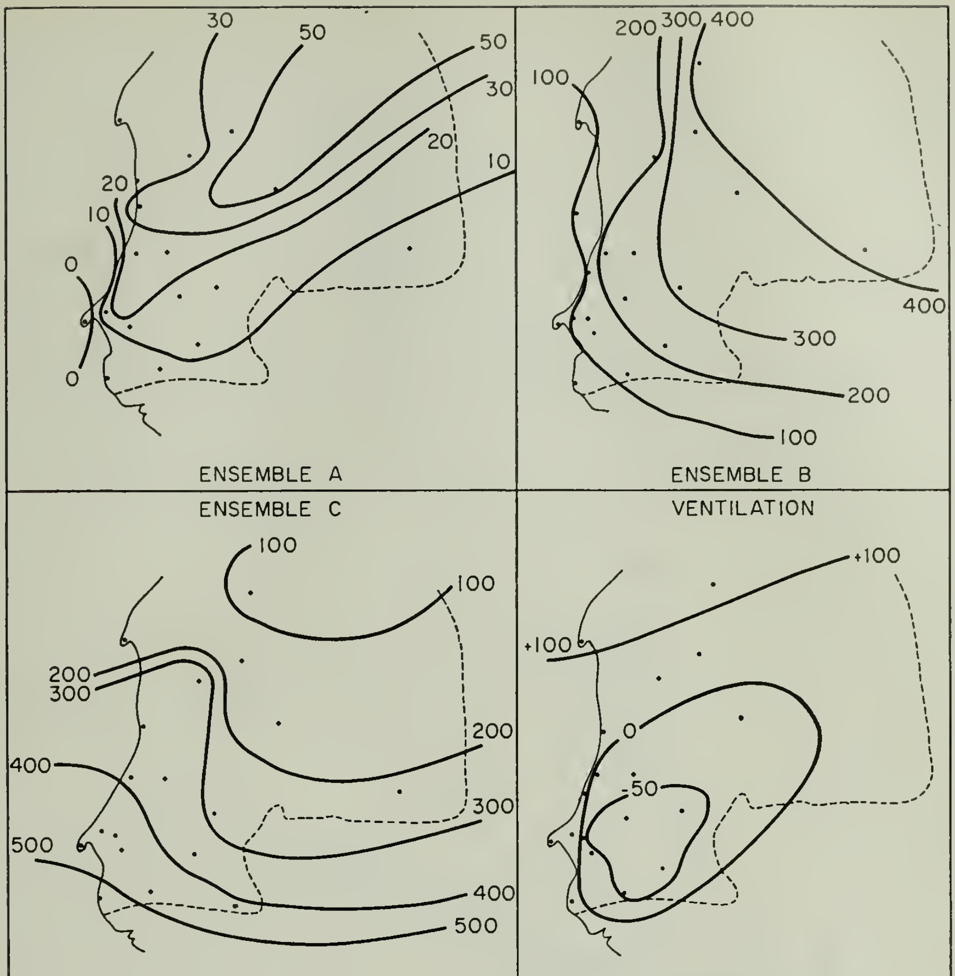

30
50
50
30
20
10
20
10
0
0
ENSEMBLE A
200
300
400
100
400
300
200
100
ENSEMBLE B
ENSEMBLE C
100
100
200
300
200
300
400
500
400
500
VENTILATION
+100
+100
0
-50

Fig. 1.

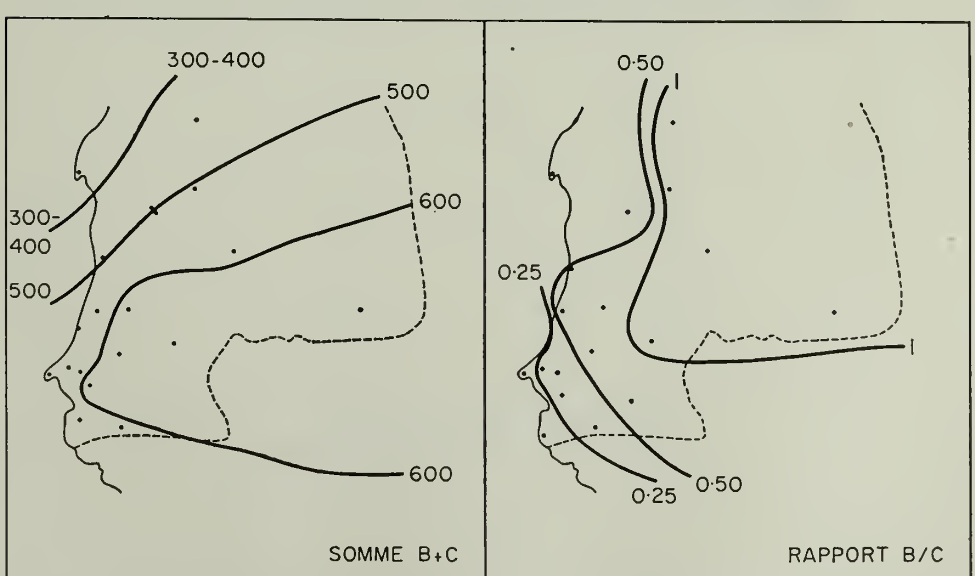
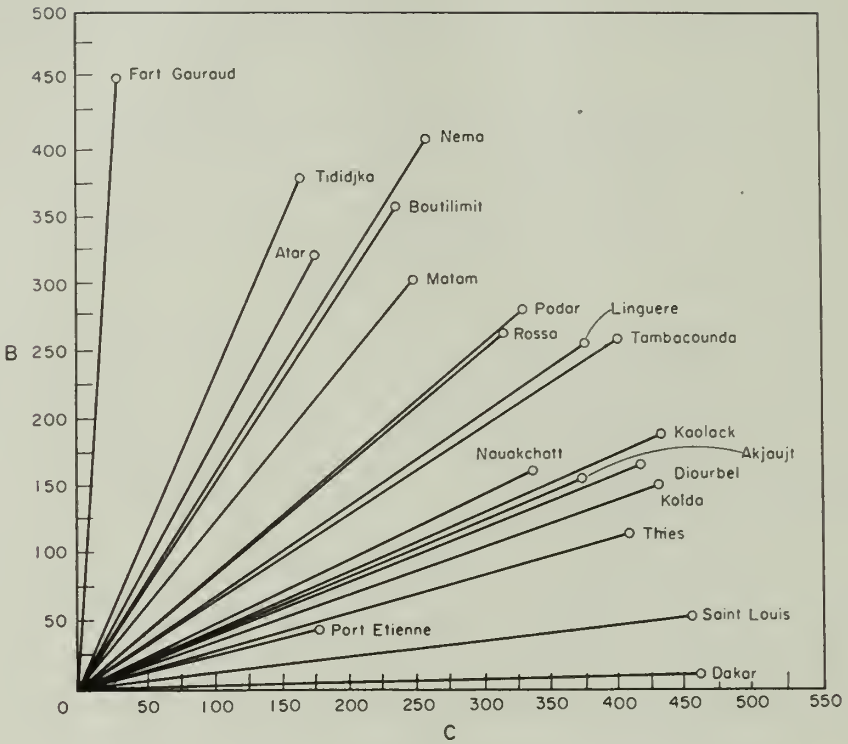

300-400
500
600
300-
400
500
600
SOMME B+C
0·50
1
0·25
1
0·25
0·50
RAPPORT B/C

Fig. 2.



500
450
400
350
300
B 250
200
150
100
50
0
50
100
150
200
250
300
350
400
450
500
550
C
Fort Gouraud
Nema
Tididjka
Boutilimit
Atar
Matam
Podor
Rosso
Linguere
Tambacounda
Kaolack
Nouakchott
Akjoujt
Diourbel
Kolda
Thies
Saint Louis
Port Etienne
Dakar

FIG. 3.

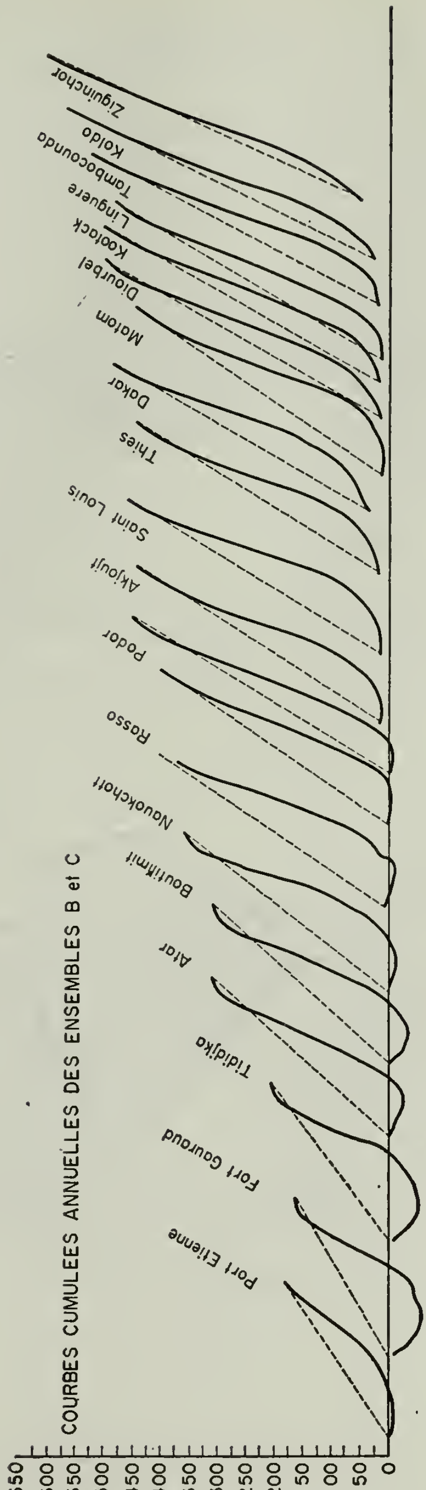

COURBES CUMULEES ANNUELLES DES ENSEMBLES B et C
Ziguinchor
Kolda
Tambacounda
Linguere
Kaolack
Diourbel
Matam
Dakar
Thies
Saint Louis
Akjoujt
Podor
Rosso
Nouakchott
Boutilimit
Atar
Tidjikja
Fort Gouraud
Port Etienne
650 600 550 500 450 400 350 300 250 200 150 100 50 0

Fig. 4.

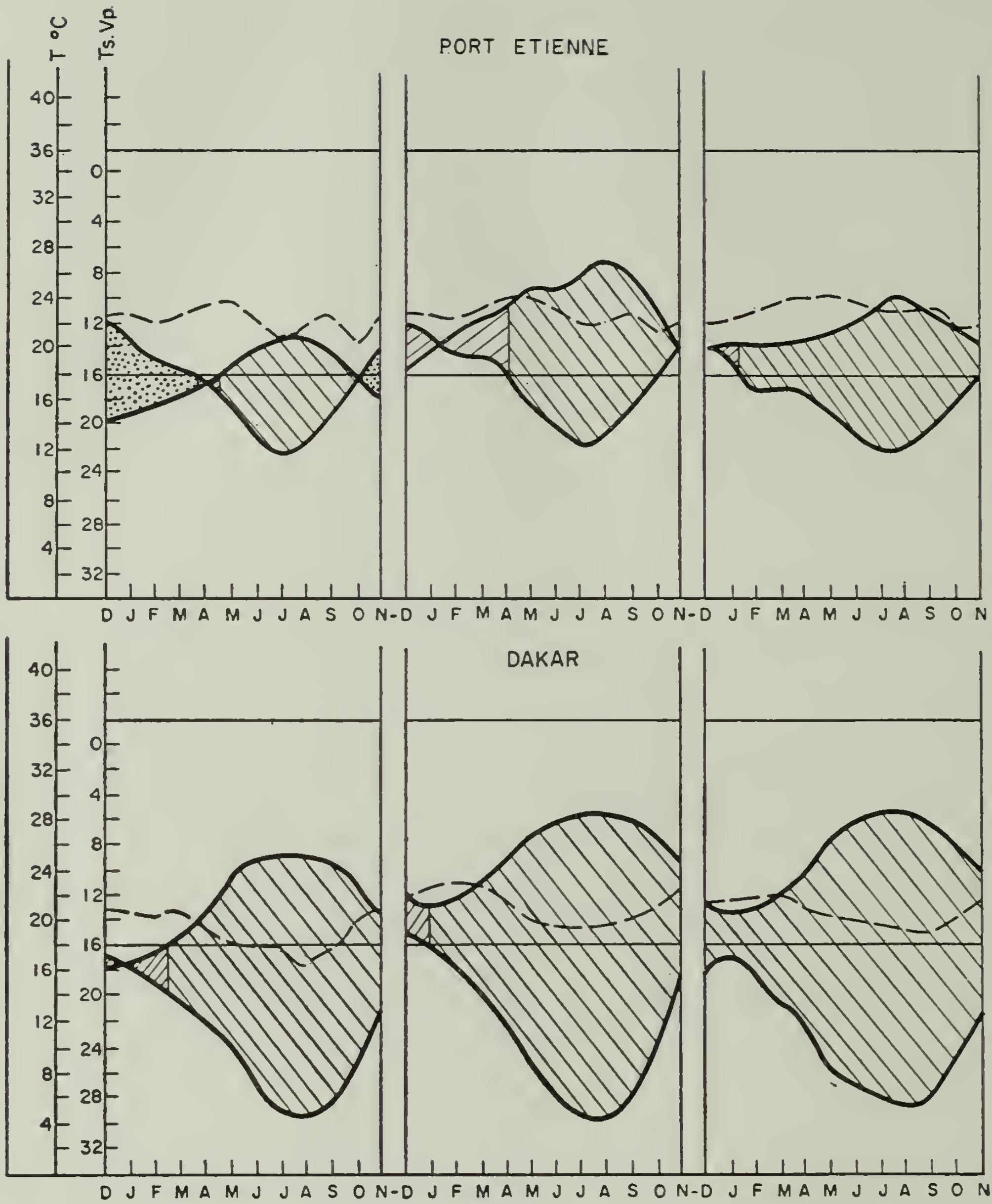

T °C
Ts.Vp
PORT ETIENNE
DAKAR
40
36
32
28
24
20
16
12
8
4
0
4
8
12
16
20
24
28
32
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N

Fig. 5.

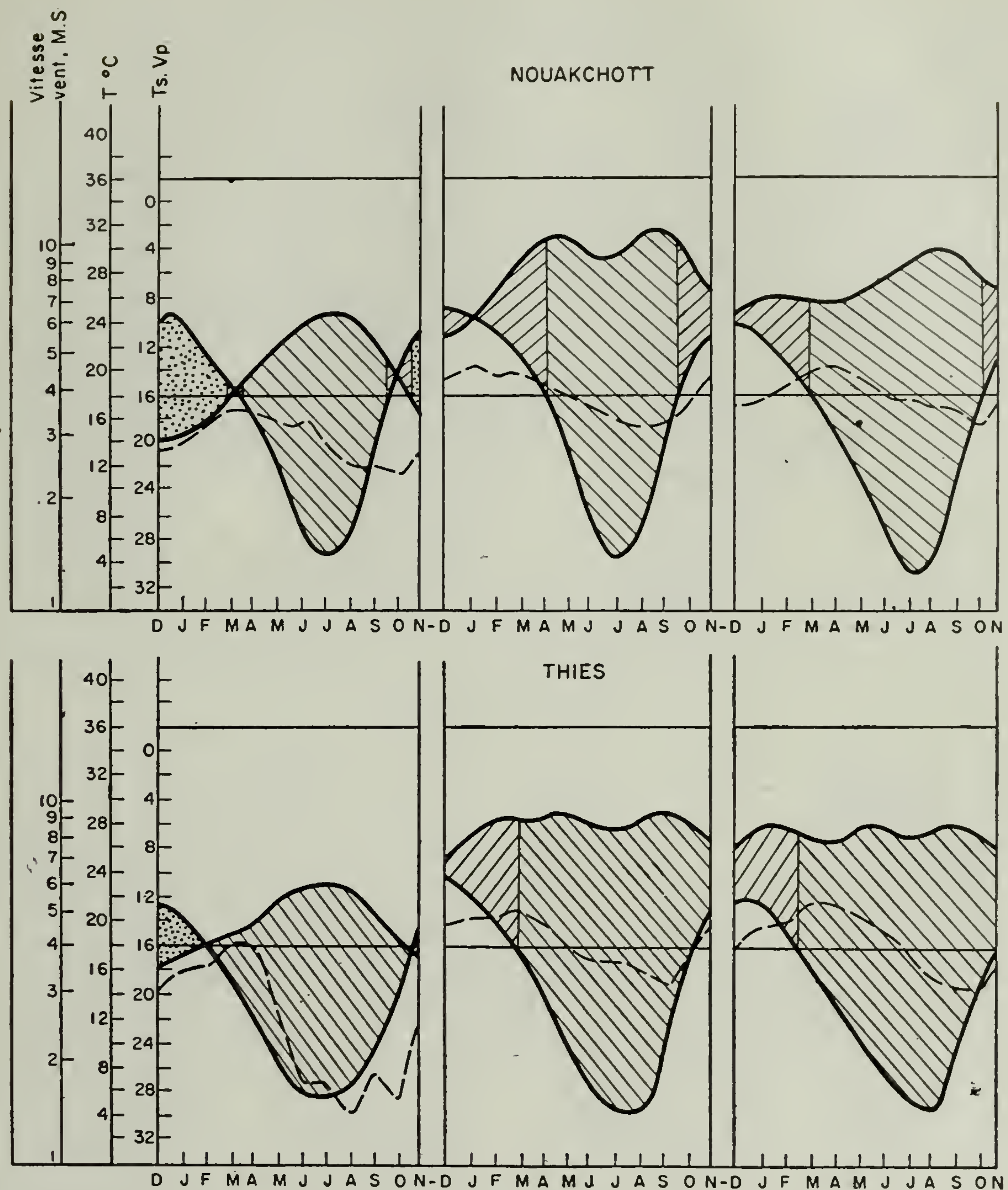

Vitesse vent, M.S
T °C
Ts. Vp
NOUAKCHOTT
THIES
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N

Fig. 6.

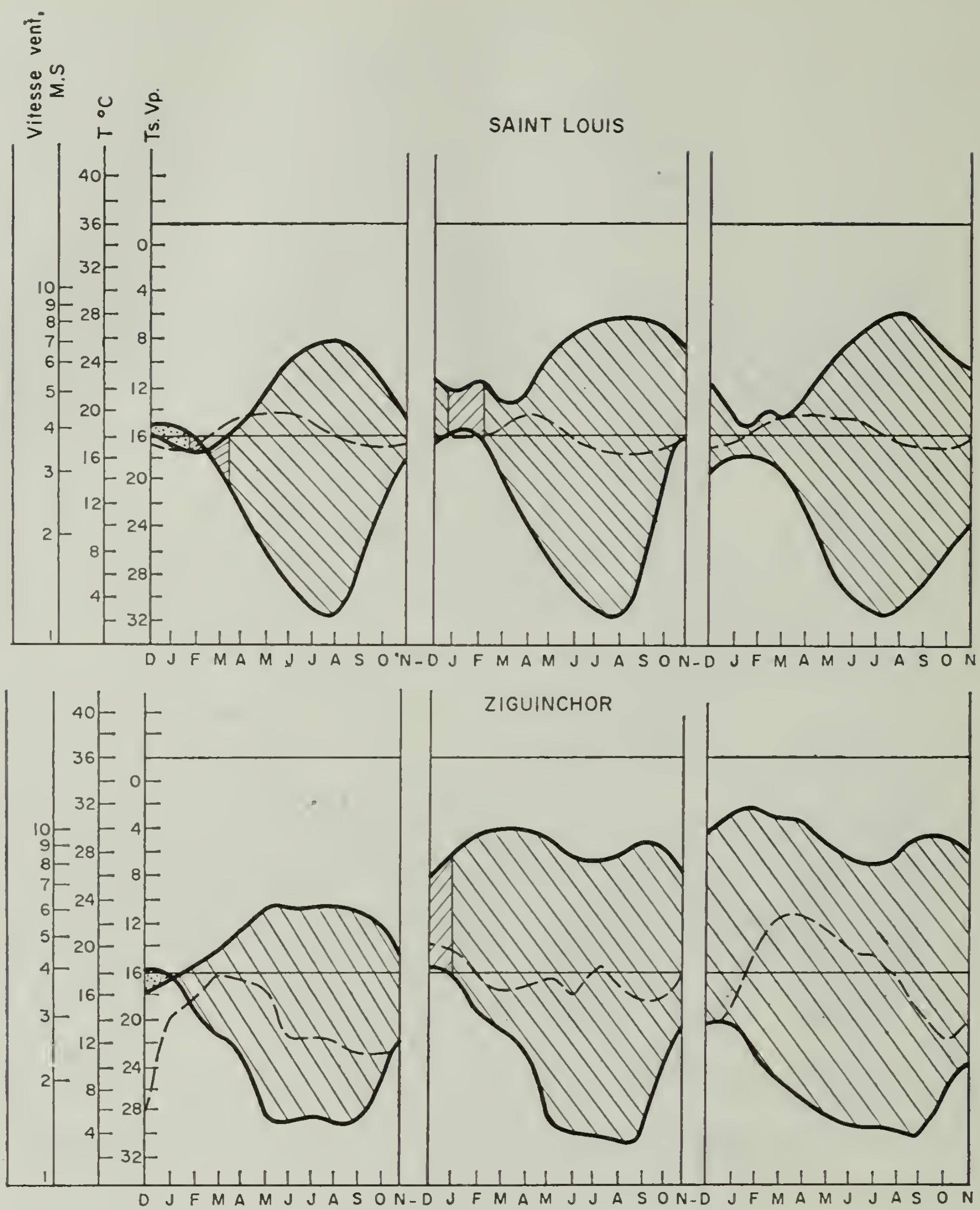

Vitesse vent, M.S
T °C
Ts. Vp.
SAINT LOUIS
ZIGUINCHOR
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N

FIG. 7.

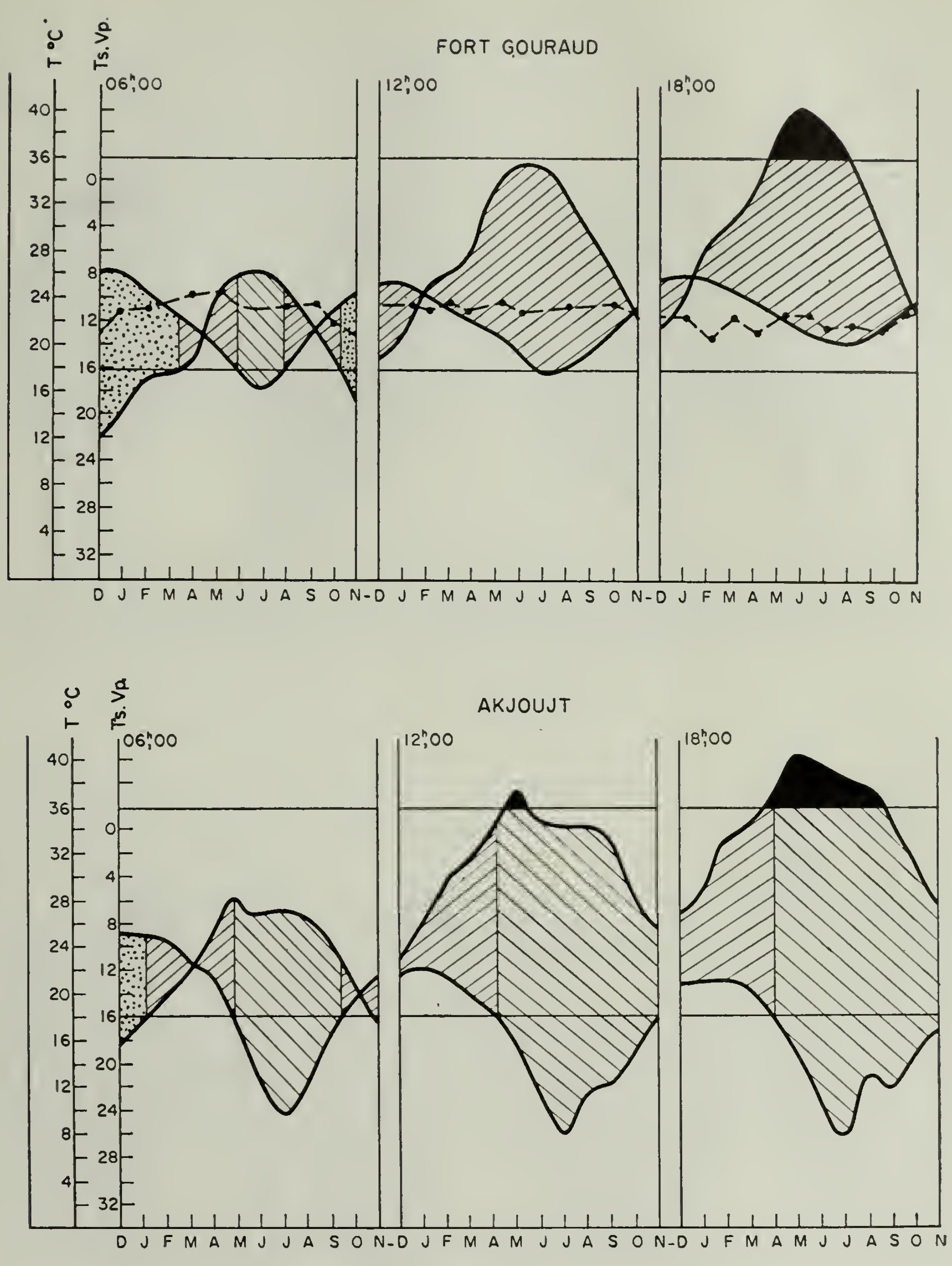
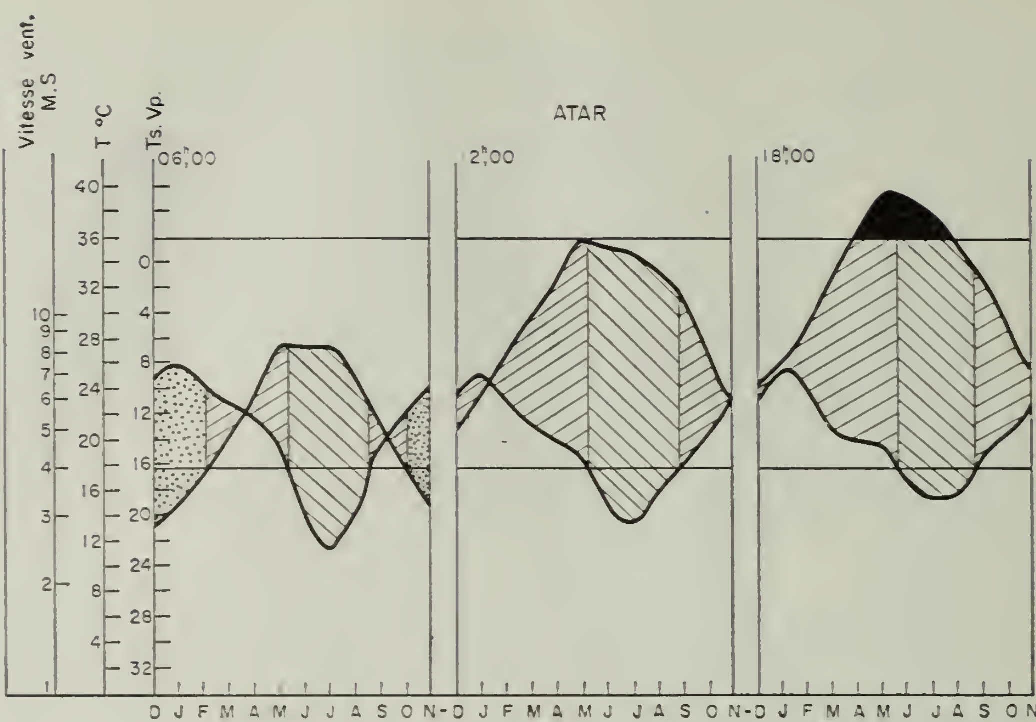

FORT GOURAUD
T °C
Ts. Vp.
06h00
12h00
18h00
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N
AKJOUJT
T °C
Ts. Vp.
06h00
12h00
18h00
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N

FIG. 8.


Vitesse vent. M.S
T °C
Ts. Vp.
ATAR
06h00
12h00
18h00
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N

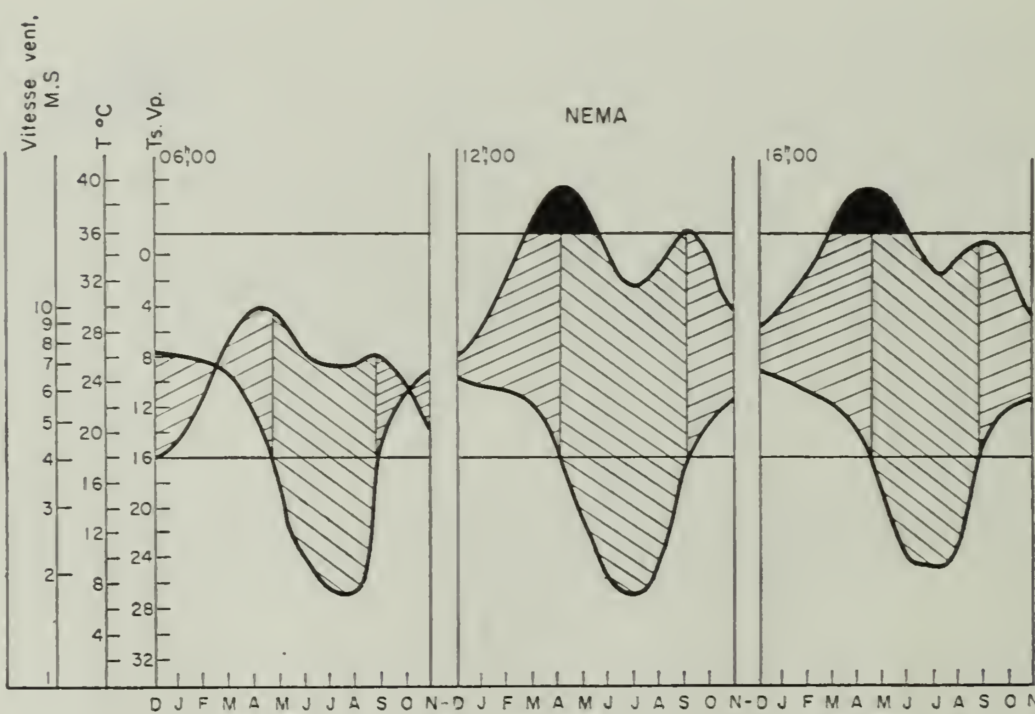
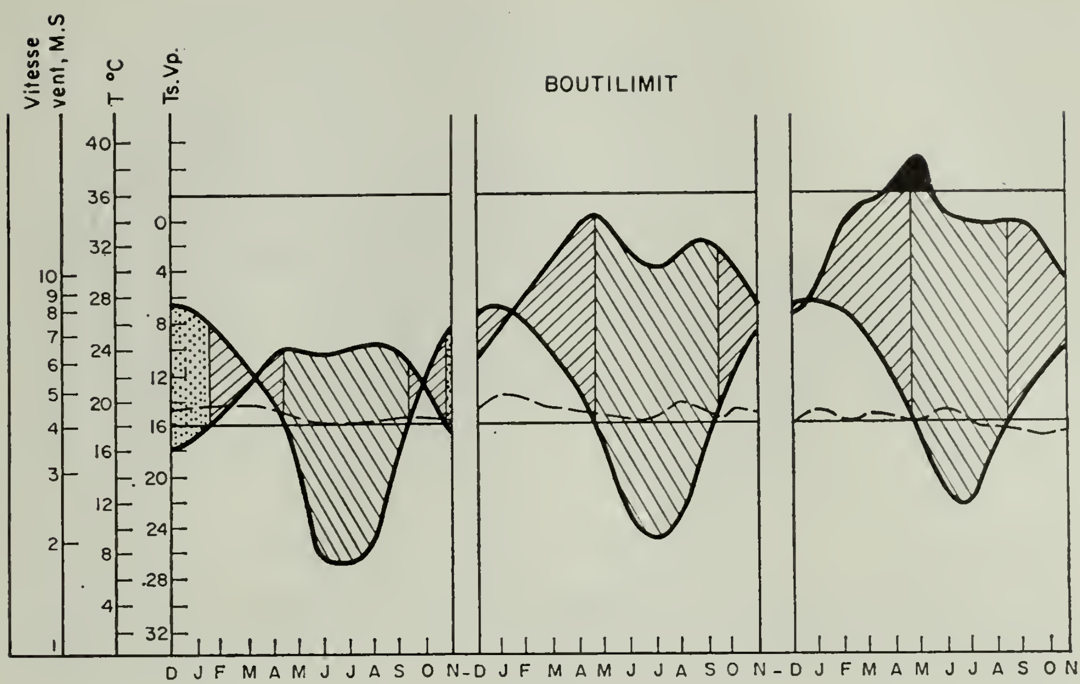

Vitesse vent. M.S
T °C
Ts. Vp.
NEMA
06h00
12h00
16h00
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N

Fig. 9.


BOUTILIMIT
Vitesse vent, M.S
T °C
Ts. Vp.
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N

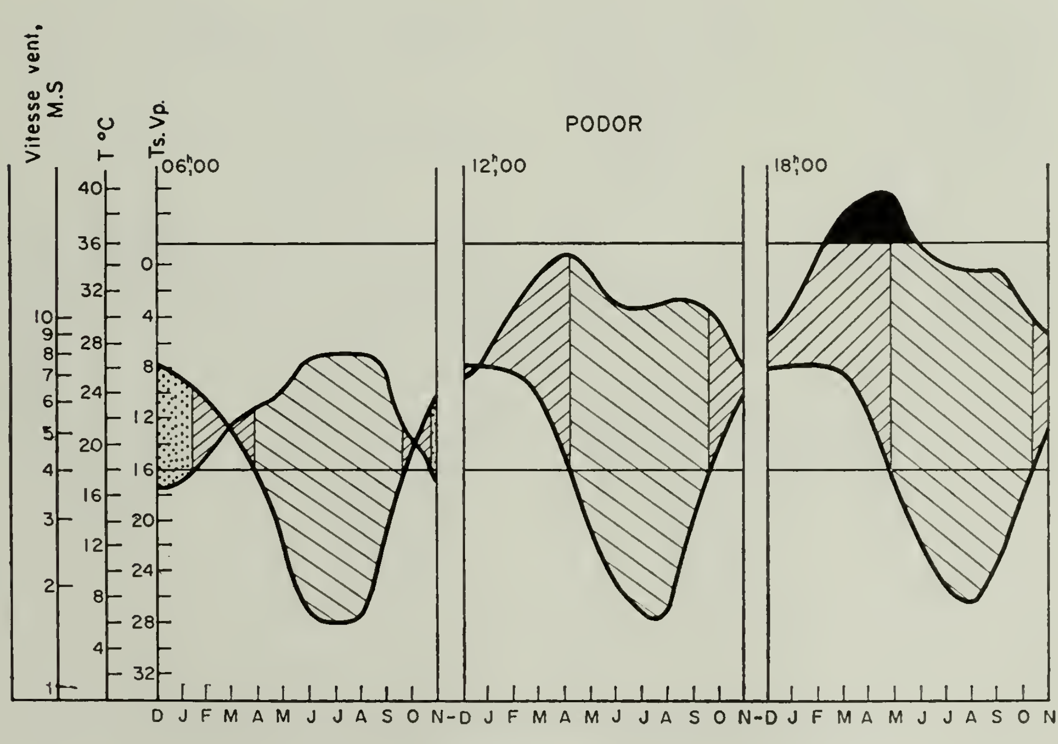

PODOR
Vitesse vent, M.S
T °C
Ts. Vp.
06h00
12h00
18h00
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N

FIG. 10.

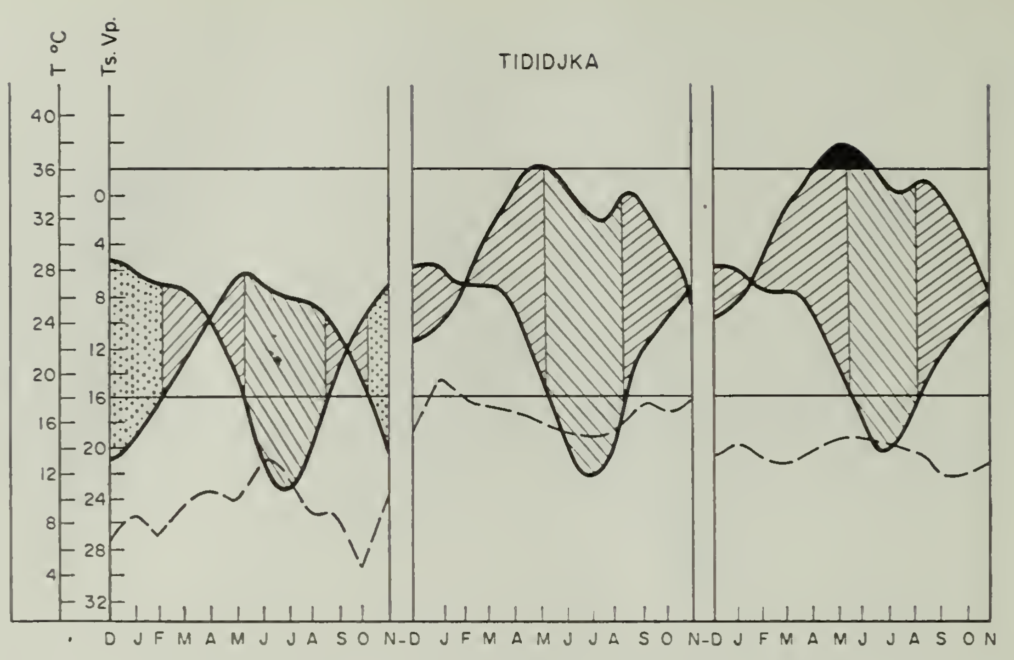

TIDIDJKA
T °C
Ts. Vp.
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N

FIG. 11.

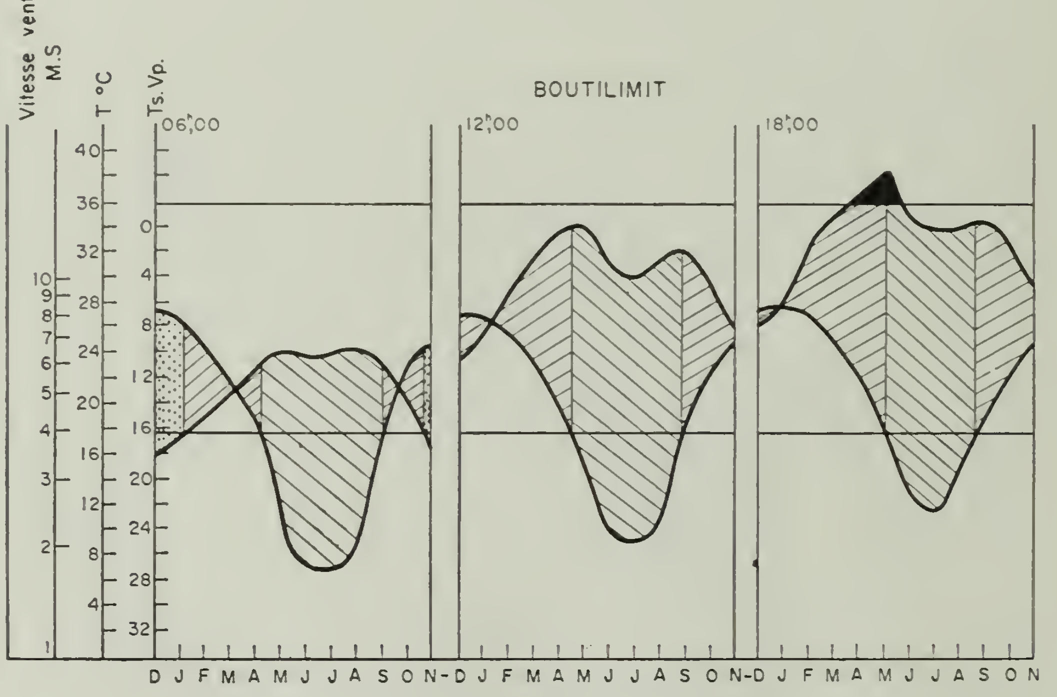
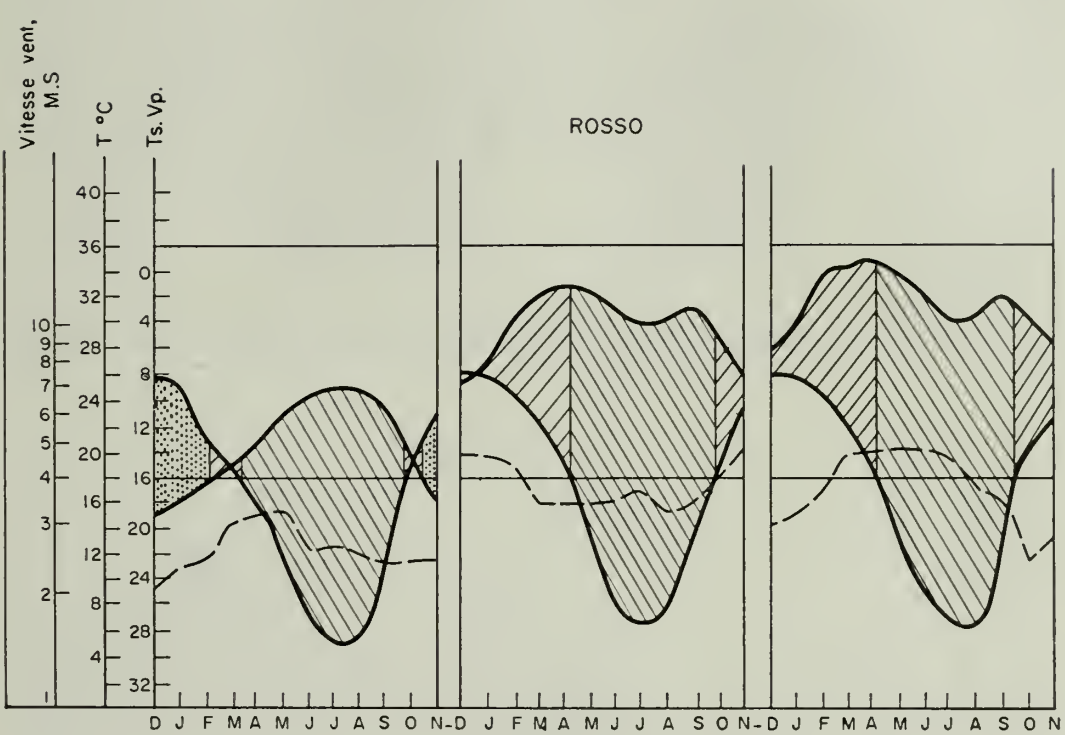

BOUTILIMIT
Vitesse vent, M.S
T °C
Ts. Vp.
06,00
12,00
18,00
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N

FIG. 12.



Vitesse vent, M.S
T °C
Ts. Vp.
ROSSO
40
36
32
28
24
20
16
12
8
4
0
4
8
12
16
20
24
28
32
10
9
8
7
6
5
4
3
2
1
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N

Fig. 13.

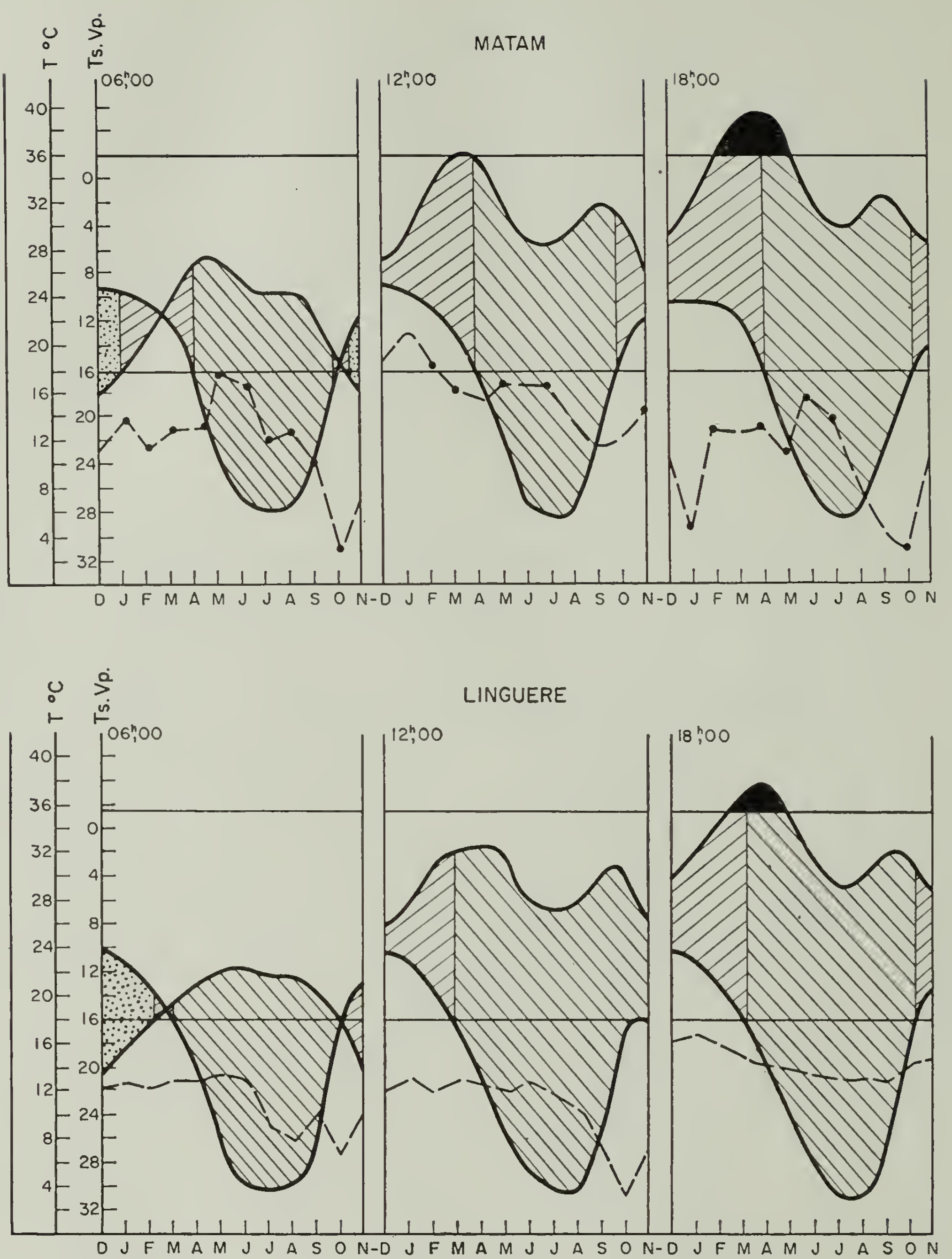


Fig. 14.

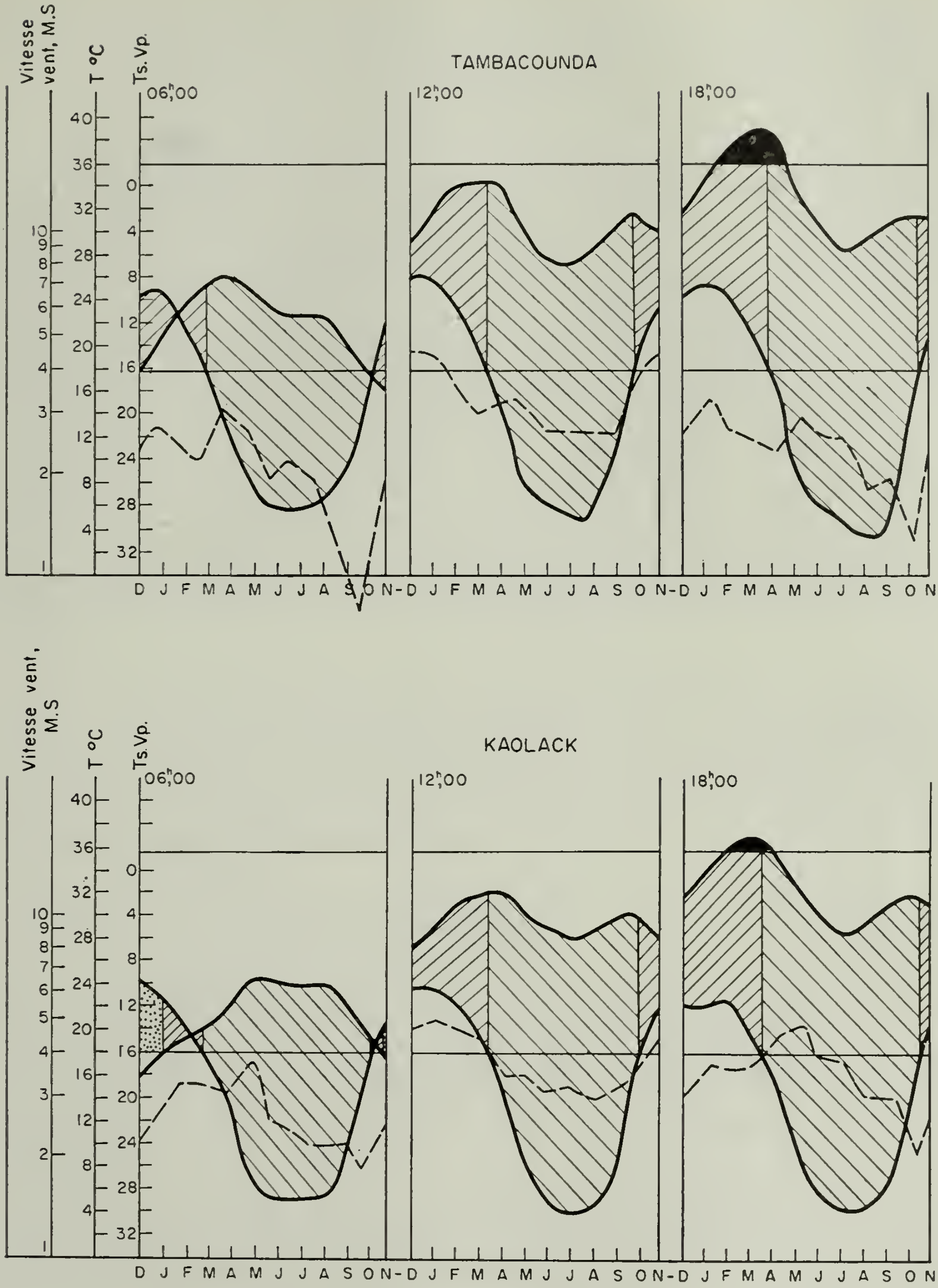
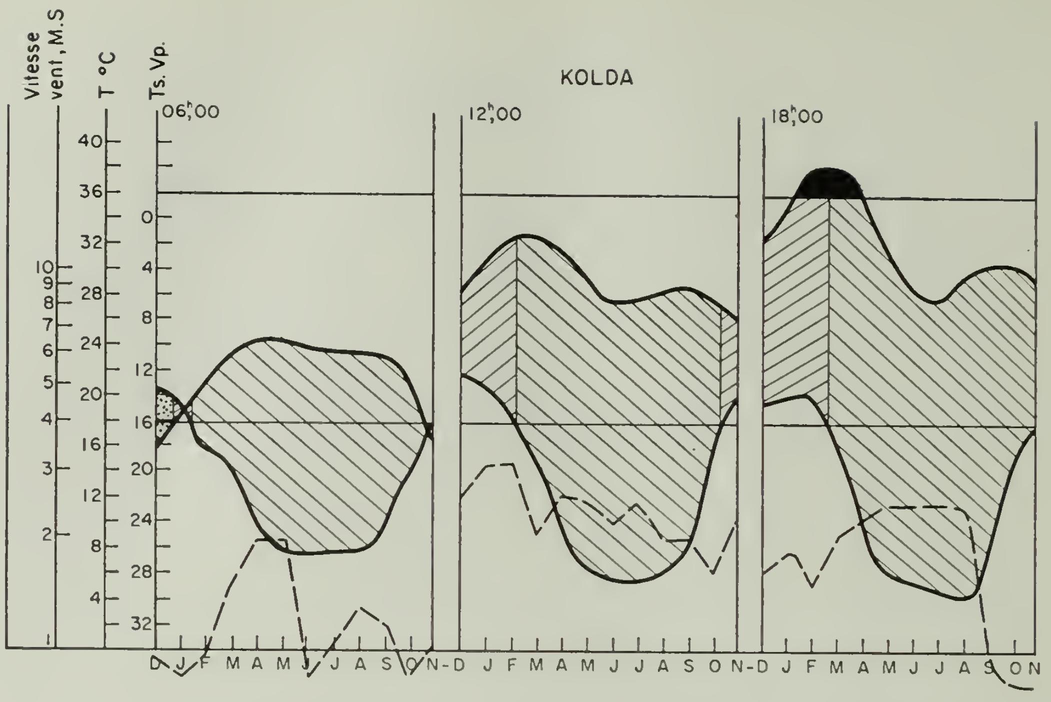

TAMBACOUNDA
Vitesse vent, M.S
T °C
Ts. Vp.
06h00
12h00
18h00
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N
KAOLACK
Vitesse vent, M.S
T °C
Ts. Vp.
06h00
12h00
18h00
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N

Fig. 15.


KOLDA
Vitesse vent, M.S
T °C
Ts. Vp.
06h00
12h00
18h00
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N

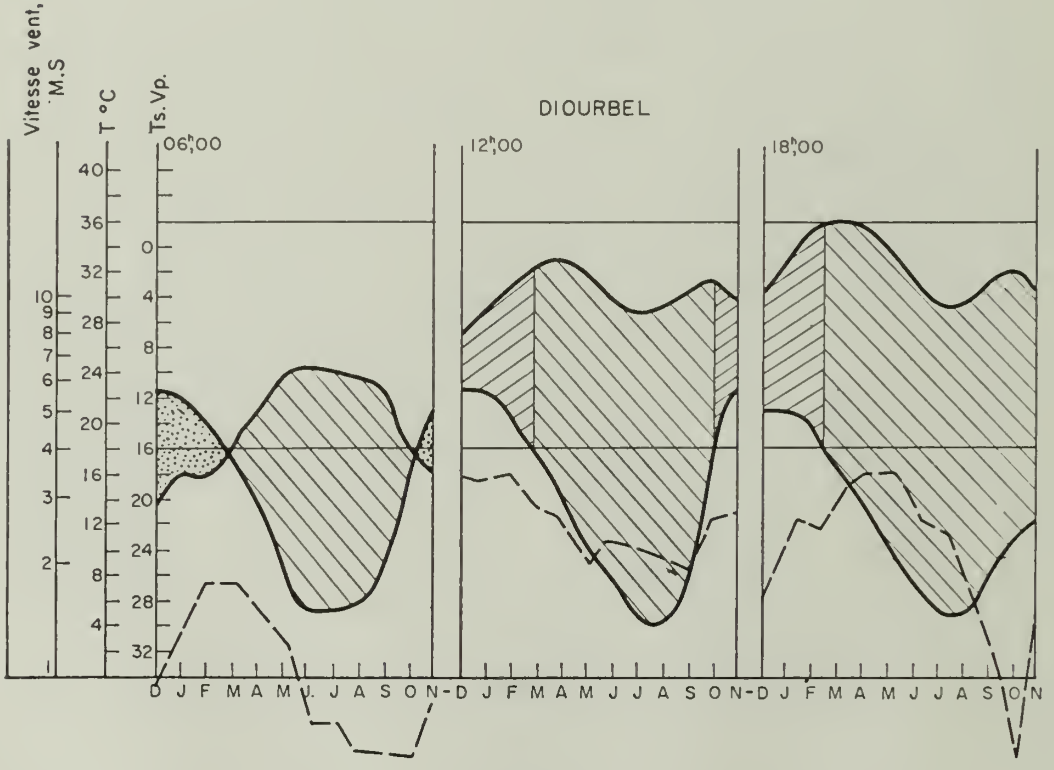

DIOURBEL
Vitesse vent, M.S
T °C
Ts. Vp.
06h00
12h00
18h00
D J F M A M J J A S O N-D J F M A M J J A S O N-D J F M A M J J A S O N

Fig. 16.

WORLD POPULATION AND MAXIMUM CROP YIELD

T. L. NOFFSINGER
Dr. T. L. Noffsinger, Land Study Bureau, Univ. of Hawaii 14, Honolulu, Hawaii

Abstract—At the present level of conversion of solar energy to dry-matter energy of the cereal plants (1 per cent), it was shown that crops such as wheat, barley or rice grown on existing arable land and under an average sunshine regime can produce a protein-carbohydrate balanced diet sufficient for more than fifteen times the present world population.

Résumé—Se basant sur le niveau actuel de conversion de l'énergie solaire en énergie de matière sèche des plantes céréales, l'auteur a montré que des récoltes de graminacées, telles que le blé, l'orge ou le riz qui ont poussé sur une terre arable effective, sous un régime d'insolation moyenne, peuvent donner une nourriture équilibrée de protéine-carbohydrade, suffisante pour une population 15 fois plus forte que la population mondiale actuelle.

Auszug—Bei dem gegenwärtigen Stand der Umwandlungsmöglichkeit von Sonnenenergie in Trockenmasse-Energie der Getreidepflanzen (1%) wurde aufgezeigt, daß Getreidearten, wie z. B. Weizen, Gerste oder Reis, die auf dem vorhandenen Ackerland gebaut werden, bei einer durchschnittlichen Sonneneinwirkung eine in Bezug auf Protein und Kohlehydrate ausgewogene Ernährung für mehr als das 15-fache der gegenwärtig vorhandenen Weltbevölkerung gewährleisten.

I. INTRODUCTION

Authorities on population growth and statistics, including the economic staff of the United Nations, estimate that the world population is increasing at the rate of 100,000 per day and that by 2000 A.D. the world population will be four to five billion (4). The present world acreage of arable land is estimated at 3.84 billion acres (7) with the possibility that an additional 1.3 billion could be made available as the pressure demands.

The present distribution of world population (3 billion) and arable land (3.84 billion) is equivalent to 1.25 acres per capita. Although more than one acre of arable land (on an average) is available for the production of food and fiber for each person of the world, Thirring (7) estimated that two-thirds of the total population or two billion people suffer from squalor, hunger and deficiency diseases.

On the basis of the aforementioned estimate it would seem that the Malthusian Principle, that population is kept under control by famine, pestilence and war applies over a large part of the earth. Although this condition seems to prevail, the picture warrants further examination. What yield should be expected from an acre of land in terms of food energy and finally, what is the approximate world population that could be adequately fed ($3000\ \mathrm{cal\,day^{-1}\ person^{-1}}$) by optimum use of the present acreage of arable land?

II. YIELD LAWS

Law of Diminishing Increments

Yield of total dry matter of any crop is dependent on the proper balance of all the factors of plant growth which include heat, light, water, oxygen, carbon dioxide, nitrogen, phosphorous, potassium, calcium and all the other mineral nutrients. Work by Mills in the 1820's resulted in what is now known as the "law of diminishing returns". Mitscherlich (5) reporting on the results of 27,000 field tests using graded levels of N, P_2O_5 and K_2O developed the "law of diminishing increments" which states that increments in yield corresponding to successive equal increments of nutrients applied to a crop are terms of a decreasing geometric series. That is, as additional equal increments of a growth factor are applied, the yield produced by the second increment is to the first yield as the third is to the second. For example, if 100 lb of phosphate fertilizer increased the yield of a crop 20 bushels per acre, a second 100 lb would increase the yield by 10 bushels above the first, the third by 5 bushels above the second, etc. Mitscherlich, over a period of 45 years using various plant nutrients for a large number of crops, showed that the change in yield per unit increase in a limiting nutrient was described by the differential equation:

$$\frac{\mathrm{d}y}{\mathrm{d}x} = (A - y)\,c \tag{1}$$

where $\mathrm{d}y$ is the increase in yield, $\mathrm{d}x$ is the increase in the limiting growth factor, A is the maximum possible yield, and c is a factor representing the yield effect of the growth factor x. In Mitscherlich's work the value for c was found to be 0.122 for nitrogen (N), 0.40 for potash (K_2O) and 0.60 for phosphate (P_2O_5). Upon integration equation (1) becomes,

$$\log\,(A - y) = \log A - cx \tag{2}$$

Using equation (2), Baule (1) replaced A by the number 100 which represents 100 per cent of the maximum yield. His units of plant growth factors were chosen as the amount which would be sufficient to produce one-half or 50 per cent of the maximum possible yield and equation (2) became,

$$\log\,(100 - y) = \log 100 - kx \tag{3}$$

where k incorporates the constant c of the Mitscherlich equation. From equation (3) Baule developed a set of units, now called *baules*, which is of such magnitude that 1 baule increases the yield to 50 per cent of the maximum possible production, 2 baules increases the yield to 75 per cent of the maximum, 3 baules to $87\frac{1}{2}$ per cent of the maximum so that 10 baules produced a yield which approximates the absolute maximum.

In a recent paper, Willcox (8) has shown that the value k in equation (3) is 0.30103, and that 1 baule unit is obtained by dividing 0.30103 by Mitscherlich c value for each element. For nitrogen, 1 baule is equivalent to 223 lb per acre, 1 baule of potash (K_2O) equals 76 lb per acre, 1 baule phosphate (P_2O_5) equals 45 lb per acre and 1 baule of magnesium (MgO) equals 1.4 lb per acre, etc. Then according to his line of reasoning 10 baules of each growth factor would produce the maximum possible yield for any crop. In other words, for "full development of any kind of crop, whether a high yielder or a low yielder, the soil must contain 10 baules of each plant nutrient". Ten baules will require 2230 lb nitrogen (N); 450 lb phosphate (P_2O_5); 760 lb potash (K_2O); 14 lb magnesium (MgO); 4.5 lb of sulphur (S); etc.

Inverse Yield—Nitrogen Law

From the amount of growth factors required for maximum production, Willcox then presents his "inverse yield—nitrogen law" which specifies that "of two or more different kinds of plants growing simultaneously on the same normal soil,

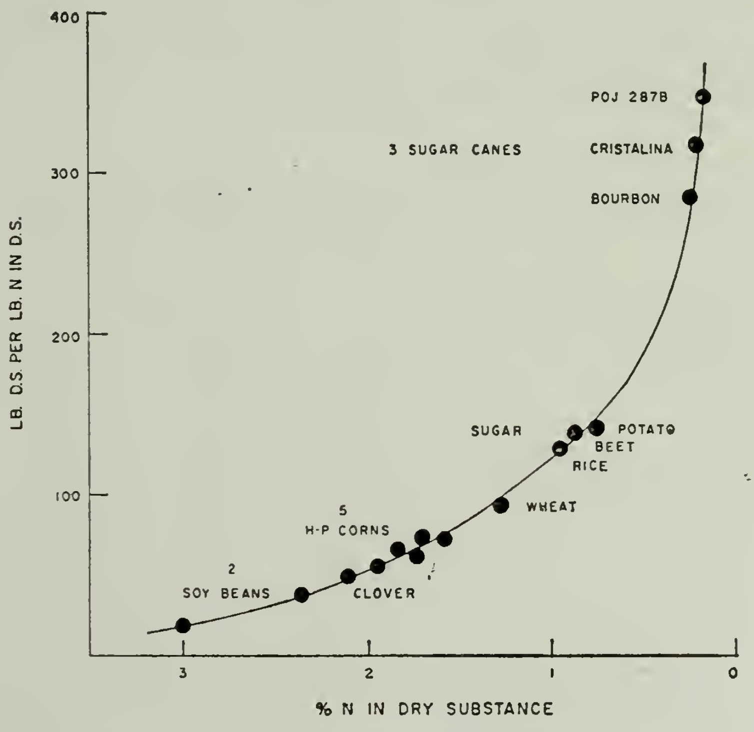


FIG. 1. The "two-way ladder of quantity of plant life" (O. W. Willcox)

the crop with the smallest percentage of nitrogen in the dry substance will be found giving the largest acre-yield". That is, yield of dry matter is always inversely proportional to percentage of nitrogen in the crop. According to him, after nearly 30 years in pursuit of the correlation, he has yet to find a sustainable exception.

Of the 10 baules or 2230 lb of nitrogen in the soil for a maximum yield crop, the portion which can be taken up by the plant is given by the equation

$$Xp = 2 - \log(100 - y)/0.122 \tag{4}$$

where 0.122 is Mitscherlich constant for nitrogen. Upon converting from metric units to English units of pounds per acre, Xp turns out to be 318 lb. In other words, any kind of plants growing in soil containing 10 baules (2230 lb) nitrogen can ultimately absorb only 318 lb of nitrogen or 318×6.25 or approximately 2000 lb of protein per acre per crop cycle. Now according to the *inverse yield—nitrogen law*, maximum energy yield for a crop with 10 baules of nutrients in the soil is that crop which has the smallest percentage of nitrogen in the dry matter. Fig. 1 shows Willcox's "two-way ladder of quantity of plant life," which shows that crops with high nitrogen content produce relatively small amount of total dry matter in comparison to those of low nitrogen content.

From his calculation the maximum possible dry-matter (DM) yield for various crops is given by the formal

$$DM = \frac{318}{n} \tag{5}$$

where n is the percentage of nitrogen in the dry matter of the crop. Table 1 gives the maximum theoretical yields for selected crops.

*Table 1. Theoretical Yield Per Acre**

Crop	Nitrogen (%)	Protein (%)	D.M. yield per acre
Soybeans	2.6	16.25	12,230
Alfalfa⁻	2.2	13.75	20,000
Corn	1.2	7.50	26,500
Rice	0.92	5.75	34.565
Sugar cane (cristalina)	0.356	2.23	44,662
Sugar cane (POJ2878)	0.285	1.78	111,579
X	0.160	1.00	198,750
Y	0.100	0.62	318,000
Z	0.080	0.50	397,500
W	0.05	0.31	636,000

* From Willcox (8).
⁻ Hawaii data.

Since plant life is dependent upon the function of the cells whose nuclei are composed of protein substance, a reduction of the nitrogen content to zero is impossible. Sugar cane variety POJ2878 has a protein content of 1.78 per cent or 0.285 per cent N and a dry-matter yield potential of 111.579 lb. Theoretically, if a crop could be found whose protein content was 0.31 per cent or 0.05 per cent nitrogen, the potential dry-matter yield would be 636,000 lb. This would appear to be about the maximum theoretical yield value and probably well beyond any obtainable value. Without accepting or rejecting the inverse yield-nitrogen law, it is interesting to see how this maximum theoretical value compares to the theoretical value obtained from the absorption of solar radiation by plants.

III. RELATIONSHIP OF YIELD TO INCIDENT SOLAR ENERGY

Storage of Incident Solar Energy

The ultimate source of energy for sustaining life is the radiant energy of the sun. Energy from the sun is absorbed by chlorophyll of plants and is used to build carbohydrate molecules from carbon dioxide and water. The plant material produced by the process of photosynthesis is the source of all animal food. The chemical elements and energy involved in photosynthesis are shown in the following simplified chemical equation:

$$CO_2 + H_2O + \text{chlorophyll} + \text{light}\ (122.2\ C) = H_2O + O_2 + \text{chlorophyll} \qquad (6)$$

Approaching the problem of ultimate yield from the radiation viewpoint, it can be shown that probably not more than from 20 to 25 per cent of the incident

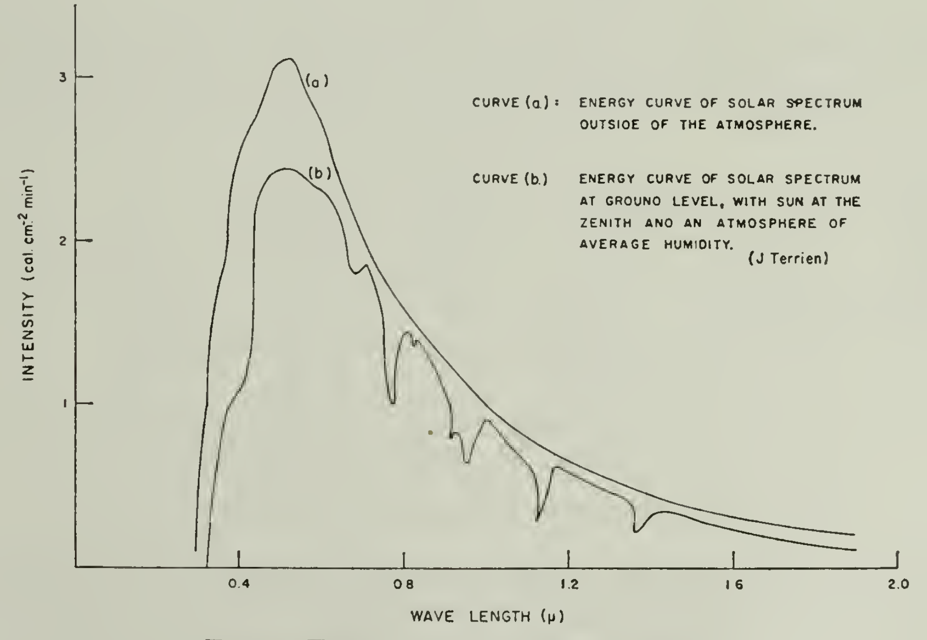


Fig. 2. Energy curve of solar spectrum

solar radiation could be stored as energy in plants. Chlorophyll, which is necessary for photosynthesis, absorbs only visible light (from 0.4μ to $0.75\ \mu$ or from 4000 Å to 7500 Å) while approximately 50 per cent of the solar energy consists of infrared radiation (see Fig. 2).

Since the plant consists of material other than chlorophyll, part of the absorbed short wave energy is absorbed by portions of the plant material which are not capable of carrying on photosynthesis. The width of the absorption band of chlorophyll shows that probably not more than one-third (1/3) of the solar energy can be absorbed by it (6). Respiration is the continuous process through which the cells of the plant obtain energy for growth and the other life processes. Energy for the process is obtained from part of the stored energy which has been provided by photosynthesis. According to Boysen—Jensen (2) the energy loss through respiration in light-tolerant mustard plant is about 27 per cent of the total yield. For trees he found approximately the same value. Using a figure of 30 per cent as the proportion of the photosynthetic energy and field crops used in respiration then,

$$(33\%)\,(100 - 30) = 23.1 \tag{7}$$

or 23 per cent of incident solar energy could theoretically be stored as chemical energy in the dry matter of the plant.

Table 2 shows the nitrogen and protein content of some selected crops, their maximum dry-matter yield as predicted by Willcox, the total energy yield and the percent of solar radiation stored. Solar radiation values are for Hawaii, whose annual solar radiation amounts to about 440 ly per day of 160 kcal/cm^2 per year.

Table 2. Yield Per Acre

Crop	Nitrogen (%)	Protein (%)	Dry-matter yield (lb)	Energy (kcal$\times 10^{-7}$)	% of solar radiation
Soybeans	2.6	16.25	12,230	2.7762	0.44
Alfalfa	2.2	13.75	20,000	4.5400	0.70
Corn	1.2	7.50	26,500	6.0155	0.93
Rice	0.92	5.75	34,560	7.8463	1.2
Sugar cane (cristalina)	0.356	2.23	44,660	10.1383	1.5
Sugar cane (POJ2878)	0.285	1.78	111,580	25.3284	3.9
X	0.160	1.00	198,750	45.1163	7.0
Y	0.100	0.62	318,000	72.1860	11.2
Z	0.080	0.50	397,500	90.2325	14.0
W	0.050	0.31	636,000	144.3720	22.0

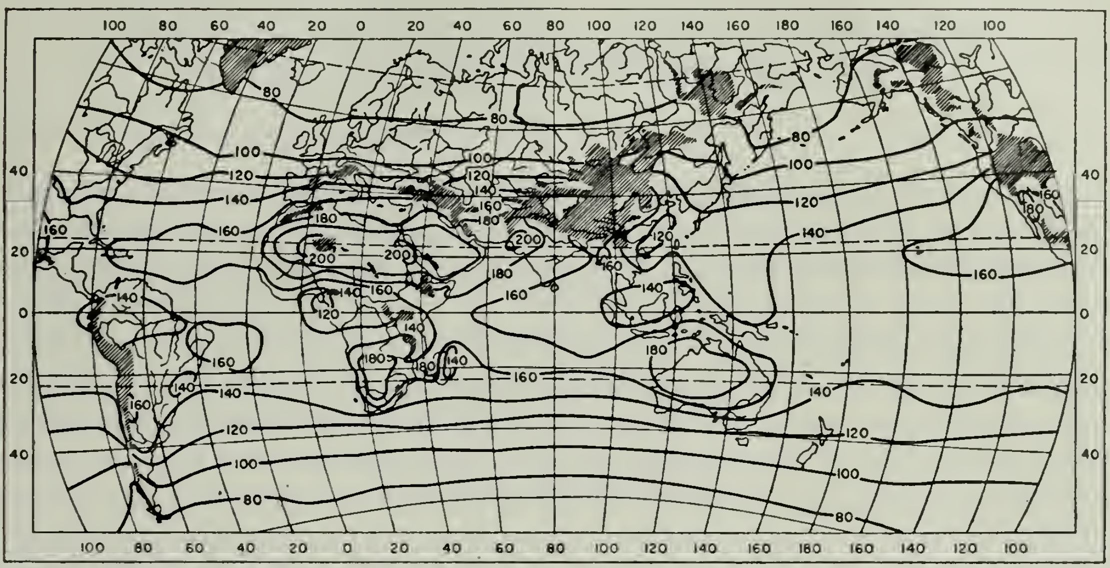
The inverse yield-nitrogen law predicts for a theoretical crop whose nitrogen content is 0.050 per cent a maximum dry-matter yield of 636,000 lb per acre. Assuming approximately five kcal/g of dry matter, the total energy per acre would be $144.4 \times \times 10^7$ kcal which is 22 per cent of the average annual solar radiation at the latitude of the State of Hawaii (Table 2, columns 5 and 6). In other words, Willcox's inverse yield—nitrogen law predicts a theoretical maximum yield for a crop composed of 0.31 per cent protein which agrees rather closely with that predicted from solar radiation data (equation 7).

Yield as a Fixed Proportion of Incident Solar Radiation

Fig. 3 shows the global distribution of average annual total radiation kcal/cm². The 80 kcal line represents 323.7 kcal/acre per year.

$$(80\ \text{kcal/cm}^{-1})\ (4.047 \times 10^7\ \text{cm}^2\ \text{per acre}) = \\ = 323.7 \times 10^7\ \text{kcal/acre per year} \tag{8}$$

A crop grown in the sunshine regime represented by the 80 kcal line which converted



ANNUAL VALUES (kg-cal./cm.²/year)

FIG. 3. Total radiation (M. I. Budyko)

1 per cent of the insolation to chemical energy would provide 3.24×10^7 kcal/acre per year.

$$(323.7 \times 10^7)\ (0.01) = 3.24 \times 10^7\ \text{kcal/acre per year} \tag{9}$$

Assuming a cereal is grown which consists of approximately 35 per cent edible grain then 1.134×10^7 kcal/acre per year edible grain would be produced.

$$(3.24 \times 10^7)\ (0.35) = 1.134 \times 10^7\ \text{kcal/acre per year} \tag{10}$$

This amount is sufficient energy for ten people receiving a ration of 3000 kcal daily for 1 year.

$$\frac{1.134 \times 10^7}{3000 \times 365} = \frac{1.134 \times 10^7}{1.095 \times 10^6} = 10.4\ \text{persons per acre} \tag{11}$$

In an area along the line receiving 200 kcal/cm² per year food energy, assuming again a one percent conversion would be produced equivalent to 8.094×10^7 kcal/acre per year.

$$(200)\,(4.047 \times 10^7) = 8.094 \times 10^7 \text{ kcal/year per acre} \tag{12}$$

$$(8.094 \times 10^7)\,(0.35) = 2.833 \times 10^7 \tag{13}$$

$$\frac{2.833 \times 10^7}{3000 \times 365} = 25.87 \tag{14}$$

Since the greater portion of the land surface of the globe is in a sunshine regime of from 80 kcal/cm^2 per year to 160 kcal/cm^2 per year, assume an average figure of 120 kcal/cm^2 per year.

$$\frac{(120 \text{ kcal/year per cm}^2)\,(4.047 \times 10^7 \text{ cm}^2 \text{ per acre})\,(1.0\%)\,(35\%)}{(3000 \text{ kcal person per day})\,(365 \text{ days per year})} =$$

$$= 15.5 \text{ people per acre} \tag{15}$$

Equation (15) shows that an acre of cereal grain storing 1 per cent of the incident solar energy as plant energy in the dry matter of which 35 per cent is edible grain would provide sufficient energy to feed fifteen people for 1 year. This value is almost exactly the value found by the inverse yield—nitrogen law as proposed by Willcox.

On the basis of solar radiation and also on the basis of the Willcox inverse yield—nitrogen law, a diet balanced in relation to carbohydrate and protein can be produced from a single cereal crop which will provide food for fifteen people per acre per year. Using a mean value of fifteen people per acre, since both food and fiber are required for subsistence assuming one-fourth of the arable land is required for fiber products and three-fourths for food production, then $15 \times 0.75 = 11$ people per acre could be fed and clothed from 1 per cent of the incident solar energy from the sun over the approximate 4 billion acres of arable land. Four billion $\times\ 11 = 44$ billion people could be adequately fed and clothed from a cereal and fiber type of agriculture. This value for world population is about ten times the predicted world population for 2000 A.D. and about fifteen times the present world population. If cellulose from wood and other inedible plant products were used for production of synthetic fiber so that all arable land could be used to its capacity for food production,

$$4 \text{ billion} \times 15 = 60 \text{ billion} \tag{16}$$

people could be adequately fed from the present arable land of the world.

IV. DIET FROM A SINGLE CEREAL GRAIN

Rice, barley and other cereals under existing cultural techniques can convert 1 per cent or more of the incident solar energy to dry-matter energy of which approximately 35 per cent is edible grain. This cereal food is near the recommended proportion of protein to carbohydrates which is 1 : 11 (7, 9). Recommendations for an adequate diet is one containing 3000 kcal of energy in which is contained 70 g of protein (9).

Using the value of 4 kcal/g of protein,

$$4 \times 70 = 280 \text{ kcal from protein} \tag{17}$$

$$\frac{280 \text{ kcal}}{3000 \text{ kcal}} = 9.33\% \text{ protein} \tag{18}$$

$$\frac{9.33}{6.25} = 1.50\% \text{ N} \tag{19}$$

The maximum acre yield of a single cereal providing a balanced diet is, according to Willcox's inverse yield—nitrogen law,

$$\frac{312}{1.50\%} = 21{,}200 \text{ lb} \tag{20}$$

of which 35 per cent is edible

$$21{,}200 \times 0.35 = 7420 \text{ lb edible grain} \tag{21}$$

$$\frac{(7420 \text{ lb/acre per year})\ (454 \text{ g/lb})\ (5 \text{ kcal/g})}{(3000 \text{ kcal/person per day})\ (365 \text{ days/year})} = 15.4 \text{ persons/acre per year} \tag{22}$$

The predicted value of 15.4 people per acre per year for a cereal crop whose dry matter is 9.3 per cent protein is in agreement with the value predicted from the 1 per cent solar energy level (see equation 15).

V. OTHER FOOD SOURCES

To this point food production estimates have been made on the basis of existing crops using already known cultural practices. Food from the ocean in the form of both plant and animal life have not been considered in these estimates, neither has the possibility of production of high protein foods by the action of yeast on carbonaceous materials such as wood, waste from wood pulping industry, and vegetable waste such as corn stalks, cereal straw and sugar cane bagasse. In addition to these possibilities with cheap energy for converting sea water to fresh water, the desert areas of the world which are potentially high yielders of food energy because of available solar radiation could be turned into high producing arable land.

Since the total food energy produced in any region or area in an optimum nutritional environment is limited by the efficiency with which solar energy is transferred or converted to food energy, the problem of plant breeders, plant physiologists and agronomists is to breed, select and grow plants which store maximum food energy under the appropriate sunshine regime. It will not be sufficient to develop crops that tolerate both high temperature and large amounts of incident solar radiation but yield only amounts of energy comparable to crops of lower sunshine areas or tolerate low temperature and small amounts of solar energy with extremely low yields. For maximum food energy, production crops must be developed that produce a maximum of food energy; i.e. make maximum conversion of solar energy to food energy in *each* solar energy regime.

VI. SUMMARY

Examining the concept of maximum theoretical dry-matter (energy) yield from the viewpoint of (a) Willcox's inverse yield-nitrogen law, and (b) on the basis of incident solar energy and the absorption spectra of chlorophyll, it was found that approximately 20 per cent (see equation (7) and Table 2, column (6) of the incident solar energy is the maximum theoretical energy in the dry-matter yield.

Although two-thirds of the world population now suffers from squalor, hunger and deficiency diseases, it does not follow that the conditions of the Malthusian Principle prevail and that as the world population increases more and more people are doomed to starvation. Using farming methods already well-known, 1 per cent of the incident solar energy can be converted by cereals to stored plant energy of which 35 per cent is edible grain. Crops such as sugar cane can convert up to 4 per cent of the incident solar energy to dry-matter in the plant and theoretically plants may eventually be developed which can convert up to 15—20 per cent.

The problem of hunger and deficiency diseases is one of inefficiency in the use of available resources rather than one of unavailability of arable land for sufficient food production. Optimum use of available arable land to grow crops converting 1 per cent of the solar energy to dry-matter energy in the plant could adequately provide food and fiber for more than fifteen times the present world population.

REFERENCES

1. Baule B., *Landw. Jahrb.* **51**, 363—85 (1918).
2. Boysen-Jensen P., *Growth Hormones in Plants,* McGraw-Hill, New York (1936).
3. Harrow B., *Textbook of Biochemistry,* W. B. Saunders, Philadelphia and London (1946).
4. Luck J. M., *Science* **128**, 3333 (1958).
5. Mitscherlich E. A., *Landw. Jahrb.* **38**, 537—52 (1909).
6. Terrien J., G. Truffaut and J. Carlos, *Light, Vegetation and Chlorophyll.* Philosophical Library (1957).
7. Thirring H., *Energy for Man.* Indiana University Press (1959).
8. Willcox O. W., Footnote to Freedom from want. *J. Agric. & Food Chem.* **7**, 12 (1959).
9. Willcox O. W., *Soil Sci.* **79**, 467—73 (1955).

HUMAN BIOCLIMATOLOGY

BRONCHIAL ASTHMA

DER KURVERLAUF BEI ASTHMA BRONCHIALE IM KINDESALTER WÄHREND VERSCHIEDENER JAHRESZEITEN AN DER NORDSEE

W. MENGER

Dr. W. Menger, Seehospitz "Kaiserin Friedrich", Benekestrasse, Norderney, Deutschland

Abstract—In the course of 490 climatic health cures of children from 1 up to 15 years of age at the North Sea in 1959 as few complaints occurred in spring and autumn as occurred in summer. In winter we were occasionally able to record an increased occurrence of slight difficulty of breathing than during the other seasons; with younger children this was more marked than with older ones.

Résumé—Dans 490 cures curatif-climatiques des enfants du 1er au 15e ans en 1959 au mer du Nord se présentaient au printemps et autumme tout aussi peu incommodités comme à l'été. A l'hiver étaient occasionnellement à noter des étouffements légers un peu plus souvent comme dans les autres saisons, chez les enfants plus jeunes plus prononcé que chez les enfants plus âgés.

Auszug—Bei 490 heilklimatischen Kuren des Jahres 1959 an der Nordsee bei Kindern vom 1. bis 15. Lebensjahr traten im Frühjahr und Herbst ebenso wenig Beschwerden auf wie im Sommer. Im Winter waren gelegentlich leichte Atembeschwerden etwas häufiger zu verzeichnen als in den anderen Jahreszeiten, bei jüngeren Kindern ausgeprägter als bei älteren.

Innerhalb des Fragenkomplexes Wetter, Jahreszeit und Asthma soll über den Verlauf von heilklimatischen Kuren während der verschiedenen Jahreszeiten berichtet werden. Es handelt sich um Beobachtungen, die in der Kinderheilstätte Seehospitz "Kaiserin Friedrich" auf der Nordseeinsel Norderney angestellt und jetzt nach dem Hollerith-Verfahren ausgewertet wurden. Diese Erhebungen umfassen zunächst einen Jahrgang und werden fortgesetzt.

Die klimatherapeutische Behandlung wird ganzjährig bei vollbelegtem Hause durchgeführt. Die Dauer des Aufenthaltes richtet sich in erster Linie nach dem Befund und liegt durchschnittlich bei 3 Monaten. Die Beurteilung des Verlaufes innerhalb der verschiedenen Jahreszeiten wird dadurch erschwert, daß der Anteil der an Asthma erkrankten Kinder innerhalb der Gesamtbelegung wechselt, ebenso ist die Aufnahmezahl während der einzelnen Monate und die Verteilung auf die einzelnen Altersjahrgänge unterschiedlich.

Von den 1703 Kindern, die im Jahre 1959 aus der Heilstättenbehandlung entlassen wurden, waren 490 wegen eines Asthma bronchiale nach Norderney geschickt worden.

Eine Differenzierung nach den Erscheinungsformen ergibt folgendes Bild:

(1) Asthmoide Bronchitis bei Kleinkindern, keine Deformierung des Thorax, gelegentliche Atembehinderung, 46.

(2) Asthmoide Bronchitis bei Kleinkindern mit Atemnot und anhaltend spastischem Auskultationsbefund, 42.

(3) Spastische Bronchitis bei Kindern ohne Atemnot, 180.

(4) Asthma bronchiale ohne Deformierung des Thorax, 134.

(5) Asthma bronchiale mit häufigen typischen Anfällen, 40.

(6) Asthma bronchiale mit Thorax piriformis oder faßförmigem Thorax, 43.

(7) Asthma bronchiale mit starkem Emphysem, 5.

Bei 118 von diesen 490 Kindern lag außerdem eine Kombination mit konstitutionellem Ekzem vor.

Da die Kenntnis der klimatherapeutischen Möglichkeiten noch nicht ausreichend verbreitet ist, soll an Hand unserer Unterlagen gezeigt werden, daß an der Nordsee auch die Frühjahrs- und Herbstkuren sehr erfolgreich sind, vielfach wirken sie sogar günstiger als Sommerkuren. Oft ist auch der Winter sehr geeignet. Es können vorläufig nur Angaben über den Verlauf der Kur gemacht werden, doch haben wir bereits katamnestische Erhebungen eingeleitet, um zu erfahren, wie der Erfolg der Kur nach Rückkehr an den Heimatort im Ablauf eines Jahres gewesen ist.

Einen Überblick über den Kurverlauf bei allen Kindern gibt die folgende Tabelle. Die Kalendermonate wurden dabei so nach Jahreszeiten zusammen gefaßt, daß jeweils der größte Teil der Kurzeit in eine nach klimatologischen Gesichtspunkten begrenzte Jahreszeit fällt. Der Jahreszeit und der herrschenden Witterung während der ersten Zeit der Akklimatisation kommt die größte Bedeutung zu.

Asthma bronchiale geordnet nach Monat der Aufnahme und Verlauf:

	Frühjahr (II+III+IV)	Sommer (V+VI+ +VII)	Herbst (VIII+IX+) +X)	Winter (XI+XII+I	Ganze Jahr
Nie asthmatische Beschwerden	72 (58%)	66 (64%)	78 (57%)	42 (33%)	258 (52%)
Nur ein- oder zweimal leichte asthmatische Beschwerden	28 (22%)	21 (20%)	33 (24%)	55 (44%)	137 (28%)
Mehrfach leichte asthmatische Beschwerden	15 (12%)	10 (10%)	16 (12%)	26 (21%)	67 (14%)
Starke oder häufige asthmatische Beschwerden	10 (8%)	6 (6%)	9 (7%)	3 (2%)	28 (6%)
	125 (100%)	103 (100%)	136 (100%)	126 (100%)	490 (100%)

Die günstigsten Verläufe wiesen im Jahre 1959 die Kuren auf, die im Juli und August begannen, und zwar traten bei 80% bzw. 74% der Kinder niemals asthmatische Beschwerden auf. Am ungünstigsten schnitten der November mit 33% und der Dezember mit 24% ab.

Es war aber nicht anzunehmen, daß die Aussichten auf einen beschwerdefreien Verlauf in allen Altersstufen gleich sein würden. Die Auswertung war deshalb auch nach einzelnen Jahrgängen vorgenommen worden. Um die Ergebnisse übersichtlicher zu gestalten, wurden jeweils einige Altersjahrgänge zusammengefaßt. Außerdem ermöglichen nur relative Zahlen einen Vergleich, da die Anzahl der Kinder in den Altersgruppen und Jahreszeiten unterschiedlich groß ist. Von den 490 asthmakranken Kindern hatten innerhalb der einzelnen Altersstufen während der 4 Jahreszeiten einen von asthmatischen Beschwerden freien Verlauf:

	Frühjahr	Sommer	Herbst	Winter	Kinder
1.— 3. Lebensjahr	17%	7%	44%	9%	73
4.— 6. Lebensjahr	57%	61%	59%	31%	159
7.—10. Lebensjahr	79%	81%	60%	38%	156
11.—15. Lebensjahr	48%	76%	63%	56%	102

In der jüngsten Altersstufe treten beschwerdefreie Verläufe verständlicher Weise wesentlich seltener auf, als bei den älteren Jahrgängen, da ein Kleinkind nur bei wirklich schwerer Krankheit in eine Heilstätte verschickt wird. Den Prozentzahlen kommt nur eine begrenzte Bedeutung zu, da durch die mehrfache Aufteilung des Gesamtmaterials die einzelnen Zahlen klein geworden sind. Es läßt sich aber deutlich erkennen, daß in allen Altersstufen die Frühjahrs- und Herbstkuren durchschnittlich einen etwa ebenso günstigen Verlauf aufweisen, wie die Sommerkuren. Der Verlauf der Winterkuren war dagegen umso weniger günstig je jünger die Kinder waren. Bei diesen besonders empfindlichen Kindern geht die Akklimatisation an die oft stark veränderten klimatischen Verhältnisse nur langsam vonstatten. Da asthmatische Anfälle bei jüngeren Kindern meist durch fieberhafte Infekte ausgelöst werden, müssen auch Infektanfälligkeit und Begünstigung von Infekten der Luftwege berücksichtigt werden. Es wurde deshalb die relative Häufigkeit von Infekten der Luftwege je Altersjahrgang der Asthmatiker bestimmt und mit der Infektanfälligkeit aller Heilstätten-Kinder verglichen. Die Gesamtzahl der hierbei berücksichtigten Heilstätten-Kinder ist dreimal so groß wie die der Asthmatiker, wobei aber letztere eingeschlossen sind. Unterschiede ergaben sich nicht. Neben Asthma ist Infektanfälligkeit und rezidivierende Bronchitis die häufigste Indikation zur Heilstätten-Einweisung.

Es wurde weiterhin versucht festzustellen, ob innerhalb der asthmatischen Erkrankung des Kindesalters, nämlich zwischen der asthmoiden Bronchitis und der Asthma bronchiale, Abweichungen voneinander hinsichtlich des Verlaufes während der verschiedenen Jahreszeiten festzustellen sind. Die Gruppe der asthmoiden Bronchitis umfaßte Kinder vom 2. bis zum 8. Lebensjahr, die des Asthma bronchiale vom 3. bis 15. Lebensjahr. In jeder Gruppe waren es — zufällig übereinstimmend — 88 der am schwersten erkrankten Kinder. Beschwerdefreier Verlauf trat in beiden Gruppen von Frühjahr bis Herbst annähernd gleichhäufig auf, im Winter seltener, wobei der Unterschied bei der asthmoiden Bronchitis größer als beim Asthma bronchiale war. Das ist darauf zurückzuführen, daß in der ersten Gruppe das Durchschnittsalter niedriger war als in der zweiten, nämlich 4 Jahre 2 Monate gegenüber 8 Jahre 8 Monaten. Wenn in beiden Gruppen der beschwerdefreie Verlauf im Winter auch seltener war, so traten dafür desto häufiger nur ein- oder zweimal leichte Beschwerden auf. Wird der Verlauf ganz ohne Atembeschwerden und mit nur 1 oder 2mal leichten Beschwerden zusammengefaßt, so besteht bei beiden Krankheitsgruppen fast völlig Übereinstimmung der Häufigkeit in allen Jahreszeiten.

Es muß nun aber noch betont werden, daß der Krankheitsverlauf im Winter am Heimatort oft ganz besonders schlecht ist, denn die Mehrzahl unserer Kinder kommt aus dem Industriegebiet an Rhein und Ruhr, wo die winterlichen Inversionen zu einem für Asthmatiker besonders schädlichen Luftmilieu führen.

Es kann also festgestellt werden, daß der Verlauf einer heilklimatischen Kur an der Nordsee bei Asthmatikern im Frühjahr und Herbst ebenso gut ist wie im Sommer, und daß nur im Winter häufiger gelegentlich leichte Beschwerden auftreten. In dieser Jahreszeit sind die Kuren aber vielfach besonders nötig. Hinsichtlich der Kurdauer muß die erhöhte Infektanfälligkeit und langsamere Akklimatisation der Kleinstkinder berücksichtigt werden. Bei einer Dauer von mindestens 3 Monaten sind sogar in dieser Altersstufe Winterkuren sehr erfolgreich.

BIOMETEOROLOGICAL ANALYSIS OF THE FREQUENCY AND DEGREE OF ASTHMA ATTACKS IN THE WESTERN PART OF THE NETHERLANDS (PERIOD 1953-1959)

S. W. TROMP

Head Bioclimatological Research Centre, Leiden, the Netherlands

Abstract—A review is given of the most important conclusions, possible interpretations and future lines of research of a seven-year study of the possible relationships between climate, weather and bronchial asthma, carried out partly at the Asthma Centre "Heideheuvel" at Hilversum, Netherlands, and partly at the University Medical Centre Leiden.

The meteorological, clinical and statistical methods used, are briefly discussed, followed by a summary of the most important results. Finally a tentative interpretation is given of the observed weather-asthma relationship.

Résumé—L'auteur donne le compte-rendu des conclusions les plus importantes, des interprétations possibles et des indications des voies de recherches éventuelles au sujet d'une étude, relative à une période de sept ans, concernant les relations possibles entre le climat, le temps et l'asthme bronchique, étude faite moitié au Centre d'asthma «Heideheuvel» à Hilversum (Pays-Bas) et moitié au Centre Médical Universitaire de Leiden.

Les méthodes météorologiques, cliniques et statistiques ont été discutées brièvement, suivies d'une récapitulation des résultats les plus importants.

A la fin est donné un essai d'interprétation des relations observées entre le temps et l'asthme.

Auszug—Eine Behandlung der wichtigsten Schlussfolgerungen, möglichen Auslegungen und zukünftigen Richtlinien für die Forschung in einer siebenjährigen Untersuchung der möglichen Beziehungen zwischen Klima, Wetter und Bronchialasthma, durchgeführt zum Teil in der Asthmazentrale »Heideheuvel« in Hilversum und teilweise in der Universitätsklinik in Leiden.

Die angewendeten meteorologischen, klinischen und statistischen Verfahren werden kurz behandelt, woran sich eine Zusammenfassung der wichtigsten Ergebnisse anschliesst. Zum Schluss wird eine versuchsweise Erklärung des beobachteten Verhältnisses zwischen Wetter und Asthma gegeben.

THIS report gives a review of the most important conclusions, possible interpretations and future lines of research of a 7-year study of the possible relationships between climate, weather and bronchial asthma. A more complete report will be published in April 1962 as Vol. VI of the monographs of the Bioclimatological Research Centre, Leiden.

The biometeorological analysis of diseases requires two groups of data, viz., meteorological and clinical data.

I. METEOROLOGICAL DATA

These are collected daily at the private meteorological station of the Bioclimatological Research Centre, located in the University Medical Centre at Leiden, the Netherlands. In addition to atmospheric pressure, temperature, humidity, wind velocity and cloudiness, the electric potential gradient, electromagnetic infra-long waves (wavelengths 6—100 km and frequencies 3—50 kHz, emitted by storm centres) and ionization of the air are recorded. Readings of the daily rate of cooling are taken with Hill's Kata-thermometer. These local data, together with information collected from the regional weather charts (such as information on weather fronts, air masses, etc.), are recorded in specially designed charts known as "biometeorological logs". The numbers of spores and pollen are determined daily at Hilversum, where the Asthma Centre is situated; also these data are plotted in the biometeorological log.

II. CLINICAL DATA

These are collected at two different places, viz.:

(1) The Asthma Centre "Heidcheuvel" at Hilversum (medical director Dr. J. E. C. Schook). Since 1953 a fairly constant group of children is daily observed and the degree of complaints is recorded. The children go to a school nearby but live and eat at the Asthma Centre. Here they sleep in four residences, i.e. three for boys of 11—13, 12—14, 17—18, and one for girls of 10—20. A number of children of the same age group share a bedroom. There are about twenty-five boys in the youngest group, twenty-one of 12—14, twenty-one of 17—18, and twenty-eight girls, making a total of about ninety-five. During holidays (of which strict note is kept) the total number may decrease to twenty.

Apart from clinical observations, all psychosomatically disturbing factors (festivities, visits of parents, etc.) are carefully recorded. At 6 p.m, the sister or physician, who has been observing the children during the day make a short asthma report. In these lists the complaints are indicated as follows: no complaints (= 0), wheezy (usually a whistling breath, value 1). slightly breathless (= 2), breathless (= 3), very breathless (= 4). With these data a day-to-day check can be kept of the percentage of children suffering from an attack of asthma (i.e. complaints 2 or higher) and of the average degree of attack. These records are kept for each residence separately and for the total number of children.

(2) Adult asthmatic patients. Former patients of the otorhinolaryngological department of the University Medical Centre at Leiden (director Prof. H. A. E. v. Dishoeck) are requested to fill in daily complaint charts. Whereas the "Heideheuvel" data are based on entirely objective observations, this adult group provides subjective data. Despite this disadvantage, the complaints of this adult group were found to tally pretty well with the children's.

The group at Hilversum has been studied daily since 1953. All the daily clinical data of this 7-year period have been compiled in a great number of clinical charts. The most important results are given in this report. The adult group has been studied since 1956.

III. CORRELATION OF METEOROLOGICAL AND CLINICAL DATA

The first entries in the clinical charts are the days or periods of asthma frequency above or below the monthly average. The standard deviation:

$$\text{s. d} = \sqrt{\left(\frac{\Sigma(x-\bar{x})^2}{(n-1)}\right)}$$

is determined in order to discover whether deviations from the monthly average are statistically significant. In the chart only asthma peaks higher than twice this standard deviation are considered to be high and are correlated with the weather data. Two methods were used for the weather analysis, viz.

(1) The periods showing a gradual rise in asthma frequency (up to a maximum) followed by a gradual fall were selected and all these periods during the last 7 years were compared with the weather charts before, during and after these periods.

(2) As the previous method showed a clear relationship between active cold fronts or influx of cold polar air and rise in asthma frequency, a statistical analysis was made using the Gauss integral of probability (I.P.):

$$\text{I. P.} = \frac{Z_n - \left(\dfrac{n \times Z_N}{N}\right)}{\sqrt{\left\{2 \times \left(\dfrac{n \times Z_N}{N}\right) - \left[1 - \left(\dfrac{n \times Z_N}{N^2}\right)\right]\right\}}}$$

in which N = total number of days during which the asthma and weather front relationship was studied.

n = number of days with active cold fronts or influx of cold polar air;

Z_n = number of times that on those n days (or within 24 hr afterwards) an increase in asthma frequency was observed;

Z_N = number of times that during the total period on N days a day is followed by a day of higher asthma incidence.

Using this Gauss method, it was found in 1956, for example — a year of high asthma incidence in the Netherlands — that I.P. = 3.22. As I.P. = 2.33 is already significant at the 1 per cent level, the observed correlation proves to be highly significant. It is even more so if holiday periods (with less trustworthy asthma percentages because of the small number of children and the greater influence of psychosomatic factors on children who are not permitted to go home) are eliminated. In this case the statistical significance is very much greater.

Nor should we disregard the fact that asthma frequency may cease to increase when a third front follows upon two previous ones in quick succession. As in most physiological processes, overstimulation may even have the reverse effect. If this fact is taken into consideration and only the first front passage is considered, we may speak of an almost perfect correlation between active cold fronts and the increase of asthma in the Netherlands.

IV. SUMMARY OF THE MOST IMPORTANT RESULTS

(1) Every month periods of high and low percentages of asthma occur, the periods varying in length from a few days to a week or even 10 days.

(2) Every year the same pseudo-seasonal rhythm in asthma frequency is observed, both in the children at Hilversum and the adults at Leiden. In winter and early spring the asthma frequency is low; it is high in summer, particularly in autumn.

(3) The fluctuations in the daily amplitudes of asthma frequency suddenly increase at the end of June. The same is true for the monthly averages. In 1951 and 1952 the maximum monthly averages were observed in September; in 1953 and 1954 in August (15 per cent and 11 per cent, respectively), in 1955 and 1956 in October (8 per cent and 18 per cent), in 1957 in November (8 per cent), in 1958 in September (12 per cent), in 1959 with its abnormally warm spring, summer and autumn, the values were very low all through the year (less than 3 per cent, in September only 1.6 per cent). The shift in month of maximum values has proved to be related to a shift in the beginning of winter in the Netherlands.

(4) In 1957 and 1958, 62 per cent of the average asthma frequency values for the boys' residences was higher than that of the girls'.

(5) Fog, except perhaps in cities with much air pollution (which is extremely rare in the Netherlands), has no asthma-producing effect; the contrary is, rather, the fact, for periods of fog (characterized in the Netherlands by periods of little atmospheric turbulence and usually high barometric pressure) show very low asthma frequency. In February 1959 with 19 days of fog (against 7 normally to be expected) the monthly percentage of asthma frequency was less than 2 per cent.

(6) No direct relationship was found between days, months or years with very high pollen or spore content of the air and asthma frequency. In fact, periods of very high asthma frequencies are observed in late autumn during which hardly any pollen or spores were found in the atmosphere. In some of the cases a correlation seems to exist, but a careful analysis shows that this correlation is not a causal one but is entirely due to the observed correlation between temperature, humidity, hours of sunshine, air turbulence and the number of pollen and spores in the air.

(7) A highly significant statistical relationship was found between asthma frequency and certain phases in the weather.

(a) The asthma frequency increases rapidly after a sudden increase in general turbulence of the atmosphere if combined with the influx of cold air masses. The increase is most striking after a preceding quiet period. This change in turbulence is characterized by a sudden rise or fall in atmospheric pressure. Periods of steep barometric fall, due to rapidly approaching low pressure areas, have a particularly marked asthma-increasing effect if all these weather changes are accompanied by a sudden influx of cold polar or continental air masses followed by one or more active cold fronts. The latter are usually accompanied by great speed of movement, sudden change in atmospheric pressure and temperature after the passage of the front; strong precipitation (rain, snow or hail), considerable disturbances in the electric field of the atmosphere (fluctuations of the electric potential gradient between high positive and high negative values), sudden changes in direction and velocity of the wind and so forth. Owing to these specific weather conditions, the average daily temperature and the maximum temperature gradually drop, often below the monthly average. In some instances the actually observed drop in the average dry bulb temperature is small; the kata-thermometer, however, indicates clearly a sharp increase in the cooling effect of the atmosphere due to the increase in general turbulence.

(b) During periods of slight atmospheric turbulence (usually coinciding in the Netherlands with a high pressure area in W. Europe), or with the influx of warm tropical air masses and active warm fronts, a sharp decrease in asthma frequency is observed.

(c) The rapid succession of periods of cold and warm air masses, or cold and warm fronts, may create sinusoidal waves of periods with increasing and decreasing asthma frequency, but each with a relatively small maximum amplitude. If the succession is too rapid (e.g. within a few hours), often no effect at all is observed.

(d) If a sudden change in weather occurs, because a rapidly approaching deep low pressure area with warm tropical air is filling up with cold polar air, accompanied by decrease in general atmospheric turbulence, the asthma frequency increases but the amplitude remains small.

(e) The same weather phase with cold air influx causes a considerable smaller increase in asthma frequency in winter than in summer.

(f) A gradual fall in temperature, e.g. during a quiet cloudless night, or extending over several days without any appreciable turbulence, usually does not affect the asthma frequency.

(8) In a healthy population group at Leiden (e.g. Red Cross blood donors), a general increase in diastolic pressure and haemoglobin content of the blood and low blood sedimentation rates are usually observed during or after periods of weather conditions creating an increase in asthma.

(9) Usually the sharp increase in asthma during approaching cold fronts starts at different times in boys and girls.

V. TENTATIVE INTERPRETATION OF THE OBSERVED WEATHER—ASTHMA RELATIONSHIPS

Although the available data are not yet sufficiently comprehensive to provide a satisfactory physiological explanation of the weather—asthma relationship, a number of well-established physiological facts may help to understand the observed phenomena.

The various weather—asthma relationships described above suggest that severe dyspnoea is caused in asthma patients in the Netherlands predominantly by a sudden drop in environmental temperature combined with marked cooling effects resulting from considerable atmospheric turbulence. On the other hand, we have seen that during the cold months of January and February the average incidence of asthma is low and that, even when on certain days there is a noticeable increase in the incidence of asthma compared to the monthly average, this increase has far less amplitude than in summer or autumn. These two, apparently contradictory, phenomena suggest that at least two biometeorological processes in relation to asthma have to be distinguished, i.e.:

(1) A general increase in physiological susceptibility to meteorological factors in relation to asthma from winter and early spring to summer and autumn.

(2) Superimposed on this pseudo-seasonal rhythm, short-term fluctuations in meteorological factors triggering off asthma.

The former factor is probably related to a number of well-established seasonal rhythms of a group of physiological and physicochemical processes in the human body which affect asthma patients very closely. An important factor is the change in sensitivity to thermal stress after acclimatization.

Acclimatization to cold stress during summer has proved to be more difficult than in winter; also increased thyroid activity and metabolism after sudden cold stress is less in winter than in summer, due to the continuous cold stress in winter; a long warm period leads to thyroid inactivity and therefore a sudden influx of cold air in such a warm period affects thyroid activity (and metabolism) more seriously than in a cold period.

Sudden cold stress, either during summer or winter, may start off the following physiological events: Abrupt increase in thyroid activity, metabolism and oxygen requirements which may lead to increased pulmonary ventilation and alkalaemia. Studies of healthy persons at Leiden revealed a regular decrease in acidity of urine during influxes of cold polar air and the passage of active cold fronts.

During spring and summer, with their increased ultra-violet radiation, more histamines are formed in the skin, supporting the parasympathetic action, i. e. contraction of the bronchioles. During the summer period the average 17-ketosteroid level of the body is also lower. All these, and probably several other, factors make the summer—autumn period a particularly favourable period for dyspnoea in persons (like asthmatics) with an apparently overstimulated parasympathetic system (or understimulated) orthosympathetic system.

FUTURE RESEARCH

The previously discussed asthma—weather relationships suggests a difference in functioning of the autonomic nervous system of asthmatics and of normal persons. Also the thermoregulation system of asthmatics seems to be less efficient.* Further studies in a climatic chamber are required, both for fundamental research into these problems and for the therapeutic application of the findings.

Such a research programme may help us to understand the excellent results obtained after the treatment of asthmatics in climatic chambers (e. g. at Bad Lippspringe in Westfalen, Germany) and the improvement of Dutch patients after their removal from Holland to the mountains at Davos (Switzerland), an improvement which cannot be explained by psychosomatic factors only.

* Note: Recent thermo-regulation efficiency tests of asthmatics and normals have confirmed this statement.

IONIZATION OF THE AIR

THE SEDATING EFFECT OF POLARIZED AIR*

TH. A. DAVID[1], J. V. DERAU[2], I. H. KORNBLUEH[3], F. C. J. McGURK[4] and J. R. MINEHART[5]

[1]Associate in Surgery, Department of Surgrey, Northeastern Hospital of Philadelphia
[2]Consulting Engineer
[3]Graduate School of Medicine, Graduate Hospital, University of Pennsylvania, Philadelphia, and the American Institute of Medical Climatology
[4]Associate Professor of Psychology, Villanova University, Villanova, Pennsylvania, and the American Institute of Medical Climatology
[5]Chief of Surgery, Northeastern Hospital of Philadelphia

Abstract—The effects of intermittent exposures to negatively ionized air were studied on surgical patients on the first and second postoperative day. The sedating and pain relieving quality of this method, observed previously in a large series of burned persons and in repeated electroencephalographic tests, was confirmed. No adverse symptoms were recorded.

The results of this carefully controlled and evaluated experiment are reported here for the first time.

Résumé—Les effets de l'exposition intermittente à l'air ionisé négativement ont été étudiés sur des opérés le premier et le deuxième jour après l'opération. La qualité sédative et curative de cette méthode, observée auparavant dans de nombreux cas de personnes brûlées et dans des tests électrocéphalographiques répétés, a été confirmée.

Aucun symptôme contraire n'a été observé.

Les résultats de cette expérimentation soigneusement contrôlée et élaborée sont exposés ici pour la première fois.

Auszug—Die Wirkungen von negativ ionisierter Luft auf Patienten der Chirurgischen Abteilung, die am ersten und zweiten Tage nach der Operation dieser negativ ionisierten Luft periodisch ausgesetzt wurden, sind untersucht worden. Die beruhigenden und schmerzlindernden Eigenschaften dieser Methode, die bereits vorher bei einer langen Reihe von Brandverletzten sowie bei wiederholten elektroencephalographischen Testen beobachtet worden waren, wurden bestätigt. Es wurden keine nachteiligen Symptome festgestellt.

Die Ergebnisse dieses sorgfältig überwachten und ausgewerteten Experiments werden an dieser Stelle zum ersten Mal berichtet.

GROWING cognizance of the biological effects of electric space charges has in the last quinquennium stimulated a number of pertinent research projects. The concentric efforts directed towards exploration of space with manned vehicles will undoubtedly

* This study was supported in part by a grant of the Philco Corporation

speed up the development of more refined instrumentation vital to progress in the field of unipolar aeroionization.

Meanwhile, artificial ionization of the air is being used clinically and experimentally in a variety of conditions. This paper reports on the effects of aeroions on 187 (96 F and 91 M) unselected surgical patients treated from the end of January 1958 to 31 August, 1958, and again from 28, January 1959 to 31 March, 1959.

PROCEDURE

Transportable ion generators, called the Ionitron, and built by the Advanced Studies Group of the Philco Corporation, were used throughout this study. The Ionitron produces ions by corona discharge. When an electrical potential is applied between two electrodes of unequal radius, the electric field between them is non-uniform; it is greater in the direction toward the electrode of smaller radius. The ratio of the radii, the distance separating the electrodes, and the potential applied are controlling factors.

As the potential is raised above the critical disruptive voltage for the geometry of the system, a corona discharge takes place between the electrodes, causing ions to be formed in the zone separating them. Ions of opposite polarity of the electrode of the smaller radius (the discharge electrode) are drawn rapidly toward it, and assist in the formation of additional ions through collision. Ions of the same polarity as the discharge electrode move less rapidly toward the electrode of larger radius (the collecting electrode). Some of the gas ions formed by the corona discharge become attached to airborne particles passing through the zone between the electrodes. A blower behind the electrodes transfers the charged particles and ionized gas molecules to the atmosphere of the room.

The discharge electrode is a round nichrome wire 0.0635 mm in radius. This wire is supported by a rectangular plastic frame to form eleven parallel passes with a total effective length of 216.3 cm. The distance between each pass is 2.86 cm. The collecting electrodes consist of two flat aluminum foil filters, each 33.02 cm by 23.49 cm, and spaced 1.9 cm on either side of the discharge electrode.

An upstream filter is isolated from ground and connected through a capacitor and a neon light. Ions collecting on this filter are discharged through the neon light causing it to blink periodically thereby indicating a proper performance. The rate of blinking permits a rough estimate of the quantity of ions that are being produced. A downstream filter is connected to ground.

A d. c. negative voltage power supply applies a fixed potential of 6000 V on the discharge electrode. The power supply is equipped with hydrogen-charged electronic regulator tubes which prevent the potential from exceeding 6000 V, so that the ozone formed by the corona discharge is of such insignificant amount that it will not increase measurably the background level of the room in which the generator is operating.

Because of lack of precedents the following technique was adopted which varied from the method used in the treatment of burns:

While the great majority of the burned patients was treated in a special room with relatively high ion densities, this group of surgical patients was exposed at the bedside to lower levels of negative and a negligible amount of positive ions.

Upon their return from the operating room, all patients were watched closely for signs of pain on recovery from general anaesthesia. Patients who had spinal or local anaesthesia were instructed to report immediately the onset of pain. In this stage, instead of analgesics, all patients were exposed for 30 min to negatively polarized air.

The Ionitron, mounted on a carriage, was wheeled into the sickroom and placed at the bedside facing the patient at the height of his head, and at a distance of about 2 to 3 ft. The curtains around the bed were drawn tightly, forming a small compartment. The patients were placed in a comfortable position — either on the back or on one side. Smoking and visitors were not permitted during the period of ionization. Such exposures to ionization were repeated once to twice on the first, and up to three times on the following day at intervals of from to 2½ hr.

The technicians who administered the ion therapy were instructed to refrain from making any comments about the effects of ionization. The patients were told only that the treatment would improve their breathing. It was unavoidable, however, that in some instances the patient heard from other room-mates about the treatment. Some looked forward to this therapy with the expectation of being made to "feel better". On the other hand, a few patients regarded the treatment with suspicion and fear. A number of older persons complained of the "draught" created by the gentle breeze of the generator fan despite the fact that the entire body except the head was covered with blankets in the winter, and a sheet in the summer. This was not regarded as unusual behavior for the patients as the air conditioning of the sickrooms was occasionally the source of similar complaints.

Certain inadequacies of technique are recognized: Technicians were present only 5½ days a week. The regular nursing staff substituted during the period from Saturday noon to Monday morning. The 8-hr day of the technicians restricted this treatment to the daylight hours. At night, sedation was necessary in some cases. In addition, the positive polarity was not used in this study.

The same technique was employed in the treatment of the controls and the experimental subjects except that "treatment" of the controls was done with units which had the ion-generating parts disconnected. With the pilot light flashing and the fans of the Ionitron running constantly, it was impossible for the patients or the technicians to know when ions were or were not being generated. This study comprises 138 experimental and 49 control patients.

The degree of recovery from postoperative pain was based on the patients' statements and on the charted observations by the technicians and the surgeons. All patients, experimental or control, were carefully evaluated after each treatment using the severity of their pain as the main criterion. Those patients who reported marked diminution of pain were classed as group *A*. Patients reporting complete cessation of pain were listed separately as group *B*. Those who were observed to have fallen asleep from 10 to 15 min after the onset of the ionization were classed as group C. Persons showing no signs of improvement formed group D.

The usual routine in the Department of Surgery includes preoperative sedation, postoperative maintenance of normal levels of blood electrolytes, blood transfusions where indicated, early ambulation, and the removal of all dressings after 24 hr.

It should be stressed here that in the entire series, except for some feeling of dryness in nose and throat, no other untoward symptoms were observed.

RESULTS

Table 1 shows the reactions of the total number of patients to the experimental and control treatments. Improved patients are listed in groups A, B and C; Not improved patients in group D.

Table 1. *Recovery from Postoperative Pain*
(Total group)

	Not improved patients	Improved patients	Total
Experimental group	59	79	138
Control group	38	11	49
Total	97	90	187

Chi-square = 18.71.
d. f. = 1.
P $>$ 0.001.

The chi-square obtained indicates that there is less than one chance in 1000 that such a distribution of responses could have been caused by chance factors alone. In addition, the difference between the percentage of those improving under ionization treatment (57.3 per cent) is significantly different from the percentage of those improving under the control treatment (22.5 per cent). The probability that such a difference in percentages could have occurred by chance is also one in 1000.

From the data in Table 1, it cannot be maintained that the difference in recovery rate of these two groups of patients is largely the result of the difference in treatments. It is almost certain that the type of surgery was a factor in the degree of pain and in its remission. The reported recovery from pain may also be a function of both age and sex of the patient, and although each of these factors was almost evenly divided among the four categories of patients in Table 1, there were some variations which could be a possible explanation of the obtained differences in reported pain recovery.

Therefore, control patients were matched with experimental patients for type of surgery, age and sex. Only those patients who reported complete cessation of pain (group *B*) and those who fell asleep (group *C*) were included as improved patients. Group *A* patients were added to group *D* and treated as "not improved" in this matched classification. Of the thirty-four pairs so obtained (one of a pair being a control and the other a negatively ionized patient), each patient of a pair was identical for type of surgery and sex, but approximately matched for age. The mean age of the experimental patients was 44.85 years, and the mean age of the control patients was 45.06 years. The results of the ionization treatment for this matched group are shown in Table 2.

Table 2. Recovery from Postoperative Pain
(Matched group)

	Not improved patients	Improved patients	Total
Experimental group	26	8	34
Control group	33	1	34

Chi-square = 6.40.
d.f. = 1.
$P > 0.02$.

The chi-square computed from Table 2 indicates that such a distribution could have occurred by chance only twice in 100 times. Moreover, the difference between the percentages of improvement for the experimental group and the control group is significant at about the 0.02 level.

DISCUSSION

Unfortunately, there exists no literature on the therapeutic use of negative air ions on postoperative pain. The findings reported here do confirm previous observations of David *et al.* (1—3) that negative aeroions aid in treatment of burned patients. The present findings corroborate the conclusion that negative ions lessen the discomfort from pollinosis (4—8) and exert a tranquilizing effect on some patients (9—11). Indirectly, these findings support the evidence presented by McGurk (12) that negative air ions create a feeling of relaxation and well being in human subjects working under very uncomfortable environmental conditions.

While the figures presented here must be regarded as tentative only, the probabilities that such data could have occurred by chance are remote. In view of these findings, it appears that a significant number of patients can be made comfortable even during the critical period after surgery, without the use of sedatives or narcotics. In addition, the safety and low cost of this method of relieving postoperative pain are further arguments for a more extensive study of the effects of unipolar aeroionization.

CONCLUSIONS

Further research should include the intermittent exposure of postoperative patients to negative or positive air ions at fixed periods of time for the entire duration of the postoperative convalescence. This included 24-hr treatment schedules, 7 days a week. Exposure to higher concentrations of ions should be attempted, provided that such higher concentrations can be achieved without the production of ozone and nitrous compounds. An objective criterion such as the amounts of sedatives and/or narcotics required for pain relief should be used in conjunction with the patients' subjective reports for comparative purposes.

REFERENCES

1. Th. A. David, J. R. Minehart, J. Fasano and I. H. Kornblueh, Observations of the effects of artificial ionization on the burned patient, Preliminary Report. Presented at the *First Annual Congress of the International Society of Bioclimatology and Biometeorology in Vienna, Austria, September* 1957.
2. J. R. Minehart, Th. A. David and I. H. Kornblueh, Artificial ionization and the burned patient. *Med. Sci.* **3,** 6 (1958).
3. Th. A. David, J. R. Minehart and I. H. Kornblueh, Polarized air as an adjunct in the treatment of burns. In press.
4. I H. Kornblueh and J. E. Griffin, Artificial air ionization in physical medicine. *Amer. J. Phys. Med.* **34,** 618—31 (1955).
5. I. H. Kornblueh, G. M. Piersol and F. P. Speicher, Relief from air-borne allergies through air ionization. Presented in New York City, 1 October (1956).
6. I. H. Kornblueh and J. E. Griffin, Die Künstliche Ionisation der Luft in der physikalischen Medizin. *Wetter und Leben,* **8,** 57—64 (1956); edited and translated by Prof. Dr. Marius Kaiser, Wien.
7. I. H. Kornblueh, G. M. Piersol and F. P. Speicher, Relief from pollinosis in negatively ionized rooms. *Amer. J. Phys. Med.,* **37,** 18—27, February 1958.
8. I. H. Kornblueh and F. P. Speicher, Present Status of Artificial unipolar ionization of the air. Presented at the *Thirty-fifth Annual Session of the American Congress of Phys. Med. and Rehabilitation, Los Angeles, California, September 1957.*
9. D. Silverman and I. H. Kornblueh, Effect of artificial ionization of the air on the electroencephalogram, Preliminary Report. Presented at the *Meeting of the Eastern Association of Electroencephalographers, New York City,* 5 *December, 1956.*
10. D. Silverman and I. H. Kornblueh, Ionization and the EEG. *EEG Clin. Neurophysiology* **9,** 180 (1957).
11. D. Silverman and I. H. Kornblueh, with the technical assistance of T. Sannit and S. Piwoz, Effect of artificial ionization of the air on the electroencephalogram. *Amer. J. Phys. Med.* **36,** 352—8 (1957).
12. F. C. J. McGurk, Psychological effects of artificially produced air ions. *Amer. J. Phys. Med.* **38,** 4, 136—7 (1959).

ON THE INFLUENCE OF ARTIFICIAL IONIZATION OF THE AIR ON THE OXYGEN UPTAKE DURING EXERCISE

R. J. HAMBURGER

Abstract—The effect is studied of positive or negative ions on the oxygen uptake in man during exercise. The exercise was performed on a bicycle ergometer and amounted to 200—300 W during 8 min. During the performance of this task the subject was breathing artificially ionized air which was analysed for oxygen by suction through a diaferometer. In this way the amount of oxygen used in different comparable exercise tests, could be determined. Our studies suggest that the oxygen uptake during exercise is highest when the air is positively ionized. This may be caused by an influence of the positively ionized air on the mucous membrane of the respiratory tract. in such a way that oxygen may be taken up more easily into the lung tissue.

Résumé—On examine l'effet des ions positifs ou négatifs sur la consommation d'oxygène pendant le travail. Ce travail de 200—300 W pendant 8 min est fait sur une bicyclette ergométrique. L'air respiré était ionisé artificiellement et son taux d'oxygène déterminé par le diaférométre. Cette détermination est faite dans des épreuves comparables. Nos études suggèrent une plus grande consumption d'oxygène pendant une ionisation positive. Hypothétiquement la cause de cette consommation augmentée pourrait être trouvée dans une influence de l'ionisation positive sur les parois muqueuses de l'appareil respiratoire.

Auszug—Der Einfluss von positiven oder negativen Ionen auf die Sauerstoffaufnahme während der Arbeit wird untersucht. Diese Arbeit, 200—300 W während 8 Minuten, wird geleistet auf einem Fahrrad Ergometer. Es wird künstlich ionisierte Luft geatmet deren Sauerstoffgehalt mit Hilfe eines Diaferometers bestimmt wird. Es erschien dabei dass positive Ionisation eine vermehrte Sauerstoffaufnahme gibt. Hypothetisch könnte das verursacht sein durch einen direkten Einfluss von positiven Ionen auf die Sauerstoffaufnahme durch die Schleimhaut der Atmungswege.

For a long time man has speculated on the possible importance of electrical phenomena on biological functions. But it is only since the beginning of this century that the whole problem has become more amenable to experimental investigation. In 1899 Elster and Geitel (1) and independently Wilson (2) expressed the opinion that the conductivity of the air must be attributed to small charged particles which were called air ions. In 1901 Aschkinass and Caspari(3) published their view that these air ions might be of biological importance. Since then a number of observations and experiments have been published on this subject among others by Dessauer (4) and his collaborators. In 1955 Kornblueh and Griffin (5) gave a report on artificial air ionization in physical medicine and noted the beneficial effect of negative ionization on patients with hay-fever and asthma. Silverman and Kornblueh (6) noted an influence of ionization on the electroencephalogram in man. The problem of the influence of either positive or negative ionization on biologic functions on man, was studied by Winsor and Beckett (7). They concluded that the body collects atmospheric ions and they established an irritation of the respiratory tract by positive ions. According to them, up to date a beneficial effect of air ionization has only been demonstrated for negative ions. It may be mentioned here that in the Dutch East Indies de Langen (8) drew attention to the effect of the electric potential in the tropics on the sense of well being of patients. Old studies on the effect of atmospheric electricity have been reviewed by Schmidt (9).

The consensus of opinion appears to be that negative ionization of the air has beneficial effect on biologic functions. We therefore have studied the effect — if any — of an excess of positive or negative ions on the oxygen uptake in man during exercise. It is necessary, however, to be aware of the fact that in artificial ionization the ion content of the air is much greater than is occurring naturally near the earth's surface and that under natural circumstances the amount of positive and negative ions is about the same, while in these experiments a large preponderance of one or the other sort of artificial ion exists. Therefore these experiments cannot be compared with the normally existing situation, and cannot prove or disprove the air ionization being a natural biotropic factor.

METHOD

As a source of ionization a tritium foil was used mounted on a metal plate which could be charged to either a positive or a negative voltage. The tritium foil produces air ions, by emitting ß-rays. Positive and negative ions arise in about equal amounts. By giving the metal plate a positive charge the positive ions will be repelled in the surrounding air and the negative ions will be collected on the plate. With this ionaire developed by Wesix Electric Heater Company*, it is possible to produce in a restricted space a considerable excess of either positive or negative ions.

A task was performed on a bicycle ergometer by young male persons in the age group of 18—21 years and amounted to 200—300 W during 8 min. The man was seated on the bicycle, and his head and shoulders were enclosed in a light helmet made from translucent plastic (Perspex) and aluminium. Outside air was pumped through the helmet at a rate of 200 l./min, as measured by a rotameter. A small sample of the air in the helmet was dried, freed of CO_2, and sucked continuously through a Noyons (10) diaferometer for analysis of the oxygen.

A functiocardiogram was made according to the method described by Jongbloed, *et al.* (11). From the graph that was obtained, the extra amount of oxygen uptake during exercise has been determined planimetrically. The ionaire was placed in the helmet quite near the face of the person tested, in such a way that in his

* Wesix Electric Heater Company, 390 First Street, San Francisco.

immediate vicinity an excess of either positive or negative ions was present. The air flow at the end of the experiment could pass through an ion collector and the collector plate charge measured with a sensitive micromicro ammeter. The concentration of positive ions then was approximately four million in 1 ml. The man was then asked to perform an exercise run on the bicycle with a load of 200--300 W for 8 min, and a graph of his total oxygen uptake was made during this time. This was added to the oxygen used during the rest period of 8 min necessary to balance the oxygen debt that arose during the exercise.

After artificially ionized air had been respired for 1 hr the subject was asked to perform a second, identical, run and the graphs of both runs were compared. The sequence of these experiments differed arbitrarily. In this way it should be possible to assemble data on the uptake of oxygen under different electric conditions in the breathing air.

Winsor and Beckett had found more persons showing symptoms with positive ionization, when they were electrically grounded. In their experiments temperature did not significantly change these symptoms. In a humid (80 per cent) environment they were less clear and lower than in a low (40 per cent) humidity.

In our experiments the humidity was always around 40 per cent and the temperature around 18—20°C. The air velocity in the helmet was the same during the different experiments.

RESULTS

To start with, the same person made two identical runs on the bicycle ergometer breathing normal outside air without any artificial ionization.

Table 1. Oxygen Uptake in Nonius Units during Exercise without Artificial Ionization

Persons	First run	Second run	Differences
v. Ho	3380	3257	+123
Bo	4092	4000	+92
Thi	4724	4505	+219
Her	2471	2727	—256
Mey	3469	3344	+125
Bun	4239	4028	+211
v.d. Be	3875	4009	—134
Bo	3544	3441	+103
v. Ku	2371	2926	—555
Bu	3560	3358	+202
v. St	3995	4166	—171
mean oxygen uptake in nonius units per person	3611	3615	+4

Standard deviation = 234.

Standard error in mean: $\frac{234}{\sqrt{11}} — 70.$

We see from this table a rather wide range of oxygen uptake in different persons. but also a wide difference in the uptake by the same person in two different runs. In the mean, however, we find the oxygen uptake in the first run practically the same as in the second run.

The amount of oxygen used without artificial ionization or extra work load was determined in the same person on three consecutive days. Then an amount of, respectively, 3584, 3393 and 3375 nonius units was found. Though here too a variation is present it does not differ significantly from the range previously found.

For the possible effect of positive ionization, twenty-two persons were examined and the results are given in Table 2. We see from this table that the number of cases with an increase of oxygen uptake equals the number where a decrease is found. In the mean there appears to exist a small increase. With positive ionization only 49 nonius units more oxygen are taken up. This amounts to $49 \times 5.11 = 250$ ml oxygen.

Table 2. Oxygen Uptake in Nonius Units during Exercise with Positive Ionization, compared to that in Air not Artificially Ionized

Persons	Normal air	Positively ionized air	Difference
De	3238	3207	—31
v.d. Ko	2949	2940	—9
Ho	3583	3539	—44
Le	3589	3279	—310
Sa	3033	3167	+134
Me	2814	2400	—414
Sch	3451	3393	—58
de Kr.	3101	3348	+247
v. Ho	3345	3313	—32
La	3897	3929	+32
Ma	3016	3020	+4
v. Go	2789	2873	+84
Ki	3160	3553	+393
Im	3289	3786	+497
Wo	3827	3621	—206
Klu	2947	3092	+145
Jo	3566	4145	+579
Ne	2966	3693	+727
Jon	3500	3520	+20
Ca	2998	2716	—282
Ri	3223	3145	—78
v. Ti	3433	3115	—318
mean oxygen uptake in nonius units	3260	3309	+49

Standard deviation: 288.

Standard error in mean $\frac{288}{\sqrt{22}} = \frac{288}{4.69} = 61.$

Considering the large range found in determinations even in the same person, it may be said the difference in oxygen uptake when working in non- or in positively ionized air, is not statistically significant. This can be verified quantitatively by comparing the average and the variation.

In Table 3 the comparative results for the oxygen uptake in eleven persons are given, when one exercise run is performed in normal air, the other in negatively

Table 3. Oxygen Uptake in Nonius Units during Exercise in Negatively Ionized air Compared to that in Air not Artificially Ionized

Persons	Normal air	Negatively ionized air	Difference
Ba	3145	3697	+552
La	3755	2869	—886
Vr	2466	2681	+215
de Jo	2717	2788	+71
Sch	2460	2725	+265
Ry	3551	3463	—88
Sn	3197	3066	—131
Kr	1800	1605	—195
Ho	2817	3135	+318
Ven	2988	3000	+12
Lo	3998	3615	—383
mean oxygen uptake per person in nonius units	2990	2968	—22

Standard deviation: 371.

Standard error in mean $\frac{371}{\sqrt{11}} = \frac{371}{3.32} = 110.$

ionized air. Here too the number of persons increasing their oxygen uptake on negative ionization, practically equals those who decrease it. Subsequently a comparison was made of the oxygen uptake while the same amount of work was done either in positively or in negatively ionized air. When positive ions were to have an effect opposed to the negative ions this could be expected to become apparent in these experiments. However, in biometeorology it is often found that the effect of a biotropic factor is more dependent on the fact of the change itself than on its sequence (for instance cold and warm fronts).

The results of the experiments are given in Table 4. We see from this table also a rather wide range in oxygen uptake, but we find there is not the same oxygen uptake in positively and negatively ionized air. Only four persons show a decrease and seven an increase in oxygen uptake on positive ionization. In the mean an increase of oxygen uptake of 111 nonius units, approximately 111 $\times$ 5.11 = 567 ml of oxygen at outside pressure and temperature is present. From the other tables

Table 4. Oxygen Uptake in Nonius Units during Exercise in Negatively Ionized Air as Compared to that in Positively Ionized Air

Persons	Negatively ionized air	Positively ionized air	Difference
v. Ha	4142	4052	—90
Vl	3407	3691	+284
We	3474	3514	+40
Br	3282	3668	+386
Ko	3363	3029	—337
Re	2412	2448	+36
Sp	3446	3305	—141
Ho	3220	3380	+160
Fi	3464	4501	+1037
Bo	3981	3807	—174
Al	3606	3626	+20
mean oxygen uptake per person in nonius units	3436	3547	+111

Standard deviation: 354.

Standard error in mean $\frac{354}{\sqrt{11}} = 105.$

we see that by comparison of exercise in normal air and by positive ionization, the oxygen uptake is increased $49 \times 5.11 = 250$ ml of oxygen.

In negative ionization the oxygen uptake decreases 22 nonius units = 112 ml of oxygen and in two runs in normal air it remains practically the same, the second run showing an increase of only 4 nonius units = 20 ml of oxygen.

Finally the exercise test was done by the same person on three different days, each time the run in normal and in positively ionized air was done on the same day. We then found the results tabulated in Table 5.

Table 5. Oxygen Uptake in Nonius Units during Exercise by the Same Person from Normal Air as Compared to that from Positively Ionized Air

	Normal air	Positively ionized air	Difference
first day	2089	2197	+108
second day	2759	3072	+313
third day	2789	2873	+84
mean oxygen uptake in nonius units	2544	2714	+170

Standard deviation: 100.

Standard error in mean $\frac{100}{\sqrt{3}} = 116.$

DISCUSSION

Although the evidence given is not more than an indication and not statistically significant these studies seem to *suggest* that the oxygen uptake during exercise is greater when the air is positively ionized. In negative ionization hardly any difference could be found. Though in positive ionization the oxygen uptake appeared higher, this could be more clearly seen when the oxygen uptake in positive ionization was compared to that in negative ionization. It then increased by 567 ml. When combining Tables 1 and 2, i.e. normal air or negative ionization, we find a decrease in oxygen uptake of $+20 - 112 = 92$ ml oxygen, while from Tables 3 and 4 in which positive ionization occurs, an increase in oxygen uptake is seen of $+250 + 567 = 817$ ml.

It appears thus that in positive ionization a greater amount of oxygen is taken up during exercise than occurs when an excess of negative ions is present or when normal air is not artificially ionized at all.

It is remarkable that a great majority of the subjects felt that the work was more easily done while they were breathing an excess of positive ions. On the other hand the majority of those working in an excess of negative ions noticed no difference between breathing normal air or negatively ionized air. None of the persons, however, noticed any change in well-being related to artificial ionization either positive or negative. Such effects as mentioned by several authors could not be confirmed.

We must now try to explain what causes the higher uptake of oxygen in positive ionization of the air. It might be that the measuring apparatus itself is influenced by artificial ionization of the air flow. Though this did not appear very probable we have tested normal and ionized air flowing through the diaferometer without any exercise being done and even without a person breathing in the helmet. No differences in the oxygen curve could be demonstrated.

Secondly one may consider another possibility, i.e. a change in the energetic value of oxygen in ionized air. In case the energetic value of the oxygen in ionized air was diminished, a greater amount of oxygen would be needed for the same expenditure of energy in exercise. This explanation does not appear probable and its further evaluation lies beyond the scope of this study.

A direct influence of ionized air on the surface of the respiratory tract was observed by Krueger and Smith (12) in the ciliary movements in the rabbit trachea. Frey (13) found a disappearance of positive ions in the respiratory tract during inspiration. This is attributed to a negative charge in the tissues themselves. Therefore a third, and seemingly more likely explanation of the experimental observations, suggests itself in the hypothesis that the positive ionization of the air acts on the mucous membrane of the respiratory tract in such a way that the oxygen may be taken up more easily into the lung tissue.

Another hypothesis brought forward by Krueger (14) postulates that positively ionized CO_2 may be more stimulating to the respiratory centre than the non-ionized variety. The consequence would be an increased total respiratory exchange.

It is obvious, however, that our empirical data cannot support any of the abovementioned hypotheses.

REFERENCES

1. Elster and Geitel, *Terrestr. Magazin* **4** (1899).
2. Wilson, *Proc. Roy. Soc.* **65**, (1899).
3. Aschkinass and Caspari, *Pflüg. Arch. ges. Physiol.* **86**, (1901).
4. Dessauer, *Zehn Jahre Forschung auf dem Physikalisch Medizinischen Grenzgebiet.* Georg Thieme, Leipzig (1931).
5. Kornblueh and Griffin, *Amer J. Phys. Med.* **34**, 6 (1955).
6. Silverman and Kornblueh, *EEG Clin. Neurophysiol.* **9**, 180 (1957).
7. Winsor and Beckett, *Amer. J. Phys. Med.* **38**, 2 (1958).
8. C. D., de Langen, *Proc. of the 2nd General Meeting of the 6th Nederl.-Indisch Natuurwetenschappelijk Congres, Bandung 1931.*
9. A. Schmidt, *Biol. Wirkungen der Luftelektrizität, 1936*, p. 54 *et sek.*
10. Noyons, *Ann. Physiol.* **13**, 909 (1937).
11. Jongbloed, van Nieuwenhuizen and van Goor, *Circulation* 15, 1, 1 (1957).
12. Krueger and Smith, *J. Exp. Biol. Med.* **96**, 807—9 (1957).
13. Frey, *Schweiz. Med. Woch. Schr.* **80**, 1387 (1950).
14. A. P. Krueger, Personal communication.

STUDIES ON THE EFFECTS OF GASEOUS IONS ON THE MAMMALIAN TRACHEA*

ALBERT PAUL KRUEGER A.B., M.D.
and RICHARD FURNALD SMITH B.S., M.S.
Department of Bacteriology and the Naval Biological Laboratory of the School of Public Health, University of California, Berkeley, U.S.A.

Abstract—Experimental methods were developed to study the effects of gaseous ions on the tracheal mucosa *in situ* and in excised strips.

Positively charged CO_2: decreased the ciliary rate, contracted the posterior tracheal wall, induced a state of exaggerated susceptibility to mild mechanical trauma, caused vasoconstriction in the tracheal wall and increased the respiratory rate.

Negatively charged oxygen: increased the ciliary rate, reversed the positive ion-induced contraction of the tracheal wall, did not alter the mucosal response to mild trauma, did not change the normal vascularity and decreased the respiratory rate.

All five effects are demonstrable in the living tracheotomized animal; only the first three can be demonstrated in the excised strip.

All the tracheal effects attributed to positively charged CO_2 are also produced by the intravenous injection of 5-hydroxytryptamine (5-HT). We have tested the hypothesis that: (1) Positive air ion effects on the trachea are due to the release and local accumulation of 5-HT and (2) Negative ions reverse positive ion effects by accelerating the rate at which 5-HT is oxidized. The experimental results obtained to date are compatible with the hypothesis.

Résumé—Des méthodes expérimentales ont été développées pour étudier les effets des ions gazeux sur la muqueuse trachéale *in situ* et sur des fragments excisés.

Effets du CO_2 chargé positivement:

Diminution de la fréquence ciliaire, contraction de la paroi trachéale postérieure, provocation d'un état de susceptibilité exagérée au traumatisme mécanique léger, cause de vaso-constriction dans la paroi trachéale et augmentation de la fréquence respiratoire.

Effets de l'oxygène chargé négativement: Augmentation de la fréquence ciliaire; Inversion de la contraction de la paroi trachéale, induite par l'ion positif, aucun altération de la réaction de la muqueuse au traumatisme léger, aucun changement de la vascularité normale et diminution de la fréquence des mouvements respiratoires.

Les 5 effets peuvent être mis en évidence grâce à la trachéotomie d'un animal vivant, par contre seul les 3 premiers peuvent être constatés sur des fragments excisées.

* This research was supported by: (1) a contract with the United States Air Force (A.F. 49 (638—669) monitored by the Air Force Office of Scientific Research of the Air Research and Development Command: (2) a grant from the National Institutes of Health and (3) a grant from the Committee on Research of the University of California. The opinions expressed herein are not necessarily those of the Navy Department or of the Air Force.

Tous les effets sur la trachée attribués au CO_2 chargé positivement sont égalcment produits par l'injection intraveineuse de 5-hydroxytryptamine (5-HT).

Nous avons examiné l'hypothèse suivante: (1) Les effets des ions positifs de l'air sur la trachée sont dus à une décharge et à une accumulation locale de 5-HT. (2) Les ions négatifs inversent les effets des ions positifs en accélérant la vitesse à laquelle le 5-HT est oxydé. Les résultats expérimentaux obtenus jusqu'à ce jour sont compatibles avec l'hypothèse.

Auszug—Es wurden Versuchsverfahren zur Untersuchung der Einwirkung gasförmiger Ionen auf die Luftröhrenschleimhäute an Ort und Stelle und in sezierten Streifen entwickelt.

Positiv geladenes CO_2 verringerte die Ziliartätigkeit, zog die hintere Luftröhrenwand zusammen, bewirkte einen Zustand überempfindlicher Reaktion gegen schwaches mechanisches Trauma, verursachte eine Gefässverengung in der Luftröhrenwand und verstärkte die Atemtätigkeit.

Negativ geladener Sauerstoff erhöhte die Ziliartätigkeit, löste die durch die positiven Ionen bewirkte Zusammenziehung der Luftröhrenwand, änderte die Reaktion der Schleimhaut auf schwaches Trauma nicht, änderte ferner nicht die normale Vaskularität und verminderte die Atemtätigkeit.

Alle fünf Wirkungen können am lebenden Tier demonstriert werden, während nur die ersten drei am sezierten Luftröhrenstreifen nachzuweisen sind. Sämtliche Reaktionen, die durch positiv geladenes CO_2 eintreten, werden auch durch eine intravenöse Injektion von 5-Hydroxytryptamin (5-HT) verursacht. Wir haben die Hypothese geprüft, wonach (1) die Wirkungen positiver Luftionen auf die Luftröhre auf die Freimachung und örtliche Ansammlung von 5-HT zurückzuführen sind und (2) negative Ionen die Wirkung der positiven Ionen durch Beschleunigung der Oxydation von 5-HT umkehren. Die bis heute erzielten Versuchsergebnisse sind mit dieser Hypothese vereinbar.

At the First International Bioclimatological Congress of the International Society of Bioclimatology and Biometeorology in Vienna (September 1957) we reported on the "Effects of unipolar air ions on microorganisms and on evaporation" (1). The phenomena described were of some interest, largely because they were quantitative and reproducible, but the changes resulting from air ion action admittedly were of a low order of magnitude and were far from being dramatic. Since the completion of our experiments on bacteria the laboratory has been devoted to a study of the effects of gaseous ions on the mammalian trachea; this has proved to be a fortuitous choice of subject for demonstrating profound ion-induced alterations in function and for developing some understanding of the mechanisms underlying these changes.

The trachea was selected because of its easy accessibility and because it is lined with a mucosa representative of that covering the major distribution channels of the respiratory tree. The unique combination of cells with cilia on their free border and cells capable of forming mucus provides the anatomical structure which permits the specialized and very important clearing mechanism of the respiratory tract to operate. Any inhaled particulate matter such as pollens, dust or bacteria ultimately is trapped in the mucus film coating the epithelium and joins in its cephalad flow. This flow is largely dependent on the wave-like action of the cilia beating at rates approximating 900/min.

To conduct experiments on tracheal function, a glass and plastic chamber was constructed (Fig. 1) which permitted microscopic observation of an enclosed tracheal strip in an atmosphere maintained at ca. 23°C and a relative humidity of $>$ 80 per cent. A tritium ion generator protruding through the roof of the chamber was

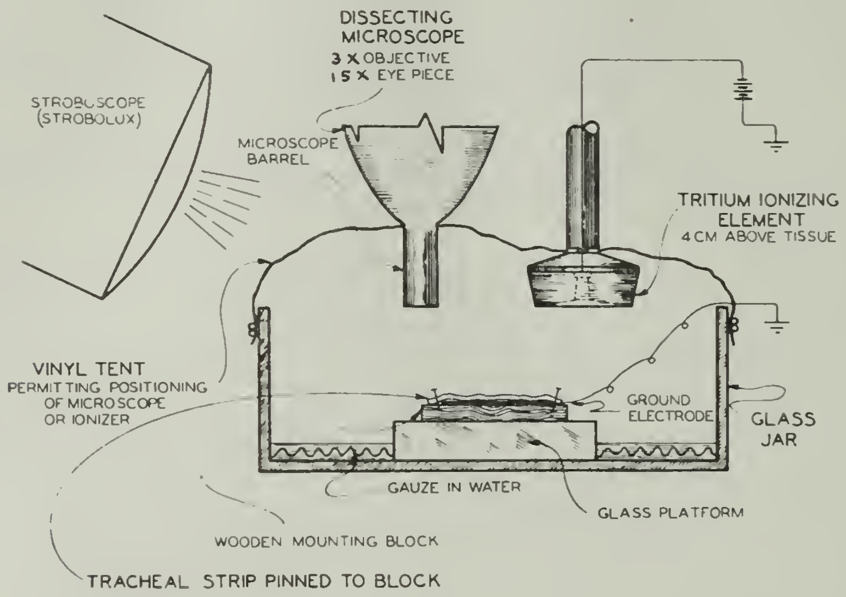


Fig. 1. Chamber for observing effect of air ions on excised tracheal strips

equipped with a reversible rectifying circuit allowing selection of ions of either charge. By watching the ciliary movement while the surface of the tracheal strip was illuminated by a strobolac—strobolux combination it was possible to determine the rate of beat with an accuracy of $\pm$ 50 beats/min. The rate of mucus flow was measured by timing the progress of air bubbles trapped in the mucus film along the grating of an eye-piece micrometer. The general effects (2) observed in excised tracheal strips from rabbits, guinea pigs, mice, and rats are presented in Fig. 2.

In addition it was noted that positive ions:

(1) Caused the membranous posterior wall of the trachea to contract; in this condition the peristaltic wave normally produced by stretching the tissue laterally no longer could be elicited. Here again treatment with negative ions reversed the positive ion effect, the posterior wall relaxed and the peristaltic reflex was re-established.

(2) Dried the mucosal surface. Negative ions either had no effect on the surface or brought about the appearance of a watery fluid.

(3) Rendered the cilia remarkably vulnerable to mechanical trauma. A single, very gentle stroke with a moist cotton-tipped applicator which had no lasting effect on the control completely abolished ciliary activity over the area treated with positive ions. This state of enhanced vulnerability dissapeared

gradually if the strip were permitted to stand in an un-ionized atmosphere for 1 hr or quite promptly if the tissue were treated with negative ions. Subsequently, these experiments were repeated on living rabbits, rats, mice, guinea-pigs and monkeys (3), administering the ions directly to the mucosa through

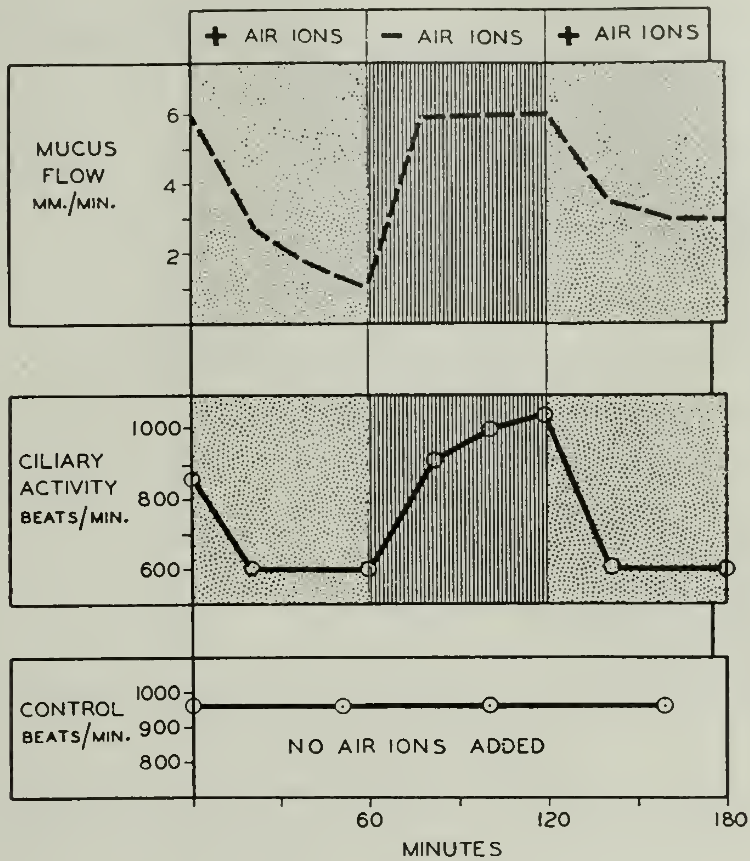


Fig. 2. Effects of air ions on ciliary activity and mucus flow

a tracheotomy aperture (Fig. 3). Positive ions produced the same sort of changes noted in the isolated strip, and, in addition, there was apparent clear-cut evidence of increased irritability of the mucosa. The slightest pressure with a probe produced either a web-like network of dilated capillaries or a disk-shaped ecchymosis in the mucosa of the trachea exposed to positive ions but evoked no such response in non-treated controls or in animals treated with negative ions. This response was especially marked in animals such as the rabbit, whose tracheal walls are characterized by an abundant vascular supply.

The inhalation of moderate densities of air ions by intact (un-oparated) ambulatory mice brought about similar but not identical functional changes (4). With positive ions these consisted of decreased ciliary activity, paleness and contraction of the posterior tracheal wall, and enhanced vulnerability to trauma; there was no clear cut effect on mucus flow. Negative ions increased the rate of ciliary beat but did not alter the flow of mucus.

It was found that an exposure period of 60 min sufficed to initiate these changes and that, once established, they tended to persist. For example, groups of mice were

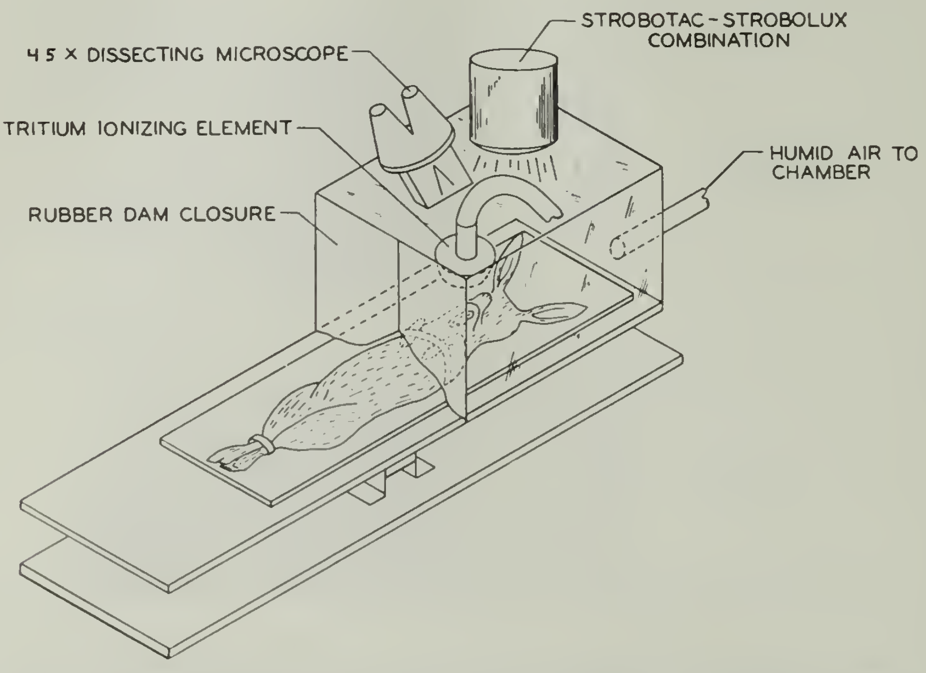


Fig. 3. Arrangement for observing air ion effects on trachea *in situ*

kept in non-ionized and unipolar ionized atmospheres for 3 days; at intervals thereafter individuals were removed, anesthetized with rectally administered pentobarbital, tracheotomized, and the condition of their tracheas studied by the techniques already described. Typical positive and negative air ion effects were uniformly encountered even 4 weeks after exposure to ionized atmospheres, while animals maintained in untreated air showed no changes. This is a rather surprising result for which we can offer no ready explanation, but it occurred so regularly in all the animals studied that we are convinced of its validity.

In experiments such as these all the gaseous components of the atmosphere are subject to ionization and it would be difficult to infer *a priori* which particular gases in ionic form mediated the positive and negative effects. Consequently, a series of tests was conducted on the ciliary activity of tracheal strips, replacing the air in the ionization chamber with various gases (5). Negative ion effects were observed only when oxygen was present; none occurred when the chamber was filled with nitrogen or carbon dioxide (Fig. 4). When conditions for positive ion formation were imposed, typical results were obtained with carbon dioxide and none with nitrogen or oxygen. It was concluded, therefore, that negatively charged oxygen and positively charged carbon dioxide are the mediators of physiological effects occurring in the trachea as a result of atmospheric ionization.

Additional work was done on this subject more recently using living rabbits (6). An area for observing gaseous ion effects was prepared by tracheal fenestration just

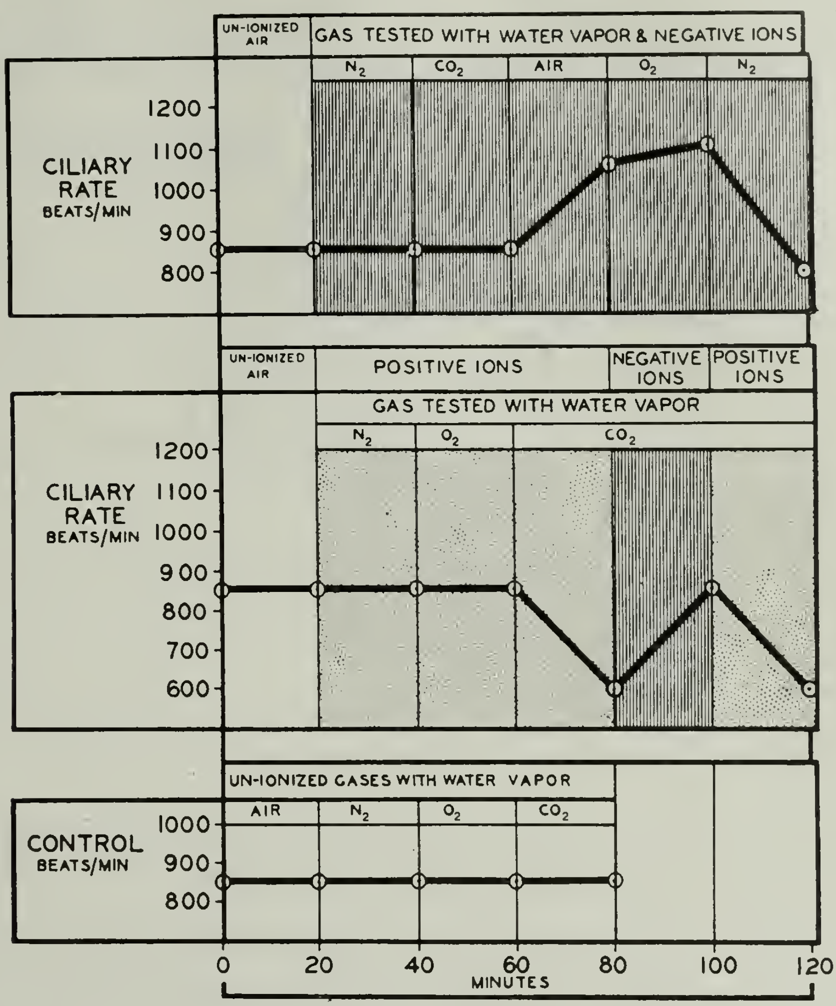


Fig. 4. Ciliary rates in excised tracheal strip with various gases, ionized and un-ionized, filling the exposure chamber

caudal to the larynx. This zone was isolated from the lower trachea, bronchi and lungs by intubating the trachea very close to the manubrium sterni, thus providing a separate airway through which respiration could be carried on while gases such as nitrogen and carbon dioxide filled the upper trachea (Fig. 5). Using an exposure period of 20 min and maintaining a relative humidity of $>$ 90 per cent throughout the experiments it was found that non-ionized nitrogen, oxygen and carbon dioxide had no effect on ciliary activity nor did they elicit the E.V.T. (enhanced vulnerability to trauma) response. Under conditions permitting the formation of negative ions, negatively charged oxygen raised the rate of ciliary beat but did not increase vulnerability to trauma; nitrogen and carbon dioxide were without effect. When the rectifying circuit was reversed to remove negative ions and to send only positive ions through the tracheal window, oxygen and nitrogen produced no changes while positively charged carbon dioxide markedly decreased ciliary activity and evoked a state of E.V.T.

It would appear, then, that direct effects of gaseous ions on individual cells and on tissues can be detected. As we reported at the First Bioclimatological Congress,

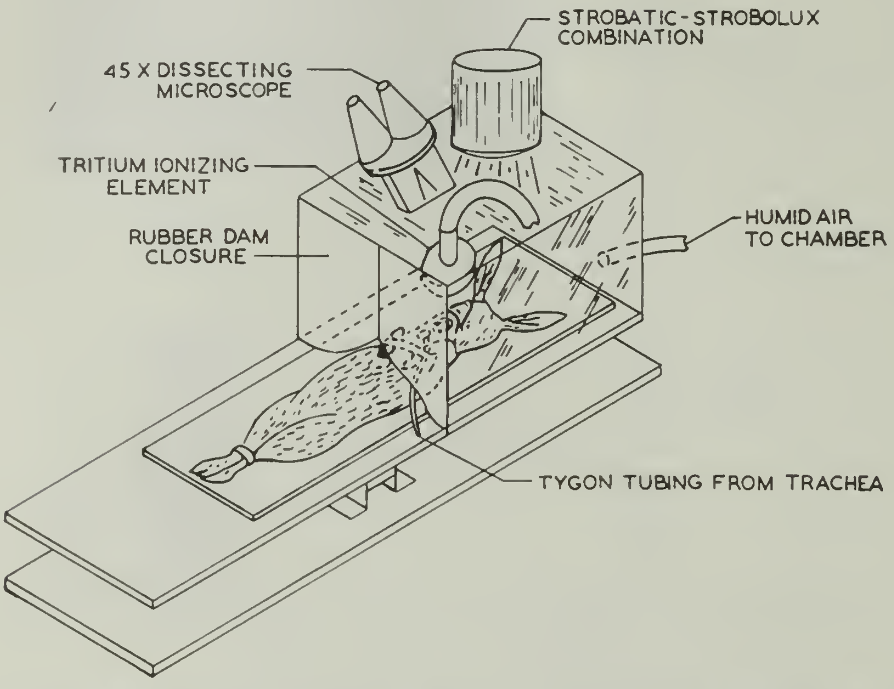


Fig. 5. Arrangement for observing gaseous ion effects on trachea *in situ*, using separate air-way for respiration

in the case of bacteria and molds exposed to ions in clean air the only result demonstrated to date is an increase in the rate of death and this occurs only when the ion content of the air is high. Unipolar ions of either charge produce the same effect. No explanation for the phenomenon has been advanced as yet.

The response of cells organized into tissues is quite different. Positive ions, in general, inhibit activity such as ciliary flicker; they induce the contracture of smooth muscle and enhance vulnerability to trauma. Negative ions accelerate ciliary activity and reverse positive ion effects. How this is brought about is not entirely clear although recent work has made it possible to postulate the biological mechanisms by which negatively charged oxygen and positively charged CO_2 produce their characteristic effects on the mammalian trachea.

All the tracheal effects attributed to (+) air ions can be duplicated by the intravenous injection of 5-hydroxytryptamine (7). Like (+) ion effects, the 5-HT effects can be reversed by treatment with (—) air ions (Fig. 6). On the basis of these facts, it seems reasonable to postulate that (+) air ions are "serotonin releasers", and that a local accumulation of 5-HT in the trachea is the immediate cause of (+) ion effects.

It can further be postulated that (—) air ions reverse (+) ion effects by speeding up the rate at which free 5-HT is oxidized. Like other oxidase systems, monamine oxidase is thought to consist of a dehydrogenase linked to a respiratory chain which may include cytochromes or flavins. Our experiments demonstrating that (—) ions have a direct action on cytochrome oxidase and accelerate the cytochrome-

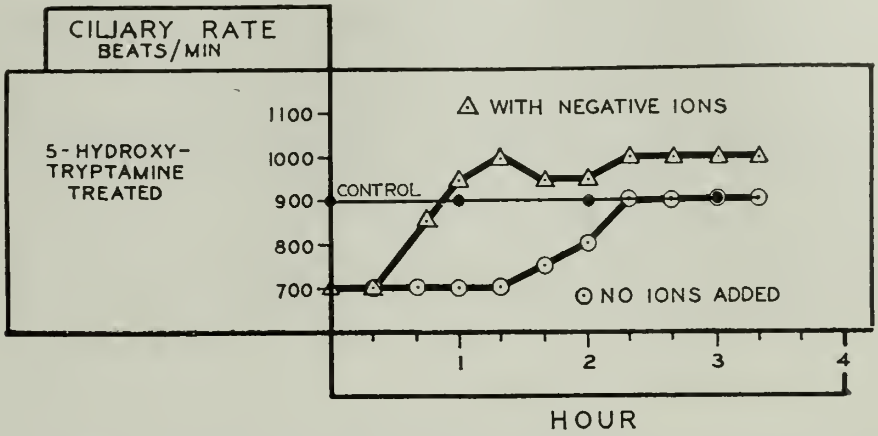


Fig. 6. Effect of 5-hydroxytryptamine on tracheal ciliary rate and reversal of this effect by negative air ions

linked conversion of succinate to fumarate (8) would suggest that this same action may produce a cytochrome-linked oxidation of 5-HT.

Experiments with reserpine and iproniazid provide indirect confirmation of this hypothesis.

Reserpine is believed to cause 5-HT to be momentarily released and then rapidly destroyed by monamine oxidase, so that the tissues are quickly depleted of 5-HT. If our hypothesis is correct, reserpine would produce a condition in the trachea resembling that induced by (—) air ions. Moreover, one would expect (+) air ions to be unable to produce their characteristic effects on a reserpine-treated animal, since the 5-HT necessary for (+) ion action is lacking. Both these expectations have been realized experimentally.

In contrast, iproniazid blocks the enzyme responsible for metabolizing 5-HT, so that an accumulation of free 5-HT develops. One would expect an iproniazid-treated animal to display tracheal effects resembling those produced by (+) air ions and to resist the normal action of (—) ions in reversing these effects. Again both these expectations have been experimentally confirmed.

The hypothesis appears to be borne out by experiments just completed in which negative ions decreased the concentrations of 5-HT in extirpated strips of rabbit trachea and in the respiratory tracts of living mice. An initial exposure of guinea-pigs to (—) air ions caused a transient rise in urinary excretion of 5 hydroxyindole-acetic acid, the specific metabolite of 5-HT.

REFERENCES

1. A. P. KRUEGER, W. WESLEY HICKS and J. C. BECKETT, Effects of unipolar air ions on microorganisms and on evaporation. *J. Franklin Inst.* **266**, No. 1, 9—19 (1958).
2. A. P. KRUEGER and R. F. SMITH, Effects of air ions on isolated rabbit trachea. *Proc. Soc. Exp. Biol., N.Y.* **96**, 807—9 (1957).
3. A. P. KRUEGER and R. F. SMITH, Effects of air ions on the living mammalian trachea. *J. Gen. Physiol.* **42**, 69—82 (1958).
4. A. P. KRUEGER and R. F. SMITH, Parameters of gaseous ion effects on the mammalian trachea. *J. Gen. Physiol.* **42**, 959—69 (1959).
5. A. P. KRUEGER and R. F. SMITH, Effects of gaseous ions on tracheal ciliary rate. *Proc. Soc. Exp. Biol. N.Y.* **98**, 412—14 (1958).
6. A. P. KRUEGER, R. F. SMITH, G. J. HILDEBRAND and C. E. MEYERS, Further studies of gaseous ion action on trachea. *Proc. Soc. Exp. Biol., N.Y.* **102**, 355—7 (1959).
7. A. P. KRUEGER and R. F. SMITH, The biological mechanisms of air ion action—I. 5-Hydroxytryptamine as the endogenous mediator of positive air ion effects on the mammalian trachea. *J. Gen. Physiol.* **43**, 533—40 (1960).
8. A. P. KRUEGER and R. F. SMITH, An enzymatic basis for the acceleration of ciliary activity by negative air ions. *Nature, Lond.* **183**, 1332—3 (1959).

ON THE MECHANISMS OF THE ACTION OF IONIZED AIR ON THE ORGANISM

A. M. SKOROBOGATOVA

Pavlov's Physiological Institute, Academy of Science, Leningrad, U.S.S.R.

Abstract—The possibility of forming a conditioned reflex by reinforcement of a conditioned stimulus with the unconditioned one (aeroionization) shows, that one of the mechanisms of the action of aeroions on the organism is, undoubtedly, the reflex mechanism.

In the experiments with cross-blood circulation, when the donor animal is inhaling ionized air, functional shiftings appear both in the donor and recipient animals.

The latent period of the action of aeroions is longer in the recipient than in the donor animal.

Aeroions exert influence on the functional state not only by means of the reflex mechanism, but also humorally or electrohumorally.

The primary "starting" link in the mechanism of the action of aeroions is the reflex link. The secondary link is the humoral one, i. e. blood with its various products of biochemical and physicochemical reactions.

Résumé—(1) La possibilité de provoquer un réflexe conditionné par le renforcement d'un stimulus conditionné avec un autre non conditionné (aéroionisation) montre que l'un des mécanismes de l'action sur l'organisme est assurément le mécanisme du réflexe.

(2) Dans les essais avec transfusion de sang, lorsque l'animal donneur de sang aspire de l'air ionisé, des déviations fonctionnelles apparaissent aussi bien chez l'animal donneur que chez l'animal receveur de sang.

(3) La période latente de l'action des aéroions est plus longue chez l'animal receveur que chez l'animal donneur de sang.

(4) Les aéroions exercent une influence sur l'état fonctionnel, non seulement sur le mécanisme du réflexe, mais aussi sur l'état humoral et électrohumoral.

(5) Le déclenchement primaire du «trésaillement» dans le mécanisme de l'action des aéroions est le déclenchement du réflexe. L'enchainement secondaire est d'ordre humoral c. à. d. l'action sur le sang avec ses divers effets de réactions biochimiques et physico-chimiques.

Auszug—Die Möglichkeit der Bildung von bedingten Reflexen durch Verstärkung eines bedingten Stimulus mit dem nicht-bedingten (Luftionisation) zeigt, daß einer der Mechanismen der Wirkung von Luftionen auf den Organismus zweifellos der Reflex-Mechanismus ist.

Bei Blutübertragungs-Experimenten wurde festgestellt, daß, wenn das blutspendende Tier ionisierte Luft einatmet, funktionelle Verschiebungen sowohl beim Spender- als auch beim Empfänger-Tier auftreten.

Die latente Periode der Wirkung der Luftionen ist beim empfangenden Tier länger als beim spendenden.

Die Luftionen üben einen Einfluß auf den funktionellen Zustand nicht nur über den Reflex-Mechanismus aus, sondern wirken auch humoral oder elektro-humoral.

Das primäre «Anfangs»-Bindeglied im Mechanismus der Wirkung von Luftionen ist das Reflex-Glied. Das sekundäre Bindeglied ist das humorale, d. h. Blut mit seinen verschiedenen Produkten on biochemischen und physiko-chemischen Reaktionen.

Investigations of long duration carried out by Prof L. L. Vasiliev and his co-workers, as well as by other Soviet and foreign scientists made it possible to assume that aeroions (airborne ions) act on the organism in two ways: (1) electrohumorally; (2) reflectorily (by irritating the interreceptors of the respiratory tract and alveola).

For a clearer understanding of the role of the reflex mechanism we made an attempt to form in rabbits a conditioned reflex using as an unconditioned stimulus negative air ions which, as it was shown, provided rise of cutaneous temperature of these animals.

A radium aeroionizer served as a generator producing light aeroions in the amount of 10^6 per 1 cm^3 of air. The conditioned reflex developed only in rabbits displaying a well-pronounced rise of cutaneous temperature while inhaling negative ions.

As a result of these experiments it has been stated, that a stable conditioned reflex to the rise of cutaneous temperature is established after the twentieth reinforcement of the conditioned stimulus (sound of a bell) by the unconditioned stimulus (aeroions).

The second stage of our experiments consisted in revealing the role of the humoral or electrohumoral mechanism of the action of aeroions on the organism. In order to get an answer to this question, experiments have been carried out on cats with cross-blood circulation. The donor animal was subjected to the action of aeroions, whereas the other animal, the recepient, was fully isolated from their direct action. The changes in the same indices of the functional state of the organism were determined simultaneously in both animals. Shifts of arterial pressure and of the rheobase and chronaxy of the gastroenemic muscle served as such indices.

These experiments enabled us to state, that inhalation of negative aeroions produced marked shifts of the maximum arterial pressure and in the excitability of the neuromuscular apparatus in both the donor and the recipient. A two-phase alteration of arterial pressure, observed by us in the course of the experiment on negative aeroionization, is a characteristic peculiarity. In some experiments the two-phase alteration of arterial pressure was observed only in the recipient, the first transitory rise of pressure being absent in the donor. Alterations of blood pressure and chronaxy in both animals, taking place in result of inhalation of ionized air were of regular character, though the absolute values of the alterations were insignificant.

It is known that the effectivity of the action of aeroions on the organism is stronger if its physiological norms are disturbed. To make our conditions more convincing, we undertook a series of experiments in which we disturbed the level of arterial pressure by means of an extraneous agent, e.g. adrenaline, provoking a rise of the arterial pressure. Injections of adrenaline soon altered the level of arterial pressure in both animals. Against the background of the action of negative aeroions the injection of the same dose of adrenaline led to smaller shifts in the level of arterial pressure in both animals.

The functional shifts observed in the donor animal during the inhalation of ionized air probably take place, first of all, as a result of the irritation (or at least of the intensification of the excitability) of the sensitive terminations of centripetal fibres in the pulmonary branches of the vagus nerve. The arising impulses are directed towards the nerve centres, altering their functional state and through them, by way of subordination, influence the various organs and systems of the organism, in particular, the working of the cardiovascular system. Yet the functional changes occurring in the recipient animal cannot be explained by means of this purely reflex mechanism. No doubt, aeroions act upon the organism humorally, and, possibly, electrohumorally.

It is known that the physiological action of aeroions is extensive. It involves a series of functions of individual organs and systems of humans and animals. Inhalation of aeroions provokes also changes in biochemical and physicochemical reactions (Vasiliew and Goldenberg, 1943; Landa-Glaz, 1934; Ivanov, 1939; Kamenev 1939; Bulatov, 1951; Nielsen and Harper, 1954; Worden, 1954; Kornblueh and Griffin, 1955; Hicks, 1956).

In the course of the experiments on aeroionization, the products of these reactions penetrate through blood from the donor- into the recipient animal, provoking in him functional shifts. Thus, the changes in arterial pressure and chronaxy observed by us in the recipient animal, could not be induced by means of the reflex mechanism but must be induced through blood, i.e. humorally or electrohumorally.

PHYSICOCHEMICAL STATE OF THE BLOOD

ZUR FRAGE DES UMWELTEINFLUSSES AUF DEN PHYSIKALISCH-CHEMISCHEN ZUSTAND DES BLUTES UND DIE PRAKTISCHE BEDEUTUNG IN DER KLINIK

D. ASSMANN

Dr. med. Dietmar Assmann, Medizinische Klinik, Medizinische Akademie, Dresden, Deutschland (D.D.R.)

Abstract—The day-to-day fluctuations in the clottability of blood and in the composition of serum albumin were studied by various methods. Proof has been obtained of meteorological—biological influence. The practical importance on clinical findings is explained on several examples.

Résumé—Les variations de jour en jour du taux de coagulation du sang ainsi que les variations de la composition des corpuscules de sérum-albumine ont été étudiées au moyen de diverses méthodes utilisant des tests. Les influences météorobiologiques ont été mises en évidence. La signification pour le clinicien a été illustrée par plusieurs exemples.

Auszug—Die von Tag zu Tag auftretenden Schwankungen der Gerinnungsaktivität des Blutes sowie die Schwankungen der Zusammensetzung der Serumeiweisskörper wurden mit Hilfe verschiedener Test-Methoden untersucht. Meteorobiologische Einflüsse wurden nachgewiesen. Die praktische Bedeutung für die Klinik wird an mehreren Beispielen erläutert.

Fragt man sich nach dem Angriffspunkt biotroper Faktoren und dem Wirkungsmechanismus im Inneren des Organismus, so wird man zwangsläufig auf physikalisch-chemische Vorgänge im Körper gelenkt, die das Bindeglied zwischen Umwelteinfluss und äusserlich sichtbarer Reaktion des Organismus, also das Bindeglied zwischen Ursache und Wirkung, darstellen. Die physikalischen und chemischen Faktoren unserer Umwelt müssen in diese physiko-chemischen Vorgänge im Körper eingreifen. Unser Wissen über diese Primärvorgänge im Gewebe ist aber noch sehr lückenhaft. Nur in einigen Fragen, z. B. der Strahlenbiologie, haben wir gewisse Vorstellungen über die Primärvorgänge im atomaren Bereich, z. B. über die "Anregung" von Atomen und über Ionisierungsvorgänge. Erst an die Primärvorgänge schließen sich sekundär physikalisch-chemische Veränderungen an, die weiter zum biologischen Effekt, zur Beeinflussung des Stoffwechsels und des vegetativen Nervensystems führen. So kann es durch den Einfluß biotroper Umweltfaktoren auch zu Veränderungen des physikalisch-chemischen Zustandes des Blutes kommen. Die

Erfassung derartiger Veränderungen ist natürlich von theoretischem Interesse, da sie uns den Weg weisen zur Aufdeckung des Wirkungsmechanismus und damit der höheren Zusammenhänge. Die Erfassung ist aber auch jetzt schon von erheblicher praktischer Bedeutung, da ein großer Teil der Blutbestandteile täglich in den klinischen Laboratorien mit Hilfe chemischer Methoden untersucht wird. Die Ergebnisse dieser Untersuchungen bilden eine wichtige Unterlage zur Diagnose-Stellung und zur Beurteilung des Krankheitsverlaufes. Wenn man weiß, wie und in welchem Ausmaß die Ergebnisse medizinisch-chemischer Untersuchungen durch Umwelteinflüsse beeinflußt werden können, kann man häufig etwas unklar erscheinende Befunde besser beurteilen und auch eine fehlerhafte Bewertung der Ergebnisse und eine fehlerhafte Beurteilung des Krankheitsverlaufes vermeiden.

Die praktische Bedeutung der durch die Umwelteinflüsse hervorgerufenen von Tag zu Tag auftretenden Schwankungen wichtiger Blutbestandteile soll an einigen Beispielen erläutert werden, und zwar an den Schwankungen der Gerinnungsaktivität des Blutes und an den Schwankungen der Zusammensetzung der Serumeiweißkörper.

Sowohl bei der Differentialdiagnose hämorrhagischer Diathesen, als auch bei der Behandlung mit Antikoagulantien spielt die Untersuchung der Blutgerinnung mit Hilfe verschiedener Testmethoden eine große Rolle. Bei derartigen Untersuchungen beobachteten wir öfters von Tag zu Tag auftretende Schwankungen der Meßwerte, die häufig das Mehrfache der methodischen Fehlerbreite betrugen. Auffallend war, daß sich die Werte der verschiedenen Patienten meistens in der gleichen Richtung änderten, obwohl die Untersuchungsbedingungen (Temperatur, Blutentnahme nüchtern jeden Tag zur gleichen Zeit) konstant gehalten wurden.

Um genauere Einblicke in die Schwankungen der Gerinnungsaktivität des Blutes und deren Ursachen zu erhalten, wurden an unserer Klinik größere Untersuchungsreihen durchgeführt (4). Hierbei wurden vor allem Methoden angewandt, die im klinischen Laboratorium als Routinemethoden gebräuchlich sind, und zwar die Prothrombinzeitbestimmung, die Bestimmung der Rekalzifizierungszeit, der Heparintoleranztest und das Zählen der Thrombocyten.

Abb. 1 zeigt die graphische Darstellung der Rekalzifizierungszeiten von acht gesunden Versuchspersonen im Verlauf von 28 Tagen. Man sieht deutlich, daß die Rekalzifizierungszeiten der einzelnen Versuchspersonen von einem Tag zum anderen grossen Schwankungen unterworfen sind. Auffallend ist ferner der gleichsinnige Kurvenverlauf bei allen Versuchspersonen, der an Tagen mit größeren Abweichungen vom individuellen Mittelwert besonders deutlich hervortritt und auf einen Umwelteinfluß hindeutet.

Entsprechend verhielten sich auch die Meßwerte der übrigen Blutgerinnungsuntersuchungen. Dies geht aus Abb. 2 hervor. Dargestellt ist hier der Verlauf der Mittelwerte der täglichen Messwerte von 8 gesunden Versuchspersonen von Prothrombinzeit, Heparintoleranztest, Rekalzifizierungszeit und Thrombocytenzahl für den gleichen Zeitraum wie in Abb. 1. Auch bei den Mittelwerten kommen die zum Teil erheblichen Schwankungen zwischen den Tagen deutlich zum Ausdruck.

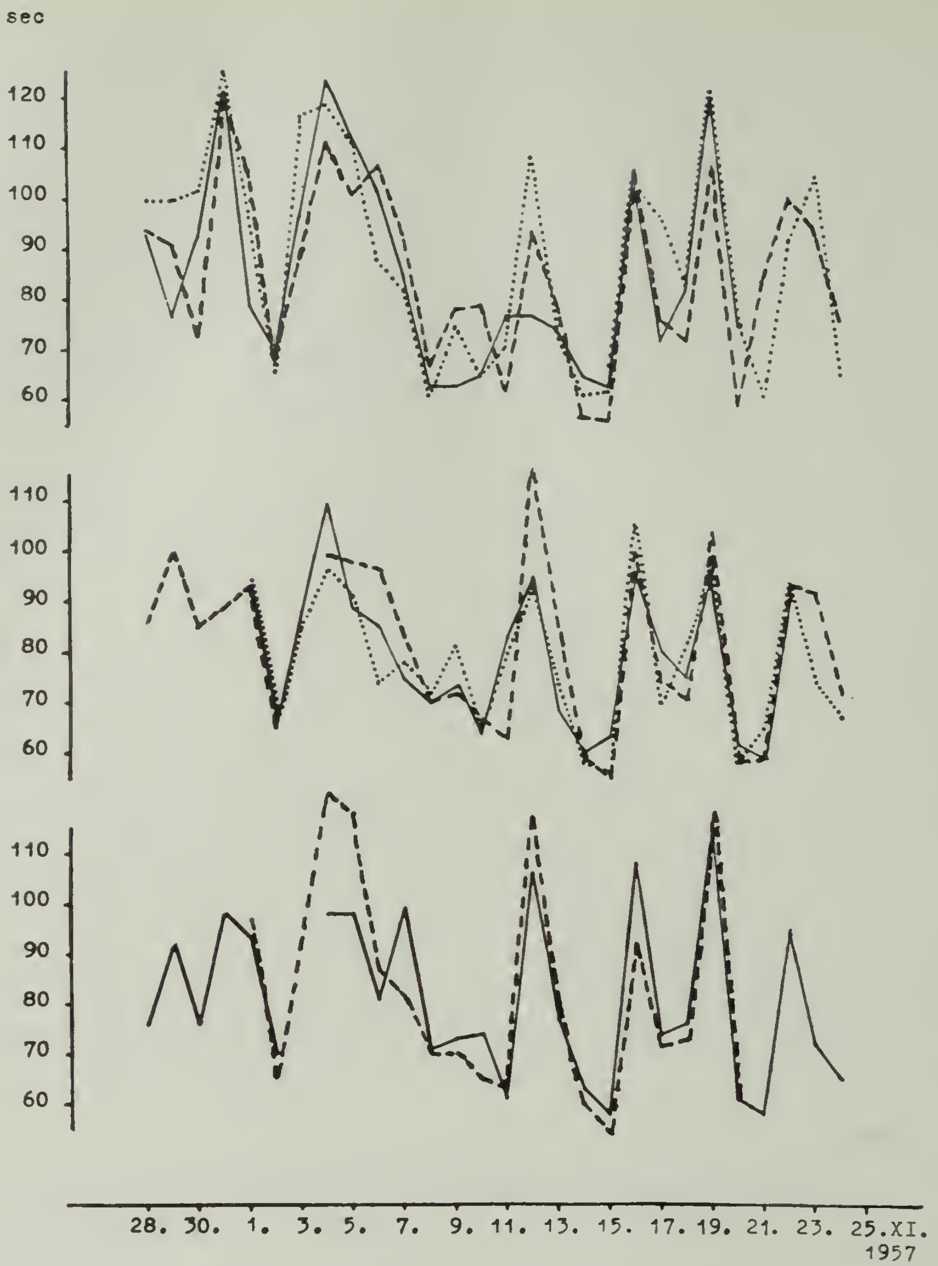


Abb. 1. Rekalzifizierungszeiten bei 8 gesunden Versuchspersonen im Verlauf von 28 Tagen.

Abb. 3 zeigt den Verlauf der prozentualen Abweichung der Tagesmittel der Messwerte vom Periodenmittel bei den oben erwähnten Testen und bei zwei weiteren Meßreihen mit 2 gerinnungshemmenden Substanzen, mit Thrombocid und Thrombo-Holzinger-Reagenz. Man sieht auch hier, daß die Gerinnungszeiten gleicher Kollektive beachtliche interdiurne Schwankungen zeigen, die zuweilen um 30 bis 50% vom Periodenmittel abweichen können, ohne daß hierfür pathologische Vorgänge verantwortlich zu machen wären.

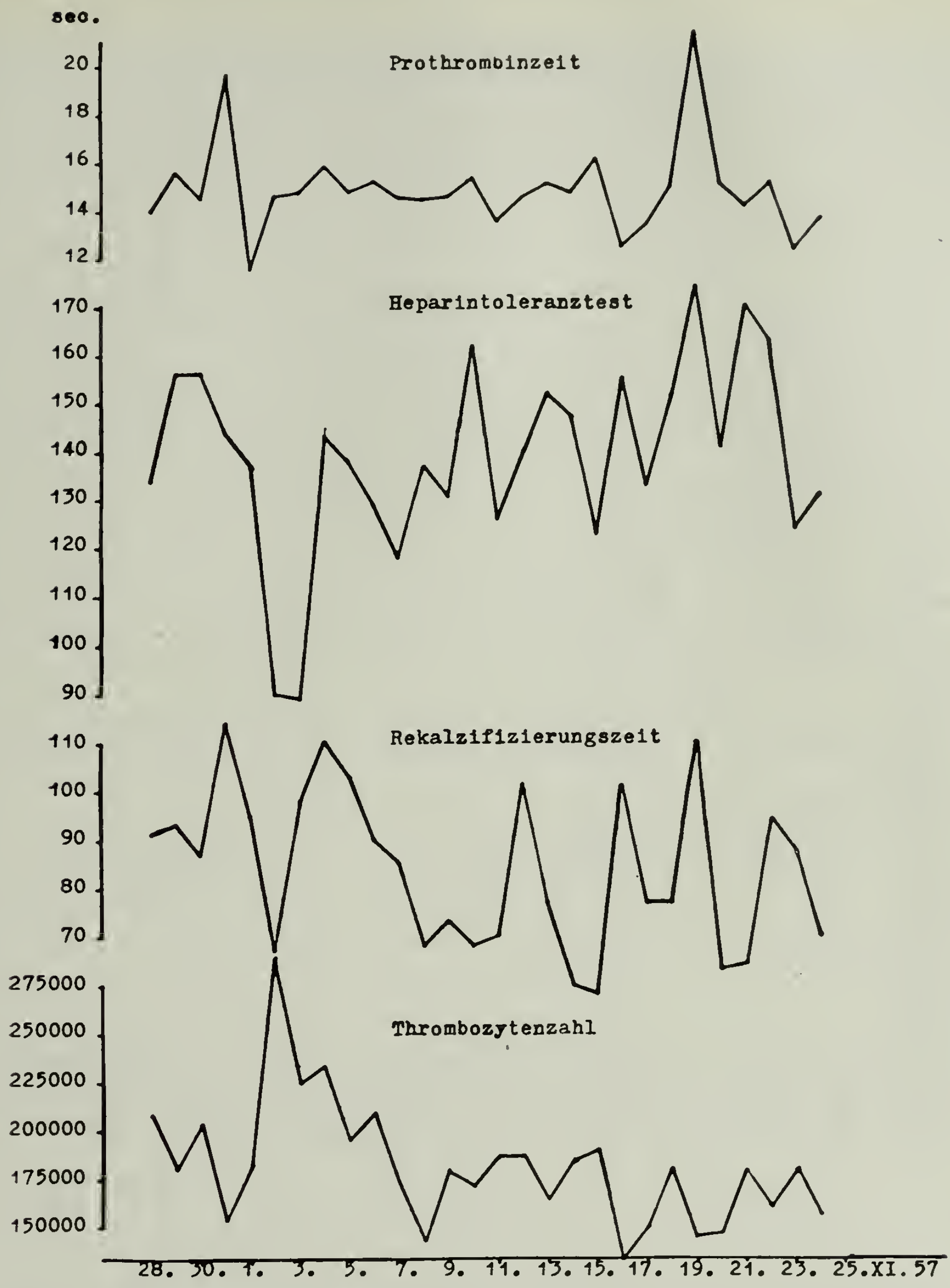


Abb. 2. Mittelwerte der täglichen Meßwerte von 8 gesunden Versuchspersonen (Zeitraum wie in Abb. 1)

Die statistische und meteorobiologische Bearbeitung erfolgte in Zusammenarbeit mit Dr. W. Warmbt, dem Leiter der Bioklimatischen Forschungsstation, Dresden-Wahnsdorf, mit dem wir seit einigen Jahren besonders über Fragen von Umwelteinflüssen auf medizinisch-chemische und klinische Untersuchungen zusammenarbeiten (1).

Die statistische Auswertung der vorliegenden Meßreihen der Gerinnungsaktivität des Blutes mit Hilfe der doppelten Streuungszerlegung ergab, daß in allen Versuchsabschnitten bei allen Testen zwischen den Tagesmitteln statistisch gesicherte Unterschiede bestehen, was auf einen Umwelteinfluß hindeutet.

Die Bestimmung der Variabilitätsanteile zeigte, daß der grősste Teil der Unterschiede der Meßwerte bei den einzelnen Testen auf die Unterschiede zwischen den

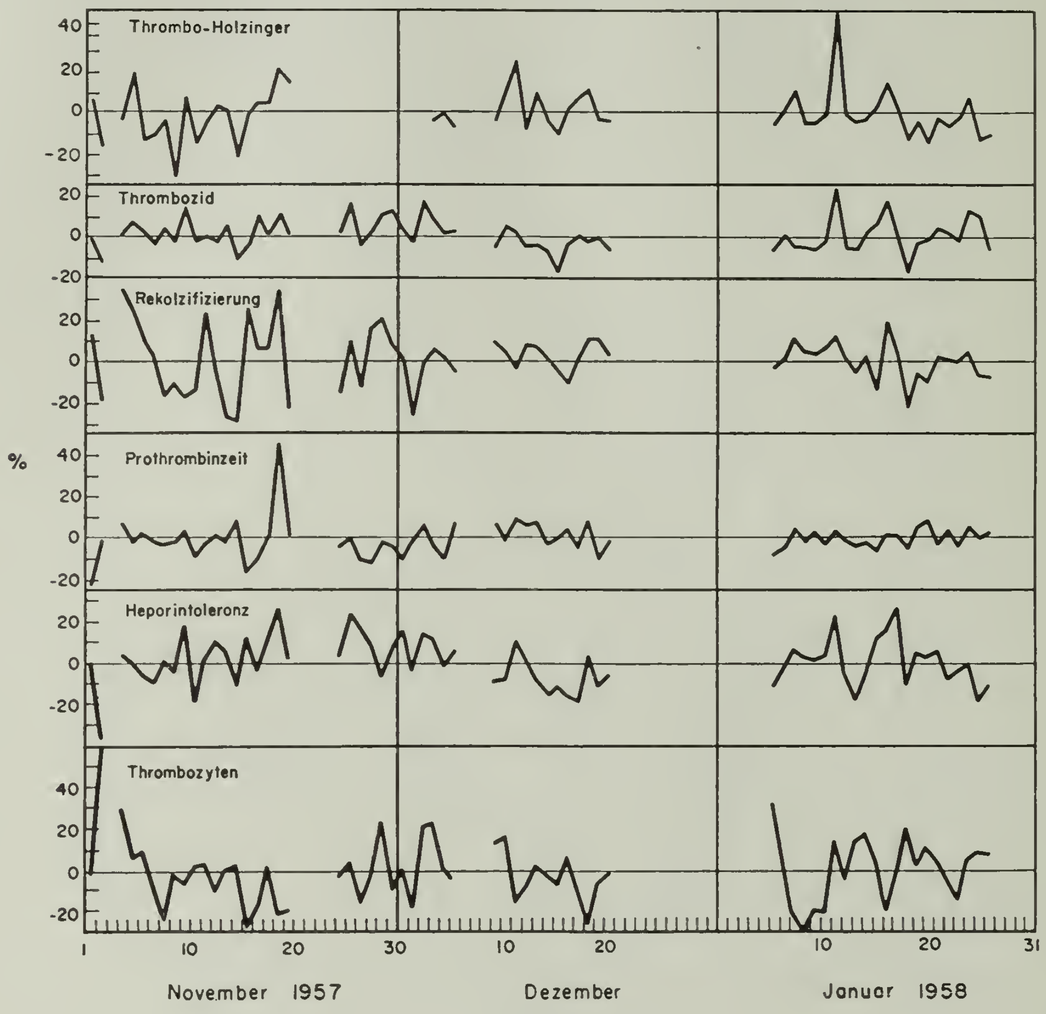


Abb. 3

Tagen zurückgeführt werden kann, nicht, wie man annehmen könnte, auf die Unterschiede zwischen den Versuchspersonen. So entfielen z.B. bei der Rekalzifizierungszeit, bezogen auf die Gesamtvariabilität von 100 %, in einem Versuchabschnitt 83,71 % auf die Variabilität zwischen den Tagen, 1,36 % auf die Variabilität zwischen den Probanden und 14,93 % waren als sogenannte Restvariabilität durch nicht näher bekannte Ursachen bedingt.

Nun kann man schon aus Abb. 2 ersehen, daß zwischen den Tagesmitteln der verschiedenen Teste gewisse Zusammenhänge bestehen. Die statistische Untersuchung auf korrelative Zusammenhänge zwischen den Tagesmitteln ergab auch erwartungsgemäß ein gleichsinniges Verhalten der mit den verschiedenen Methoden ermittelten Gerinnungszeiten und einen gegensinnigen Kurvenverlauf von Thrombocytenzahl und Rekalzifizierungszeit. Die Korrelationen sind mit $P = 1\%$ gesichert. Dagegen zeigte die Kombination von Prothrombinzeit mit Thrombocytenzahl und Rekalzifizieruugszeit keinen gesicherten Zusammenhang, was sich aber theoretisch leicht erklären läßt (1). Die Unsicherheit der Korrelationen zwischen Prothrombinzeit und Blutgerinnungszeit entspricht auch der klinischen Erfahrung, weshalb es zweckmäßig ist, bei der Antikoagulantientherapie die Bestimmung der Prothrombinzeit durch eine Bestimmung der Blutgerinnungszeit zu ergänzen.

Da man nun nach den vorliegenden Ergebnissen eine Meteorotropie der Gerinnungsaktivität des Blutes beim Menschen annehmen mußte, und da Caroli und Pichotka (2) im Tierexperiment an Kaninchen einen Zusammenhang zwischen Blutgerinnungszeiten und Frontendurchgängen gefunden hatten, haben wir auch unsere Meßreihen auf einen Zusammenhang mit Frontendurchgängen hin untersucht. Ein Zusammenhang mit Frontendurchgängen konnte allerdings nur bei der Rekalzifizierungszeit statistisch gesichert werden. Das besagt natürlich nicht etwa, daß ein meteorologischer Einfluß auf die anderen Teste gar nicht vorhanden ist, nur läßt er sich, jedenfalls für Frontendurchgänge, mit statistischen Methoden eben nicht beweisen. Aber die Wirkung von Tag zu Tag wechselnder exogener Einflüsse erkennt man ja daran, daß bei allen Testen zwischen den Tagesmitteln statistisch gesicherte Unterschiede bestehen; and auch die gesicherten Korrelationen zwischen den verschiedenen Testen lassen ein Ansprechen auch der anderen Teste auf exogene Einflüsse erkennen. Daß sich gerade bei der Rekalzifizierungszeit ein Fronteneinfluß statistisch nachweisen ließ, könnte daran liegen, daß für die anderen Teste, zur Bestimmung der Prothrombinzeit, zur Durchführung des Heparintoleranztestes, zur Untersuchung mit Thrombo-Holzinger und Thrombocid außer $CaCl_2$ noch Zusätze erforderlich sind, die als zusätzlicher Unsicherheitsfaktor gewertet werden können.

Schwankungen der Gerinnungsaktivität des Blutes können während einer Behandlung mit Antikoagulantien mitunter zu verhängnisvollen Folgen führen; denn wenn durch einen Wettereinfluß die Gerinnungsaktivität des Blutes gesenkt, die Gerinnungszeit also verlängert wird, kann es unter einer Behandlung mit Antikoagulantien plötzlich zu einer Blutung kommen, wenn der Quick-Wert vor dem Absinken nur knapp oberhalb der unteren Grenze lag. Wird andererseits die Gerinnungszeit durch einen Wettereinfluss vorübergehend verkürzt, so kann man sich hierdurch zu einer nicht nötigen Erhöhung der Antikoagulantiendosis verleiten lassen. Nach Abklingen der gerinnungsfördernden Wetterlage kann dann leicht eine Blutung auftreten, weil die Gerinnungsaktivität des Blutes dann unter den zulässigen Wert gesenkt wird. Es ist deshalb ratsam, wie auch Zürn (7) betont hat, den Quick-Wert bei der Behandlung mit Antikoagulantien nicht bis knapp an die untere Grenze zu senken, sondern ihn etwas höher einzustellen.

Wie man sieht, kann man bei der Behandlung mit Antikoagulantien die gewonnenen Erkenntnisse über die Wirkung von Umwelteinflüssen auf die Gerinnungsaktivität des Blutes in der Praxis am Krankenbett erfolgreich anwenden und hierdurch Zwischenfälle bei der Behandlung mit Antikoagulantien vermeiden.

Das zweite Beispiel, an dem wir die praktische Bedeutung der Wirkung von Umwelteinflüssen auf das Blut erörtern wollen, betrifft die Pathologie der Serumeiweißkörper. Die Untersuchung der Serumeiweißkörper mit Hilfe der Serumlabilitätsproben und der Serumelektrophorese spielt heute im klinischen Laboratorium eine große Rolle. Schon verhältnismäßig leichte Parenchymschädigungen der Leber lassen Verschiebungen im Spektrum der Serumeiweißkörper erkennen und führen bekanntlich zu einer Zunahme der grobdispersen Globuline auf Kosten der feindispersen Albumine. In den letzten Jahren haben nun die Erkrankungen an Hepatitis epidemica, die als typische Saisonkrankheit mit Gipfel von September bis Oktober auftritt, erheblich zugenommen. Für die Diagnose, Differentialdiagnose und für die Verlaufsbeurteilung der Hepatitis epidemica spielen die Serumlabilitätsreaktionen eine große Rolle. Wir machten nun die Beobachtung, daß die Werte der Thymol-Trübungsreaktion bei ein und demselben Patienten öfters von Tag zu Tag auftretende Schwankungen zeigen, die im stärker pathologischen Bereich besonders deutlich zum Ausdruck kommen und das Mehrfache der Fehlerbreite der Bestimmungsmethode betragen können. Auffallend war, daß sich die Werte der verschiedenen Patienten häufig in der gleichen Richtung änderten, obwohl auch bei diesen Untersuchungen die Bedingungen (Temperaturkonstanz, Blutentnahme nüchtern jeden Tag zur gleichen Zeit usw.) konstant gehalten wurden. Somit waren auch die von einigen Autoren für Schwankungen der Serumeiweißkörper angeschuldigten Einflüsse der Nahrungsaufnahme und des tageszeitlichen Rhythmus ausgeschaltet worden.

Um unsere Beobachtungen statistisch zu sichern, und den möglichen Ursachen nachzugehen, wurden an unserer Klinik größere Untersuchungsreihen durchgeführt (6), wobei täglich gleichzeitig bei meist 10 an Hepatitis epidemica erkrankten Patienten die Thymol-Trübungswerte bestimmt wurden. An insgesamt 71 Tagen wurden 629 Einzelbestimmungen vorgenommen. Die Werte wurden mit dem Pulffrich-Stufenphotometer ermittelt. Da bei dem größten Teil der Messungen die Werte während des Beobachtungszeitraumes abnahmen, was sich aus einer Besserung der Krankheit der Patienten in dieser Zeit erklärte, wurde für die statistische Auswertung die von Gebelein (3) angegebene Methode der gleitenden Durchschnitte angewandt und so der zeitliche Verlauf der Thymol-Trübungswerte, die sogenannte «Trendlinie», herausgearbeitet und die auf den Trend bezogene Streuung errechnet.

Die praktische Bedeutung der festgestellten Schwankungen der Werte der Thymol-Trübungsreaktion geht deutlich aus Abb. 4 hervor. Sie zeigt die graphische Darstellung der Ergebnisse der Bestimmungen der Thymol-Trübungswerte von 8 Personen im Zeitraum von 14 Tagen. Eingezeichnet sind außer den Beobachtungswerten die sog. Trendlini - - - - - und die den Trend bezogene Streuung (. . . . . .). Auffallend sind die bei einigen Versuchspersonen auftretenden starken Schwankungen der Thymol-Trübungswerte von einem Tag zum anderen. So sind z. B. bei der zweiten Versuchsperson innerhalb von 2 Tagen, vom 10.11.57. bis 12.11.57, die Thymol-Trübungswerte um vier Einheiten gefallen, stiegen jedoch am folgenden Tage, am 13.11.57, wieder um drei Einheiten an, so daß die Trendlinie praktisch unverändert verläuft. (Ein Extinktionswert von 0,04 entspricht bei uns einer Thymol-Trübungseinheit.)

In der Klinik werden die Kontrollen der Thymol-Trübungswerte im Verlauf einer Hepatitis gewöhnlich vierzehntägig bezw. aller drei Wochen vorgenommen. Die festgestellten Änderungen der Thymol-Trübungswerte werden dann zuweilen nicht

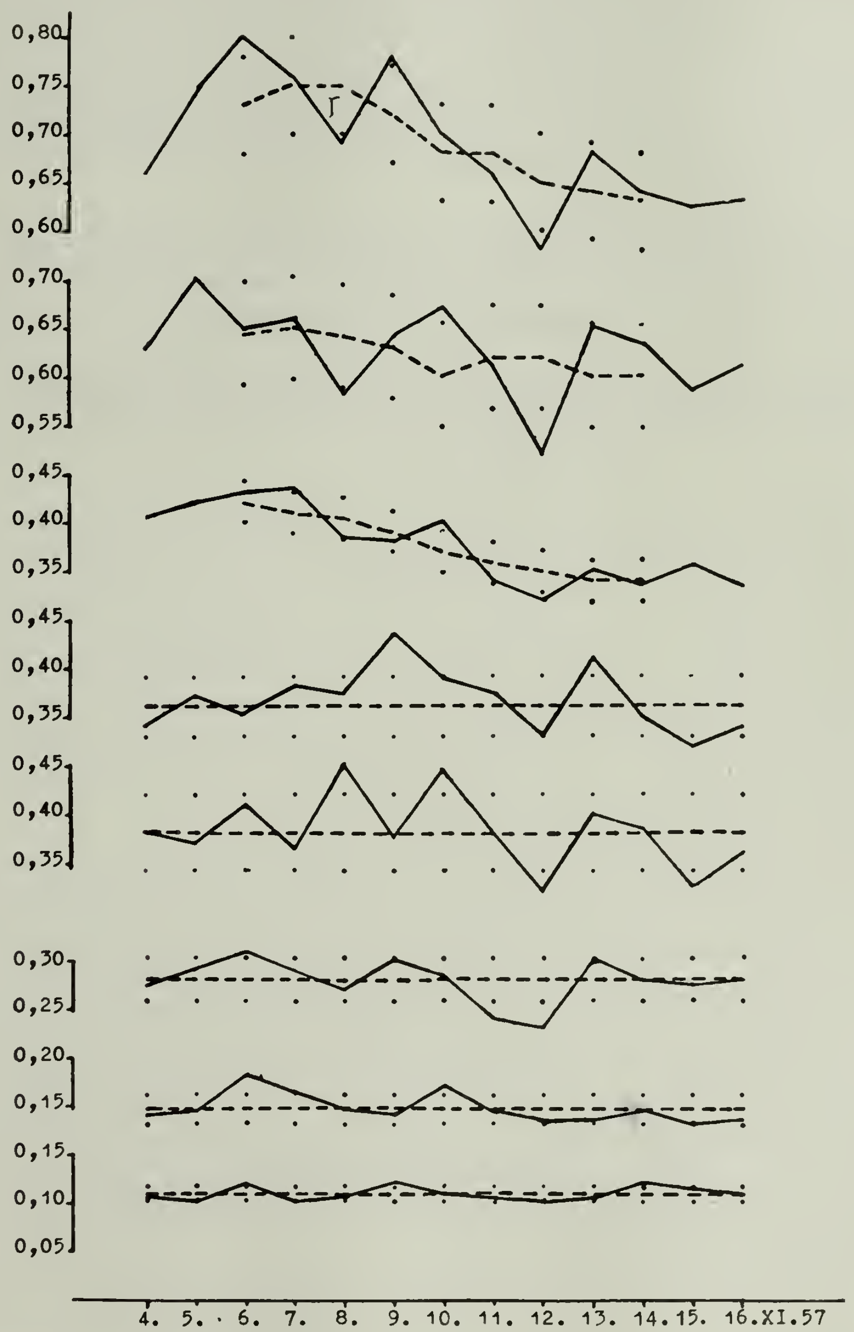


Abb. 4. Thymol-Trübungswerte von 8 an Hepatitis epidemica Erkrankten im Verlauf von 13 Tagen

ganz richtig eingeschätzt, da bisher zu wenig bekannt ist, daß die Ergebnisse der Thymol-Trübungsreaktion wie auch anderer medizinisch-chemischer Untersuchungen oft durch exogene Faktoren beeinflußt werden und deshalb nicht unbeträchtliche Schwankungen von einem Tag zum anderen zeigen können. Häufig warten auch die Patienten gespannt auf das Ergebnis der Kontrolluntersuchung und sind deprimiert, wenn die Werte um 1 bis 2 Einheiten angestiegen sind. Bei Abfall dagegen sind sie oft zu optimistisch, und bei der nächsten Kontrolle folgt dann eine Enttäuschung.

Auffallend sind in Abb. 4 die Thymol-Trübungswerte am 12.11.57. Sie waren alle gegenüber dem Vortag stark abgefallen und lagen alle unterhalb der um den Trend errechneten Streuungsbreite. Meteorologisch war am 12.11.57 eine Kaltfrontpassage zu verzeichnen.

Die meteorobiologische Bearbeitung des gesamten Untersuchungsmaterials auf Grund der meteorologischen Daten des Meteorologischen Observatoriums in Dresden-Wahnsdorf ergab zwischen den außerhalb der Streuung liegenden Thymol-Trübungswerten und Frontenpassagen insgesamt eine Korrelation mit einer Überschreitungswahrscheinlichkeit von 1,8%, für Kaltfrontpassagen von 2,1%.

Ebenso wie bei der Thymol-Trübungsreaktion kann man auch bei der Serumelektrophorese von einem Tag zum anderen auftretende Verschiebungen im Spektrum der Serumeiweißkörper feststellen. In mehreren Versuchsreihen haben wir jeweils bei ein und derselben Person Schwankungen der Elektrophoresewerte beobachtet, die beim γ-Globulin häufig 4%, aber auch 5 bis 6% betrugen. Es kann also zuweilen vorkommen, daß man, z.B. bei einer Leberparenchymschädigung mit im Mittel gering erhöhten γ-Globulinwerten, bei einer einmaligen Untersuchung ein normales Elektropherogramm erhält, weil die γ-Globulinfraktion zufällig am Untersuchungstage um einige Prozent, bis in den Normalbereich hinein, abgesunken war. Eine Wetterabhängigkeit der Serumeiweißfraktionen beim Menschen ist bereits von Prager, *et al.* (5) nachgewiesen worden.

Zweck der Ausführungen sollte es sein, zu zeigen, daß Änderungen im physikalisch-chemischen Zustand des Blutes, die durch biotrope Umwelteinflüsse hervorgerufen werden können, nicht nur von theoretischem Interesse sind, sondern daß ihrer Erforschung auch eine nicht unbeträchtliche praktische Bedeutung in der Klinik zukommt. Wenn man weiß, welche medizinischen Untersuchungen durch Umwelteinflüsse in nennenswertem Ausmaß beeinflußt werden und wie groß die Unterschiede der bei ein und demselben Patienten an verschiedenen Tagen erhaltenen Ergebnisse dieser Untersuchungen sein können, kann man, wie anfangs schon gesagt wurde, etwas unklar erscheinende Befunde oft besser beurteilen und auch eine fehlerhafte Bewertung der Ergebnisse und somit eine fehlerhafte Beurteilung des Krankheitsverlaufes vermeiden.

LITERATUR

1. Assmann D., H. Kiessling, W. Warmbt, Zur Frage der Variabilität der Ergebnisse klinischer Blutgerinnungsuntersuchungen. *Z. ges. Inn. Med.* (Im Druck.)
2. Caroli G. und J. Pichotka, Beeinflussung der normalen Blutgerinnungszeit durch das Wetter. *Naturwissenschaften* **39,** 193—5 (1952); Untersuchungen zur Beziehung zwischen Blutgerinnung und Wetter. *Arch. Met. Geoph. Biokl., Wien* B **5,** 403—12 (1954).
3. Gebelein H. und H. J. Heite, *Statistische Urteilsbildung. Erläutert an Beispielen aus Medizin und Biologie.* Springer Verlag, Berlin, Göttingen, Heidelberg (1951).
   Gebelein H., Anwendung gleitender Durchschnitte zur Herausarbeitung von Trendlinien und Häufigkeitsverteilungen. *Mitt. math. Stat.* (Herausgeber: Dsche. Stat. Ges. München) **3,** 1, 45—68 (1951).
4. Kiessling H., Interdiurne Schwankungen der Blutgerinnung. Diss. Dresden, Med. Akad. (1960).
5. Prager Fr., Fr. Schedel und H. Ungeheuer, Eiweißfraktionen und Wetter. *Langenbecks Arch. u. Dtsch. Z. Chir., Berlin, Göttingen. Heidelberg* **275,,** 5/6, 431—7 (1953).
6. Rosahl W., Über meteorologische Einflüsse auf den quantitativen Ausfall der Thymol-Trübungsreaktion bei an Hepatitis epidemica Erkrankten. Diss. Dresden, Med. Akad. 1960.
7. Zürn H., Untersuchungen zum Problem des „Normalvergleichsplasmas“ bei der Thromboplastinzeit. Bestimmung nach Quick, *Ärztl. Forschung, München* **14,** 30—6 (1960).

ZOOLOGICAL (ENTOMOLOGICAL) BIOCLIMATOLOGY

APPLICATION OF TEMPERATURE AND RELATIVE HUMIDITY SIMULATION TECHNIQUES TO INSECT DISTRIBUTION PROBLEMS

N. E. FLITTERS

*Bioclimatic Chamber Unit, Entomology Research Div. A.R.S., P. O. Box 1033, Brownsville, Texas, U.S.A.

Abstract—Specially designed bioclimatic cabinets wherein temperature can be controlled from −5° to 125°F, and relative humidity controlled concomitantly through a range of from 10 to 98 per cent were used to simulate fluctuating patterns of temperature and relative humidity of selected areas in the United States to determine their influence on the potential distribution, development, and reproduction of four fruit fly species.

Résumé—Des cabines bioclimatiques spéciales dans lesquelles la température est susceptible d'être contrôlée entre −5° et 125° F, en même temps que l'humidité relative pour des valeurs comprises entre 10% et 98% ont été utilisées pour reproduire des types variables de température et d'humidité relative de zones choisies dans les États-Unis, afin de déterminer leur influence sur la distribution virtuelle, le développement et la reproduction de 4 espèces de mouches à fruit.

Auszug—Es wurden besonders konstruierte Kästen, in denen die Temperatur von −5° bis 125° F, und die relative Feuchtigkeit gleichzeitig über einen Bereich von 10 bis 98 Prozent geregelt werden kann, benutzt, um fluktuierende Muster von Temperatur sowie relativer Feuchtigkeit von bestimmten Gebieten der Vereinigten Staaten zu simulieren, u.zw. zwecks Feststellung des Einflusses dieser Faktoren auf die Verteilung, Entwicklung und Vermehrung von vier Frucht-Fliegen Arten.

DEVELOPMENT in laboratory studies of criteria for determining agricultural areas that may be favorable for recently introduced insect pests, or those that threaten from foreign areas, is complicated by the fact that neither the magnitudes nor intensities of factors regulating biological processes are ever constant. Temperature, relative humidity, and light fluctuate irregularly in patterns of 24 hr periodicity and these are not uniformly repetitive. Other factors also vary through time. The collection of significant climatological data for programming and the accurate simulation thereof have presented a challenging problem.

The purpose of this brief paper is to review the progress made in co-operative studies in Honolulu, Hawaii, and Brownsville, Texas, in the design of cabinets to program temperature and humidity patterns and their application to tropical fruit fly distribution problems.

Some of the early efforts to reproduce fluctuating temperatures and humidities in ecological and climatological investigations have been summarized by Shelford (14) and Uvarov (17). Much entomological information of significant value has accrued through the use of relatively simple devices such as those designed by Potter (13), Headlee (9), Stone (15), Wishart (18), and Munger (12). These, with major advances in instrumentation made during World War II, led to the highly precise equipment developed in Hawaii and Texas for tropical fruit fly studies (3, 6, 10). The practical assembly of recorders, controllers, and other devices in the large walk-in cabinets to program the diversified conditions required in these investigations, apparently was without precedent in the field of insect bioclimatology.

SIMULATION EQUIPMENT

The bioclimatic cabinets used in the tropical fruit fly investigations were described by Flitters *et al.* (8).

Each walk-in cabinet (Fig. 1), is provided with two insulated doors, separated by a vestibule measuring 4 ft × 4 ft × 7 ft high. These doors provide entry into a stain-

Fig. 1. Bioclimatic cabinet showing instrument panel and anti-room

less steel working space measuring 6 ft × 6 ft × 7 ft high. A window constructed of three pairs of glass panes, each pair with an evacuated air space in between to restrict heat transfer to an absolute minimum and provide a clear view of the cabinet interior, is built into the wall opposite the door. Attached to the exterior walls of the cabinet are various air-conditioning controls and instruments that permit the circulating air to be cooled, humidified, dried, or heated as required by the cam controller. The major advantage provided by the equipment is that of controlling temperatures and humidities in smoothly varying patterns such as occur naturally. Temperatures may be controlled to within plus or minus 1°F over the range —5 to +125°F. Humidities within this same temperature range may be controlled simultaneously to within plus or minus 3 per cent relative humidity over the range from 20 per cent to 98 per cent. Humidity can be controlled to points as critical as 10 per cent when the temperature is above freezing values.

All cabinets have sufficient capacity to raise or lower the temperature 40°F and lower relative humidity 60 per cent in 60 min. Lamps designed to give a wide spectral band of visible light provide daylight illumination requirements within the cabinets. These lights are automatically turned on and off by means of time clocks, the settings of which are periodically varied in order to simulate natural photoperiods.

For the studies fruit fly globular screen cages, each measuring 12 in. in diameter, were constructed from light sheet metal and covered with standard wire screen. To facilitate the introduction and removal of host fruits, food, water and flies, an 8-in. heavy zipper was attached to a plastic screen cover which was clamped over a circular opening in the lower frame of the cage and served as its base. A hook attached to the top permitted the cage to be suspended within the cabinet work space.

These globular cages were suspended from a bicycle wheel assembly whose shaft in turn passed through the ceiling of the chamber work space. The wheel, measuring 26 in. in diameter, permitted four globular cages to be suspended from its periphery. By using suspension hooks of varying lengths, the wheel could carry twelve cages in all.

To minimize any variation that might arise from differences in position, the cages were slowly rotated at a speed of one revolution per minute by means of a small electric motor mounted on top of the bioclimatic chamber. The motor was connected to the bicycle wheel shaft through a gear-reduction box, pulleys and belts. A slip clutch and bearing, mounted on the shaft of the wheel provided a method for stopping the cages for observation or manipulation of biological material without stopping the gear train or the motor. To reduce positional effects further, the individual globular cages were also rotated intermittently each on its own axis.

METHODS

Fruit fly studies conducted in the chambers thus far have been designed to show the effect of different patterns of fluctuating temperature and humidity on the different stages of test insects and on their life cycles in entirety. Detailed observations and measurements have been made on the preoviposition and sexual development periods, mating, reproduction, longevity, rates of development, and the velocity and extent of build up of progeny generations. Significant behaviour breakdown or change has also been noted.

The reliability of the cabinet method was evaluated by running a life history study in an outdoor insectary and then under the same conditions simulated in the cabinets. The similarity of data developed inside the chamber and outdoors indicated that vibration or other emanations from the instrumentation and cabinet machinery were not significant.

In each chamber one globular cage was maintained with mature adult fruit flies from the insectary. These flies were provided with a diet of enzymatically hydrolyzed yeast and soy bean, powdered orange juice concentrate, sucrose or water with a variation of this diet depending on species. The hydrolyzed yeast and soy provide protein requirements for adult sexual development and for optimum adult fertility, productivity and longevity.

Fruits were exposed in each cage of mature fruit flies for 24 hr three times weekly. After exposure they were placed within a combination holding box and cage, labeled with the globular cage number, the date of exposure, and the site of the simulated conditions. Rates of development and mortality in the various stages were determined.

A second group of globular cages containing flies only 1 or 2 days old at the time of their introduction was maintained in each chamber to study effects on the preoviposition period. After 8 days in the chamber, oviposition shells were exposed for 24 hr every day until eggs were found. Eggs so recovered were gathered together, placed on blackened filter paper soaked in a 2 per cent benzoic acid solution, or other comparable mold inhibitor, and held in the insectary for hatching.

Visual observation for copulation was made each evening at sundown, since the oriental, melon and Mexican fruit flies are crepuscular in their mating habits. Oviposition was considered to indicate attainment of female maturity, egg hatch, consummation of the mating process.

A third cage of 1- to 2-day-old fruit flies was maintained in each chamber to provide information on adult longevity. The mortality of these flies was measured weekly. Longevity was determined by the age of the last five survivors, rather than by the sole individual survivor.

Each globular cage of adult flies was stocked initially with 500 fruit flies, two-thirds of which were females.

Progeny adults, derived from infestations established in the different climates were collected daily as they emerged, counted by sexes, and then placed in a fourth group of globular cages to note the rate and extent of population build up. Eight days after a progeny generation began to emerge, fruit was exposed in the same manner as in the case of parent stocks, thus beginning the rearing of a second generation. In some of the cabinets, several cages containing successive generations of the fruit fly eventually accumulated within the chamber.

In addition, auxiliary studies were conducted for each of the simulated climates. Immature stages of the insect represented by eggs, infested fruit and pupae, were removed from the culture room and introduced into the chambers once weekly. The eclosion of eggs, larval development in the fruit, and pupal duration were all determined and the differences in growth rate correlated with the factors of climate under simulation at that time.

The bioclimatic chamber investigations have been in progress for approximately 10 years in a study embracing the simulation of twenty-eight climatological sites. Many of these sites were simulated in Hawaii and again during Mexican fruit fly studies in Texas. Currently efforts are being made to program or simulate other conditions such as velocity and intensity of rain droplets, moisture and temperature patterns in soils, etc., which may be related to survival.

RESULTS

The results of the fruit fly studies have been reported by Flitters (5), Flitters and Messenger (6, (7, and Messenger and Flitters (10), (11). Various criteria were used to estimate the effect of the temperature and humidity patterns on the fruit flies, including the number of months, the specific season, and extent to which successful infestation in fruits took place, the number of successive generations of progeny yielded in a single year, and their population strength and reproductive capacity. As anticipated, temperature was the dominant factor in the development of fruit flies. Soil moisture had a definite influence on the mortality of the insect in its prepupal stage, and to a lesser degree, on newly formed pupa during the first few days of its existence. But again, temperature ameliorated or enhanced these effects.

The optimum conditions for development appeared to be associated with a certain range of temperature and not a specific thermal point. Individual processes and stages of development, however, had specific thermal preferendums within this optimum range. High temperatures lethal to adults had an accelerating effect on larval development in the fruit and also upon adult emergence from puparia in the soil.

The effect of temperature upon preimaginal development was graphically illustrated by Mexican fruit fly infestations occurring in fruits at different seasons of the year. Winter conditions typical of certain simulated southern California sites depressed development, in many instances for periods up to 5 months. During early or late summer growth was accelerated and the complete preimaginal developmental cycle reduced to approximately 40 days, the near optimal value.

It is recognized that factors other than temperature may affect the activity of adult insects (1, 16), and that activity may be depressed by conditions of low humidity. Others have also reported that reproduction may be influenced by relative humidity. Conditions of high humidity characteristic of the simulated Charleston, S. C., climate restricted fruit fly adult activity and caused premature decay of host fruits. The latter, in turn, affected larval development and limited build up and population strength.

The cabinet studies indicated that self-sustaining infestations of the melon fly, oriental fruit fly, and Mediterranean fruit fly may survive winter conditions in all areas in continental United States in which the year exhibits no more than a 60-day period with an average temperature below 57°F. Roughly, this favorable zone includes all of Florida south of the thirtieth parallel, the lower delta region in Louisiana, the lower Rio Grande Valley in Texas, a coastal strip along the Gulf of Mexico from Brownsville to Galveston, Texas, the Imperial Valley of California, and the Yuma and lower Gila River areas in Arizona.

Areas having more than a 60-day period but less than a 90-day period with an average temperature below 57°F appear to be marginal with respect to their suitability for reproduction and development of immature stages. Development of the immature stages under these conditions proceeded to the pupal stage, the stage in which most mortality occurred. Mature adults reproduced but newly emerged adults were not able to develop to maturity until warmer weather occurred. The available evidence suggests that periodic infestations may arise in these marginal areas if permanent infestations occur in nearby favorable areas. The marginal zone is a rather extensive one; it includes an Atlantic coastal strip extending from the thirtieth parallel north to Charleston, South Carolina, parts of Florida north of the thirtieth parallel, extensive areas in southern Georgia, Alabama, Mississippi, Louisiana and Texas, the Greater Gila and Salt River valleys of Arizona, including the Phoenix area, the Death Valley and Coachella Valley regions in southern California, and the Lower Colorado River Valley area inland as far as the southern tip of Nevada.

All other areas on the United States mainland are capable of supporting infestations of the three Hawaiian fruit flies for parts of each year, but not on a continuous or self-sustaining basis. The fact that most of the important fruit and vegetable areas in California undoubtedly fall within this unfavorable zone is of special interest.

Comparison of the three species studied in Hawaii showed that, although the Mediterranean fruit fly is able to complete its life cycle in a shorter period of time and thus to produce more generations in a year than the melon fly or oriental fruit fly, it is not able to attain comparable population levels. The Mediterranean fruit fly developed ten successive generations in the Orlando, Fla., chamber under climatic conditions simulated for the year 1929—1930, while the oriental fruit fly was able to produce only five, yet the total progeny of the former was only slightly higher numerically than that of the latter.

Winter conditions in the southern part of California inhibited development and activity of the Hawaiian fruit flies. In the Imperial Valley where winters are relatively short, overwintering of the pupal and adult stages may be possible. Excessively hot, dry summers in the south-west, including the Imperial Valley, inhibited population build up in the cabinets.

The results of the Orlando climate simulation study provided very strong evidence to support the view that the eradication of the Mediterranean fruit fly in Florida in 1930 was due to the efforts of the pest control agencies and that climate *per se* provided very little, if any, critical environmental resistance to the insect even though several nights of subfreezing temperatures were experienced during the months of December 1929 and January 1930.

Cold periods of comparatively short duration are not likely to be catastrophic since the pupal stage can endure periods of 2½ months or slightly more at cool temperatures above freezing before mortality occurs (2). In one instance, live pupae of the oriental fruit fly were recovered after 90-days' exposure to average temperatures slightly below 57°F.

The sites simulated in the Mexican fruit fly studies at Brownsville, Texas, were for the most part the same as those reproduced in Hawaii. Indications are this fly will be able to breed almost continuously throughout the spring, summer and fall, and that development of immature stages can continue throughout the year at sites such as Chula Vista, Compton and Riverside, California, Orlando, Florida and Brownsville, Texas. The threshold temperature for copulation was approximately 55°F, and the entire preimaginal developmental cycle was completed under conditions of diurnal fluctuating temperatures and relative humidities providing a mean of 53°F with a diurnal amplitude of 20°F. Preimaginal development was inhibited when the overall temperature pattern was reduced to a mean of 52°F. The longest developmental period from egg to adult of 164 days occurred under simulated conditions of Riverside, California, when the average temperature was slightly above 53°F.

The lowest temperature at which Mexican fruit flies infested grapefruits was 55°F. This occurred during the month of February in the Fort Valley, Ga., study. Several infestations originated when mean temperatures were from 56° to 58°F.

The same mean may be derived from a variety of fluctuating temperature patterns. Natural pattern variability occurring at the selected study sites has not appeared to introduce developmental variation of practical significance unless the mean was also affected.

The cabinet studies have been primarily concerned with the effects of temperature and humidity. The availability and annual succession of suitable host fruits, the capacity for dispersal from establishment site into surrounding, uninfested areas, competition with other insects, and the extent to which insecticides are used, are other factors that may have an important bearing on the ability of fruit flies to develop to pest proportions.

Fundamental investigations of the influence of climate factors, singly and in various combinations, on the development, abundance and behaviour of other insects are also in progress. In this research, which has both field and laboratory phases, diapause, cold hardiness, and microniche variation are receiving most attention. The potential of insects for adaption to colder or warmer climates, utilizing cold and heat shock selection procedures developed in fruit fly studies by Christenson (4) in Hawaii, and the cold hardiness of stable flies, boll weevil segregates from different areas, and Rhodes grass scale are also being investigated. Definitive results are not yet available, but of interest is the fact that some species which appear to exist abundantly in cold temperate climates proved unexpectedly to be susceptible to subfreezing temperatures.

REFERENCES

1. Bodenheimer F. S., *Problems of Animal Ecology.* Clarendon Press, Oxford (1938).
2. Bodenheimer F. S., *Citrus Entomology.* W. Junk, The Hague (1951).
3. Christenson L. D., Status of oriental fruit fly investigations in Hawaii, *Third Spec. Rept. on the Control of the Oriental Fruit-Fly* (Dacus dorsalis) *in the Hawaiian Islands,* pp. 33—50, Calif. Joint Leg. Comm. on Agri. and Livestock Prob. (1953).
4. Christenson L. D., Unpublished data, U.S.D.A. (1955).
5. Flitters N. E., *Developmental Threshold for Preimaginal Development of Mexican Fruit-Fly.* Unpublished report, U.S.D.A. (1959).
6. Flitters N. E. and P. S. Messenger, Bioclimatic studies of Oriental fruit-fly in Hawaii. *J. Econ. Ent.* **47,** (3), 401—3 (1953).
7. Flitters N. E.and P. S. Messenger, Effect of temperature and humidity on development and distribution of Hawaiian and Mexican fruit flies. *J. Rio Grande Valley Hort. Soc.* **12,** 7—13 (1958).
8. N. E. Flitters, P. S. Messenger and C. N. Husman, *Bioclimatic Cabinets used in Studies on the Mexican Fruit-Fly and Pink Bollworm.* U.S. Dept. Agri. ARS 33—45 (1956).
9. Headlee T. J., An apparatus for the study of effects of constant vs. variable temperatures on the speed of insect metabolism. *J. N.Y. Ent. Soc.* **37,** 25—7 (1929).
10. Messenger P. S. and N. E. Flitters, Bioclimatic studies of three species of fruit flies in Hawaii. *J. Econ. Ent.* **47,** (5), 756—65 (1954).
11. Messengr P. S. and N. E. Flitteres, *Bioclimatic Studies of the Mexican Fruit Fly.* Calif. Avocado Soc. Yearbook (1957).
12. Munger F., An adaptation of a thermograph to regulate variable temperature. *J. Econ. Ent.,* **37,** (4), 554—5 (1944).
13. Potter G. F., An apparatus for automatically changing the temperature of a chamber. *Amer. J. Bot.* **7,** 39—43 (1920).
14. Shelford V. E., An experimental investigation of the relations of the codling moth to weather and climate *Ill. Nat. Hist. Sur. Bull.,* **16,** 307—440 (1927).
15. Stone W. E., An instrument for the reproduction, regulation, and control of variable temperature. *J. Wash. Acad. Sci.* **29,** (10), 410—15 (1939).
16. Uvarov B. P., Insect nutrition and metabolism — *Trans R. Ent. Soc., Lond.* **76,** 255—343 (1928).
17. Uvarov B. P., Insects and climate. *Trans. R. Ent. Soc., Lond.* **79,** (1), 1—247 (1931).
18. Wishart G., An adaption of a standard bimetallic thermoregulator to control variable temperatures — *Canad. Ent.* **72,** 78—81 (1940).

DIE ENTWICKLUNG DER BIENENVÖLKER UND DIE NEKTARTRACHT IN IHREN BEZIEHUNGEN ZUR WITTERUNG

H. G. KOCH

Prof. Dr. H. G. Koch, Meteorologisches Institut, Friedrich-Schiller Univ., Jena, Thüringen, Deutschland (D.D.R.)

Abstract—The instinctive flight frequency in honey bees is closely connected with the flowering season of the main foraging plants which, naturally, occurs mainly in spring through the prevailing phenological rhythm. In addition, the flight frequency as well as the quantity and consistency of the sweet juices secreted by the various blossoms are much influenced by the daily weather during the flowering season. Thus the connexion between weather and daily increase or decrease of the weight of the beehives becomes very complex indeed. With the help of records, taken over a period of many years, it is evident, that the output of honey is highest when weather, general condition of the bees and plentitude of nectar act favourably together.

Nine years' observations in a central German early foraging area and a later forest foraging area show, that the influence of direct sun rays on the smooth output of honey occurs mainly during the cooler early spring, whereas the influence of temperature is noticeable during all months which offer nectar from blossoms and plants, i.e. during May in the early foraging areas and June in the later forest foraging areas.

Résumé—La fréquence de vol commandée par l'instinct des abeilles est étroitement liée à la saison de floraison des principales plantes fourragères qui par suite du rythme phénologique dominant correspond normalement au printemps.

En outre la fréquence de vol ainsi que la quantité et la consistance du jus sucré secrété par les arbres en fleurs sont très influencées par le temps qu'il fait pendant la saison de la floraison. A vrai dire la relation entre le temps qu'il fait pendant la saison de la floraison et l'augmentation ou la diminution du poids des ruches devient donc fort complexe. D'après des observations faites pendant une période de nombreuses années il est manifeste que la production de miel devient la plus forte lorsque le temps, l'état général des abeilles et l'abondance du nectar forment un ensemble favorable.

Des observations d'une période de 9 ans faites en Allemagne Centrale dans une zone de plantes fourragères précoces et dans une zone de plantes fourragères plus tardives ont montré que l'influence de rayons solaires directs sur la régularité de la production du miel se manifeste surtout au début du printemps, pendant les jours encore un peu frais, tandis que l'influence de la température devient notable pendant les mois qui offrent le nectar des arbres en fleurs et des plantes, c. à. d. dans la zone des plantes fourragères précoces au mois de Mai et dans la zone sylvestre, plus tardive, au mois de Juin.

Auszug—Die instinktiv-bedingte Flughäufigkeit bei Honigbienen steht in engem Zusammenhang mit der Blütezeit der hauptsächlichen Futterpflanzen, die infolge des herrschenden phänologischen Rhythmus naturgemäß vorwiegend im Frühjahr vorkommt.

Hinzu kommt, daß sowohl die Flughäufigkeit wie auch die Menge und die Konsistenz der von den verschiedenen Blüten ausgeschiedenen süßen Säfte erheblich durch die während der Blütezeit herrschenden täglichen Wetterverhältnisse beeinflußt werden. Daraus ergibt sich, daß die Verbindung zwischen dem Wetter einerseits, und der täglichen Zu- oder Abnahme des Gewichtes der Bienen-Ausbeute andererseits, eine sehr enge wird. Mit Hilfe von Aufzeichnungen, die über einen Zeitraum von vielen Jahren geführt wurden, kann erwiesen werden, daß die Erzeugungsleistung von Honig immer dann am höchsten ist, wenn die Wetterverhältnisse, der Allgemeinzustand der Bienen sowie die Fülle der vorhandenen Tracht günstig zusammenwirken.

Beobachtungen, die über einen Zeitraum von 9 Jahren in Mitteldeutschland in einem frühen Futtergebiet wie auch in einem späteren Wald-Futtergebiet gemacht wurden, zeigen, daß sich der Einfluß der direkten Sonnenbestrahlung auf die reibungslose Honigerzeugung vorwiegend während der kühleren Tage des Frühlingsanfangs bemerkbar macht, während der Einfluß, den die Temperatur ausübt, in all den Monaten festgestellt werden kann, in denen Blüten und Pflanzen Nektar anbieten, d. h. während des Monates Mai in den frühen Futtergebieten, und während des Monates Juni in den späteren Wald-Futtergebieten.

Die Bindung der Lebensäußerungen an die atmosphärischen Ereignisse dokumentiert sich bei der Honigbiene *(Apis mellifica)* im wesentlichen in zwei Gruppen von Erscheinungen:

(1) Die Entwicklung der Völker ist an den Jahresgang der Witterung und an die Blühtermine der Trachtpflanzen gebunden. Dieser Fragenkreis ist ein phänologischer.

(2) Die tägliche Nektartracht ist — gleiches Nektarangebot vorausgesetzt — vom Wetter des betreffenden Tages abhängig und somit ein synoptisch-meteorologisches Problem.

Beide Themengruppen sind eng miteinander verknüpft. Denn für das Zustandekommen einer guten Honigtracht ist nicht *nur* der Termin des Blühbeginns einer Haupttrachtpflanze, sondern gleichzeitig auch das Eintreten einer günstigen Wetterlage erforderlich. Andererseits erlahmt der Flugeifer an warmen Schönwettertagen sehr rasch, wenn keine Trachtquellen vorhanden sind, was mit Beginn des Hochsommers nach Beendigung der Hauptblühperiode häufig einzutreten pflegt. Somit bestimmen der phänologische Ablauf des Frühjahres, das Trachtangebot *und* das Wetter während der Blühperiode gemeinsam den Zeitpunkt der Trachtspitzen. Dieser schwankt deshalb datumsmäßig von Jahr zu Jahr in weiten Grenzen hin und her.

Die Verknüpfung mit dem Jahresgang der Witterung ist einmal eine direkte, indem die Insekten infolge Fehlens eines eigenen thermischen Regulationsmechanismus in ihrer Volkentwicklung auf bestimmte Mindesttemperaturen angewiesen sind (Aktivitätsoptimum), zum anderen erfolgt sie über die Trachtpflanzen, deren Nektarsekretion ebenfalls von einem Wärmeoptimum abhängt und den Sammeleifer der Bienen überhaupt erst anregt. In die Relation Wetter — Tracht schiebt sich also noch die Abhängigkeit des Blühvorganges und der Nektarsekretion dazwischen, so daß das tägliche Stockgewicht nicht allein von der Witterung, sondern auch von den Assimilationsvorgängen der Blüten abhängt. So gehen zwei Effekte, die Flugfreudigkeit der Bienen sowie Menge und Konzentration des Nektarsaftes, allerdings in einer voneinander unabhängigen und graduell verschiedenen Weise auf einen gemeinsamen äußeren Faktor zurück.

Die Entwicklungsphasen der Bienenvölker, die der Beobachtung am leichtesten zugängig sind und den Jahresrhythmus am besten repräsentieren, sind (1) der erste Reinigungsflug, (2) der Beginn der Bautätigkeit, (3) das Öffnen der Honigräume, (4) die erste Schleuderung, und (5) der Beginn der Drohnenschlacht. Obwohl nur die beiden ersten Phasen nicht der Willkür des Imkers unterliegen, läßt sich bedenkenlos feststellen, daß nur im Erst- und Vollfrühling stramme Beziehungen zwischen Volk- und Pflanzenentwicklung bestehen, denn die Blüherscheinungen bestimmen den Lebensrhythmus der Bienen (Baubeginn der Bienen und Blühbeginn der Süßkirsche $r = 0{,}8$; öffnen der Honigräume und Beginn der Fliederblüte $r = 0{,}7$). Zum Frühsommer hin sinken die Beziehungen rasch ab; eben so sind sie im Vorfrühling geringer als der theoretische Mindestwert. Die Verwendung von Indikator- oder Weiserpflanzen zur Ermittlung phänologischer Phaseneintrittstermine aus der Insektenwelt ist deshalb nicht bedingungslos zulässig und zur Charakteristik wenig geeignet.

Nach den bisherigen Ausführungen ist nicht zu erwarten, daß der Verlauf der Trachtkurve eines mittleren Bienenjahres der »Wetterkurve« auch nur annähernd parallel verläuft. Auch Singularitäten der Witterung treten nicht hervor, da Volkentwicklung und Trachtangebot den Wettereffekt überlagern. Aber es gibt je nach den örtlichen Gegebenheiten des betreffenden Beobachtungsstandes »Singularitäten« im Jahresablauf der Tracht. Die beigegebene Abbildung stellt die langjährigen Mittelwerte der täglichen Waagstock-Gewichtsänderungen eines für Mitteldeutschland typischen Frühtracht-(Gera) und eines landwirtschaftlich weniger genutzten Waldtrachtgebietes (Tannroda) dar. Trotz der geringen Entfernung von nur 60 km und trotz nahezu gleicher Wetterentwicklung beider Beobachtungsstände treten erhebliche Abweichungen auf: In Gera setzt die Honigtracht früher und intensiver ein, da Obstblüte und Winterraps reichlich Nektar spenden; in Tannroda erfolgt der Anstieg sehr zögernd, da diese Quellen fehlen und die Völker sich langsamer entwickeln. Doch erreichen beide Orte Anfang Juni mit der Himbeer- und späten Rapsblüte das Jahresmaximum der Gewichtszunahme. Im Waldtrachtgebiet von Tannroda wird um den 20. Juni herum durch die Honigtracht aus dem nahen Wald (Himbeeren und Läusehonig) eine zweite Trachtspitze erreicht, die in Gera fehlt. In dieser Zeit treten in den reinen Landwirtschaftsgebieten schon erhebliche Trachtlücken auf. Anfang Juli ist beiden Orten ein weiteres Ertragsmaximum gemeinsam, das jedoch wegen der ungenügenden Nektarsekretion der Winterlinde sehr unsicher ist und nur in seltenen Jahren hohe Erträge aufweist. Von Mitte Juni an sind in allen Gebieten ohne Heidetracht keine Zunahmen mehr zu erwarten.

Es wird deshalb nicht mehr Wunder nehmen, wenn die zahlenmäßigen Beziehungen zwischen täglicher Honigmenge und den meteorologischen Faktoren nicht so eng sind, wie es bei der Wärmeempfindlichkeit der poikilothermen Insekten zu erwarten wäre.

Der rechnerischen Erfassung der Korrelation zwischen Stockgewicht und meteorologischen Wirkungsgrößen stehen erhebliche Schwierigkeiten gegenüber. Langjährige Merkmalsreihen des Honigertrages — etwa Dekaden-, Monats- oder Jahressummen — können nicht ausgewertet werden, da Konstitution und Stärke der Waagstockvölker von Jahr zu Jahr variieren, auch «relative» Volkstärken nicht zu ermitteln sind, so lange das absolute Gewicht des reinen «Bienenfleisches» (ohne Beute, Rähmschen, Wachs, Zucker- und Honigvorrat) mindestens zu Beginn und Ende der Trachtzeit nicht genau ausgewogen wird. Aus diesem Grunde dürfen auch langjährige

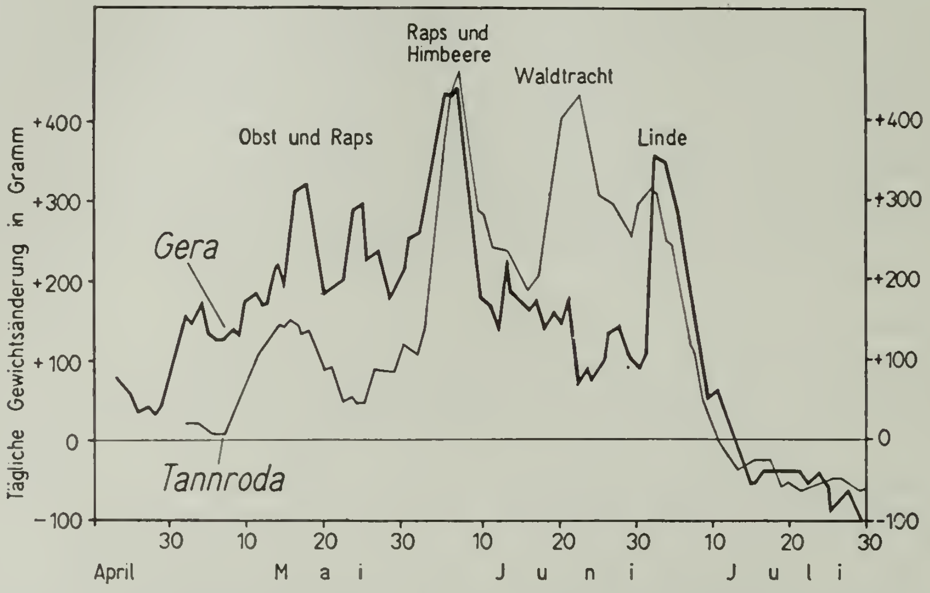


Abb. 1. Fünftägig übergreifende Mittel der täglichen Waagstock-Gewichtsänderung für ein Frühtrachtgebiet (Gera 1947/55) und für ein Waldtrachtgebiet (Tannroda 1934/56)

Mittelwerte nicht herangezogen werden. Es ist aber angängig, für Einzeljahre kürzere Merkmalsreihen etwa von der Länge von 30 Tagen zu verwenden und die Tageswerte des Waagstockgewichtes mit den meteorologischen Parametern zu korrelieren. Während der Hauptblühperiode des Frühjahres steigt die Zahl der Flugbienen und damit die Sammelkraft der Völker so stark an, daß die Beobachtungsperiode nicht zu lang gewählt werden darf und eine Reduktion der täglichen Gewichtszu- oder- abnahmen auf eine mittlere Volkstärke vorgenommen werden muß. Letzteres ist rechnerisch mit genügender Sicherheit möglich.

Die unter diesen Voraussetzungen ermittelten Korrelationsbeträge sind in der beigefügten Tabelle getrennt nach Sonnenschein und Temperatur für beide Beobachtungsstände mitgeteilt.

Die Werte sind in den einzelnen Jahren recht unterschiedlich. Die Bindungen der Erträge an die Sonnenscheindauer sind im Mittel der 9 Jahre in Tannroda strammer als in Gera. Beide Orte zeigen aber eine gleichsinnige Abnahme der Beträge vom Mai zum Juni und Juli. Daß wirklich eine Abnahme der Sonnenwirkung auf Bienen und Blüten zum Hochsommer hin vorliegt, kann aber nicht unbedingt gefolgert werden; die Verschlechterung ist trachtbedingt. Die Beziehungen der Erträge zur Wärme (untere Hälfte der Tabelle) sind enger als die zum Sonnenschein. Die Streuung von Jahr zu Jahr ist geringer. Besonders hohe Werte zeigen der Juni für Tannroda und der Mai für Gera.

Tabelle 1. Korrelationen zwischen den täglichen Gewichtszu- oder -abnahmen des Waagstockvolkes und der Zahl der täglichen Sonnenscheinstunden (oben) bzw. der betreffenden Tagesmitteltemperatur (unten) in den Einzelmonaten Mai, Juni, Juli 1947 bis 1955 für das Waldtrachtgebiet Tannroda (links) und das Frühtrachtgebiet Gera (rechts)

Jahr	Tannroda			Gera		
	Mai	Juni	Juli	Mai	Juni	Juli
Stockgewicht und Sonnenscheindauer						
1947	0,71*	0,44	0,39	0,81*	0,64*	0,15
1948	0,42	0,75*	—	0,36	0,37	0,15
1949	0,61*	0,66*	0,23	0,59*	0,60*	0,49*
1950	—	0,58*	0,48	0,48*	0,61*	0,40
1951	0,63*	0,40	0,37	0,41	0,45*	0,47*
1952	0,52*	0,52*	0,21	0,20	0,37	0,04
1953	0,61*	0,40	—	0,53*	0,38	—
1954	0,48	0,45*	—	0,48*	0,04	—0,37
1955	—	0,16	0,75*	0,48*	0,31	0,34
Mittel	0,56	0,49	0,40	0,48	0,42	0,21
Stockgewicht und Temperatur						
1947	0,64*	0,68*	0,55	0,59*	0,84*	0,41
1948	0,51*	0,80*	—	0,50*	0,29	0,10
1949	0,64*	0,77*	—0,02	0,46*	0,47*	0,56*
1950	—	0,55*	0,48	0,66*	0,13	0,53*
1951	0,48*	0,72*	0,34	0,60*	0,64*	0,56*
1952	0,45*	0,77*	0,61	0,67*	0,25	0,19
1953	0,71*	0,39	—	0,47*	0,07	0,10
1954	0,24	0,69*	—	0,73*	0,22	0,53*
1955	—	0,69*	0,13	0,70*	0,40	—0,29
Mittel	0,52	0,67	0,36	0,60	0,37	0,30

Alle Werte, die der Zahl der Freiheitsgrade entsprechend bei einer Sicherungsgrenze von 1% den Zufallshöchstwert überschreiten, d. h. als gesichert betrachtet werden können, sind mit einem* versehen.

Ganz bezeichnend für die unterschiedlichen Umweltbedingungen beider Orte ist das gegenläufige Verhalten der Monate Mai und Juni. Da in Tannroda Volkentwicklung und Tracht verspätet einsetzen, sind die Beziehungen im Mai hier noch unsicher und dem Betrag nach niedriger ($r = 0{,}52$) als die von Gera ($r = 0{,}60$), wo der Mai die sichersten und höchsten Werte von r aufweist. In Tannroda ist dafür der Witterungseinfluß im Juni am beständigsten und größten ($r = 0.67$). Hier ist ein lückenloses Nektarfließband gewährleistet, die Völker haben die Zeit der stark ansteigenden Volkentwicklung bereits hinter sich (diese fällt in Gera ungünstigerweise auf den einzigen sicheren Trachtmonat Mai) und erhalten den Juni über ihre volle Stärke, Flugfähigkeit und Trachtfreudigkeit. Der Mai in Gera und der Juni in Tannroda sind die einzigen kalendermäßigen Zeitabschnitte, für die infolge Fehlens wesentlicher Trachtlücken die Korrelationsrechnungen sinnvoll sind. Im Juni sind die Abweichungen der Beziehungen beider Trachtgebiete am größten. Daß im Juli scheinbar keine Beziehungen zwischen Tracht und Wetter besteht, ist wiederum auf die Lückenhaftigkeit des Nektarangebotes zurückzuführen. Die Winterlinden als die letzten Honigspender des Sommers stellen in den Einzeljahren recht unterschiedliche Ansprüche an das Wetter; die Ursachen hierfür sind noch nicht endgültig geklärt.

Alles in allem zeigt sich, daß abgesehen von den in den verschiedenen Trachtgebieten recht unterschiedlich auftretenden Trachtlücken eine gesicherte Abhängigkeit zwischen der täglichen Honigmenge sowie Sonnenscheindauer und Wärme nachweisbar ist, und zwar grundsätzlich in allen Monaten, die eine Tracht gewähren. Dabei scheint im allgemeinen der Temperatureinfluß die Wirkung der direkten Sonnenstrahlung zu übertreffen, doch kann unter Umständen die Besonnung an kühleren Tagen des April und Mai sowohl die Nektarsekretion der Blüten wie dadurch auch den Sammeleifer der Bienen sehr beträchtlich anregen und fördern. Hiermit in engem Zusammenhang stehen die Fragen nach der «Mindesttemperatur» bzw. «Wärmesumme» der Frühjahrs- und Sommerblüher sowie nach einer «Akklimatisierung» der Insekten (und Blüten) an die ansteigenden Wärmegrade des Frühjahres und die absinkenden des Spätsommers.

Die üblichen Handlungen eines Bienenvolkes erfolgen in einem ganz bestimmten Rahmen, sie werden durch bestimmte Reize bzw. durch den Rhythmus der Jahreszeiten ausgelöst. Es erwachsen jeweils gewisse «Triebe», die die Bereitschaft eines Organismus zum Ausführen zielgerichteter Instinkthandlungen sind. So wird zweifellos die Einsatzbereitschaft zum Fliegen durch das Wetter, der Sammeltrieb aber durch das Trachtangebot seitens der Pflanzen geweckt. Der oftmals geringe Flugbetrieb an warmen Schönwettertagen des Hochsommers deutet darauf hin, daß die Tiere mangels lohnender Tracht zu Hause bleiben, andererseits herrscht an kühlen Frühjahrsmorgen oft der regste Flugbetrieb, wenn reiche Tracht lockt. Die Flugintensität ist nur *ein* Bindeglied in der Reihe der Wirkungen: Wetter—Nektarangebot—Flugeifer—Honigtracht. Die am Waagstock täglich bestimmten Gewichtszu- oder -abnahmen vermitteln eine Vorstellung von den Beziehungen zwischen Witterung und Trachtangebot, jedenfalls nicht über eine Direktwirkung Wetter—Biene. Nur in diesem Sinn sind auch die berechneten Korrelationen zu den meteorologischen Faktoren zu werten. Der ganze Fragenkreis ist nicht nur ein phänologischer und meteorologischer, sondern auch ein tierpsychologischer und pflanzenphysiologischer. Massentrachten kommen nur dann zustande, wenn alle drei Komponenten gleichsinnig zusammenwirken.

PRINCIPLES OF BIOCLIMATIC CLASSIFICATION OF CULTIVATED AND WILD PLANTS WITH REGARD TO THEIR WATER REQUIREMENTS

A. M. ALPATIEV
Institute of Plant Industry, Leningrad, U.S.S.R.

Abstract—On the basis of his long-term experiments with different plants, the writer suggests that the classification be based on two criteria, closely linked together: (a) the gross water requirements for the whole growing period, determined by climate and length of growing period for any species and variety of plants; and (b) the intensity of moisture consumption at various phases of development, quantitatively expressed by abstract coefficients of the biological curve. The biological curve is connected with the developmental rhythm of every plant and hence it reflects, besides the influence of meteorological conditions, the action of the rates of mass accumulation and the senescence of plants in ontogeny.

Under every particular climate the water requirement of plants is the higher the longer their growing period, irrespective of their degree of drought-resistance.

Résumé—Se basant sur des expériences à long terme avec diverses plantes, l'auteur suggère d'établir la classification sur deux critères intimement liés:

(a) les conditions requises globalement en eau pendant toute la période de croissance, déterminée par le climat et la durée de croissance pour toutes les espèces et variétés de plantes, (b) la grandeur de la consommation en sève par phase de développement, exprimée quantitativement par des paramètres de la courbe biologique. La courbe biologique est liée au rythme de croissance de chaque plante et désormais elle reflète, en plus de l'influence des conditions météorologiques, le mécanisme des taux d'accumulation de masse et le vieillissement des plantes dans l'ontogénèse.

Sous chaque climat déterminé les besoins en eau des plantes sont d'autant plus forts que la période de croissance est plus longue et cela indépendamment du degré de résistance à la sécheresse.

Auszug—Auf Grund seiner über einen langen Zeitraum durchgeführten Experimente mit verschiedenen Pflanzen schlägt der Verfasser vor, die Klassifizierung unter Zugrundelegung von zwei Kriterien vorzunehmen, die eng miteinander verknüpft sind, nämlich: (a) den gesamten Wasserbedarf für die ganze Wachstumsperiode, der bestimmt wird durch das Klima sowie die Wachstumsdauer für jede der Arten, bezw. eine Vielfalt von Pflanzen, und (b) die Intensität des Feuchtigkeitsverbrauchs in den einzelnen Entwicklungsstadien; mengenmäßig ausgedrückt durch abstrakte Koeffizienten der biologischen Kurve.

Die biologische Kurve ist mit dem Entwicklungs-Rhythmus jeder Pflanze verbunden und sie zeigt daher, neben dem Einfluß der meteorologischen Bedingungen, die

Wirkung auf die Geschwindigkeit der Masse-Ansammlung sowie das Altern der Pflanzen in ihrer Ontogenese.

Der Wasserbedarf der Pflanzen wird mit der Länge ihrer Wachstumsdauer größer, u. zw. unter allen klimatischen Bedingungen, und ohne Rücksicht auf den Grad ihrer Dürrefestigkeit.

The classification of plants as regards their moisture requirements may be represented as a particular ecological classification, reflecting the laws actually existing in the plant world among separate species and forms of plants as regard the moisture factor. The knowledge of these laws is of great theoretical and practical importance, when planning hydrological measures, intended for the efficient use of moisture in agriculture and forestry.

In classifying plants according to their requirements for some ecological factor, we should consider not the casual, but the optimal growing conditions, under which the plants' highest requirements for the factor examined are being satisfied. In particular, as regard moisture it is necessary to take into consideration water requirements under optimal moisture conditions of the soil. By water requirements we understand the total water expenditure (transpiration plus evaporation from the soil) by a plant community, under an optimal soil moisture, which is in perfect accordance with the meteorological regime. In this case the gross water requirements for the whole growing period of plants, if the vegetative mass level is sufficient, is determined solely by two components: the meteorological conditions and the growing period of the plant community. If the vegetative mass is insufficient, which happens at the beginning of growth or on poor soils, this conclusion is not always true.

Taking as a basis for our classification the gross requirements of plants in water, it should be noted, that it represents not only a biological, but also a geographical category. We should like to emphasize here the conformity of water requirements with geographical conditions: different geographical conditions correspond to different water requirements of the same plant species, the difference being mainly determined by the complex of meteorological conditions.

Our long-term experience in the study of water requirements by different cultivated plants proves that the character of high drought resistance may often not be the evidence of low water requirements in plants. If a drought-resistant plant, such as sorghum, displays a long growing period, and a non-drought-resistant plant, such as radish, a short one, the gross water requirement is nevertheless higher in sorghum than in radish. The gross water requirement changes likewise from variety to variety, long-growing varieties requiring as a rule more water. Thus the same plant species may enter into different classification groups.

To a considerable extent one may correctly assert that there is something common in classifying plants as to their requirements for heat and moisture. Plants more exacting to heat are usually likewise more exigent to moisture, if we consider the gross requirements for heat and moisture, i.e. their requirements during the whole growing period of a plant.

Starting from the gross requirements of plants in water as a basic criterion, we consider it advisable to distinguish three large classification groups of plants, namely (a) woody plants, (b) grassy perennials, (c) grassy annuals. The groups are arranged in the order of decreasing requirements of plants in water. In the second and third groups the grassy perennials and annuals, the plants are again arranged in the order of decreasing length of their growing period, the shorter the growing period, the less being the water requirements. Thus the class with lowest water requirement belongs in the first place to the ephemeres, the ephemeroids and other plants related as to developmental cycle.

The gross requirements in water of any plant may be indirectly calculated by the evaporation capacity or the sum of deficits of air moisture, taken with the coefficient 0.6—0.7. The error will not exceed 10—15 per cent. The indirect method allows us to include in the classification a great number of plant species and forms.

In working out the classification, one should take into consideration another criterion besides the gross requirements for water, namely the rhythm of growth and development, which determines the accumulation of the vegetative mass in the ontogeny, and at the same time its senescence. For the quantitative calculation of the above factor we suggest the so-called biological curve, representing a series coefficients varying regularly from phase to phase. The determination of these coefficients is done experimentally, as mean values for a number of years for each 10-day period or interphasic period, beginning with emergence. This method enables us to eliminate considerably the impact of current weather conditions on the water consumption regime, and to classify the plants taking into consideration the above factor as well.

Mean long-term coefficients of the biological curve are found by dividing the total water expenditure for a given developmental phase by the sum of daily air moisture deficits for the same phase.

For all plants investigated by the writer (barley, wheat, potatoes, corn, flax, tomatoes) the biological curves have only one maximum. They allow the plants to be classified in comparable units according to the factor of water consumption intensity under conditions of optimal water supply, i.e. moisture varying from 65—70 to 100 per cent of field soil moisture capacity.

The writer thinks therefore, that the basis of bioclimatic classification of cultivated and wild plants as to their water requirements consists of two criteria: (a) the gross water requirement for the whole growing period, and (b) the intensity of water consumption by developmental phases.

ÉVAPOTRANSPIRATION POTENTIELLE ET ÉVAPORATION SOUS ABRI

R. J. BOUCHET

Station Centrale de Bioclimatologie, Institut National de la Recherche Agronomique, Rue de St. Cyr, Versailles, France

Abstract—Although the potential evaporative heat loss is related to the total radiation, it can still be estimated independently of evaporation in the shade, if a correction is made for the air temperature and the dew point.

Résumé—Bien que l'évapotranspiration potentielle, en régions humides, soit voisine du rayonnement net, elle est cependant mesurable à partir de l'évaporation sous abri, à condition d'apporter à celle-ci une correction dépendant de la température de l'air et du point de rosée.

Auszug—Obgleich die potentielle Evapotranspiration in feuchten Gegenden nicht sehr von der direkten Strahlung abweicht, ist sie jedoch von der Verdunstung im Schatten ausgehend dennoch meßbar, indem hierbei eine gewisse Korrektur vorgenommen wird, die sich nach der Lufttemperatur und dem Taupunkt richtet.

L'ÉVAPOTRANSPIRATION potentielle représente l'évaporation totale d'un couvert végétal infini, lorsque l'énergie constitue l'unique facteur limitant de cette évaporation. Cette donnée est aussi indispensable pour la définition du milieu que la pluie ou la température. Pourtant cette notion physique simple de l'évapotranspiration potentielle est très difficilement accessible à la mesure. Toute une série de précautions doivent être prises et les données expérimentales obtenues à partir d'évapotranspiromètres sont relativement rares.

De nombreux auteurs ont cherché à relier par diverses formules l'évapotranspiration potentielle ETP à des facteurs climatiques plus faciles à obtenir. Généralement, ces formules se réfèrent à l'équilibre climatique, au transfert de la vapeur ou au bilan énergétique. Ainsi Penman a considéré l'évapotranspiration potentielle comme la somme de deux termes, l'un faisant intervenir l'énergie cédée par l'air, l'autre étant une fonction du rayonnement net.

Cependant, les formules valables à très petites échelles demandent la connaissance de données que l'on ne possède pas toujours, telles que par exemple la température de la surface évaporante ou l'épaisseur de la couche limite en fonction du vent. En outre, on rencontre de nombreuses difficultés pour relier ces mesures à l'évaporation à une plus grande échelle. Inversement, de nombreuses formules climatiques, établies à une échelle importante, ne peuvent pas être utilisées à l'échelle microclimatique.

Dans ces conditions, il a semblé utile d'envisager une mesure expérimentale de l'évaporation qui intégrerait à sa propre échelle le maximum de facteurs climatiques et de la comparer à la mesure de l'ETP dans les conditions naturelles pour déterminer la correction à apporter à la mesure brute. Dans un but de simplicité et de généralité, on a cherché à utiliser les nombreuses données de l'évaporation sous abri météorologique.

On comparera donc le mécanisme de l'évaporation sous abri et dans les conditions naturelles. On supposera que la région considérée est abondamment couverte de végétation et constamment alimentée en eau. Ainsi l'énergie disponible sera le seul facteur limitant l'évaporation. En outre, on se placera à l'échelle de la journée et on admettra que les températures initiales et finales sont les mêmes, c'est-à-dire qu'il n'y a eu ni réchauffement ni refroidissement du système air—sol—végétation. Le raisonnement que l'on est conduit à faire n'est valable qu'avec ces hypothèses.

On se propose de montrer que, dans ces conditions, l'évapotranspiration potentielle est reliée directement au rayonnement net de la région et que celle-ci peut être obtenue après correction à partir de simples mesures d'évaporation sous abri. Dans la suite du texte, on exprimera indifféremment ETP en hauteur d'eau ou en énergie.

Désignons par a l'albedo moyen de la région, R_a le rayonnement atmosphérique, R_g le rayonnement global, R_t le rayonnement du sol, E et C les énergies mises en jeu respectivement par la condensation et l'évaporation, Q l'énergie positive ou négative cédée au système air—sol—végétation durant 24 hr par convection—conduction de l'air et conduction du sol. En négligeant la photosynthèse, on a le bilan suivant:

$$(1—a)\ R_g + R_a + C = E + R_t \pm Q \tag{1}$$

En raisonnant sur une période de 24 hr et si l'état initial est le même que l'état final, Q représente essentiellement les pertes du système par convection. Celles-ci sont relativement faibles et généralement en relation avec l'évaporation nette $E—C$, soit dans le cadre des hypothèses ETP. On peut donc écrire:

$$(1—a)\ R_g + R_a — R_t \# E—C \tag{2}$$

L'évapotranspiration potentielle $\text{ETP} = E—C$ correspond au rayonnement net R_n ($R_n = (1—a)\ R_g + R_a — R_t$) à l'échelle de la journée.

Il est alors possible de concevoir théoriquement une surface évaporante «modèle» dont l'évaporation, ramenée à l'unité de surface horizontale, serait égale à celle de la région considérée.

Il existe au-dessus de cette surface, une couche d'air dite «limite» dont l'épaisseur dépend des caractéristiques de la surface et de la ventilation. Dans cette couche on peut utiliser les équations de diffusion de la vapeur d'eau et de conductibilité de la chaleur à l'échelle moléculaire. En première approximation, on confondra les épaisseurs Δz des couches équivalentes relatives à la diffusion de la vapeur d'eau et à la conductibilité de la chaleur (Fig. 1).

Considérons au cours des 24 hr les températures moyennes de l'air θ_a, du point de rosée θ_r, des surfaces évaporantes θ_{sr} ou θ_s soumises au rayonnement net R_n ou en équilibre radiatif. D'autre part, soit f la tension de vapeur de l'air, $F(\theta)$ la tension saturante, $F'(\theta)$ la dérivée de $F(\theta)$ par rapport à θ, L la chaleur latente de vaporisation, K et D les coefficients de conductibilité et de diffusion moléculaire.

Par définition, ce «modèle» soumis au même rayonnement net R_n que la région précitée doit avoir une évaporation égale à ETP (ETP $= E - C$).

$$\mathrm{ETP} = D\,\frac{F(\theta)_{sr} - F(\theta_r)}{\Delta z} \tag{3}$$

En régime permanent, l'énergie reçue sur la surface est égale à l'énergie perdue (Fig. 1)

$$\text{évaporation}\quad \mathrm{ETP} = LD\,\frac{F(\theta_{sr}) - F(\theta_r)}{\Delta z} = K\,\frac{\theta_a - \theta_{sr}}{\Delta z} + R_n \tag{4}$$

De la comparaison des égalités (2), (3) et (4) on déduit:

$$\theta_a = \theta_{sr} \tag{5}$$

Ainsi la température θ_{sr} de la surface évaporante du «modèle» devra être égale à la température moyenne journalière de l'air. L'épaisseur de la couche limite sur le modèle est liée aux différentes couches limites des surfaces évaporantes par l'intermédiaire du vent. L'égalité (5) ne signifie pas que la température des surfaces évaporantes soit égale à chaque instant à celle de l'air. On peut seulement conclure que l'ensemble des surfaces évaporantes naturelles évapore comme un «modèle» dont la température de surface est celle de l'air.

On a proposé alors de montrer que ce «modèle» de l'évaporation de la région peut être réalisé à partir d'un simple évaporomètre placé sous abri. Un tel appareil est pratiquement en équilibre radiatif. En partant de l'équation (4) avec $R_n = 0$ et en désignant par Δz_1 l'épaisseur de la couche limite équivalente de l'évaporomètre, on aura pour l'évaporation sous abri E_a:

$$E_a = D\,\frac{F(\theta_s) - F(\theta_r)}{\Delta z_1} = DF'(\theta)\,\frac{\theta_s - \theta_r}{\Delta z_1} \tag{6}$$

or

$$\theta_s - \theta_r = (\theta_a - \theta_r)\cdot\frac{K}{K + LDF'(\theta)} \tag{7}$$

d'où

$$E_a = DF'(\theta)\,\frac{\theta_a - \theta_r}{\Delta z_1}\cdot\frac{K}{K + LDF'(\theta)} \tag{8}$$

Comme les égalités (3) et (5) entraînent:

$$\mathrm{ETP} = DF'(\theta)\frac{\theta_a - \theta_r}{\Delta z} \tag{9}$$

On aura:

$$\mathrm{ETP} = E_a \frac{\Delta z_1}{\Delta z}\left(1 + \frac{LDF'(\theta)}{K}\right) \tag{10}$$

L'évaporation E_a peut être évaluée à partir d'un simple évaporomètre du type Piche. On a pu montrer par ailleurs avec d'autres auteurs que la pastille de l'évaporomètre se comportait bien comme la surface évaporante que l'on vient d'étudier et que son inertie thermique était pratiquement nulle.

L'évaporation E_a prise sous abri doit donc être corrigée par le terme

$$1 + \frac{LDF'(\theta)}{K} = \lambda(\theta)$$

qui dépend de θ par l'intermédiaire de $F'(\theta)$. En première approximation, on prendra pour θ la moyenne entre les températures moyennes de l'air et du point de rosée. Les valeurs de ce terme correctif sont données dans Tableau 1.

Tableau 1

Température $\theta = \frac{\bar{\theta}_a + \bar{\theta}_r}{2}$	0°	5°	10°	15°	20°	25°	30°
Coefficient λ (θ)	1,82	2,08	2,36	2,84	3,49	4,32	5,20

Ainsi toutes les autres conditions restant égales (vitesse du vent, déficit de saturation) l'évaporomètre sous abri donne une évaporation qui est une fonction décroissante de la température. Cette variation systématique de l'évaporation avec θ explique que l'évaporation mesurée avec un appareil Piche en Forêt équatoriale soit sensiblement la même que celle mesurée à Paris. Ainsi les critiques adressées aux mesures brutes de l'évaporation sous abri se trouvent justifiées et l'on comprend mieux les difficultés rencontrées par de nombreux auteurs quand ils ont voulu relier des mesures non corrigées d'évaporation sous abri aux données de l'évaporation dans les conditions naturelles.

La formule (10) montre enfin que l'évaporation corrigée E_a est liée à l'évaporation ETP par le rapport $\Delta z_1/\Delta z$ des couches limites du «modèle» et de l'évaporomètre. Ces couches limites étant fonction des caractéristiques des surfaces évaporantes et du vent, on conçoit que, pour un type d'évaporomètre et d'abri donné, ce rapport soit constant. On aura donc

$$\mathrm{ETP} = a\, E_a\, \lambda(\theta) \tag{11}$$

Alors que $\lambda(\theta)$ dépend de la température, a est un coefficient dépendant de l'évaporomètre et de l'abri (hauteur au-dessus du sol et type d'abri) mais théoriquement indépendant des facteurs climatiques.

La valeur de a a été déterminée en 1958 et 1959 à Versailles par comparaison entre les valeurs calculées de ETP et celles observées sur deux évapotranspiromètres de 4 m^2 couverts de gazon et entourés d'un anneau de garde, dont le sol était maintenu à la capacité de rétention par un plan d'eau à 0,60 m et des irrigations superficielles.* Bien que les années considérées aient été très différentes au point de vue climatique, on trouva la même valeur pour le coefficient a ($a \# 0{,}37$). Quelques recoupements effectués dans diverses régions semblent montrer sa valeur très générale. On a pu ainsi retrouver l'évapotranspiration potentielle au centre de la France et en Côte d'Ivoire.**

Dans le cadre des hypothèses de départ, l'évapotranspiration potentielle s'écrirait donc avec l'évaporomètre Piche sous abri anglais à persienne

$$\mathrm{ETP} \# 0{,}37\ E_a\ \lambda(\theta)$$

Cette formule de calcul de l'évapotranspiration permet d'employer un matériel simple déjà utilisé dans les réseaux météorologiques. Pratiquement, il suffit de connaître la température maximale θ_M, la température minimale θ_m, et le point de rosée θ_r. Celui-ci varie relativement peu au cours de la journée. Dans les régions humides il reste généralement voisin de la température minimale. Dans ce dernier cas, on peut prendre, en première approximation, comme température moyenne déterminant le coefficient de correction, la température minimale à laquelle on ajoute le quart de l'amplitude nycthémérale $\theta_m + (\theta_M - \theta_m)/4$.

La formule permettant de corriger l'évaporation sous abri ouvrirait la possibilité d'études du pouvoir évapotranspirant de l'air à l'échelle de l'abri. Il serait alors possible de cartographier l'évapotranspiration potentielle et, puisque le calcul du pouvoir évapotranspirant de l'air se fait jour par jour, de définir la variable climatique responsable des accidents dûs à des évapotranspirations trop élevées.

On doit cependant souligner nettement la limite d'une telle formule. On a admis, dans l'égalité (2), que le terme $\pm Q$ était nul. La formule ne serait donc pas applicable lorsque la température moyenne de la journée évolue par suite de l'arrivée de masses d'air chaudes ou froides ou par suite de modifications importantes de la convection. En fait, ces apports ou ces pertes de chaleur parasites à l'échelle de la journée influ-

* L'évaporation était mesurée avec un évaporomètre Piche placé à 2 m du sol sous abri anglais à persienne. θ_a était déterminé à partir de la température maximale et minimale de l'air$(\theta_M + \theta_m)/2$ et de la moyenne des températures du point de rosée à 09,00 heures et 16,00 heures TMG.

** Nous remercions M. Vernet, Maître de Conférences à l'Institut National Agronomique, ancien professeur à l'École Supérieure d'Agriculture de Tunis; M. Mouton, Maître de Recherches à l'O.R.S.T.O.M. et M. Robelin, Chargé de Recherches à Clermont-Ferrand (I.N.R.A.), qui nous ont communiqué pour nos recoupements des données d'évapotranspiration non publiées.

encent l'équilibre climatique des jours suivants. Ainsi l'écart de température entre la température θ_a de l'air et θ_r du point de rosée intègre l'action de ces facteurs au même titre que les éléments R_g, R_a, R_t du bilan radiatif. Sur une échelle de quelques jours la formule reste donc valable, malgré les écarts existant entre l'état initial et l'état final.

Par ailleurs, on a supposé pour l'établissement de la formule que l'évaporation jouait un rôle important dans l'équilibre énergétique de la région. Si l'évaporation de l'ensemble des végétaux n'est pas normale par suite de réactions physiologiques (régulation stomatique) provoquées par une évaporation trop intense ou un manque d'approvisionnement en eau, l'évapotranspiration réelle — malgré des phénomènes de compensation — devient très inférieure à l'évapotranspiration potentielle de l'air. La température de la surface évaporante du «modèle» deviendrait alors inférieure à celle de l'air. La formule proposée conduit dans ces conditions à surestimer l'évapotranspiration potentielle. Cette surestimation est d'autant plus importante que l'évapotranspiration réelle est inférieure à l'évapotranspiration potentielle. Tout se passe comme si le coefficient a devait diminuer pour traduire le phénomène. La formule ne pourrait donc être utilisée en région plus ou moins aride qu'avec de nouveaux coefficients qui tiendraient compte du nouvel équilibre climatique réalisé plus ou moins indépendamment de l'évaporation.

En conclusion, on a vu qu'en zone humide, lorsque la température moyenne de l'air est stable, le rayonnement net d'une région correspond sensiblement à son évapotranspiration potentielle. Celle-ci serait mesurable à partir de l'évaporation mesurée sous abri, après correction de cette dernière par un terme faisant intervenir la température moyenne de l'air et du point de rosée. Si, comme le prévoit l'exposé théorique, il se confirmait que le coefficient expérimental a reste constant, on disposerait d'une formule simple ($\mathrm{ETP} = a\ E_a(\theta)$) pour l'étude de ETP à une échelle fine de temps et d'espace, à partir de données météorologiques classiques.

DÉTERMINATION DES SEUILS DE RÉSISTANCE AUX GÉLÉES

TRANSPOSITION AUX CONDITIONS NATURELLES DES RÉSULTATS OBTENUS AU LABORATOIRE

R. DURAND

Station Centrale de Bioclimatologie, Institut National de la Recherche Agronomique, Rue de St. Cyr, Versailles, France

Abstract—The thermal balance calculation during freezing indicates that the temperature of the environment is not sufficient to determine the plant killing temperature.

Résumé—L'étude du bilan thermique de la congélation montre que dans les conditions naturelles la température du milieu ambiant ne peut suffire à caractériser le seuil de résistance au gel des végétaux.

Auszug—Die Errechnung der Wärmebilanz während Frostperioden zeigt an, daß die Temperatur der Umgebung nicht ausreicht um die pflanzenzerstörende Temperatur zu bestimmen.

INTRODUCTION

Lorsque l'on cherche à déterminer le seuil de résistance au froid d'un organe végétal, on procède généralement à l'étude simultanée de la durée et de l'intensité des basses températures. Ce mode d'opérer présente l'avantage d'être facilement accessible; il semble intéressant pour le praticien qui surveille son thermomètre lors des nuits de gelée et qui désire connaître le moment propice pour mettre son dispositif antigel en marche. Il peut cependant conduire à des erreurs importantes, notamment lorsqu'il s'agit de rattacher les valeurs obtenues expérimentalement à celles que l'on peut observer dans les conditions naturelles. L'étude du bilan énergétique des organes soumis à la congélation permet une meilleure interprétation du phénomène et peut fournir l'explication d'observations en apparence contradictoires. Malheureusement, les éléments du bilan sont nombreux et difficilement accessibles. On se propose ici d'analyser les principaux facteurs qui entrent en jeu et de montrer dans quelle mesure les seuils déterminés au laboratoire peuvent être utilisés dans les conditions naturelles.

I. DÉTERMINATION DES SEUILS DE RÉSISTANCE

1. *Dans les Conditions Naturelles*

La meilleure méthode est d'enregistrer la température des organes végétaux sensibles au cours des nuits de gelée (à l'aide de thermocouples par exemple) et de relever les températures minimales pour lesquelles il y a apparition de dégâts. Mais cette méthode, très délicate et très coûteuse, ne peut être utilisée que dans des laboratoires spécialisés. Elle exige par ailleurs un très grand nombre d'observations pour que la température critique puisse être déterminée avec précision entre une température qui ne provoque pas de dégâts et une autre légèrement plus basse qui en provoque (sur 28 années d'observations au verger du Centre National de Recherches Agronomiques à Versailles, on n'a noté des gelées dangereuses au moment de la pleine floraison des poiriers que quatre fois, soit une année sur sept) (1).

La méthode la plus couramment utilisée consiste à comparer les dégâts aux indications d'un thermomètre pris comme référence. Les résultats varient beaucoup suivant la position de ce dernier (sous abri, en plein air ou, comme on le voit trop souvent encore, dans la cour de l'exploitation). On utilise de plus en plus comme référence les «indices actinothermiques»: températures indiquées par des thermomètres à minimum à alcool, placés horizontalement à un niveau donné (généralement 5 ou 40 cm du sol) et rayonnant librement. Ces thermomètres sont répartis dans le verger, pour tenir compte des variations microclimatiques. Comme la précédente, cette méthode exige un très grand nombre d'années d'observations et, comme nous le verrons plus loin, ne peut donner qu'une précision relativement faible.

2. *Détermination Expérimentale*

La détermination expérimentale du seuil de résistance consiste généralement à soumettre pendant une durée déterminée la plante, ou une partie de celle-ci, à des températures basses constantes et à noter à partir de quelle température les dégâts peuvent être observés.

Cette méthode présente l'avantage de fournir rapidement des données, mais ces dernières ne correspondent généralement pas à celles que l'on peut observer dans les conditions naturelles et dépendent souvent des conditions mêmes de l'expérience.

On sait en effet que les organes végétaux ne sont tués par le froid que lorsqu'une fraction déterminée de leur eau de constitution se trouve congelée. La congélation de cette eau libère de l'énergie qui maintient la température de l'organe au-dessus de celle du milieu ambiant. Par ailleurs, la surfusion, qui est chose courante, peut retarder le début de congélation et limiter les dégâts. On examinera donc successivement l'influence de la surfusion sur l'importance des lésions et le bilan de la congélation dans les conditions du laboratoire, puis dans les conditions naturelles.

II. ÉTUDE DE LA SURFUSION

Les végétaux peuvent être maintenus plusieurs heures au-dessous de leur température mortelle sans que des lésions se manifestent. Au laboratoire en particulier la surfusion est généralement très importante et on a pu maintenir pendant 14hr des fleurs de pommier à une température inférieure à —6°C sans qu'il apparaisse de dégâts.

Toutefois, la surfusion est généralement moins importante dans les conditions naturelles. Rogers (4) a montré qu'elle cesse généralement pour des températures comprises entre —1,7° et —2,2° C et il pense que la congélation dans les tissus résulte de la congélation de la rosée qui s'est déposée dessus. Afin de déterminer jusqu'à quelle température cette dernière peut descendre sans se congeler, nous avons placé, au-dessus d'un gazon, des coupelles remplies d'eau et nous avons enregistré leur température au cours de nuits de gelée. Nous avons trouvé des valeurs comprises entre — 3 et — 6°C, la plus fréquente étant —3,3°C. Les valeurs plus basses étaient observées lorsque l'air était sec; la température des coupelles était alors inférieure, par suite de l'évaporation, à celle des corps qui les entouraient et il n'y avait pas de rosée. La formation de gelée blanche, multipliant dans l'atmosphère les noyaux de congélation, contribue donc à faire cesser la surfusion.

C'est sur cette observation qu'est basé l'appareil avertisseur de gelées de Steinheuer (2): une pellicule d'eau est maintenue sur une plaque disposée à 40 cm au-dessus du sol, au milieu du verger ou de la vigne à protéger. Le dispositif de lutte est mis en marche lorsque l'eau se congèle. Il faut cependant noter que l'intervalle de temps séparant la congélation de deux de ces appareils ou d'un de ces appareils et un organe végétal peut atteindre une heure. Il en résulte une imprécision sur l'heure d'intervention. On trouve également là une explication sur le fait qu'après une gelée un bouquet peut être sévèrement endommagé alors qu'un bouquet voisin est indemne: le temps d'action des basses températures sur les organes congelés peut être notablement différent.

III. BILAN THERMIQUE DE LA CONGÉLATION DANS LES CONDITIONS DU LABORATOIRE

Il est maintenant universellement admis que la mort des tissus survient à la suite d'une congélation extracellulaire. Des controverses subsistent quant à la façon dont meurent les cellules, certains auteurs soutenant la thèse d'une destruction de la cellule par congélation intracellulaire consécutive à la congélation extracellulaire, d'autres pensant que la mort survient lorsque la concentration du suc cellulaire, qui augmente par suite du départ de l'eau vers la glace extracellulaire, atteint un degré tel qu'il se produit une précipitation irréversible des colloïdes. Il semble logique d'accepter le premier mécanisme lorsque la congélation est rapide (en particulier lorsque l'organe a subi une surfusion importante) et le second dans le cas d'une congélation lente.

Quoi qu'il en soit, il se forme de la glace dans les tissus avant que la mort des cellules ne survienne et cette congélation libère de l'énergie que le végétal doit évacuer. Dans les conditions du laboratoire, les échanges thermiques avec le milieu sont proportionnels à la surface S de l'organe végétal, à l'écart thermique entre ce dernier et l'enceinte $(\theta - \theta_1)$ et à son coefficient d'échange superficiel E (lui-même fonction de la nature et de la forme de l'organe et de l'agitation de l'air). Pendant l'intervalle de temps Δt, il ne pourra se congeler dans le tissu qu'une masse d'eau Δm telle que:

$$SE\ (\theta - \theta_1)\,\Delta t = L_f\,\Delta m \tag{1}$$

L_f étant la chaleur latente de congélation de l'eau (80 cal/g d'eau).

Le temps nécessaire pour congeler une fraction d'eau déterminée sera donc d'autant plus long que l'écart $\theta - \theta_1$, le rapport surface/volume et le coefficient E seront plus faibles. En particulier, il dépendra de l'agitation de l'air et les résultats obtenus en chambre calme ou en chambre ventilée sont notablement différents.

Plusieurs auteurs ont cherché à déterminer la quantité d'eau congelée au moment où survient la mort des tissus. Levitt (3) a récapitulé en un tableau les déterminations effectuées sur un certain nombre de plantes par différents auteurs. Il n'est pas fait mention des fleurs d'arbres fruitiers, mais la comparaison avec les autres plantes permet d'estimer entre 30 et 40% la fraction d'eau qui doit être congelée avant que la mort des cellules ne survienne.

IV. BILAN ÉNERGÉTIQUE DANS LES CONDITIONS NATURELLES

1. *Avant la Congélation*

Par nuit claire les principaux éléments du bilan sont constitués par une perte d'énergie par rayonnement compensée presque totalement par un gain par conduction—convection avec l'air. La variation d'énergie potentielle due à l'abaissement de température de l'organe et l'énergie de condensation ou d'évaporation sont en général très faibles et nous les négligeons. Le bilan énergétique d'un organe soumis au rayonnement s'écrira donc:

$$Rs + kS\frac{\theta - \theta_a}{z} = 0 \tag{2}$$

R = rayonnement net;

s = section droite horizontale de l'organe;

S = surface extérieure de l'organe;

k = coefficient de conductibilité thermique en air calme (3,39 10^{-3} cal cm^{-2} min^{-1} °C^{-1});

θ = température de l'organe;

θ_a = température de l'air;

z = épaisseur de la couche limite équivalente autour de l'organe;

Dans cette équation k/z remplace le coefficient d'échange E utilisé dans l'équation (1) (ce dernier intègre en effect les échanges par conduction—convection avec l'air et les échanges par rayonnement avec les parois). De cette équation on déduit que la température de l'air est supérieure à celle du corps et que l'écart thermique est d'autant plus grand que le rayonnement est plus intense et l'air plus calme (z plus grand).

Le calcul des éléments du bilan est aisé lorsque le corps a une forme géométrique simple. Tel est le cas du réservoir du thermomètre rayonnant librement dont la température est inférieure de 1 à 2°C à celle de l'air par nuit claire et calme. Il est plus complexe lorsqu'il s'agit d'un organe végétal à cause de sa forme irrégulière. L'expérience montre que sa température est généralement légèrement inférieure à celle du thermomètre; ceci est dû vraisemblablement au fait que la rugosité et le système pileux des végétaux augmentent l'épaisseur de la couche limite.

2. *Pendant la Congélation*

Lorsqu'il y a congélation, il faut ajouter au deuxième terme du bilan la chaleur libérée par la formation de la glace

$$Rs + kS\frac{\theta - \theta_a}{z} = L_f\frac{\Delta m}{\Delta t} \tag{3}$$

La température θ de l'organe remontant dès que cesse la surfusion, le terme $\theta - \theta_a$ peut devenir positif et l'air peut alors contribuer à accentuer les effets du rayonnement.

Pour fixer un ordre de grandeur du temps nécessaire pour congeler 30% d'eau par exemple, supposons que l'organe végétal est une petite sphère de 1 cm de diamètre, soumise à un rayonnement net $R = 0{,}15$ cal cm^{-2} min^{-1}. Admettons que la surfusion cesse lorsqu'il atteint la température de —3°C et que sa température de congélation est de —1.5°C. En exprimant les surfaces en centimètres carrés et la masse en grammes, et en admettant que le volume d'eau représente 80% du volume total, nous aurons les relations:

$$s = 1{,}2 \text{ m} \qquad \text{et} \qquad S = 4{,}8 \text{ m}$$

Attribuons à z deux valeurs qui peuvent sembler comme extrêmes lors des nuits de gelée: 2 mm correspondant à un air calme et 1 mm à un air agité.

(a) Température de l'air à l'arrêt de surfusion. Nous appliquerons la formule (2):

$z = 2$ mm	$z = 1$ mm
$\theta - \theta_a = -2{,}2$°C	$\theta - \theta_a = -1{,}1$°C
$\theta_a = -0{,}8$°C	$\theta_a = -1{,}9$°C

(b) Temps nécessaire pour congeler 30% d'eau. De la formule (3) nous tirons:

$$\frac{1}{L_f}\left(R\frac{s}{m}+k\frac{S}{m}\frac{\theta-\theta_a}{z}\right)\Delta t=\frac{\Delta m}{m}$$

soit

$$\frac{1}{80}\left(0{,}15\times 1{,}2+0{,}0034\times 4{,}8\frac{\theta-\theta_a}{z}\right)\Delta t=0{,}30$$

d'où nous tirons les valeurs:

z	$= 2$ mm	z	$= 1$ mm
$\theta-\theta_a$	$= -0{,}7$°C	$\theta-\theta_a$	$= +0{,}4$°C
Δt	$= 195$ min	Δt	$= 98$ min

Cet exemple, bien que très schématique, montre cependant que:

(i) l'action du froid doit se prolonger pendant un temps relativement long après l'arrêt de surfusion pour que les dégâts se manifestent;

(ii) ce temps est d'autant plus long que les organes sont plus gros (dans le cas d'une sphère, le rapport m/s et, par conséquent, le temps Δt sont proportionnels au rayon;

(iii) les conditions de rayonnement jouent un rôle important, mais le mouvement de l'air peut modifier son action dans un sens ou dans l'autre (en l'absence d'échange thermique avec l'air il faudrait, dans l'exemple précédent, une durée d'action de 130 min).

Remarques

(a) La température d'un thermomètre rayonnant librement (indice actinothermique) est voisine de celle de l'organe végétal en surfusion, mais il y a un écart notable entre ces deux températures au cours de la congélation.

(b) Dans un but de simplification, on a supposé que les différentes températures se maintenaient constantes après l'arrêt de surfusion. En réalité, elles tendent toutes à baisser et les valeurs des écarts thermiques peuvent se modifier. Bien que les dégâts apparaissent dans les fleurs de poirier lorsque leur température atteint —1,8° ou —1,9°C, aucune lésion n'a été notée dans le verger du Centre de Recherches à Versailles tant que l'indice actinothermique minimal à 40 cm n'est pas descendu au-dessous de —4,0°C.

(c) Dans un arbre fruitier les organes floraux ne sont pas les seuls à se congeler: de la glace se forme également dans les feuilles et les petites branches qui sont plus résistantes au froid et ne subissent généralement pas de dégâts. La chaleur libérée par cette congélation contribue à freiner notablement le refroidissement de l'air et par suite à protéger les fleurs. Afin de mettre ce point en évidence, deux thermomètres à minimums ont été placés dans deux pommiers voisins: les charpentes étaient semblables, mais l'un était en pleine floraison et pourvu d'un feuillage abondant, tandis que l'autre commençait à peine à débourrer. Le tableau suivant indique les températures minimales relevées après quatre nuits claires.

Date	5 cm du sol	Arbre en pleine floraison	Arbre en début de débourrement
4/5/60	—2,5	—1,7	—2,1
5/5/60	—0,5	+0,5	+0,5
6/5/60	2,2	4,0	3,9
7/5/60	2,8	3,7	3,8

Bien que l'on ne dispose que d'une seule observation par nuit de gelée, on note cependant une température supérieure de 0,4°C sur le thermomètre situé dans l'arbre fleuri alors qu'en l'absence de gelée les deux températures sont sensiblement identiques.

La forme des arbres, leur état de développement, la position des fleurs par rapport au feuillage peuvent donc contribuer à réduire ou aggraver le risque de gel. La forme des fleurs et en particulier le rapport pétales/réceptacle peuvent également suffire à expliquer les différences variétales de sensibilité (les pétales sont en effet riches en eau et assez résistants au gel, surtout lorsqu'ils sont jeunes).

CONCLUSION

Seule la mesure directe de la température des végétaux doit permettre de déterminer avec précision les seuils de résistance aux gelées. Mais cette méthode, délicate et coûteuse, ne peut être employée dans la pratique courante. L'étude des bilans thermiques au cours de la congélation montre que les essais de détermination au laboratoire des températures critiques ne sont plus valables lorsque l'on passe dans les conditions naturelles où les éléments du bilan sont très différents. Par suite de l'interaction entre les différents éléments du climat, il existe une certaine corrélation entre l'indice actinothermique et la température du végétal. Suivant les conditions de rayonnement, d'agitation de l'air et d'hygrométrie l'écart entre ces deux températures au moment de la mort des tissus peut varier de 1 à 2°C. La température de l'air, sous abri météorologique, est en corrélation moins étroite avec la température du végétal et doit être rejetée comme référence dans la lutte contre les gelées. Enfin les phénomènes de surfusion peuvent contribuer dans une large mesure à limiter les dégâts dus au gel.

BIBLIOGRAPHIE

1. Durand R., *Les Seuils de Résistance aux Gelées. Leur Détermination. Température de Référence. Mitteilungen der Informationstelle für Frostschutz,* Inst. für Physik und Meteo. der Landw. Hochschule Hohenheim.
2. Lehmann P., Ein einfaches Gerät zur Rationalisierung der Frostbekämpfung. *V.D.I.* **9** (1958).
3. Levitt J., *The Hardiness of Plants — Agronomy,* vol. VI. Academic Press, New York (1956).
4. Rogers W. S., Some aspects of spring frost damage to fruit and its control. *Report of the XIIIth Int. Congr.* (1952).

ÜBER DIE METHODIK VON MIKROMETEOROLOGISCHEN UND MIKROKLIMATOLOGISCHEN MESSUNGEN IN PFLANZENBESTÄNDEN

W. HESSE

Prof. Dr. Walter Hesse, Direktor des Instituts für Agrarmeteorologie der Universität, Leipzig, Deutschland (D.D.R.)

Abstract—Certain conditions must be fulfilled for an accurate study of the meteorological and microclimatological conditions of plant crops. When determining the size of the crop it must be possible to evaluate the measurements statistically. Furthermore, any damage by pests of animal or plant origin must be accounted for by controls, and there must be available contact with a macroclimatological station.

Diverse methods of measurements are used which require complicated methods of study, such as determinations of water and heat economy. The crops of several years were determined in this experimental series and the preliminary results are published.

Résumé—L'Exécution parfaite des enquêtes météorologiques et microclimatologiques dans les plantations requiert certains soins. Ainsi pour fixer l'ampleur de la plantation il faut s'assurer que les résultats de mesure se prêtent à un calcul statistique. D'autre part il faut tenir compte des maladies provoquées par les plantes et insectes nuisibles et faire des mesures de comparaison. Le rattachement à une grande station climatologique doit être garantie.

Les procédés de mesure sont variés et demandent des méthodes de recherches complexes telle que l'étude de l'ensemble économie hydrique et thermique. Dans l'aménagement des expériences l'auteur discute les mesures faites dans les plantations pendant plusieurs années et communique à la fin quelques résultats de mesures provisoires.

Auszug—Bei der exakten Durchführung von meteorologischen und mikroklimatologischen Untersuchungen in Pflanzenbeständen müssen bestimmte Forderungen erfüllt werden. So ist bei der Festlegung der Größe des Bestandes zu beachten, daß eine statistische Verrechnung der Meßergebnisse gewährleistet ist. Weiterhin sind Befallserscheinungen durch tierische und pflanzliche Schädlinge festzuhalten und Vergleichsmessungen anzustellen. Der Anschluß an eine Makroklimastation muß gewährleistet sein.

Die Meßverfahren sind vielseitig und erfordern komplexe Forschungsmethoden, wie der Wasser- und Wärmehaushaltskomplexe. In den Versuchsanordnungen werden die mehrjährigen Pflanzenbestandsmessungen erörtert und abschließend vorläufige Meßergebnisse bekanntgegeben.

I. ALLGEMEINES

WENN man die sehr verstreute Literatur über Bestandsklimamessungen studiert, so stellt man fest daß meist nur mikrometeorologische Messungen an Einzelpflanzen oder im Bestand durchgeführt wurden. Sehr wenige Untersuchungen beschäftigen sich dagegen mit mikroklimatologischen Messungen. Um gewisse Einblicke zu erhalten, genügen sehr oft nur sporadische Messungen; will man aber den atmosphärischen Einfluß auf das Pflanzenwachstum näher erfassen, so sind langjährige Beobachtungen und Messungen unbedingt notwendig.

II. FORDERUNG ZUR EXAKTEN DURCHFÜHRUNG VON PFLANZENBESTANDSMESSUNGEN

Um Pflanzenbestandsmessungen wissenschaftlich exakt durchführen zu können, müssen zunächst folgende Punkte berücksichtigt werden:

(a) Die *Größe des Bestandes*, die abhängig von der Dichte des Bestandes ist und in den einzelnen Abschnitten der Vegetationsperiode wechselt, muß sorgfältig festgelegt werden, damit bei Parallelmessungen (Wiederholungen) eine mathematisch-statistische Verrechnung der Meßergebnisse möglich ist. Randeffekte müssen dabei ausgeschaltet bzw. gesondert erfasst werden.

(b) Die Durchführung von *mikrometeorologischen Messungen* soll möglichst während einer gesamten Vegetationsperiode erfolgen. Nur wenn dies aus meßtechnischen Gründen nicht möglich ist, müssen sporadische Messungen wenigstens in markanten Abschnitten der Wachstumszeit (Bestockung, Blühstadium, Reifestadium, etc.) durchgeführt werden.

(c) Ist die Durchführung *mikroklimatologischer Messungen* über mehrere Vegetationsperioden bzw. während extremer Witterungsverhältnisse in einzelnen Vegetationsperioden möglich, so ist zu beachten, daß die Untersuchungen immer an der gleichen Pflanzenart und -sorte stattfinden. Bei der Fruchtfolge müssen die Pflanzenbestände innerhalb kleiner Räume wechseln, damit die mikroklimatischen Verhältnisse keine wesentliche Änderung erfahren.

(d) Bei der Auswertung mikroklimatologischer Untersuchungen muß man beachten, daß die *Aussaattermine* und damit auch die phänologischen Phasen während der einzelnen Vegetationsperioden verschieden sind. Die Schwankungen der Wachstumszeit können nach Hesse (1) recht erheblich sein.

(e) Die *Befallserscheinungen* durch tierische und pflanzliche Schädlinge müssen, um falsche Schlußfolgerungen zu vermeiden, sorgfältig studiert werden. Das Auftreten von Pflanzenkrankheiten muß durch regelmäßige Beurteilung der Pflanzenbestände festgestellt werden.

(f) Die Durchführung von *Vergleichsmessungen* auf einer Testfläche (unbewachsener Boden bzw. Rasen) ist notwendig.

(g) Der Anschluß an eine *Makroklimastation* (Basisstation), die in unmittelbarer Nähe des Meßfeldes sein muß, ist unbedingt erforderlich.

III. MESSVERFAHREN

Vielzahl und Vielseitigkeit der das Klima von Pflanzenbeständen bildenden Einzelerscheinungen erfordern sehr unterschiedliche Untersuchungsmethoden. Wechselbeziehungen zwischen dem sich durch die pflanzliche Entwicklung ändernden Pflanzenklimas und der Auswirkung des atmosphärischen Einflusses bzw. des Bestandsklimas auf die pflanzliche Produktion müssen unbedingt beachtet werden. In der Literatur beschriebene Untersuchungen sind in methodischer Hinsicht oft sehr uneinheitlich und deshalb kaum vergleichbar.

Bei der Durchführung von Bestandsmessungen sollte man sich zunächst auf bestimmte Komplexe beschränken, um Gesetzmäßigkeiten zu erkennen. Nur eine Komplexforschung ermöglicht es heutzutage, einen tiefen Einblick in den Mechanismus zu erhalten. Bei mikrometeorologischen und -klimatologischen Untersuchungen in Pflanzenbeständen schlägt Hesse (2) folgende Untersuchungsverfahren vor:

(a) Da beispielsweise 200 bis 300 l. Wasser je Kilogramm trockener Erntemasse bei Kartoffeln und Rüben und sogar 300 bis 500 l. Wasser je Kilogramm trockener Erntemasse bei Getreide erforderlich sind, sollte man sich zunächst der exakten Erfassung der Wasser- und Wärmehaushaltkomplexe widmen. Es kommt dabei darauf an, so exakt wie möglich die einzelnen Glieder der Wasser- und Wärmehaushaltgleichungen zu erfassen. Untersucht man nicht nur die Vorgänge in der bodennahen Schicht, sondern auch die im durchwurzelten Boden, so ist bei einer solchen dynamischen Arbeitsweise ein gewisser instrumenteller Aufwand notwendig.

(b) Zur Erfassung des Pflanzenwachstums sind außer phänologischen Beobachtungen unbedingt phänometrische Messungen, wie Pfeifer (3) und Stenz (4) nachwiesen, durchzuführen.

(c) Physiologische Untersuchungsverfahren, durch Fachwissenschaftler angewandt, ergeben wertvolle Hinweise, beispielsweise über den Wasser- und Nährstofftransport in der Pflanze. Die Anwendung von radioaktiven Isotopen sowie Spaltöffnungsmessungen sind u. a. geeignete Verfahren.

IV. VERSUCHSANORDNUNGEN

Während der Vegetationsperioden 1957 bis 1960 wurden auf 4 Versuchsparzellen (je 1500 m²) der Lehr- und Versuchsstation des Instituts für Agrarmeteorologie der Universität Leipzig in Holzhausen bei wechselnder Fruchtfolge mikrometeorologische und mikroklimatologische Untersuchungen an Weizen, Mais, Kartoffeln und Luzerne durchgeführt. Die Meßstationen befinden sich jeweils in der Mitte der Versuchsparzellen. Um die Pflanzen in ihrer Entwicklung nicht zu stören, werden die meteorologischen Größen im wesentlichen fernregistriert.

Die Erfassung der einzelnen Komponenten der Wasserhaushaltsgleichung ist durch den Einsatz von Kleinlysimetern nach Hesse (5—8) sowie durch Transpirographen nach Pfeifer (9, 10) gewährleistet. Im Laufe der 4 Vegetationsperioden haben sich diese Anlagen bestens bewährt (Abb. 1, 2).

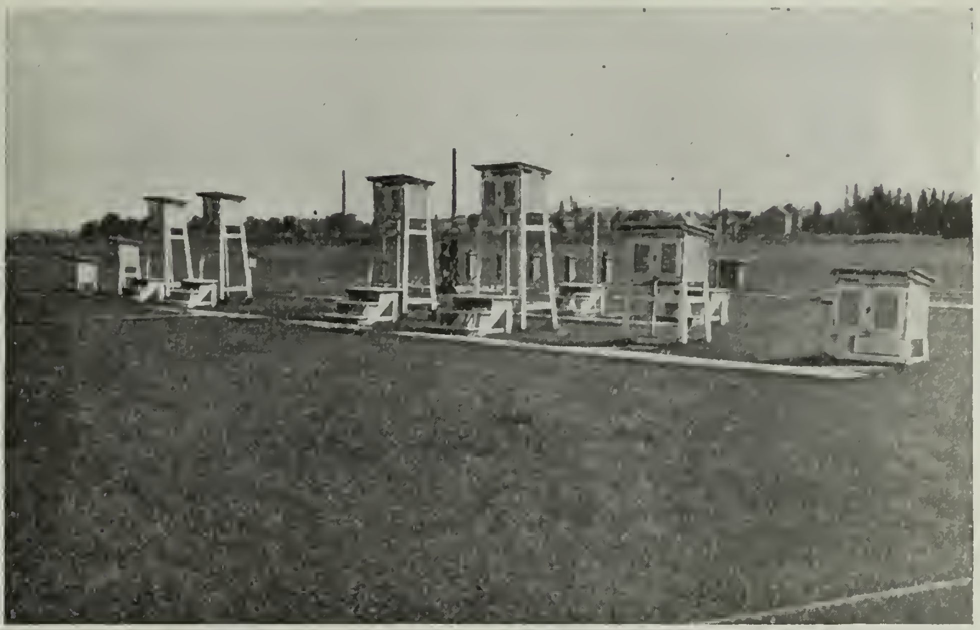


ABB. 1. Teilansicht der Lehr- und Versuchsstation

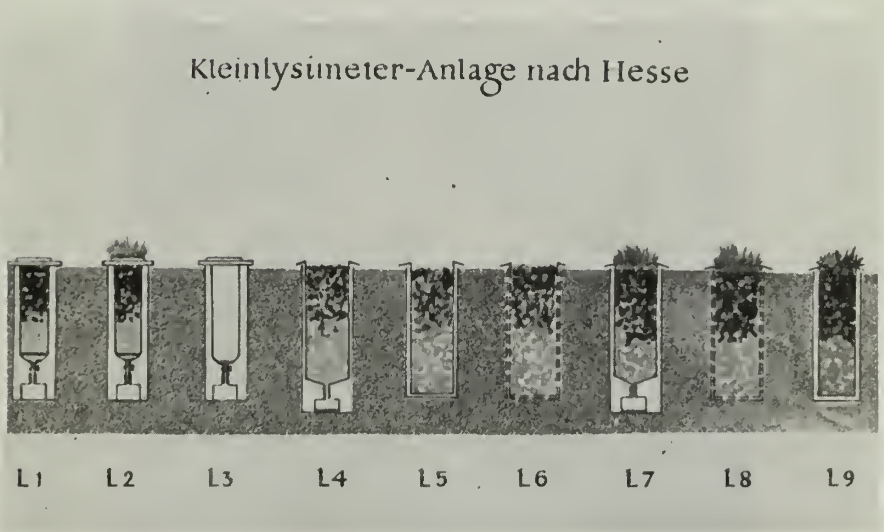


ABB. 2. Lysimeteranlage nach Hesse

Um alle Komponenten der Wärmehaushaltsgleichung im Pflanzenbestand exakt zu erfassen, gibt es noch gewisse instrumentelle Schwierigkeiten. Immerhin gelingt es wichtige Faktoren, wie die Strahlungsbilanz, laufend in Beständen registrierend zu verfolgen. Darüber hinaus ist selbstverständlich die Erfassung der Trocken- und Feuchttemperatur an Einzelteilen der Pflanze (Stengel, Blatt, etc.) und in der

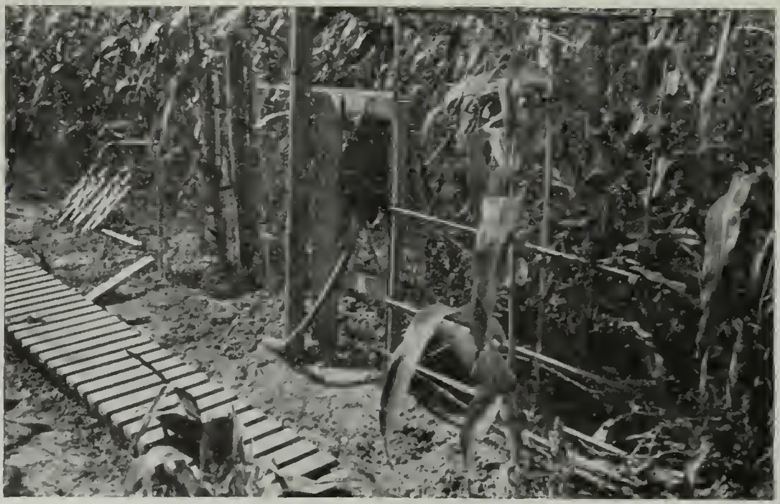


Abb. 3. Wärmehaushaltmessungen in einer Maisparzelle

Abb. 4. Wärme- und Wasserhaushaltmessungen in einer Maisparzelle

Umgebung der Pflanze in verschiedenen Höhen und Tiefen mittels Widerstandsthermometer, Thermoelementen und Thermistoren möglich (Abb. 3, 4).

Darüber hinaus wurden phänologische, phänometrische und pflanzenphysiologische Messungen angestellt.

V. VORLÄUFIGE MESSERGEBNISSE

Da die Untersuchungen noch einige Jahre fortgesetzt werden sollen, um wirklich repräsentative Meßwerte zu erhalten, die allgemeine Schlußfolgerungen zulassen, können nur vorläufige Meßergebnisse bekanntgegeben werden. Zunächst muß festgestellt werden, daß bei der Erfassung der beiden Komplexe Wasser und Wärme schon konkrete Hinweise für Pflanzenphysiologen, Pflanzenzüchter, Botaniker, etc. gegeben werden können. Eine enge Zusammenarbeit mit diesen Disziplinen ist zur vollständigen Erfassung des Bestandsklimas notwendig.

Folgende vorläufige Meßergebnisse können bekanntgegeben werden:

(a) Niederschlagsmessungen in 1 m Höhe sind für Bestandsmessungen nicht immer repräsentativ. Vergleichsmessungen in 0 m sind erforderlich.

(b) Da Tagestaumengen von 2 mm und mehr keine Seltenheit sind, ist die Erfassung des Tauniederschlags wichtig.

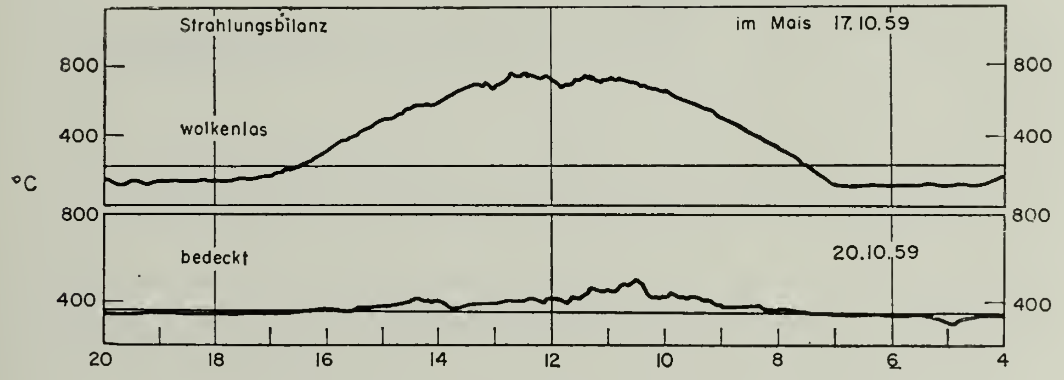


Abb. 5. Strahlungsbilanzregistrierung

(c) Nicht nur der meteorologische Niederschlag ist regelmäßig zu ermitteln, sondern es müssen Methoden entwickelt werden, die die wirkliche Niederschlagsmenge, die eine Pflanze oder ein bestimmter kleiner Pflanzenbestand erhält, erfassen. Lysimeterwägungen sind dafür geeignet.

(d) Die potentielle Verdunstung weist beispielsweise bei verschiedenen Pflanzenkulturen erhebliche Schwankungen auf; das Gleiche gilt auch für die Pflanzentranspiration. Wichtig ist, daß in einem Maisbestand die potentielle Verdunstung in 200 cm Höhe drei- bis vierfach höhere Werte liefert als in 50 cm Höhe. Bei der Pflanzentranspiration lassen sich zahlreiche meteorologische Faktoren, die die Intensität fördern oder hemmen, quantitativ erfassen. Hesse (11, 12) hat darüber mehrfach berichtet.

(e) Über die Änderungen des Wärmezustandes an Einzelpflanzen und Beständen hat kürzlich Pfeifer (3) berichtet. Die Auswertung der Strahlungsbilanzregistrierungen in Maisbeständen ist noch im Gange. Der Vergleich der einzelnen Strahlungskomponenten bei bedecktem und wolkenlosen Himmel wäh-

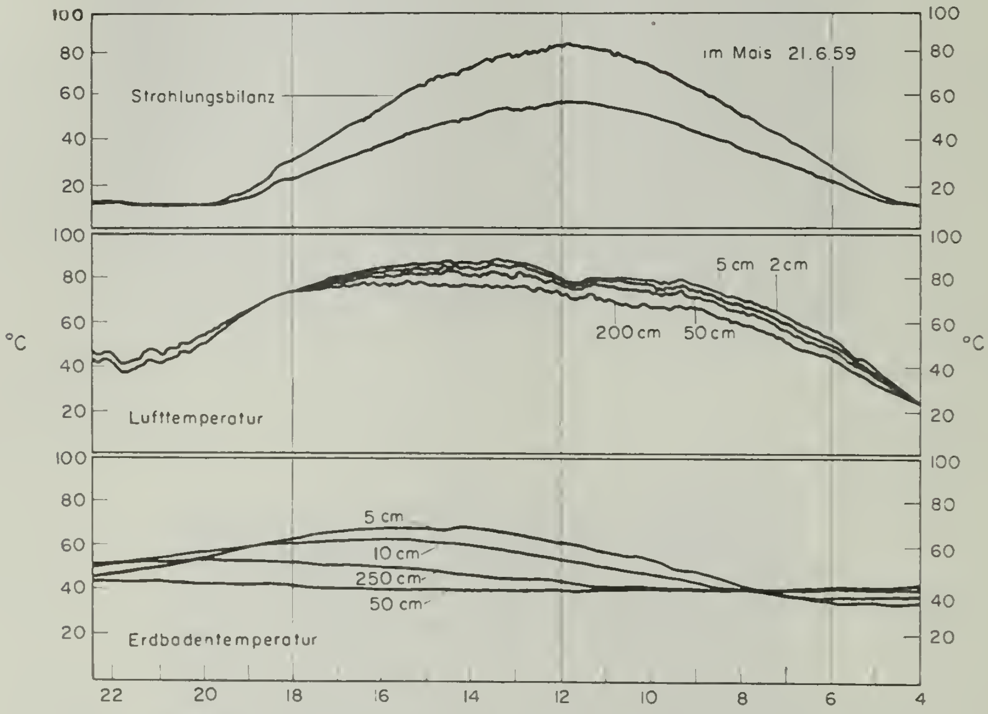


Abb. 6. Mikrometeorologische Registrierungen in Pflanzenbeständen

rend der verschiedenen Abschnitte einer Vegetationsperiode ist sehr aufschlußreich. Zeigt er doch, wie sich der Wärmehaushalt durch die Entwicklung des Pflanzenbestandes ständig ändert bzw. wie durch die geänderten Ein- und Ausstrahlungsbedingungen die Entwicklung des Pflanzenbestandes mitbestimmt wird (Abb. 5, 6).

LITERATUR

1. W. Hesse, Schwankungen der Vegetationsperiode. *Dtsch. Landw., Berl.* **4**, 4 (1953).
2. W. Hesse, Einfluß des Wärme- und Wasserhaushalts auf das Pflanzenwachstum. *Ber. Dtsch. Wetterd.* Nr. 51 (1958).
3. F. Pfeifer, Untersuchungen über den Wärmehaushalt von Pflanzen in Verbindung mit phänometrischen Messungen. *Veröff. Inst. Agrarmeteorologie* **1**, 4 (1959).
4. S. Stenz, Die Größenveränderung der Früchte von zwei Apfelsorten im Zusammenhang mit meteorologischen Umweltbedingungen. *Schweiz. Z. Obst- u. Weinb.* **11, 12** (1959).
5. W. Hesse, Messung der Pflanzentranspiration mit Kleinlysimetern. *Z. Acker- u. Pflanzenb.* **98,** 1 (1954).
6. W. Hesse, Eine neu entwickelte physikalisch-meteorologische Methode zur exakten Messung der Transpirationsintensität der Pflanzen. *Dtsch. Landw. Berl.* **5,** 7 (1954).

7. W. Hesse, Wasserhaushalt der Kulturpflanzen. *Netherl. J. agr. Sci.* **4**, 1 (1956).
8. W. Hesse, Der Wasserhaushalt von Kulturpflanzen. *Geofis. pur appl.* **34** (1956).
9. F. Pfeifer, Eine Schwimmwaage zur Registrierung der Transpiration. *Z. Meteor.* **10**, 1 (1956).
10. F. Pfeifer, Untersuchungen über die Transpirationsintensität von Erbsen (Pisum sativum) mittels einer registrierenden Schwimmwaage. *Angew. Meteor.* **2**, 12 (1957).
11. W. Hesse, Ergebnisse von Pflanzentranspirationsmessungen mit Kleinlysimetern im Zusammenhang mit meteorologischen Einflüssen. *Angew. Meteor.* **2**, 3 (1954).
12. W. Hesse, Ergebnisse von Pflanzentranspirationsmessungen. *Ann. Meteor.* **7**, 1/2 (1955/56).

MIKROKLIMATISCHE MESSUNGEN AUF OEDLANDFLÄCHEN

R. INTRIBUS
Forschungsinstitut für Forstwirtschaft der Tschechoslowakischen Akademie der Landwirtschaftswissenschaften—Zweigstelle Zvolen, Tschechoslowakei

Abstract—Studies of the microclimate of devastated soils in Czechoslovakia have shown that the detrimental effect of the microclimate and bioclimate can be overcome by phytomelioration and by afforestation of the ridges. Any form of grazing must be eliminated in these areas. The consequences of deforestation of calcareous and dolomitic slopes is more dangerous than in crystalline rock regions because of the faster drying of the upper facies of these soils and the general lack of water which does not accumulate there. The progressive succession of a variety of plant crops on the southern slopes of limestone surface soils which often had been altered by the detrimental effect of afforestation, pasture and grazing rotations, has been the cause of greater destruction here than in the regions with crystalline rock. These regions must be left out of any future planning and the community thus loses part of its ground through its own fault; it can be replaced in the distant future only at the expense of economic and financial hardship.

Furthermore, these studies have shown that the uniform, microclimatic conditions of forests, although depending on vertical and horizontal surface conditions, are characterized by even air and ground temperature throughout the day or year, delayed extremes of temperature and a low potential of evaporation.

It is therefore in the interest of national economy to plant gradually all the devastated areas of Czechoslovakia with trees and leave a proportion of $\geqslant 0{,}8$ of forests existing in the soutern and south-western exposures, at the same time abandoning any extensive form of pasture and grazing in those areas.

It is also recommended in the interest of a uniform procedure for carrying out research on the bioclimatology of forests to nominate a working commission with representatives from Central Europe as advocated by academician Novak at the second All-Union bioclimatological conference held in Liblice in 1958. One of the main tasks of this commission was to co-ordinate and to organize meetings of an international character to exchange knowledge. The creation of such a contact between scientists would fulfill the undoubted demand of forestry practice and production.

Résumé—L'étude microclimatique des sols dévastés en Tchécoslovaquie a montré que les influences défavorables du micro- et du bioclimat peuvent être éliminées par l'exécution accélérée de la régularisation du phytoamendement et en particulier par le boisement dans la partie des crêtes, à condition bien entendu d'exclure les pâturages sur ces terrains. Les conséquences du déboisement sur les pentes en pierres calcaires et dolomitiques sont plus dangereuses que sur des terrains de formation cristalline, à cause de la plus grande aptitude au dessèchement des niveaux supérieurs du sol et par suite du manque d'eau en général, l'eau se dispersant très vite dans le sol. La succession progressive des associations de plantes sur les pentes méridionales de la couche de carbonate,qui fut très souvent modifiée par suite des influences de dégradation telles que le déboisement, le pâturage et

le piétinement du gazon, succombe plus rapidement à la dévastation qu'un terrain cristallin. En tout cas ces zones finissent par être éliminées du groupe des terrains exploités et la Société perd par sa propre faute une partie des éléments de production dont le remplacement dans un avenir lointain demandera des efforts économiques et financiers accrus.

De plus l'étude a montré que les conditions microclimatiques les mieux compensées de la végétation sylvestre dépendent de la structure verticale et horizontale des organes aériens, ce qui se reflète dans la courbe compensée de la température de l'air et du sol au cours de la journée et de l'année avec un décalage appréciable de l'époque des maxima et des minima de température et dans une faible évaporation potentielle.

Sur le plan de l'économie politique ily avait donc intérêt à boiser toutes ces zones dévastées, dans les plantations d'orientation S et SW on maintient en particulier la plantation au rang $\geqslant$ 0, 8, renonçant d'une façon générale à une forme extensive de ces pâturages.

Il est tout indiqué que le Congrès dans l'intérêt d'un plan d'ensemble dans les travaux de recherches de bioclimatologie forestière, y compris l'application de méthodes homogènes, envisage la désignation d'une Commission de Travail, formée par des représentansts d'Europe Centrale, nécessité sur laquelle le Professeur Novák a déjà insisté en 1958, à l'occasion de la II^e^ Conférence Bioclimatologique Publique à Liblice. Une des tâches essentielles de cette Commission serait une coordination et échange d'expériences sous forme de Séminaires Bioclimatologiques de caractère international. Créer de telles relations entre les scientifiques dans ce domaine serait tenir compte des exigences de la pratique et de la production en sylviculture.

Auszug—Die mikroklimatische Erforschung devastierter Böden in der ČSR hat gezeigt, dass die ungünstigen Einwirkungen des Mikro- und Bioklimas durch eine beschleunigte Durchführung der Phytomeliorationsregulierung und insbesondere durch Bewaldung der Kammteile beseitigt werden können, allerdings unter Ausschluss jedweder Formen der Weidewirtschaft an diesen Flächen. Die Folgen der Entwaldung auf kalksteinigen und dolomitischen Abhängen sind gefährlicher als im kristallinischen Gebiete gerade wegen der grösseren Austrocknungsfähigkeit der oberen Bodenlagen und infolge des gesamten Mangels an Wasser, das sich sehr schnell im Boden verliert. Die progressive Sukzession der Pflanzengemeinschaften auf den Südabhängen der Karbonatunterlage, die sehr oft durch Degradationseinflüsse wie Bewaldung, Viehweide und Zertreten des Rasens geändert wurde, unterliegt schneller der Verwüstung als ein kristallinisches Gebiet. Jedenfalls kommt es zur Ausschliessung dieser Flächen aus dem Erzeugungsprozess und die Gesellschaft verliert durch eigene Schuld einen Teil der Produktionsgrundlage, die in einer weiten Zukunft nur mit erhöhten wirtschaftlichen und finanziellen Schwierigkeiten ersetzt werden kann.

Die Erforschung zeigte weiter, dass die am meisten ausgeglichenen mikroklimatischen Verhältnisse der Waldvegetation, abhängig von der vertikalen und horizontalen Gliederung, der oberirdischen Organe schafft die sich im ausgeglichenen Gang der Luft- und Bodentemperatur im Verlauf des Tages und des Jahres, in beträchtlicher Zeitverschiebung der Temperaturmaxima und -minima und in einer niedrigeren potentialen Ausdunstung widerspiegeln.

Vom Standpunkt der Volkswirtschaft aus werden deswegen nach und nach alle verwüsteten Flächen in der ČSR bewaldet, in den existierenden Beständen auf den südlichen und südwestlichen Expositionen bleibt insbesondere der Bestandesanschluss $\geqslant$ 0,8 erhalten und man verzichtet überhaupt auf eine extensive Form der Weidewirtschaft in diesen Gebieten.

Es wäre zu empfehlen, dass der Kongress im Interesse eines gemeinsamen Verfahrens bei der Durchführung von Forschungen auf dem Gebiete der forstlichen Bioklimatologie einschliesslich der Anwendung einheitlicher Methoden die Nennung einer Arbeits-

kommission von Vertretern aus Mitteleuropa als notwendig erklärt, wie schon darauf an der II ganzstaatlichen bioklimatologischen Konferenz im Jahre 1958 in Liblice der Akademiker Novák hingewiesen hat. Eine der Hauptaufgaben dieser Kommission wäre die Koordination und der Austausch von Erfahrungen in Form bioklimatologischer Seminare mit internationalem Charakter. Die Schaffung derartiger Beziehungen zwischen den Wissenschaftlern im angeführten Gebiete würde vor allem die unvermeidlichen Anforderungen der Praxis und Produktion in der Forstwirtschaft erfüllen.

EINFÜHRUNG

Die forstlich-klimatologische Forschung in der Tschechoslowakei hängt ausser anderem mit der Forderung nach einer beschleunigten Bewaldung von Kahlflächen und der durch Erosion zerstörten Gebiete zusammen. Die Notwendigkeit einer bioklimatologischen Erforschung der Oedlandflächen ist vor allem durch den Umstand begründet, dass die Fragen der Bewaldung dieser sekundär vernichteten Böden in den ersten und entscheidenden Lebensjahren der Sämlinge und Setzlinge der Waldbäume vorwiegend mikroklimatische Fragen darstellen. Die empfindlichen Sämlinge und Setzlinge sind auf den entblössten Böden ganz abweichenden und aussergewöhnlichen mikroklimatischen Verhältnissen zum Unterschied von denjenigen, die in den historisch angepassten Bedingungen des Waldbestandes geschaffen werden, ausgesetzt.

In unserem Beitrag wollen wir auf einige Beziehungen zwischen den Pflanzengemeinschaften und der Umwelt in den typisch erodierten Gebieten mit Rücksicht auf die geologische Unterlage, die Bodenverhältnisse, die durch Höhe und Art abweichende Vegetation, auf die Exposition der Abhänge gegen die Weltrichtungen und auf die Abhangsneigung hinweisen. Die mikroklimatischen Messungen im Terrain wurden in den Jahren 1955—1959 im Rahmen der komplexartigen Erforschung der Wassererosion in der ČSR und zwar auf dem mit geographischen Koordinaten $\varphi = 48°00'$ bis $49°00'$ der nördlichen Breite und $\lambda = 17°00'$ bis $21°00'$ der östlichen Länge begrenzten Gebiete verwirklicht. Die Messungen wurden in der Regel bei stabilisiertem anticyklonalem Witterungstyp in der Vegetationszeit, wenn die Änderungen im Tagesverlauf der meteorologischen Elemente am ausgeprägtsten sind, durchgeführt.

An diese ersten Messungsergebnisse schliesst sich derzeitig eine weitere Etappe der Erforschung des Bioklimas in Hochgebirgsgebieten bei deren Bewaldung, weiters bei der Änderung der Monokulturen in gemischte Wälder, beziehungsweise der niedrigen, nicht zuwächsigen strauchartigen, Wälder in hochstämmige Wälder mit einem genügenden Anschluss an.

DIE PROBLEMATIK

Die primäre Ursache aller natürlichen Prozesse, die sich in der sogenannten Biogenosphäre, d. h. in der geographischen Sphäre der Erde abspielen, ist die strahlende Sonnenenergie. Durch ihre Einwirkung gestaltet sich auch das Klima, das in den bodennahen Luftschichten, abhängig vom Relief, eine wichtige Rolle spielt, da es auch das Wasser- und Wärmeregime des Bodens, der anliegenden Atmosphäre, weiters die chemische, biologische und physikalische Entwicklung des Bodens, die Nährstoffaufnahme der Pflanzen aus dem Boden, also das gesamte Leben der Organismen beeinflusst. Auf der anderen Seite wirken die Pflanzengemeinschaften selbst aktiv auf die Entwicklung des Mikroklimas ein, womit zwischen der Vegetation, dem Boden und dem Mikroklima enge Beziehungen gestaltet werden, die der Mensch günstig oder nachteilig ändern kann. Mitteleuropa mit seinen Naturverhältnissen zeichnet sich durch eine bunte Mosaik erheblicher klimatischer und Witterungsunterschiede aus, da es im Übergang zwischen dem ausgesprochen kontinentalen östlichen und einem ausgeprägten ozeanischen Klima Westeuropas liegt. Beträchtliche Änderungen im Verlauf der klimatischen Elemente werden auch infolge der Mannigfaltigkeiten in den orographischen, geomorphologischen und geologischen Verhältnissen, mit denen ausser dem Klima auch eine grosse Buntheit in Bodentypen und -arten, weiters die Verschiedenartigkeit der Kulturen auf verhältnismässig kleinen Entfernungen (9) zusammenhängt, hervorgerufen.

Die mikro- und bioklimatische Forschung bezieht sich immer auf die meso- und mikroklimatischen Probleme insbesondere im Vegetationsklima und schliesst sich zweckmässig an das Makroklima unter vorwiegender Anwendung deren Methodik an. Unter dem Begriff Makroklima sind nicht nur die Witterungsverhältnisse in der bodennahen Luftsphäre bis zu 2 m über dem Boden, sondern alle kleinen Lufträume verschiedener Formen des Bodenreliefs mit dem Höhenunterschied etwa bis 50 m über und unter dem Niveau des Terrains, Vegetationsräume und auch die sehr kleinen submikroklimatischen Räume, wie sich im Terrain in verhältnismässig kleinen Entfernungen wechseln (8), zu verstehen.

Unsere ambulanten mikroklimatischen Messungen wurden vorwiegend auf die Erforschung des verschiedenartig ausgeprägten Mikroklimas der Abhänge nach den Weltrichtungen und der Hangneigung bestimmt. Die erreichten Ergebnisse ermöglichten uns die Beurteilung, inwieweit die Vegetationsdecke in der Lage ist, abhängig von deren Höhe und Dichte den Boden vor einem übermässigen Erwärmen zu schützen. Während der Messungen, die in der Regel 24 Stunden dauerten, wurden 10—12 mikroklimatische Stationen auf verschiedenen Standorten eingerichtet, wobei in einstündigen, im Zeitabschnitt des Temperaturmaximums auch in halbstündigen Intervallen die Boden- und Lufttemperaturen mit Hilfe von Quecksilberthermometern, weiters die potentiale Verdunstungsfähigkeit, und zwar für die Atmosphäre in den Höhen von 2, 5 und 20 cm ermittelt wurden. Überdies wurden auch die relative Luftfeuchtigkeit mittels eines Aspirationspsychrometers und das Windregime in einer Höhe von 150 cm und zuletzt die Feuchtigkeitsverhältnisse des Bodens bis in eine Tiefe von 100 cm mit Hilfe der Sondierstange und der Waagenmethode vor und nach der Austrocknung der Proben bei einer Temperatur von 105° C binnen 6 Stunden verfolgt. Die Kugeln der Quecksilberthermometer in den über den Boden liegenden Horizonten wurden mit einer Doppeldecke aus einem weisslackierten Aluminiumblech versehen. Die potentiale Verdunstungsfähigkeit wurde mit Piches-Verdunstungsmessern mit rundem Löschpapier im Durchmesser von 3 cm festgestellt.

Neben den ambulanten mikroklimatischen Messungen wurden auf einigen Standorten Jalousiehütten mit ganzjähriger Registrierung der Lufttemperatur und der

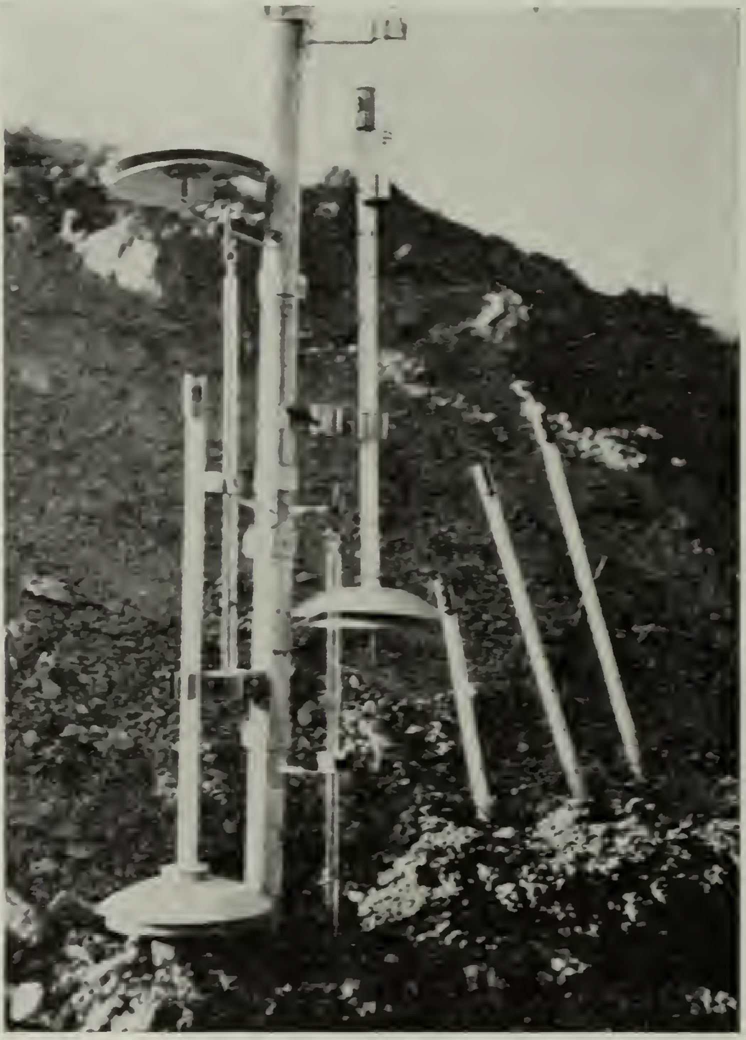


Abb. 1. Ein Detail der mikroklimatischen Station

relativen Feuchtigkeit in einer Höhe von 2 m installiert. Auf der Hauptstation wurden regelmässig auch die Niederschläge gemessen.

Trotz der Tatsache, dass die ambulanten mikroklimatischen Messungen in verschiedenartigen physikalisch-geographischen Bedingungen auf der ganzen Welt ausgiebig geltend gemacht werden und viele Erkenntnisse auch in die Problematik der forstlichen Bioklimatologie bringen, haben einige Tatsachen aus unserer Erforschung doch die Fragen beantwortet, wie die gemessenen Angaben für die Forstzwecke ausgenützt werden können und welche personalen und materiellen Besatzungen die Messungen in komplizierteren Bedingungen des Waldmikroklimas erfordern. Es genügt deshalb, einige Erkenntnisse aus der Erforschung des Abhangmikroklimas auf devastierten Flächen, wo diese bisher in der ČSR nicht durchgeführt wurde, ganz fragmentarisch anzuführen. Die Angaben beziehen sich einerseits auf das Karbonatgebiet in den Seehöhen von 400—500 m und andererseits zum kristallinischen Gebiet mit den Seehöhen von 700—1100 m. Im ersten Fall handelt es sich um ein Gebiet mit mässig warmen und mässig feuchtem Hügellandklima mit < 50 Sommertagen und mit Julitemperaturen von 16° C und mehr, mit einer durchschnittlichen Jahrestemperatur von 7,8° C und jährlicher Niederschlagsmenge von 712 mm. Das zweite, das kristallinische Gebiet ist durch den Typ eines kühlen Vorgebirgsklimas mit einer durchschnittlichen Julitemperatur von $< 16°$ C, mit einer durchschnittlichen Jahrestemperatur der Luft von 5,6° C und einer ganzjährigen Niederschlagsmenge von 815 mm charakterisiert.

Der pädologischen Seite nach kommen auf der Karbonatunterlage sandig-lehmige Böden, die Rendzinas gräupchenartiger Struktur, brüchig, mit einem hohen Skelettgehalt vor, und in der Bergland- und Hochlandzone des kristallinischen Gebietes befindet sich wieder eine bunte Skala von Übergängen vom Sand- bis zum Lehmboden mit einer verhältnismässig hohen Feuchtigkeitskapazität.

DIE ERKENNTNISSE AUS DER FORSCHUNG

1. *Die Temperaturverhältnisse*

Eine anschauliche Darstellung über den Tagesverlauf der Luft- und Bodentemperatur im Profil von einer Höhe von 150 cm bis zu einer Tiefe von 20 cm auf der Karbonatunterlage ist aus der Abb. 2 zu ersehen.

Die mit den römischen Zahlen bezeichneten Flächen stellen dar: eine Karstkahlfläche an der Exposition S., eine Gruppe 4-jähriger Schwarzkiefern, Exp. S., eine Gruppe 7-jähriger Schwarzkiefern, Exp. S., eine Karstkahlfläche, Exp. W., eine Gruppe 4-jähriger Schwarzkiefern, Exp. W., einen 25-jährigen Buchenbestand, Exp. N., eine Karstkahlfläche, Exp. E., eine Gruppe 4-jähriger Schwarzkiefern, Exp. E. und zuletzt eine entwaldete Kammlage (Gipfellage).

Aus dem Verlauf der Kurven auf der Abb. 2 sind deutliche Unterschiede in der Grösse der Temperaturamplituden nicht nur auf den einzelnen, standortsgemäss abweichenden Flächen, sondern auch in den einzelnen Horizonten zu ersehen. Die Grösse der Amplitude wird direkt durch die Art der Vegetationsdecke, durch deren Höhe und Dichte, bezw. durch die vertikale und horizontale Gliederung der überirdischen Organe bedingt. Z.B. im Buchenbestand (Abb. 2[IV]) ist die Schwingungsweite in der dünnen, nahe der Oberfläche liegenden Luftschicht um das zweifache, in der Tiefe von 20 cm bis um das zehnfache geringer als an der Karstkahlfläche mit der Exp. S. (Abb. 2[I]). In der Gruppe 4-jähriger Schwarzkiefern erscheint dieser Unterschied wesentlich niedriger und in der Gruppe 7-jähriger Schwarzkiefern mit der Exp. S. sind die Amplituden den Werten im angeschlossenen Buchenbestand

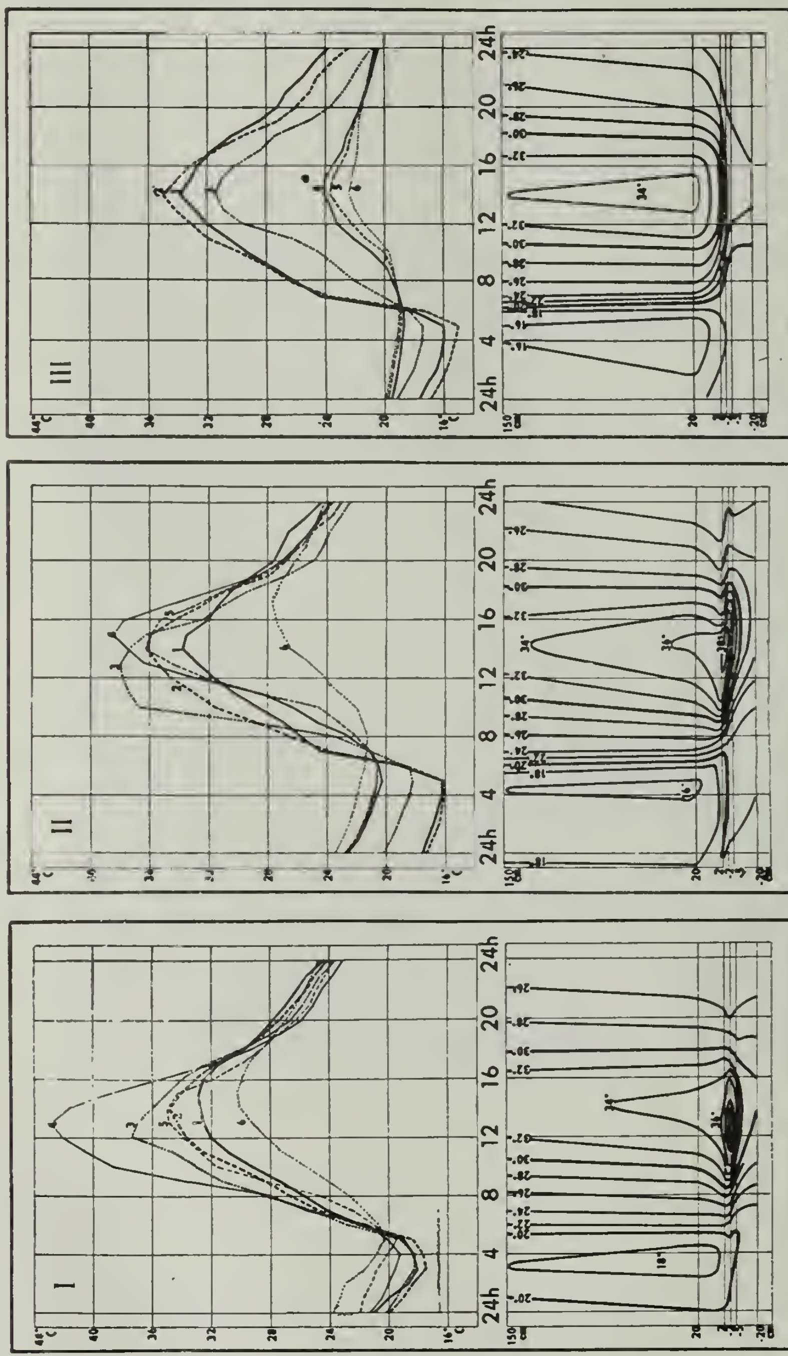
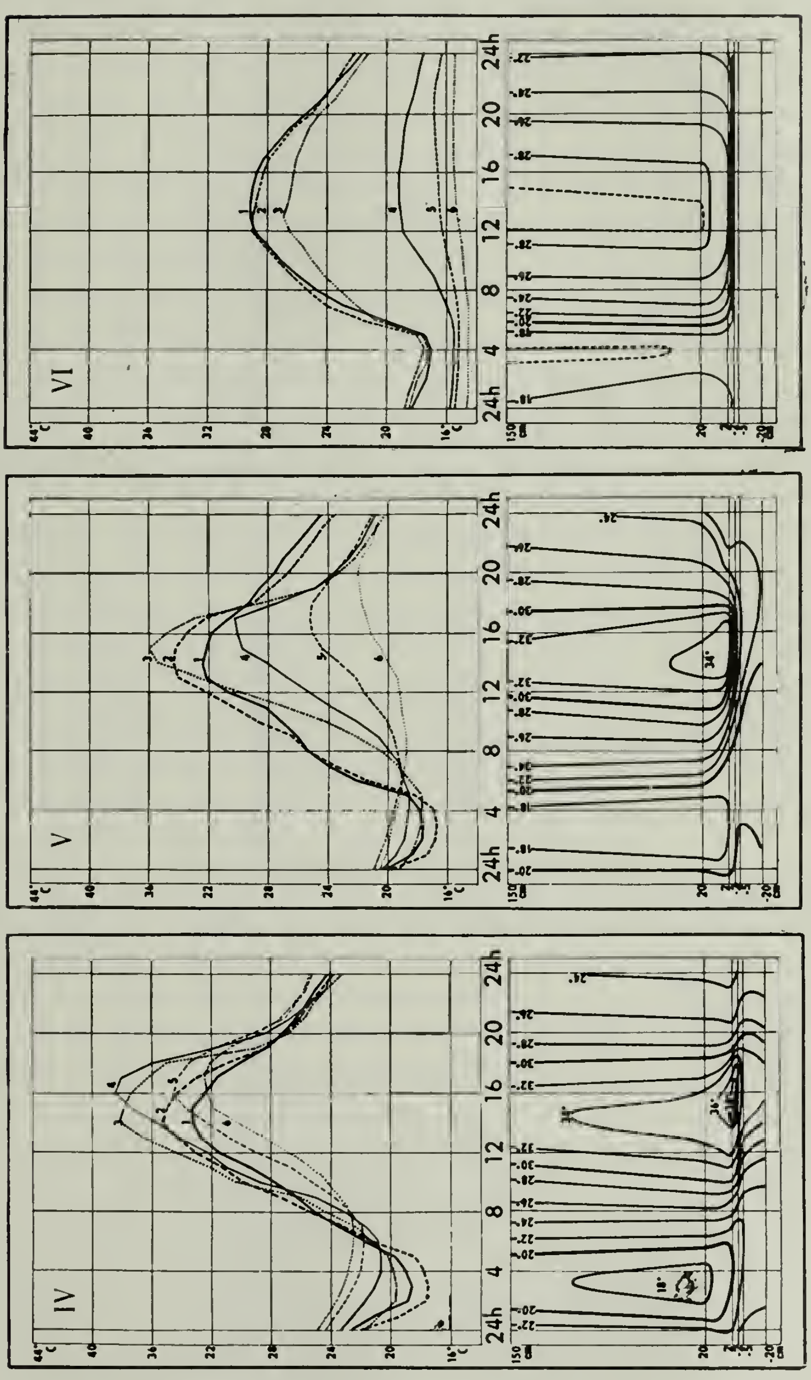
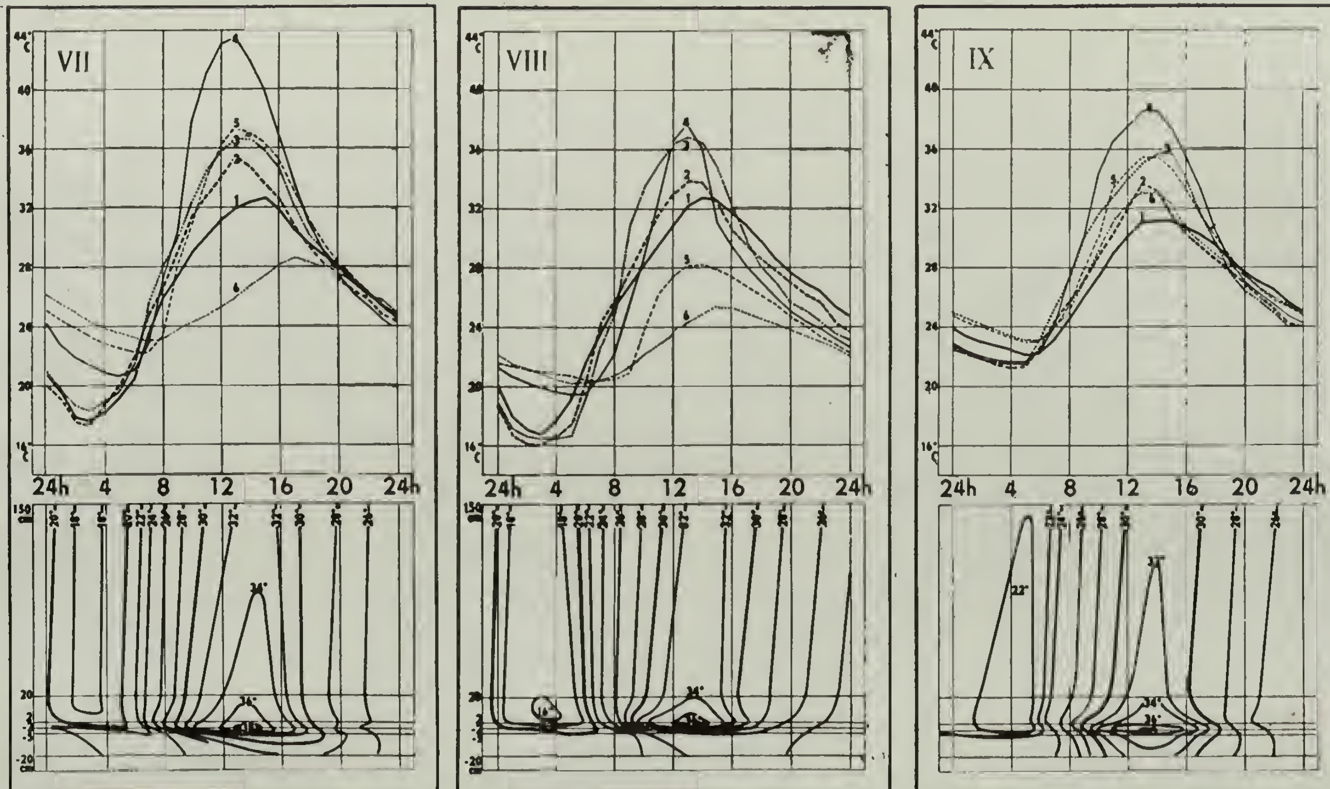


Abb. 2. Der Tagesverlauf der Luft- und Bodentemperatur auf der Karbonatunterlage (I) Karstkahlfläche, Exp. S. (II) Eine 4-jährige Schwarzkieferngruppe (*Pinus nigra*), Exp. S. (III) Eine 7-jährige Schwarzkieferngruppe (*Pinus nigra*), Exp. S.



(IV) Karstkahlfläche, Exp. W. (V) Eine 4-jähr. Schwarzkieferngruppe, Exp. W. (VI) 25-jähriger Buchenbestand, Exp. N.



(VII) Karstkahlfläche, Exp. E. (VIII) Eine 4-jähr. Schwarzkieferngruppe, Exp. E.
(IX) Offene Gipfellage

(1) Lufttemperatur in der Höhe von 150 cm
(2) ,, ,, von 20 cm
(3) ,, ,, von 2 cm
(4) Bodentemperatur in der Tiefe von 2 cm
(5) ,, ,, von 5 cm
(6) ,, ,, von 20 cm

ähnlich. Dies bedeutet, dass auch der Boden unter diesen 7-jährigen, noch nicht ganz angeschlossenen Schwarzkiefern vor der schädlichen Erwärmung und vor der Erosionseinwirkung geschützt wird.

Aus dem Tagesverlauf ist weiters zu ersehen, dass die Temperaturamplituden unter den Beständen von der Höhe von 150 cm in der Richtung zum Boden auch in die Bodentiefe eine sinkende Tendenz aufweisen und im ganzen niedriger sind als auf den offenen Karstkahlflächen, wo die Amplituden in der Richtung zum Boden zuerst rapid anwachsen und sich weiter mit der Tiefe wieder verringern. Die grösste Amplitude überhaupt kam in einer Tiefe von 2 cm auf einem Karstgeröll an der Exp. S. mit dem Wert von 23,6° C und die niedrigste in der Tiefe von 20 cm unter einem Buchenbestand an der Exp. N. mit dem Wert von 1,0° C vor.

Zu dem interessanten Temperaturverlauf an der Kammlage (Gipfellage) sei bemerkt, dass die Verringerung der Temperaturamplitude im ganzen untersuchten Profil insbesondere durch die ununterbrochene und verhältnismässig erhebliche Ventilation der Luft herbeigeführt wurde. Durch die Erwärmung der bodennahen Luftschicht war die Amplitude in der Höhe von 2 cm im Vergleich mit dem Inneren des Bestandes fast um 10° C höher, in der Tiefe von 20 cm war in der Zeit des Temperaturmaximums die Temperatur bis 33° C zu verzeichnen, was eine um 18° C höhere Temperatur als im Innern des Bestandes darstellt. Überdies wurde in den Nachtstunden in dieser Gipfellage in der Luft- und Bodenschichte von ± 2 cm die höchste Temperatur überhaupt von allen untersuchten Flächen gemessen. Um 4 Uhr frühmorgens war die Lufttemperatur in der Höhe von 2 cm am Abhangsgipfel 21,5° C, während der Südabhang eine um 4° C niedrigere Temperatur aufwies. Diese Besonderheit hängt unter anderem mit dem Abströmen der kalten Luft während der Wärmeausstrahlung in der Nacht dem Abhang entlang und mit deren Ansammlung im Tal und dem Vorkommen der Inversion zusammen.

Der tägliche Temperaturverlauf der Luft und des Bodens ist gut auch nach dem zeitgemässen Eintritt der maximalen und minimalen Temperaturen ausgedrückt. An der Karstkahlfläche mit der Exp. S. werden die oberflächlichen Bodenschichten intensiv schon in frühen Mittagsstunden, während an der Westexposition erst zwischen 15—16 Uhr durchwärmt werden (Abb. 2[I]) und 2[VI]). Dies ist die grösste Verschiebung des Temperaturmaximums mit Rücksicht auf die anderen untersuchten Flächen (der südlichen und östlichen Exposition). Es wird damit erklärt, dass die Südabhänge mit einer Neigung von 25° bis 30° ein Maximum an Sonnenstrahlung bei der höchsten Sonnenlage über dem Horizont, das heisst gegen Mittag erhalten, während die westlichen Abhänge am meisten — aber im ganzen bei einer niedrigeren Strahlungsintensität erst in den Nachmittagsstunden erwärmt werden. Die Bodentemperatur in einer Tiefe von 2 cm erreichte das Maximum im ersten Fall um 13 Uhr mit einem Wert von 42,8° C und im zweiten Fall um 16 Uhr mit einem Wert von 38,4° C. Dieser Umstand hat vom bioklimatologischen Standpunkt für die günstige Entwicklung der Vegetation auf den westlichen und westlich-südwestlichen Abhängen, auf denen die erfolgreichste Bewaldung verläuft, eine besondere Bedeutung, An den westlichen Expositionen ist eine ausgeprägtere Verschiebung nicht nur unmittelbar unter der Bodenoberfläche in einer Tiefe von 2 cm sondern auch in den Tiefen von 5 und 20 cm und zwar beiläufig gegen 17 Uhr und in der Gruppe der Schwarzkiefern in der Tiefe von 20 cm sogar um 20 Uhr zu verzeichnen.

Die zeitgemässe Verschiebung der Temperaturminima war im ganzen weniger ausgeprägt und betrug in den Beständen im Vergleich mit den Karstkahlflächen ungefähr 2 Stunden. Dieser Umstand hängt einerseits mit der gesamten Wärme-

Abb. 3. Nördliche bewaldete und südliche verkarstete Abhänge an der dolomitischen Unterlage

bilanz während der Insolation am Tage und der Ausstrahlung in der Nacht und andererseits mit der Vegetation selbst, wobei die Laubfläche des höchsten Bestandes mit ihrer aktiven Schicht eine Menge der Strahlung, die aus dem Boden kommt und von diesem wieder in den Weltraum ausgestrahlt wird, modifiziert.

Auf Grund der durchgeführten Analyse der Temperaturverhältnisse und der Entwicklung der Vegetation auf dolomitischer und kalksteiniger Unterlage kann es festgestellt werden, dass die am extremsten entblössten Böden mit den Expositionen S., SSW. mit den Anfangsstadien bezw. Gemeinschaften von *Festucetum glaucae* besiedelt werden und durch die darauffolgende Entwicklung über weitere Gemeinschaften von *Carex humilis* + *Festucetum sulcatae* auch die Bodenverhältnisse im äussersten Horizont verbessert werden, da die Quantität der Feinerde durch die Wirkung des Wurzelsystems dieser wärmeliebenden Pflanzen gesteigert wird. Die nächst folgende Entwicklung zielt zur Ausbildung einer strauchartigen Vegetation und zuletzt eines angeschlossenen höheren Bestandes, allerdings bei vollkommener Ausschliessung der Viehweide an diesen Flächen und anderer Eingriffe des Menschen. Es zeigte sich auch, dass die Pflanzenwelt nach der Bewaldung der verkarsteten Böden eine Schutzwirkung nicht nur auf den Boden in den angepassten Rigolenschüsseln sondern auch zwischen diesen ausübt, wo eine reichlichere Grasvegetation ansiedelt, da die Erosionsentwicklung aufhörte und auch die mikroklimatischen Wirkungen günstig geändert wurden.

Im kristallinischen Gebiete haben ähnliche Messungen der Luft- und Bodentemperatur gezeigt, dass auch in den Bedingungen des Vorgebirgs- und Bergklimas

Abb. 4. Die Art der Bewaldung auf den Oedlandflächen in Rigolschüsseln

mit einer Seehöhe von 700—1100 m eine stärkere Insolation auf entwaldeten südlichen und südwestlichen Abhängen während der antizyklonalen Witterungstypen eintritt, wobei oft grössere Temperaturamplituden und höhere Temperaturmaxima in den oberflächlichen Bodenschichten als in den niedrigeren Lagen vorkommen können. Dies wird durch den Umstand erklärt, dass in diesen Berggebieten die Atmosphäre transparenter als in den Niederungs- oder Talteilen in der Nähe von Ansiedlungen und Industriebetrieben ist. Eine wichtige Rolle spielt hier insbesondere die grössere Intensität der kurzwelligen Strahlung in den höheren Lagen, die bei dem weiteren Durchdringen durch die Atmosphäre infolge der steigenden Menge von Staub- und Rauchbeimischungen abgeschwächt wird.

Analogisch mit dem vorigen Beispiel beachten wir in diesem Gebiete wieder die Temperaturamplituden und den zeitgemässen Eintritt der Temperaturextreme.

Zur Illustration führen wir nur Angaben über die Bodentemperatur aus den Messungen in den Tagen von 19—20 Juli 1958. Die Werte der Temperaturmaxima und -minima mit den entsprechenden Amplituden sind aus der Tabelle 1 zu ersehen.

Tabelle 1. Bodentemperaturenextreme (19—20. VII. 1958) in °C

Nr.	Messtelle	Bodentiefe in								
		2 cm			5 cm			20 cm		
		Max.	Min.	Ampl.	Max.	Min.	Ampl.	Max.	Min.	Ampl.
1	80-jähr. Fichtenbestand (geschlossen)	13,3	11,6	1,7	12,6	11,8	0,8	12,1	11,7	0,4
2	Kiefernbestand, Exp. SSW.	14,9	12,1	2,8	14,7	12,3	2,4	13,2	12,7	0,5
3	Lärchenjungwuchs, Exp. NNE.	18,0	11,5	6,5	17,5	11,7	5,8	13,8	12,3	1,5
4	Roggenbestand, Exp. S.	24,1	15,4	8,7	23,2	16,0	7,2	20,3	16,8	3,5
5	Weide-Kammlage	24,5	13,4	11,1	21,0	15,0	6,0	18,3	16,4	1,1
6	Weide, Exp. NNE.	24,6	15,6	9,0	21,9	16,4	5,5	19,8	17,6	2,2
7	Wiesenbestand nicht gemäht Exp. S.	25,6	15,4	10,2	24,4	16,0	8,4	20,0	17,3	2,7
8	Wiesenbestand, gemähtes Gras, Exp. S.	26,2	15,6	10,6	23,8	16,8	7,0	22,0	18,0	4,0
9	Wiese, Exp. SSW.	28,4	13,8	14,6	23,9	15,4	8,5	20,7	16,6	4,1
Extreme schwanken zwischen einzelnen Messtellen um		15,1	4,1	12,9	11,8	5,1	7,7	9,9	6,3	3,7

Wir sehen vor allem, dass die Werte der Maxima in einer Tiefe von 2 cm von den angeschlossenen Beständen zu den offenen Weideflächen ansteigen und diese Tendenz mehr oder weniger auch in den Tiefen von 5 und 20 cm beibehalten. Bei den Minima sind die Unterschiede erheblich geringer und betragen in der Tiefe von 2 cm nur 4,1° C, in der Tiefe von 5 cm 5,1° C und in der Tiefe von 20 cm 6,3° C, d.h. die Werte der Minima steigen mit der Tiefe, während die der Maxima mit der Tiefe sinken. Grössere Unterschiede bei den Temperaturmaxima in Beständen und auf den entwaldeten Flächen sind durch die aktive Schicht der Laubfläche selbst im Bestand bedingt, die selektiv nur einen gewissen Teil, insbesondere den grünen Teil des Spektrums durchlässt, der mit der diffusen Strahlung zum Waldboden mit einer kleineren Intensität gelangt, während die zerstörte und geringe Grasdecke den vorwiegenden Teil der direkten Radiation in den Boden durchlässt. Das intensive Aufnehmen der Wärmestrahlen durch den Boden bedingt auch eine erhöhte Ausstrahlung der langwelligen, wirksamen Wärmestrahlung in die umliegende Atmosphäre und dadurch auch höhere Temperaturen, was in der Atmosphäre unter den Kronen der angeschlossenen höheren Bestände in einem kleineren Ausmass zur Geltung kommt.

Die gesamte Verminderung der Wärmeamplitude mit der Bodentiefe bestätigen auch die Angaben in der Tabelle 2.

Man sieht z. B., dass die Tagesamplitude im Durchschnitt aller Standorte in einer Tiefe von 2 cm 8,4° C und in einer Tiefe von 20 cm nur 2,3 °C misst, ferner,

Tabelle 2

Bodentiefe (cm)	Die Tagesschwankung beträgt im Mittel der 9 Mess-stellen (°C)	Die grösste	Die kleinste	Die Schwankungen differieren also an den Einzelmessstellen um (°C)
		Schwankung, die an einer der 9 Messstellen erreicht wurde, beträgt (°C)		
2 cm	8,4	14,6	1,7	12,9
5 cm	5,7	8,5	0,8	7,7
20 cm	2,3	4,1	0,4	3,7

dass der grösste Unterschied zwischen den Amplituden in einer Tiefe von 2 cm ist und allmählich in die Tiefe von 20 cm fast um das vierfache sinkt.

Der Eintritt des Temperaturmaximums, ähnlich wie im vorigen Fall in der Tiefe von 2 cm, war in Beständen bis um 5 Stunden und des Minimums beiläufig um 3 Stunden mit Rücksicht auf die offenen Weideflächen verschoben. (Das Maximum auf der Weide mit der SSW.-Exp. um 13 Uhr, das Minimum um 5 Uhr und im Fich-

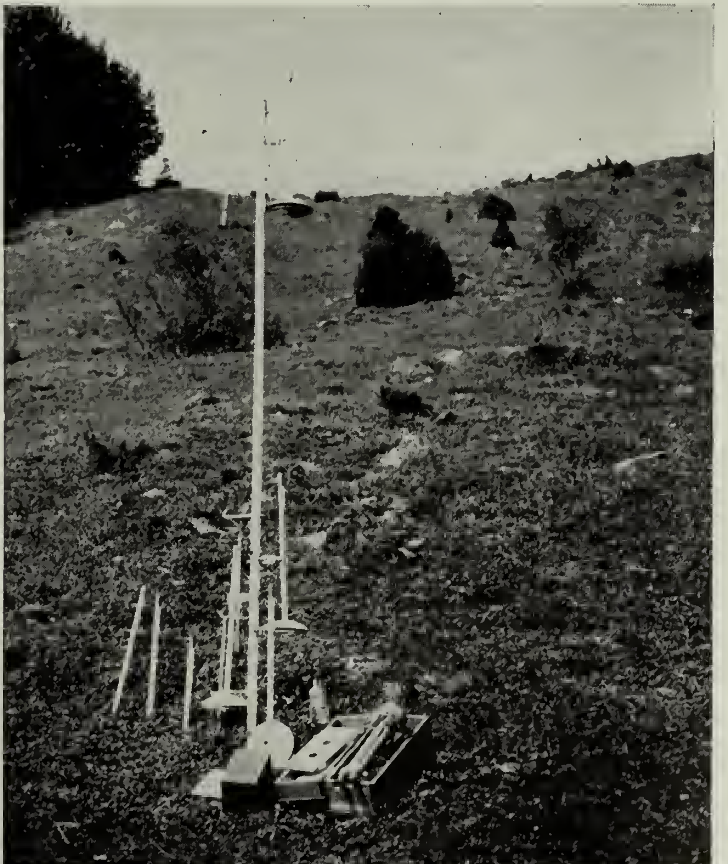


Abb. 5. Eine mikroklimatische Station auf der Weidefläche im kristallinischen Gebiete

tenbestand das Maximum um 18 Uhr und das Minimum um 7 Uhr.) Der intensive Temperaturanstieg auf den offenen Weideflächen oder in lichten und niedrigen Beständen tritt also wesentlich später als in den angeschlossenen Beständen ein.

2. *Die potentiale Evaporation und relative Luftfeuchtigkeit*

Eine kurze Analyse des Temperaturverlaufes wies auf die Schutzwirkung der Vegetation vor der nachteiligen Erwärmung der oberflächlichen Bodenschichten und auf deren direkte Abhängigkeit von der potentiellen Evaporation hin. Ergänzen wir deshalb diese Analyse wenigstens durch einige Angaben über die Vor- und Nachmittagsintensität der potentialen Verdunstung und über die gesamte Menge des verdunsteten Wassers in cm³ während der Dauer von 24 Stunden auf den untersuchten Flächen. In beiden untersuchten Gebieten übertraf die Evaporation am Nachmittag die des Vormittags und zwar im dolomitischen Gebiete etwa 2,5 mal in den Beständen und um 1/3 auf den Karstkahlflächen im kristallinischen Gebiete auf den Weideflächen um 10—20% und in den Beständen um 20—50%. Eine Ausnahme bildete der Roggenbestand mit der S.-Exp., wo die Evaporation in den Nachmittagsstunden fast um das dreifache höher war als am Vormittag. An der entblössten Gipfellage im dolomitischen Gebiete zeigten sich in den beiden Tagesabschnitten keine Unterschiede infolge eines deutlichen Einflusses einer dynamischen Turbulenz, die zusammen mit dem thermischen Effekt die höchste potentiale Evaporation von allen Standorten bedingte. Nehmen wir die Werte von der Gipfelstation als 100%, so ergibt sich die durchschnittliche Verdunstung während der Dauer von 24 Stunden (in cm³ Wasser) auf den Karstkahlflächen: S.-Exp. 74%, E.-Exp. 55% und W.-Exp. 50%; in Gruppen der 4-jährigen Schwarzkiefern *(Pinus nigra)* : S.-Exp. 45%, E.-Exp. 41% und W.-Exp. 49%. Diese Werte bestätigen den Einfluss der Vegetation auf die Höhe der potentiellen Evaporation, die mit der Verringerung der Bestandeshöhe und mit der Steigerung der Lückenhaftigkeit (Durchlichtung) deutlich anwächst.

Für das Forstwesen sind auch die absoluten Minima der relativen Luftfeuchtigkeit, die in einer länger andauernden Trockenperiode ungünstig auf die Pflanzenwelt im Walde wirken, oder die Verbreitung von Schädlingen begünstigen können, von Bedeutung. Die Beobachtungen auf den ständigen Objekten haben gezeigt, dass im Vegetationszeitabschnitt sehr niedrige Werte in der relativen Feuchtigkeit vorkommen können, wie es im Juli 1958 der Fall war, wo über der offenen Weidefläche ein Minimum der relativen Feuchtigkeit von nur 16% beobachtet wurde. In kürzeren Intervallen einer trockenen Witterung sind die Bestände in der Lage, sich an Feuchtigkeitsverluste bei herabgesetzter Ausdunstung und niedrigeren Temperaturen, bei gleichzeitiger Stagnation der Luft im Stammraum der Bestände und einer höheren Bodenfeuchtigkeit im Wurzelsystem anzupassen. Im Gesamtdurchschnitt während der antizyklonalen Witterung überstieg die relative Luftfeuchtigkeit 80% nicht und die Minima schwankten über der Weide um 35% und in den Beständen um 55%.

3. *Die Feuchtigkeit des Bodens*

Die primäre Ursache eines abweichenden Wasserregimes im Boden ist eine ungleichmässige Aufnahme der strahlenden Sonnenenergie von verschiedenartig exponierten Abhängen gegen die Weltrichtungen. Infolge der Insolationswirkung haben die Böden an den Südabhängen, insbesondere die Weideflächen einen geringeren Humusgehalt und eine geringere Durchlässigkeit als die Böden an den Nordabhängen. Eine intensive Durchwärmung bewirkt die Austrocknung des Bodens, dessen Zementisierung und grosse Verluste an Bodenfeuchte durch physikalische Verdunstung, wodurch die Infiltrationseigenschaften des Bodens verschlechtert werden. Im kristallinischen Gebiete war z. B. die Wassereinsickerung auf der Weide durchschnittlich bis 5mal niedriger als auf den Ackerfeldern und die augenblickliche Bodenfeuchtigkeit auf der Weide mit der Nordexposition im Vergleich mit den Werten auf den Südabhängen war mehr als zweimal so gross.

Auf den Kalksteinen und Dolomiten waren diese Unterschiede noch markanter, wobei der Humushorizont auf dem Südabhang in der Regel um 4—6 cm seichter als auf dem Nordabhang zu sein pflegt und infolgedessen auch der Boden auf den Südabhängen grobkörniger und kalkhältiger ist. Wenn wir beide Lokalitäten gemäss der durchschnittlichen augenblicklichen und relativen Feuchtigkeit in der Schicht 0—60 cm vergleichen, so ergeben sich folgende Werte (Tabelle 3).

Tabelle 3

Messtelle	Mittelwerte von momentaner Bodenfeuchte	Relat. kapillare Bodenfeuchte
Kristallinisches Gebiet		
(Seehöhen 700—1200 m)		
Exp. SSW., Neigung 19°	20%	59%
Exp. N., Neigung 18°	41%	95%
Karbonatunterlage		
(Seehöhen 400—500 m)		
Exp. S., Neigung 22°	11%	36%
Exp. N., Neigung 18°	23%	57%

Gemäss der angeführten Angaben besitzen die in den höheren Lagen auf sonnigen Abhängen gelegenen Böden mehr oder weniger eine optimale Feuchtigkeit, während auf den niedriger liegenden Stellen die optimale Feuchtigkeit auf den Schattenabhängen vorgekommen ist. In den angeführten Seehöhen des kristallinischen Gebietes leiden die Nordabhänge an Durchnässung, Anhäufung des Rohhumus und Bodenabtragung, während wir im zweiten Fall ein entgegengesetztes Extrem infolge einer grösseren Durchlässigkeit in der Unterlage beobachten können (13).

LITERATUR

1. Geiger R., *Das Klima der bodennahen Luftschicht.* Braunschweig (1950).
2. Göhre K., Kleinklimatische Untersuchungen auf einer Kiefernkultur unter Birkenvorwald. *Arch. Forstw.* **3**, (1954).
3. Göhre, K. und R. Lützke, Der Einfuss von Bestandesdichte und- Struktur auf das Kleinklima im Walde — *Arch. Forstw.* **5**, 7/8 (1956).
4. Intribus R., *Mikroklimatické merania v Juhoslovenskom krase,* Vodná erózia na Slovensku. SAV, Bratislava (1958).
5. Intribus R., Príspevok k mikroklíme spustnutých pôd na Slovensku. *Les. časop., roč.*, **6**, (1960).
6. Junghans H., Klimaaufnahme für forstliche Zwecke. *Wiss. Z. Tech. Hochschule Dresden.* **7**, (1957).
7. Lundegardh H., *Klima und Boden.* Jena, 1954.
8. Novák V. Mikrolimatické situace. *Met. zpr.* 3 (1949).
9. Novák V., O metodologické problematice v zemědělském bioklimatologii. *Sbor. dokumentů II. celostát. biokl. konf. v Liblicích,* 3—5. XI. 1958, *Praha.* ČSAV (1960).
10. Pasák, V.: Mikroklimatologická a hydrologická měření v kmenovém prostoru lesa — Věd. práce VÚLHM, 1957.
11. Sapožnikovová, S. A.: Mikroklíma a místní klímabrázda, Praha, 1952.
12. Zachar, D., O príčinách vodnej erózie v oblasti Pohorelej na dolnej hranici lesà — Les. časop. roč. II, č. 2, 1956.
13. Zachar, D., Vplyv reliéfu na vlhkost' pôdy — Poľnohospodárstvo, roč. VII, č. 1, 1960.

INFLUENCE OF AIR POLLUTION UPON THE VEGETATION IN THE UPPER SILESIAN INDUSTRIAL DISTRICT

E. PAPRZYCKI

Climatological Department of the Institute of Geography of the Polish Academy of Sciences, Warszawa, Poland

Abstract—In the Upper Silesian Industrial District observations were made in regard to the damage due to air pollution effected in pine and fir trees during their vegetative period. The distinct correlation between the extent of the damage in pine and fir and the amount of deposited dust have been proved; the observed limit of damage ran between 0.5 and 1.0 g of deposited dust per m^2 per day.

Résumé—Dans la Haute Silésie des observations ont été faites au sujet des dégâts causés parmi les pins et les sapins pendant leur période de végétation par la pollution de l'air. La corrélation caractérisée entre l'importance des dégâts causés parmi les pins et les sapins et la quantité de poussière déposée a été mise en évidence, la limite constatée de détérioration variait entre 0,5 et 1,0 gr de poussière déposée par mètre carré et par jour.

Auszug—Im oberschlesischen Industriegebiet wurden Untersuchungen angestellt in Bezug auf die Schäden an Kiefern und Tannen in der Wachstumsperiode aufgrund der Luftverunreinigung. Der genaue Zusammenhang zwischen dem Ausmaß der Schäden an Kiefern und Tannen und dem Staubgehalt der Luft wurde nachgewiesen. Die beobachtete Grenze der Schäden lag bei 0,5—1,0 g abgelagertem Staub pro m^2 und Tag.

The central part of the Upper Silesian Industrial District, an area of approximately 400 km^2, mostly urbanized and industrialized, has a large number of coal mines, smelting works, coking plants and other industrial plants which produce a significant degree of air pollution. This apparently has an influence on the adjacent forests of the areas discussed. In 1953 and 1954 observations were made as regards the damage effected in pine and fir trees during their vegetative period due to industrial air pollution.

The following criteria, based on H. Marter's investigations, on the extent of damage distinctly affecting forests have been accepted.

For pines, the zone within which more than 80 per cent of the trees of up to 20 years of age consists of the tortrix *(Evetria buoliana* and E. *resinella)* : the colour of needles changed from bright green to grey-green; when cutting the trees on a clear day, a cloud of dust rose into the air from the crowns and branches of the trees.

For firs, the zone where a distinct shortening of needles has been observed and where the trees preserved their needles for no more than 3 years.

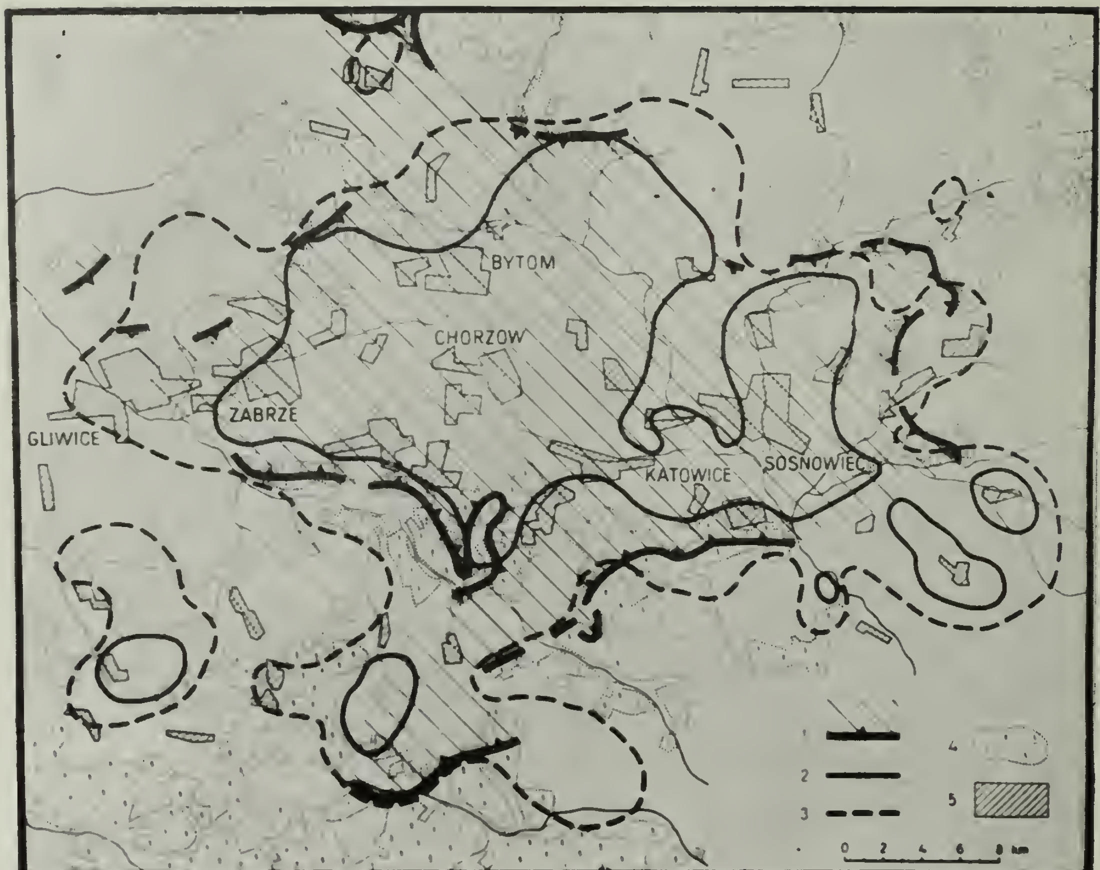


Fig. 1. Influence of air pollution upon the vegetation in the Upper Silesian Industrial District. (1) The observed limit of damage. (2) The isoline of 1.0 g of deposited dust per cm^2 per day. (3) The isoline of 0.5 g of deposited dust per m^2 per day. (4) Forests. (5) Settlements

From an inventory of these phenomena it was possible to show on a map the extent of the damage in the forest areas.

Simultaneously with these studies, the amount of deposited dust was also measured in more than 200 places in the Upper Silesian Industrial District for the years 1953 and 1954, as well as for later years. This resulted in the form of mean monthly values in grammes per square metre per day, thus indicating the spatial distribution of the deposited dust on the earth's surface.

The extent of the damage in pine and fir forests and the isolines showing the dust fall, when presented on the map, indicated distinct correlation between the appearance of these two phenomena. The observed limit of damage ran in a belt between the isolines 0.5 and 1.0 g/m^2 per day. Certain deviations from this principle were due to the sparsity of places in which the dust fall was measured; this fact, consequently, caused some local sources of air pollution not to be taken into account during the drawing of the isolines.

On the basis of these results, a supposition may be postulated that the degree of damage to vegetation within industrial areas largely depends on the quantity of the deposited dust, although other factors may play a serious role (e. g. the concentration of SO_2 in the air).

According to the hygienic standards in the Soviet Union, the admissible quantity of deposited dust in the housing districts is 0.5 g/m^2 per day. Thus the conclusion is that housing estates should not be built in the areas of air pollution harmful to pine and fir. In this way, without instruments for special measurements, which are often timewasting and expensive, the areas of concentration of air pollution harmful to the health of man can be determined on the basis of the observed extent of the damage to the trees.

REFERENCES

1. Polish Academy of Sciences, *Committee for the Problems of the Upper Silesian Industrial District*. Commission on Climate. Bulletin No. 2, Warszawa (1956); *Ibid.* Bulletin No. 10, Warszawa (1957).
2. H. Marter, *Der ostoberschlesische Wald und seine Nutzung*. Berlin (1936).
3. A. N. Marziejew, *Municipal Hygiene* (in polish). Warszawa (1953).
4. J. Paszyński, Investigation of local climate in the Upper Silesian industrial district. *Proceedings of the Anglo-Polish Geographical Seminar on Applied Geography*. Polish Academy of Sciences, Institute of Geography, Warszawa (1960).

NIEDERSCHLÄGE IN DEN WALDBESTÄNDEN UND IHRE RADIOAKTIVITÄT

V. PASÁK

Forschungsinstitut für Meliorationen, Tschechoslowakische Akademie der Landwirtschaftswissenschaften, Prag, Tschechoslowakei

Abstract—The measurement of atmospheric precipitation inside an afforestated area covered with a variety of trees has been carried out in forests to the south of Prague (central Moldau[Vltava] region). The growth density is almost maximal and the timber of felling age (age group 6). The measurements were carried out in a plantation of oak mixed with pine (11 a_1) which was regarded to be the right cover after mixing in the floor-protecting types of timber. Other determinations were made in plantations carrying spruce mixed with various other tree types (pine, larch, oak) and bushy undergrowth, such as ash trees (16 b_1) and compared with the results in pine woods of the same age (16 b_2).

The crowns of these types of woods retain all low intensity precipitation. Fig. 1 shows that pure pine stands are able to retain a daily total rain fall of 1 mm while the presence of bushy top trees helps the penetration of an average of 0.4 mm into the pine plantation. In oak and fir plantations most of the rain fall will reach the ground, where 90 per cent of a daily rainfall of 30 mm will reach the ground.

The measurement of the radioactivity of atmospheric precipitation is at present regarded as informative owing to the small number of determinations made to date. Nevertheless, it is evident from the tables that forests filter out a certain amount of this radioactivity. It must be remembered that this refers to the precipitation which had penetrated through the crowns and that it is more marked in forests of leafy trees.

Résumé—Les précipitations atmosphériques à l'intérieur des forêts de structure différente en ce qui concerne les essences ont été mesurées au sud de Prague dans la région du cours moyen de la Vitava. Les plantations sont presque complètement garnies d'arbres dont l'âge de la coupe correspond à la 6^e classe. Les mesures ont été faites dans le secteur de la forêt d'essences de chêne et de pin, 11a_1, considéré comme la plantation conforme à l'habitat après implantation d'essences préservatrices du sol. D'autres mesures ont été faites dans la plantation d'épicéas, où se trouvent disséminées des essences de pin, de mélèze, de chêne et le taillis des arbres à feuilles caduques, notamment du sorbier, 16 b_1, et dans la plantation d'épicéas, exempte d'autres essences, abres du même âge 16 b_2.

Ces plantations retiennent dans la couronne des précipitations atmosphériques de faible intensité. Il ressort du diagramme No 1 que dans la plantation d'épicéas, exempte d'autres essences, les précipitations sont intégralement retenues en moyenne jusqu'à la valeur de 1 mm de pluie par jour, par contre dans le secteur où sont implantés des arbres à feuilles caduques la pluie pénètre encore à l'intérieur de la plantation d'épicéas pour une quantité de pluie de 0,4 mm par jour. C'est dans le secteur où le chêne et le pin ont été implantés que la plus grosse quantité de précipitations arrive jusqu'au sol, là, déjà à partir d'une quantité de pluie de 30 mm par jour, 90 % du total des précipitations tombées en pleine campagne arrivent jusqu'au sol.

Vu le petit nombre de mesures faites à l'heure actuelle, la mesure de la radioactivité de l'eau de pluie ne peut servir que de simple information. Toutefois les tableaux indiquent une certaine filtration de la radioactivité des précipitations qui se manifeste dans la forêt. Il s'agit là de précipitations pénétrant par la couronne. Cette propriété de filtration se présente dans les plantations formées d'arbres à feuilles caduques.

Auszug—Das Messen der atmosphärischen Niederschläge im Innern der Waldbestände von verschiedener Bestandesstruktur wird in den Beständen südlich von Prag (mittlerer Moldauraum) durchgeführt. Die Bestände sind fast vollbestockt und von Hiebsalter (6 Altersklasse). Die Messungen wurden im Mischbestande der Eiche mit der Kiefer (11 a_1) vorgenommen, den man als standortsgerechten Bestand nach der Einmischung der bodenschützenden Holzarten betrachtet. Weitere Messungen wurden im Fichtenbestand mit vereinzelt eingemischten Holzarten (Kiefer, Lärche, Eiche) und dem Laubholzunterwuchs namentlich der Eberesche (16 b_1) und in dem gleichaltrigen Fichtenbestand durchgeführt (16 b_2).

Diese Bestände halten in Kronenraum atmosphärische Niederschläge von geringer Intensität zurück. Wie sich aus der Abb. 1 deutlich ergibt, kommt die völlige Zurückhaltung im Fichtenreinbestand im Durchschnitt noch bei der Regentagssumme von 1 mm in Frage, durch die Einmischung der Laubhölzer dringt der Regen in das Innere des Fichtenbestandes in der Tagesmenge von 0,4 mm ein. Die meisten Niederschläge fallen im Bestande mit der Eiche und Kiefer zum Boden, wo schon bei der Regentagsmenge von etwa 30 mm 90 % der im Freiland herabgefallenen Niederschläge zum Boden gelangen.

Das Messen der Radioaktivität des Niederschlagswassers betrachtet man infolge der kleinen Zahl von Messungen vorläufig als informativ. Trotzdem ist aus den Tabellen eine bestimmte Radioaktivitätsfiltration der Niederschläge, die die Waldbestände aufweisen, ersichtlich. Es ist zu beachten, dass es sich um Niederschläge, die durch den Kronenraum durchdringen, handelt. Die Filtrationsbeschaffenheit tritt bei den Beständen, die von Laubholzarten gebildet werden, in Erscheinung.

Der Waldbestand beeinflusst stark die Menge und die Verteilung der auf den Waldböden herabfallenden atmosphärischen Niederschläge. Die Baumkronen halten einen Teil der freifallenden atmosphärischen Niederschläge zurück, die aus den Kronen ohne Erreichung des Waldbodens verdunsten. Andererseits kann jedoch der Waldbestand zur Bereicherung der atmosphärischen Niederschläge im Bestand durch Auffangen der Tauwassertröpfchen unter günstigen Bedingungen, namentlich im Gebirge, beitragen.

Von grosser Bedeutung ist die Niederschlagsverteilung in der Jahreszeit. Der Schnee z. B. wird in den Kronen der Nadelhölzer aufgefangen, während er bei den Laubholzarten fast unbehindert bis zu dem Waldboden herabfällt. Schwache, langfristige Niederschläge üben auch einen anderen Einfluss aus als starke Regenfälle, obwohl die absolute Wassermenge in beiden Fällen gleich ist.

Durch die physikalische Beschaffenheit des Bodens wird dann die Niederschlagsmenge, die zu den Baumwurzeln durchdringt und dort bleibt, sowie die Grösse des Abflusses bestimmt. Die Hauptbedeutung der Waldbaumkronen besteht in dem Zeitunterschied des Fallens der Niederschläge zum Boden. Die Wälder weisen die

Fähigkeit auf, die Niederschläge richtig zu bewirtschaften und den Wasserhaushalt in einem weiten Gebiet zu beeinflussen. Die Waldböden besitzen im allgemeinen eine höhere Wasserversickerungsfähigkeit, bilden vollkommene, technisch unnachahmbare natürliche Dränagen.

Der Einfluss der Waldbeständestruktur auf die Verteilung der atmosphärischen Niederschläge und ihre Infiltration im Waldboden untersuchten wir in den Versuchswäldern im Forstrevier Jíloviště südlich von Prag. Die Bestände liegen an der Moldauterasse über Zbraslav, vom eingeschnittenen Tal der Moldau und des Berounka-Flusses, etwa 350 m ü.d.M., begrenzt.

Die Witterung ist verhältnismässig trocken und warm. Klimatisch wird dieses Gebiet in die Übergangszone eingereiht, die zwischen dem mitteltrockenen bis mässig feuchtem Gebiete steht.

Der Bestand 16 b_1 ist ein Fichtenbestand von sehr schönem Wuchs auf der Fläche 2,16 ha, 107 Jahre alt, Mittelhöhe 25 m, Bestockung 9. Die Holzartenzusammensetzung: Fichte 8, Kiefer 2, Lärche 2, Eiche, mit dem Unterwuchs der Eberesche, die das Niveau des Unterbestandes erreicht. Der Boden ist vom Fichtenhumus bedeckt, hie und da treten Gräser, Maiglöckchen, Himbeere und Brombeere, auch Fichtenanflug auf.

Der Bestand 16 b_2 ist ein gleichaltriger Fichtenreinbestand von sehr schönem Wuchs auf der Fläche 2,37 ha, 92 Jahre alt, Mittelhöhe 22 m, volle Bestockung 10. Der Boden ist nur vom Fichtenrohhumus bedeckt.

Der Bestand 11 a_1 ist ein vereinzelt gemischter Bestand der Eiche mit der Kiefer, vom Ausmasse 5,24 ha, 107 Jahre alt, Mittelhöhe 18 m, Bestockung 9. Der Boden ist von einer üppigen Bodenvegetation mit häufigem Eichenanflug bedeckt. Der Bestand 11 a_1 kann als ein für den Standort geeigneter Bestand angesehen werden, allerdings unter der Vorbedingung einer Einbringung der Meliorations- und bodenschützenden Holzarten.

In der ganzjährlichen Niederschlagssumme dringen zum Waldboden in den nach Niederschlägen übernormalen Jahren im gleichaltrigen Fichtenreinbestand (16 b_2) über 60%, im Fichtenmischbestand mit dem Unterwuchs (16 b_1) von 50 bis 60% und im Eichenbestand mit der Kiefer (11 a_1) etwa 80% Niederschläge durch. In den nach Niederschlägen unternormalen Jahren dringen in den Bestand 16 b_2 etwa 50%, in den Bestand 16 b_1 weniger als 50% und in den Bestand 11 a_1 etwa 80% Niederschläge ein, die im Freiland fallen.

Die Menge der Niederschläge, die durch die Baumkronen durchdringen, hängt nicht nur von der Intensität des Regens, sondern auch vom Gesamtstand der Witterung, vor allem von der Blattbefeuchtung stark ab. Bei den stärksten Regenfällen in den Tagen 7, 8, 9 Juli 1954, als im Freiland 108,4 mm fielen, gelangten zum Waldboden des Fichtenmischbestandes (16 b_1) 86,3 mm, d. i. 80%, des Fichtenreinbestandes (16 b_2) 92,1 mm, d.i. 85% und in den Mischbestand der Eiche mit der Kiefer (11 a_1) 93,5 mm, d. i. 86% Niederschläge.

Im Mischbestand der Eiche mit der Kiefer (11 a_1) ist vor allem in der Periode ohne Belaubung der Eichen eine grosse Niederschlagsdurchlässigkeit in das Innere des Bestandes vermerkt. Durch das Auffangen des Nebels und durch die Rauhreifbildung auf kahlen Eichenzweigen sowie durch ihr Abtropfen fällt in das Bestandesinnere eine grössere Wassermenge als im Freiland.

In Abb. 1 wird in der logarithmischen Stufe das Verhältnis der Niederschläge, die in das Bestandsinnere fallen, zu den Niederschlägen des Freilandes dargestellt. Aus Abb. 2 ergibt sich deutlich, dass diese Bestände überhaupt keine Niederschläge

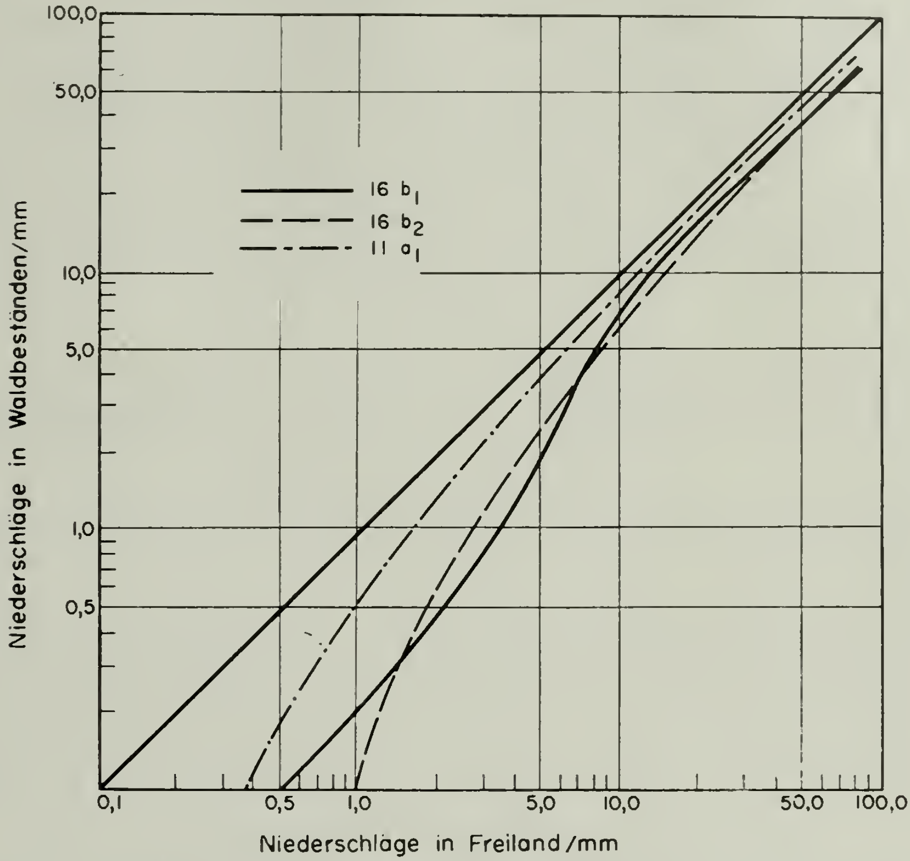


ABB. 1. Verhältnis der Niederschläge in Waldbeständen zu den Niederschlägen des Freilandes

von niederer Intensität durchlassen. Im Fichtenreinbestand (16 b_2) wird der Regen im Durchschnitt noch völlig in einer Tagesmenge von 1 mm zurückgehalten, während im Fichtenmischbestand (16 b_1) der Regen in einer Tagesmenge von 0,5 mm und im Eichenbestand mit der Kiefer (11 a_1) der Regen schon bei einer Menge von 0,4 mm zum Waldboden durchzudringen beginnt.

Das Verhältnis der Niederschlagsdurchdringung bei verschiedener Tagessumme wird prozentuell in der halblogarithmischen Stufe in Abb. 2 dargestellt. Der höchste Prozentsatz der Niederschläge dringt in den Eichenbestand mit der Kiefer ein (11 a_1). Bei der Tagessumme der Niederschläge von etwa 30 mm dringen schon 90% durch. Die Zurückhaltungsfähigkeit dieses Bestandes nimmt bei der Tagesmenge von 0,4 bis 2,5 mm rasch ab, da die Durchdringung nur schon 30% erreicht.

Bei der Interzeptionsmessung in den einzelnen Beständen entnahm man gleichzeitig das Regenwasser zwecks Radioaktivitätsmessung. Es steht fest, dass in der Natur fortwährend radioaktive Stoffe in der Aerosolform vorhanden sind. Radioaktive Stoffe sind einerseits natürlichen Ursprungs, namentlich durch den Zerfall von Radon und Thoron entstanden, die aus dem Boden als Produkte einer allmählichen Umwandlung des Elementes ${}_{88}Ra^{226}$ und des Elementes ${}_{90}Th^{232}$ entsprin-

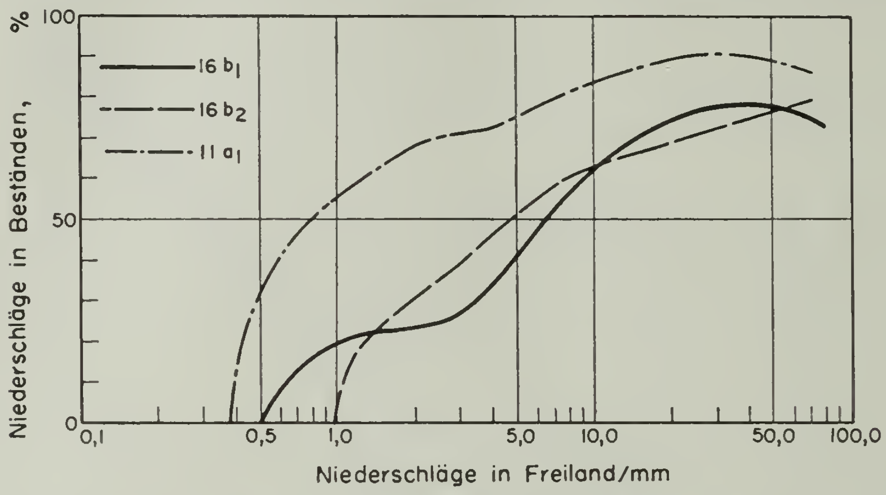


Abb. 2. Niederschläge in Waldbeständen in Prozentsatz zu den Niederschlägen des Freilandes

gen. Ausser den Naturquellen des radioaktiven Aerosols kommen in unserer Atmosphäre radioaktive Stoffe künstlichen Ursprungs vor, namentlich aus den Atom- und Wasserstoffbombenexplosionen und durch die Tätigkeit der Atomreaktoren. Radioaktive Teilchen treten in der Atmosphäre entweder selbständig auf oder sind namentlich an Staubteilchen und Kondensationskernen gebunden. Es handelt sich um Teilchen, deren Durchmesser maximal nur einige Zehntel μ beträgt. Bei der Entstehung der Wolke und der Niederschläge wirken die Teilchen einerseits direkt als Kondensationskerne auf die Bildung der Wolkentropfen, andererseits können sie indirekt durch Koagulation, die durch die Brownsche Bewegung verursacht wird, eventuell durch die Mikroturbulenz des Luftstroms in der Wolke, an die Wolkentropfen gebunden werden. Die Geschwindigkeit, mit der die radioaktiven Teilchen an die Wolkentropfen gebunden werden, hängt vor allem von der Konzentration und der Grösse der Teilchen und der Tropfen ab (7).

Die sedimentierenden radioaktiven Aerosole werden an der Oberfläche des Bodens und der Pflanzen abgelagert und gelangen gemeinsam mit den durch atmosphärische Niederschläge getragenen Aerosolen durch die Wasserversickerung in den Boden und von hier aus kommen sie in die Pflanzenteile.

Im allgemeinen ist schon die Funktion des Waldes für die Reinigung der Luft vom Staub in der Bodenschicht der Atmosphäre anerkannt. Die grosse Fläche der Assimilationsorgane hält an ihrer Oberfläche eine beträchtliche Staubkornmenge zurück, die in der Luft zerstreut ist. Es ist zu bedenken, wie der Waldbestand auf radioaktive Aerosole in der Luft und auf radioaktive Stoffe im Niederschlagswasser reagiert.

Die Radioaktivität des Niederschlagswassers messen wir gemeinsam mit dem Hygiene-Institut in Prag (Dr. Vladimír Stružka und Dr. Milan Hašek) nach deren Methodik. Die Niederschläge werden in zylindrischen Glasgefässen von 25 cm Höhe und 19 cm Durchmesser aufgefangen. Der Rand der Auffangsfläche der Gefässe befindet sich in derselben Höhe wie der Rand der Auffangsfläche des Regenmessers, d. i. 1 m über dem Boden. In das Gefäss wird destilliertes Wasser bis zur Höhe von 2—3 cm gegossen, das etwa 1% Isopropylalkohol (oder *n*-Propylalkohol) zur Herabsetzung der Oberflächenspannung des Wassers beinhaltet.

Im Winter wird in das destillierte Wasser etwa 50% denaturierter Spiritus gegen Wassereinfrierung gegossen. Die Expositionszeit der Gefässe in den Beständen war ursprünglich ein Vierteljahr, nun beträgt sie einen Monat. Die Höhe des Wasserspiegels in den Gefässen wird immer kontrolliert und auf demselben Niveau gehalten.

Nach der Exposition wird das Sediment gemeinsam mit der Flüssigkeit und dem Regenwasser quantitativ zusammengegossen und das Gefäss mit destilliertem Wasser ausgespült, wobei das Übergiessen über einem Standartfilterpapier vor sich geht. Auf diese Weise werden zähe unlösbare radioaktive Stoffe von den flüssigen und lösbaren getrennt. Das Filtrationspapier wird dann mit dem Sediment verbrannt und die Radioaktivität der Asche gemessen, die in einem speziellen Gehäuse aufbewahrt wird. Die Messung erfolgt an Hand eines Geiger—Müller-β-Rohres tschechoslowakischer Produktion. Abschatten gegen die kosmische Strahlung wird durch Blei von 10 cm Stärke oben, 5 cm an den Seiten durchgeführt. Der Untergrund des Rohres beträgt 25—31 imp/min. Die restliche Flüssigkeit verdunstet bis auf den Rauminhalt von 50 cm³, und ihre Radioaktivität wird in einem speziellen GM-

Tabelle 1. Gesamtradioaktivität des Regenwassers

Quartal	Freiland	16 b_1	16 b_2	11 a_1	
1958					
2	424,6	220,0	202,6	93,6	imp/min
	118,2	61,2	56,2	26,0	mμc/m²
3	394,7	80,0	318,9	127,9	imp/min
	102,7	20,8	82,9	33,3	mμ/cmin²
4	378,3	180,1	191,3	153,1	imp/min
	87,2	41,6	44,1	35,4	mμc/m²
1959					
1	281,9	141,5	85,9	183,6	imp/min
	56,3	28,3	17,2	36,7	mμc/m²
2	514,3	254,8	225,9	258,2	imp/min
	102,9	51,0	45,2	51,6	mμ/cm²
4	25,0	23,0	15,0	11,0	imp/min
	5,13	4,72	3,08	2,26	mμc/m²

Trichterrohr für die Flüssigkeitsmessung gemessen. Die Impulse werden durch die Registrierapparatur des GM-Types tschechoslowakischer Produktion registriert.

Aus der Tabelle 1 ist die beträchtlich schwächere Radioaktivität des zum Boden unter dem Bestande fallenden Niederschlagswassers zu ersehen. Wie schon oben erwähnt, hält der Waldbestand in seinem Kronenraum eine bestimmte Niederschlagsmenge, die in der Tabelle 2 angeführt wird, zurück. Di · Radioaktivität des Regenwassers wurde aus der Gesamtniederschlagsmenge, die durch das Kronendach durchdrang und eventuell im Freilande fiel, festgestellt. Im Bestandesinneren ist also die aufgefangene Niederschlagsmenge um den in den Kronen zurückgehaltenen Wert niedriger.

Tabelle 2. Niederschlagsmenge in den Beständen und im Freilande

Quartal	Freiland	16 b_1	16 b_2	11 a_1	
1958					
2	174,9	94,9	116,0	137,1	mm
	100	54,24	66,30	78,38	%
3	250,7	147,9	169,7	197,0	mm
	100	59,00	67,70	78,57	%
4	138,5	78,7	94,6	119,6	mm
	100	56,82	68,30	86,35	%
1959 1	32,1	16,4	15,2	22,2	mm
	100	51,09	47,35	69,15	%
2	138,7	65,0	85,2	104,0	mm
	100	46,86	61,42	74,98	%
4	82,6	39,1	50,4	57,0	mm
	100	47,33	61,01	69,97	%

Tabelle 3. Radioaktive Gesamtstrahlung in der gleichen Menge des Niederschlagswassers

Quartal	Freiland	16 b_1	16 b_2	11 a_1	
1958					
2	424,6	405,6	305,6	119,4	imp/min
	118,2	112,8	84,8	33,1	$m\mu c/m^2$
3	394,7	135,6	471,0	162,7	imp/min
	102,7	35,2	122,4	42,4	$m\mu c/m^2$
4	378,3	316,9	280,0	177,3	imp/min
	87,2	73,2	64,5	41,0	$m\mu c/m^2$
1959					
1	281,9	276,9	181,5	265,5	imp/min
	56,3	55,3	36,3	53,0	$m\mu c/m^2$
2	514,3	543,7	367,8	344,8	imp/min
	102,9	108,8	73,6	68,8	$m\mu c/m^2$
4	25,0	48,6	24,5	15,7	imp/min
	5,13	9,9	5,0	3,2	$m\mu c/m^2$

Falls man die ermittelte Gesamtradioaktivität der entnommenen Probe auf dieselbe Niederschlagsmenge, die zum Boden fallen würde, umrechnet, drückt man dadurch die Radioaktivität der Niederschlagsmenge aus, die im Freilande den Boden erreichte, allerdings durch den Kronenraum der Bestände filtriert.

Aus den angeführten Tabellen kann man eine bestimmte Fähigkeit des Waldbestandes der Radioaktivitätsfiltration des Niederschlagswassers voraussetzen. Infolge der bisher kleinen Anzahl von Messungen sind diese Angaben nur von informativem Charakter. Die Messungen werden weiter präzisiert und die Abhängigkeiten erforscht, vor allem werden sie bei der verschiedenen Regenintensität und durch das Messen der Radioaktivität der Assimilationsorgane in der vertikalen Gliederung, die Aktivitätsmessung der Bodenoberfläche, die Messung der sedimentierten Aktivität an Assimilationsorganen usw. ergänzt.

LITERATUR

1. Baumgartner A., *Die Regenmenge als Standortsfaktor am Grossen Falkenstein.* Forstwissenschaftliches Central-Blatt (1955).
2. Eitingen G. R., *Zaderženie osadkov pologom lesa.* Les i step (1951).
3. Hašek M., Zásady sledování radioaktivity v okolí atomového reaktoru. *Sborník IV. celostátní meteorologické konference, Praha 1958.*
4. Horák J. und J. Podzimek, Měření umělé radioaktivity srážek a ovzduší v MGR. *Sborník IV. celostátní meteorologické konference, Praha 1958.*
5. Mařan B. und O. Lhota, Význam druhové skladby lesních porostů a hospodářských zásahů na zasakování vody do půdy. *Sborník ČAZ* (1952).
6. Pasák V., Mikrometeorologická a hydrologická měření v kmenovém prostoru lesa. *Vědecké práce VUZIM, Praha 1957.*
7. Podzimek J., Vztah mezi radioaktivitou ovzduší a srážek. *Sborník IV. celostátní meteorologické konference, Praha 1958.*
8. Stružka V., Metodiky měření radioaktivity při biometeorologickém a hygienickém průzkumu krajiny. *Sborník IV. celostátní meteorologické konference, Praha 1958.*

AGROCLIMATIC WHEAT CROP TYPES IN THE WORLD

ANTONIO J. PASCALE and EDMUNDO A. DAMARIO

Associate Professor and Research Assistant, respectively, of the course of Agricultural Climatology and Phenology of the Facultad de Agronomia y Veterinaria, Avda San Martin 4453, Buenos Aires, Argentina

Abstract—After analysing the deficiencies found in the application of the climatic classifications to agricultural problems, Burgos's outline of agroclimatic classification is given in detail (CAgM. II/Doc. 18/24 IX 1958 Item 10) and the application of same in the wheat crop. For this species it is thought that the climatic variants found in the different world wheat-crop areas, can be grouped into photoperiodic, thermic and hydric regions and that the agroclimatic parameters that define them, would be, respectively, annual photoperiodical range, mean coldest-month temperature, mean ripening temperature, and earing month water balance. This study ends with the application of the classification to the Argentine wheat region.

Résumé—Après l'analyse des insuffisances trouvées dans l'application des classifications climatiques aux problèmes agricoles, l'auteur donne, en entrant dans les détails, l'aperçu de la classification agroclimatique de Burgos (CAgM.II/Doc. 18/24 IX 1958 Item 10) et son application à la récolte de blé. Pour cette espèce on pense que les variantes climatiques constatées dans les différentes zones mondiales de récoltes de blé peuvent être groupées en régions photopériodiques, thermiques et hydriques, et que les paramètres agroclimatiques qui les définissent seraient respectivement: la variation annuelle photopériodique, la température moyenne du mois le plus froid, la température moyenne au moment du jaunissement du blé et le bilan hydrologique du mois où le blé monte en épi.

Cette étude se termine par l'application de la classification aux régions à blé d'Argentine.

Auszug—Nach erfolgter Analysierung der bei der Anwendung der klimatischen Klassifizierungen auf Agrarprobleme festgestellten Mängel, wird eine Überblick von Burgos über die agrar-klimatische Klassifizierung (CAgM. II/Doc. 18/24 IX 1958 Item 10) im einzelnen, sowie deren Anwendung für den Weizenanbau gegeben. Bei dieser Getreideart wird angenommen, daß die in den verschiedenen Weizen-Anbaugebieten der Welt festgestellten klimatischen Varianten eingruppiert werden können in photoperiodische, thermische und feuchte Regionen. Zur Bestimmung dieser Regionen würden folgende agrarklimatische Parameter Verwendung finden: jährlicher photoperiodischer Bereich, mittlere Temperatur des kältesten Monats, mittlere Reife-Temperatur sowie die durchschnittliche monatliche Niederschlagsmenge. Diese Untersuchung wird abgeschlossen mit der Anwendung der Klassifikation auf das argentinische Weizen-Anbaugebiet.

INTRODUCTION

Climatic classifications, be they descriptive, genetic or rational, do not fill the requirements of their application in agriculture, and more specifically, in the distribution of agricultural crops, or in the comparative study of the climates of their distribution areas.

In effect, Burgos (1958b) on analysing the three groups of classifications mentioned above, came to the conclusion that descriptive classifications are of purely geographic interest, and that genetic classifications tend to the explanation of the genesis of climates, and that they cannot therefore be applied to concrete agricultural problems. Insofar as systematic or rational classifications based on the utilization of climatic elements are concerned, they are the ones that have been used each time there has been a need to solve an agroclimatic problem, to place crops, to limit regions according to different bioclimatic requirements, to demarcate best crop zones, to establish homoclimes, and so on.

However, even though rational climatic classifications are the best suited for agroclimatic purposes they have deficiencies, which can be enumerated in the following way:

(1) climates that are similar according to these classifications, may have different agroclimates, and vice versa.

(2) Systematic classifications utilize few elements — generally temperature and precipitation — or combinations of these, which are sometimes insufficient, or which are expressed in such a way that they cannot be utilized for agricultural purposes, due to the particular bioclimatic requirements of the crops.

(3) The elements or combinations of elements are not expressed as index values for the different crops, for they show their own distribution in the course of the year, seasons, or months. That is to say, they have not (nor should they really have since their aim is different) a particular sensibility within the phenological period of the crop, where the element should be expressed, besides, at different levels and in different hierarchies to those normally used by rational climatic classifications.

These reasons amply justify the attempt to arrive at classifications to be used in agriculture exclusively, i. e. agroclimatic classifications, which will necessarily be different for each crop since diverse climatic elements or agroclimatic indices will be used, with hierarchies and levels in accordance with the particular bioclimatic requirements and tolerances.

With this end in view, the aforementioned investigator developed a method for agroclimatic classifications, which he has followed when preparing the classifications of the date palm and seed potato crops (Burgos, 1958a, b). In this study an attempt is made to classify a wheat crop agroclimatically, with the object of characterizing the different agroclimatic types that are to be found in the widespread distribution of this species in the world.

MATERIALS AND METHODS

A study of this type requires ample material, which must comprise the three aspects that the integration of agroclimatic classification signifies, i.e. the bioclimatic, climatic and phenological aspects.

As regards phenological data, it should be stated that not all the existing information on the subject has been consulted, for besides being a very laborious task indeed, it was not essential to attain the desired object. In effect, if it is possible to find indices with which to characterize the agroclimates of the principal wheat regions of the world, in which besides it is possible to encounter very diverse agroclimatic combinations, it is logical to suppose that the parameters used in the cases, can be utilized for the remaining crop areas. It must be kept in mind that on selecting climatic parameters, which are to be utilized in the classification, the bioclimatic requirements, tolerances and limitations of the species must be taken very much into account. This is the process followed to determine the agroclimatic types of the wheat crop, for the mean phenological values of few countries have served as a basis, among which can be cited the U.S.S.R., the U.S.A., Canada, Australia, Argentina, Mediterranean countries, Czechoslovakia, Finland, and Brazil (Nuttonson, 1953, 1955; Azzi, 1928, 1959, Hounam, 1947a, b, 1950; Pascale and Damario, 1959; Boeuf, 1932; DaMota, 1960; Tirlok Singh *et al.*, 1957).

The meteorological information was obtained from different statistical sources, which are listed in the bibliography. The studies of a bioclimatic nature consulted in the drawing up of the agroclimatic indices, will be mentioned in the course of this report.

The climatic computations effected are simple and merit no special mention, except in the case of the water balance, in which there was estimated for all the localities studied a water holding capacity of 300 mm, which is not real but which has the advantage of making possible the comparison of values.

In the method of study it must be stated that the steps to be followed for the compilation of any agroclimatic classification are established in the report by Burgos cited above and that they are listed below methodically for the wheat crop.

(a) *Determination of the Bioclimatic Type of Crop*

Wheat is a parathermocyclical and paraphotocyclical species (Burgos, 1952), i. e. its tissues are active to temperature in partial coincidence with the negative and positive thermophases of the annual thermoperiod, and with both phases of the period of annual variation of day-length.

(b) *Evaluation of the Agroclimate of the Native Region of a Species*

The origin of wheat is poliphyletic (Vavilov, 1951), there being considered three principal centres of geographic origin for the different types of wheat. The bread wheats *(Triticum aestivum)* have originated in a high region that comprises Afghanistan, Bokhara, Kashmir, Turkistan, and NW. of India, characterized by little annual rainfall (250—300 mm) and marked annual thermic amplitude.

These climatic characteristics might mean the requirements of a species of scanty distribution in the world, which does not occur in the case of wheat, which has varieties capable of adapting themselves to the most diverse conditions. Nevertheless, the climate of the native region of wheat should be considered an ancestral requirement that has been handed down to a greater or lesser degree to the present-day species, and thus when selecting the parameters for the classification, has to be taken into account.

(c) *Evaluation of the Agroclimate of the Region where the Species is Grown*

Fig. 1 shows the widespread distribution of the wheat crop areas in the world, it being observed that it is practically possible to find this species in appreciable concentration between the Tropic of Cancer and the Arctic Circle in the Northern Hemisphere, and between the Tropic of Capricorn and the southernmost regions of the Southern Hemisphere. The intertropical regions have scattered centres of wheat crop areas with particular climatic conditions and varieties of wheat.

This great distribution leads to the consideration of a widespread range of hierarchies that may include every possibility of combinations.

(d) *Evaluation of the Agroclimate of Regions where Experience has proved the Impossibility of Growing the Species*

As the consequence of what has just been said above, and comparing the regions (Fig. 1) that do not support wheat crops, it can be deduced which are the adverse climatic parameters, and which are not required or do not harm the development of the species.

(e) *Evaluation of Agroclimatic Indices Derived from Experimental Work on Bioclimatic Requirements of the Species*

Great emphasis has been given to this aspect for the selection of climatic parameters that should be included in an agroclimatic classification of wheat. Due to its being an ancient agricultural crop, with a wide range of distribution, and due to its economic importance, a great number of investigators have done experimental work of all sorts to find out as much about the species as possible.

The bioclimatic characteristic of the species (of being parathermocyclical and paraphotocyclical), correctly marks the predominant features at which the proposed agroclimatic investigation should aim. But, it is necessary that the temperature and the length of day (and also moisture, not included in the preceding bioclimatic definition) be hierarchized in the classification with a logical criterion, in accordance with the investigation carried out in each case, and with the fundamental object

FIG. 1. Geographical distribution of world wheat crop areas. Each dot: 2000,000 ha. (Schnelle, 1955)

of including all the bioclimatic requirements and agroclimatic possibilities that it is possible to find in the world with relation to the wheat crop. During the development of this study the criterion adopted will be indicated in each case and the scientific or experimental basis on which it is founded.

Before going into the analysis of the classification itself it is opportune to explain that cultivated wheats may be grouped according to their climatic requirements into winter wheats and spring wheats. In this study the bases are given for the agroclimatic classification of winter wheat but that does not exclude the possibility of their being used for spring wheat in those aspects where the requirements are the same, e. g. temperature during ripening or available moisture in the critical period of earing. On the other hand, there is a third intermediate group with particular bioclimatic requirements, that correspond to the wheats grown in the Southern Hemisphere. The classification can be applied to these crops without any disadvantage.

AGROCLIMATIC TYPES FOR THE WHEAT CROP

I. *Photoperiodic Regions*

Wheat is a paraphotocyclic species, but evidently must have a great photoperiodic plasticity since this crop may be found from the Equator (Nairobi, Kenya, 1°16′S.) to the Arctic Polar Circle (Rovaniemi, Finland, 66°30′ N.). Discounting the fact that the bioclimatic characteristics of wheats sown in the two localizations must be quite different, cases are cited, on the other hand, of the very same variety grown across several degrees of latitude. Nuttonson (1955) cites the case of Marquis sown from Fairbanks, Alaska, (64° N.) to Lincoln, Nebr., U.S.A. (41° N.) and Tlanepantla, Mexico (19° N.). Earing in the three locations took place with day-lengths of 19 hr 30 min, 15 hr, 05 min and 12 hr 40 min, respectively.

The variable aspect is of the greatest importance in this accommodation to the length of day, but in winter wheats it is indispensable that the crop should pass the first stages of growth with short daylengths, to reach earing with long days. The spring wheats on the other hand, can be sown without being subject to a first period of short days. Many experiments bear out these statements, among which we only refer here to those of McKinney and Sando (1933), and those of Gregory and Purvis which have been widely commented upon by Murneek and Whyte (1948).

Due to all this, it is estimated that the photoperiodical characteristic of the wheat crop can be represented by the difference between the day-length of earing and that of the shortest day with vegetative tissues exposed to light.

Climatically, the parameter that can be utilized is the photoperiodic range between the longest and shortest days of the year, since it has been proved that a close correlation exists expressed by a parabola of slight curvature (almost a straight line) between this photoperiod and the one corresponding to the crop, according

Table 1. World Agroclimates for Wheat

Location and country	Co-ordinates			Photoperiodic regimen					
	1	2	3	4	5	6	7	8	9
Omsk, U. S. S. R.	54°58′N	73°20′E	88	19,10	8.35	19.10	11.25	10.35	7.45
Moscow, U. S. S. R.	55°50′N	37°33′E	167	19.30	8.05	19.30	11.25	11.25	8.05
Havre, U. S. A.	48°34′N	109°40′W	758	17.20	9.40	17.20	10.15	7.40	7.05
Kharkov, U. S. S. R.	49°59′N	36°09′E	123	17.55	9.20	17.40	10.15	8.35	7.25
Tammisto, Finland	60°16′N	24°58′E	15	22,00	8.00	22.00	11.15	14.00	10.45
Sheridan, U. S. A.	44°51′N	106°52′W	1158	16.50	9.55	16.50	10.35	6.55	6.15
Odessa, U. S. S. R.	46°29′N	30°44′E	61	17.00	9.50	16.25	10.35	7.10	5.50
Lincoln, U. S. A.	40°51′N	96°37′W	375	16.10	10.15	16.00	11.00	5.55	5.00
Horice, Czechoslovakia	50°23′N	15°32′E	310	18.00	9.15	17.45	10.10	8.45	7.35
Belluno, Italy	46°08′N	12°14′E	404	17.00	9.55	16.15	9.55	7.05	6.20
Woodward, U. S. A.	36°25′N	99°24′W	602	15.40	10.40	14.50	10.40	5.00	3.10
Burgos, Spain	42°20′N	3°42′W	860	16.25	10.20	16.10	10.20	6.05	5.50
Molong, Australia	33°06′S	148°50′E	—	15.10	10.55	13.40	10.55	4.15	2.45
Coronel Suárez, Argentina	37°30′S	61°57′W	234	15.45	10.35	14.40	10.35	5.10	4.05
Foggia, Italy	41°27′N	15°31′E	87	16.25	10.20	15.30	10.20	6.05	5.10
Guatraché, Argentina	37°38′S	63°34′W	176	15.55	10.30	14.35	10.30	5.15	4.05
Inverell, Australia	29°47′S	151°08′E	500	15.00	11.00	13.05	11.00	4.00	2.05
Deniliquin, Australia	35°32′S	145°02′E	95	15.35	10.45	14.15	10.45	4.50	3.30
Pergamino, Argentina	33°56′S	60°33′W	66	15.25	10.55	13.55	10.55	4.30	3.00
Tunis, Tunisia	36°48′N	10°10′E	32	15.40	10.45	13.50	10.45	4.55	3.05
Alicante, Spain	38°22′N	0°25′E	26	15.40	10.50	14.45	10.50	4.50	3.55
Rafaela, Argentina	31°11′S	61°33′W	100	15.00	11.00	12.55	11.00	4.00	1.55
Yalgoo, Australia	28°23′S	116°40′E	318	14.50	11.15	13.10	11.15	3.35	1.55
Bagé, Brazil	31°20′S	54°06′W	216	15.00	11.00	12.20	11.00	4.00	1.20
New Delhi, India	28°39′N	77°17′E	219	14.50	11.10	12.05	11.10	3.40	0.55
São Borja, Brazil	28°40′S	56°00′W	96	14.50	11.10	12.20	11.10	3.40	1.10

(1) Latitude. (2) Longitude. (3) Altitude. (4) Duration of longest day of year (hr and min) (5) Duration of shortest day of year (hr and min). (6) Length of day at earing time (hr and min) (7) Length of shortest day with active tissues exposed to daylight (hr and min). (8) Photoperiod between 4 and 5 (hr and min). (9) Photoperiod between 6 and 7 (hr. and min). (10) Mean temperature coldest month (°C). (11) Number of days of daily mean temperature below 5° C. (12) Mean temperature of warmest 3-month period (°C). (13) Mean temperature of 3-month period following vernal equinox (°C). (14) Mean temperature of ripening month in agroclimates without winter cold (°C). (15) Precipitation during growing season (mm). (16) Water surplus in water balance of growing period (mm). (17) Water deficit in water balance of growing period (mm). (18) Water surplus in water balance in earing month (mm.) (19) Water deficit in water balance in earing month (mm.) (20) Length in days of growing period of crop (from emergence to ripening)

to the definition given in the preceding paragraph. It should be pointed out that the twilights are included in the calculations because of the photoperiodical effect they have.

Crop (Agroclimatic Indexes)

	Thermal regimen				Hydric regimen						Agroclimatic type
10	11	12	13	14	15	16	17	18	19	20	
—21.8	212	16.7			284	0	146	0	44	344	$A\ A'\ C_1'\ E''$
—11.5	192	17.0			576	12	35	0	14	332	$A\ A'\ B_1'D''$
—10.5	166	19.8			275	0	134	0	24	303	$B\ A'\ B_1'\ D''$
—8.8	163	19.7			420	0	69	0	16	315	$A\ A'\ B_1'\ D''$
—7.8	193	15.3			662	246	28	0	12	347	$A\ A'\ C_1'\ D''$
—6.7	164	19.1			302	0	91	0	18	302	$B\ A'\ B_1'\ D''$
—4.8	131	21.1			298	0	113	0	38	288	$B\ A'\ A_1'\ E''$
—4.5	127	23.9			448	3	2	3	0	278	$C\ A'\ A_1'\ C''$
—3.9	144	17.7			379	0	49	0	9	295	$A\ A'\ B_1'\ D''$
1.0	115	19.6			881	487	0	9	0	278	$B\ B'\ B_1'\ C''$
1.7	78	26.5			372	0	24	0	2	248	$C\ B'\ A_1'\ D''$
2.3	89	17.7			408	2	10	0	0	242	$C\ B'\ B_1'\ C''$
6.1	0		17.5		329	21	3	0	0	219	$D\ C'\ B_1'\ C''$
6.3	0		16.8		336	0	4	0	0	189	$C\ C'\ C_1'\ C''$
6.3	0		18.1		308	0	69	0	24	227	$C\ C'\ B_1'\ D''$
6.7	0		18.8		249	0	62	0	18	193	$C\ C'\ B_1'\ D''$
8.2	0		18.8		350	9	1	9	0	191	$D\ C'\ B_1'\ C''$
9.0	0		19.7		272	0	106	0	20	224	$D\ C'\ B_1'\ D''$
9.2	0		19.3		349	87	0	15	0	171	$D\ C'\ B_1'\ C''$
10.3	0			18.9 (V)	297	0	53	0	11	191	$D\ D'\ B_1'\ D''$
10.8	0			22.1 (VI)	245	0	111	0	33	212	$D\ D'\ A_1'\ E''$
10.9	0			19.1 (X)	204	0	0	0	0	153	$D\ D'\ B_1'\ C''$
12.1	0			19.1 (X)	150	0	138	0	27	183	$D\ D'\ B_1'\ E''$
12.3	0			22.2 (XII)	720	354	0	84	0	173	$D\ D'\ A_1'\ A''$
13.9	0			22.5 (III)	70	0	195	0	8	163	$D\ D'\ A_1'\ D''$
14.4	0			22.3 (XI)	630	349	0	85	0	158	$D\ D\ A_1'\ A''$

In the work sheet of agroclimatic indices, Table 1, there is a series of localities with different photoperiodical ranges, in which the correlation mentioned is fulfilled.

Table 2. Photoperiodical Regions—Range between the Daily Photoperiod of Earing and the Shortest Daily Photoperiod with Tissues Exposed to Light

Zones	Climatic index: Annual photoperiodical range (including twilights)	Types of agroclimate
A	longer than 8 hr	Very long photoperiod
B	between 6 hr 30 min and 8 hr	Long photoperiod
C	between 5 hr and 6 hr 30 min	Moderate photoperiod
D	between 3 hr 30 min and 5 hr	Short photoperiod
E	shorter than 3 hr 30 min	Very short photoperiod

Zones *A*, *B* and *C* are usually found in the Northern Hemisphere and, only in the southernmost crops of the Southern Hemisphere are zones *B* found. The typical agroclimates of the Southern Hemisphere are eminently short (*D*). Isolated crops that may be encountered between tropics have the *E* characteristic, earing being produced in those cases when day-lengths approach 12 hr; that is why those agroclimates are said to be of a very short photoperiod for it is the shortest that is to be found for a species of long days. The opposite extreme is to be found in zone *A*, where earing is achieved with day-lengths of over 18 hr.

II. *Thermic Regions*

(a) *Negative thermophase of the vegetative cycle.* Wheat is a parathermocyclical species, and thus the temperatures of the positive and negative thermophase of the annual thermoperiod influence its development.

As regards the former aspect, there are innumerable studies that confirm the existence of the need of the crops of wheat for low temperatures. Murneek and White (1948) have developed the subject extensively. This is why no experimental work in particular is mentioned. The satisfaction of the cold requirement of wheat crops can be expressed by means of different parameters, such as: mean temperature or mean minimum temperature of the crops coldest month, by the number of days that the crop is latent below the zero of growth, etc. In this study the first temperature is utilized, for it is estimated that the climatic value of the mean temperature is that which is most commonly found in the statistics. It was with this criterion that the various localities were arranged in Table 1.

Table 3. Thermic Regions : Negative Thermophase of the Vegetative Cycle

Zones	Climatic index	Types of agroclimate
	Mean temperature of the coldest month of the year °C	
A′	below 0	Very cold
B′	between 0 and 5	Cold
C′	between 5 and 10	Temperate
D′	over 10	Without cold

The mean temperature of the coldest month of the year always occurs after sowing. For analysing the two extreme thermic conditions of the negative thermophase of the crop of winter wheat, it is found that:

(i) If the winter is very cold, the sowing must be carried out in autumn for the wheat to be able to emerge and pass the winter under the covering of snow in the form of grass. If it is a hard winter and the ground is not covered with snow, it is not possible to grow winter wheat, which would be spoiled by low temperatures (e.g. nearly all the west of Canada). In this last case winter growing of wheat must be avoided and spring sowing is resorted to with varieties that have little or no cold requirement.

(ii) If the winter is mild, sowings must be effected prior to the coldest part of the year so that the crops may receive this minimum and thus satisfy the relatively low cold requirements of the varieties sown. This is the case of the wheat regions of the Southern Hemisphere.

The thermic scale of values adopted in this classification deserves a commentary. Many more hierarchies might have been effected, but tending towards simplification this criterion was adopted of only four zones:

Zone A′—For all the regions that have at least 1 month with mean temperatures below 0°C, which represents a large part of the Northern Hemisphere, that practically extends from 40° N. to the northernmost border of the wheat crop area. The principal bioclimatic characteristic of this region is that of utilizing varieties of great cold requirements and a long vernalization period.

Zone B′—In this zone varieties requiring low temperatures are still sown, since the crops have 1 month (referred in mean values) of interrupted growth. The temperature of 5° C is taken as the limit of vegetative activity, following the present criterion of Russian investigators and because it is a whole number, although various studies utilize other levels, but always approximating that thermic figure. This vegetative limit is not found either as a monthly mean thermic value in any wheat area in the Southern Hemisphere.

Zone C′—This is the thermic winter characteristic of the principal wheat areas of the Argentine, Australia, and South Africa. It represents the bioclimatic behaviour that allows the wheat crops having moderate cold requirements to enjoy uninterrupted growth except on days when the temperature is below a certain level, a period of time that is never as long as a month. On growth being uninterrupted, the duration of the growing period is not so prolonged as in the Northern Hemisphere, nor is it ever as short as is characteristic in spring wheats. Wheats sown in the Southern Hemisphere are intermediate between winter wheats and spring wheats; they are classified into semi-late and semi-early (Pascale and Damario, 1954, 1959).

Zone D′—In this agroclimatic zone are included the regions having winters without the necessary cold for wheat. They are areas where the crop has this bioclimatic deficiency, so much so that varieties are sown having little or no cold requirements, a requirement that is satisfied on those few days on which the temperature drops below 10 °C. This includes some zones of subtropical India, the plains in the north of Africa, and the northernmost borders of the wheat areas in the Southern Hemisphere. Between the Tropics, the few wheat crops that can be found always have temperatures above the lowest thermic level of this zone during their vegetative cycle, but the varieties sown in these cases cannot be compared bioclimatically with those sown throughout the typical wheat regions.

(b) *Positive thermophase of the vegetative cycle*—Once the wheat crop has developed after having passed the stage of the low temperature requirement, the increase of temperature in spring results in earing and ripening. It is desired to characterize here the way in which ripening is reached, a sub-period which is achieved after a determined summation of temperatures. Evidently, the lower the temperature, the longer the sub-period will be, and vice versa. The longest duration of the sub-period determine abnormal situations with unfavourable consequences for the quality or the yield. The optimum mean temperature accepted for ripening is 18 °C, determined by Azzi in his well-known geographic studies (Azzi, 1959). With this basis the climatic index was drawn up for the classification of the positive thermophase of the vegetative cycle.

Table 4. Thermic Regions : Positive Thermophase of the Vegetative Cycle

<table>
<tr><th rowspan="4">Zones</th><th colspan="2">Climatic index</th><th rowspan="4">Types of agroclimate</th></tr>
<tr><th colspan="2">With mean temperature of coldest month of the year</th></tr>
<tr><th>below 5°C</th><th>between 5.1 and 10°</th></tr>
<tr><th>Mean temperature of the hottest three-month period</th><th>Mean temperature of the 3 month period following the vernal equinox</th></tr>
<tr><td>A'_1</td><td colspan="2">above 20 °C</td><td>Hot</td></tr>
<tr><td>B'_1</td><td colspan="2">between 17 and 20 °C</td><td>Temperate</td></tr>
<tr><td>C'_1</td><td colspan="2">below 17 °C</td><td>Cold</td></tr>
</table>

The lapse of the annual thermophase in which maturity is reached will depend upon the way in which the winter period is fulfilled. Undoubtedly there exists a whole range, but in general it may be accepted that the mean temperature of the hottest 3-month period characterizes the temperature of the ripening of wheat in the Northern Hemisphere, while as the growth of wheat crops in the Southern Hemisphere is not interrupted, that characterization can be expressed by the mean temperature of the 3-month period following the month of the vernal equinox.

In the wheat crops of the Northern Hemisphere having mean coldest-month temperatures between 5° and 10° C, the temperature of the 3-month period following the month of the vernal equinox does not fit the facts in the same way as in the Southern Hemisphere, due, no doubt, to the difference of gradient in the daily increase of the spring temperature.

When the temperature of the coldest month of the year is above 10°C, it is impossible to indicate the time of ripening for it is achieved in different months, according to the pattern of the temperature or according to the date of sowing. In general the mean temperature of the month following earing seems to be acceptable as an index. It is because of this, that, in Table 1, a column is included in which the temperature of the month of ripening is indicated, when the temperature of the coldest month is above 10°C.

In the warmer areas of the wheat regions (A'_1), there is periodically an acceleration in the process of ripening with danger of shrunken grain. This is more evident when spring wheats are sown, which ripen later in the summer. In the opposite case (C'_1) the lowest mean temperatures of the warmest 3-month period which allow heading and ripening to occur are to be found between 13° and 14° C. (Alatornio, Finland: 13.5°C; Matanuska, Alaska: 13.3°C; Beaverlodge, Canada: 14.6°C). These figures also correspond to spring wheat crops.

The zone B'_1, with a temperature between 17° and 20°C, represents the condition of normality in the ripening of wheat crops.

III. *Hydric Regions*

The moisture conditions under which wheat is grown throughout the world represent the most variable climatic parameter, and to a great degree influence the yield.

The wheat crop is active vegetatively preferably during the winter-spring months, but the pluviometric regimen of each region determines two principal moisture characteristics for the crop: (a) extreme conditions for permanent high moisture or persistent drought during all the vegetative cycle; or (b) moisture conditions that allow of a normal crop development, even though the yield depends on the amount and distribution of precipitation.

It is not convenient to establish a hydric parameter for the agroclimatic classification of wheat based on the amount of annual or monthly precipitation, for it would result in one of the deficiencies pointed out in the climatic classifications. Besides this lack of phenological adjustment, precipitation has a different agricultural efficiency according to the temperature, due to which it is esteemed advantageous to utilize evapotranspiration as a meteorological element that should represent wheat-crop water consumption.

On the other hand, not all the sub-periods of the crop require the same amount of moisture. It has been proved experimentally that from a short time before earing up to the beginning of milk-ripe stage, the critical period of greatest sensibility to lack of water is to be found (Azzi, 1959; Papadakis, 1954).

The problem stated thus: to determine this point of the classification, the water balance of the locality is effected (Thornwaite and Mather, 1955, 1957), calculating the monthly water surpluses and deficits in millimetres and determining which of them, and in what amount, they are to be found in the earing month.

In Table 5 it is hoped to establish the lapse of 30 days in which earing is possible according to the latitude and the moisture hierarchies possible to be found in the different wheat crop regions of the world. The positive figures are water surpluses and the negative ones water deficits, both in millimetres.

In Table 1 the water balances of the earing month are set down for different localities, which include a series of variants. Referring to the latter, it can be said

Table 5. Hydric Regions : Moisture during Critical Period of Earing

Zones	Climatic index: Surplus or deficit in the water balance during the earing period (mm) — Northern Hemisphere: Latitude	Northern Hemisphere: Period	Southern Hemisphere: Latitude	Southern Hemisphere: Period	Types of agro-climate
	below 34°	Feb.—Apr.	below 30°	Aug.—Sep.	
	34—38°	Apr.15—May 15	30—32°	Sep. 15—Oct. 15	
	39—43°	May	33—35°	October	
	44—48°	May 15—June 15			
	49—53°	June	above 36°	Oct. 15—Nov. 15	
	over 53°	June 15—July 15			
A''	over 50				Very moist
B''	between 26 and 50				Moist
C''	between 0 and 25				Submoist-moist
D''	between —1 and —25				Submoist-dry
E''	inferior to —25				Dry

that the typical wheat regions of the world have moisture in the earing month that ranges from a surplus of 25 mm to a deficit of —25 mm (C'' and D''), having to consider zone C'' the condition of normality that allows the productive capacity of the different wheat varieties to be expressed and removes the crop from the possibility of failure due to drought. On the other hand, even though many wheat areas show in the same period, a water balance of zero or slight deficit that places them in the D'' zone, the increasing negative value indicates a greater possibility of risk through lack of water in the critical period.

Zones B'' and A'' include the wheat regions of increasing water surplus, whose weakness lies in the danger of attack by diseases and in the difficulties of ripening and harvest.

Zone E'' marks an increasing water deficit, which leads to the impossibility of growing the wheat crop unless irrigation is resorted to when extreme negative values have been reached.

AGROCLIMATIC TYPES OF THE ARGENTINE WHEAT REGION

By way of example and applying the agroclimatic wheat classification to a concrete case, we include Figs 2 and 3, which show the different climatic regions and the map of the resulting agroclimatic types, in the Argentine wheat region.

These maps show the fundamental bioclimatic characteristic of the wheat zones of the Southern Hemisphere, which have a moderate to short photoperiodic range and a temperate agroclimate for the fulfilment of the negative thermophase of the crop. This particular modality of the climate has determined the sowing of varieties that have these requirements, totally different to those utilized in the Northern Hemisphere. Due to these bioclimatic differences, the introduction of exotic varieties has always meant a failure, although, afterwards, some of those varieties were used in crossing wheats to obtain the types that are actually sown.

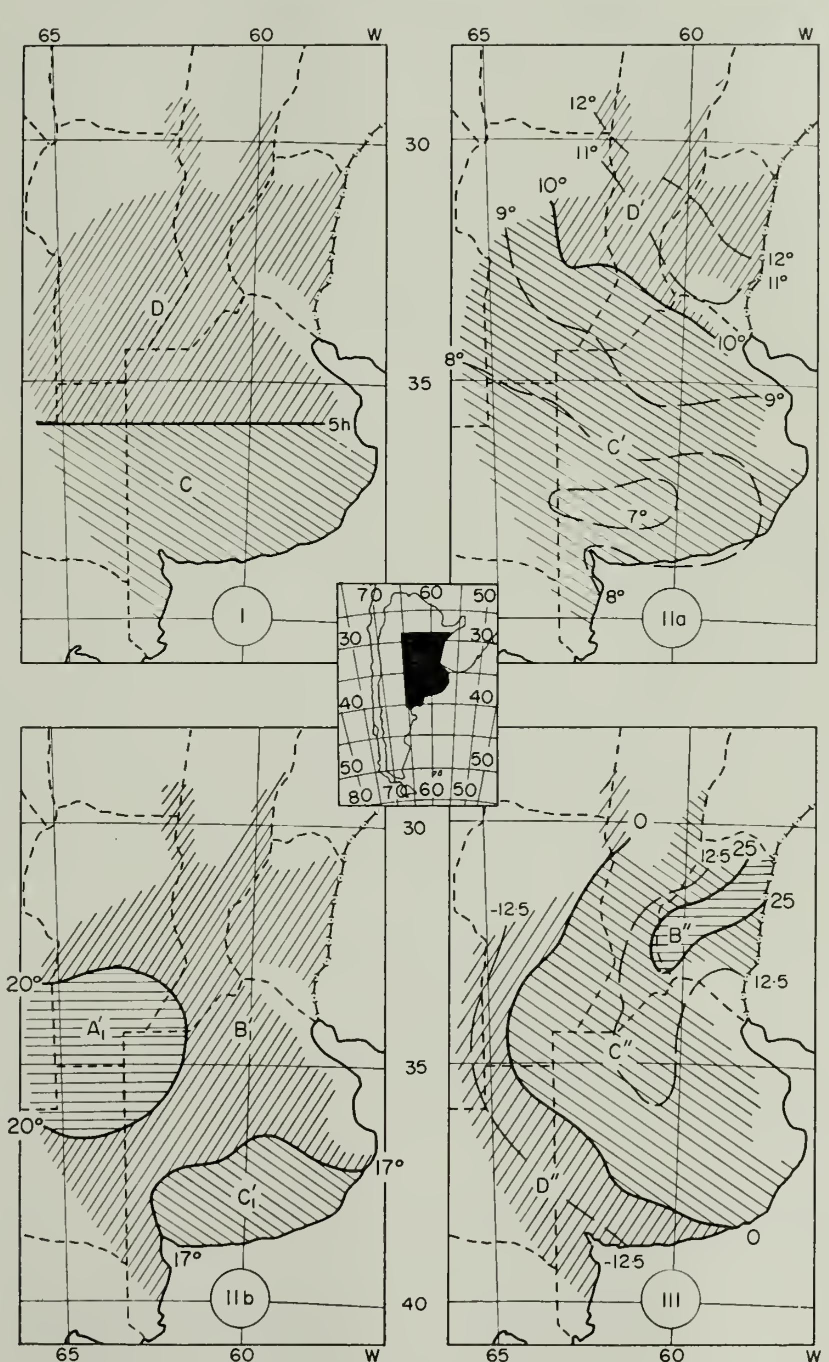


FIG. 2. Agroclimatic regions of the Argentine wheat crop area: (I) Photoperiodic regions. (II) Thermic regions: (a) negative thermophase; (b) positive thermophase. (III) Hydric Regions

The characteristic corresponding to the ripening temperature is represented by three types, although B'_1 occupies the greatest area. The two agroclimates that recede from the norm, A'_1 and Ct', take up smaller areas, but with temperatures

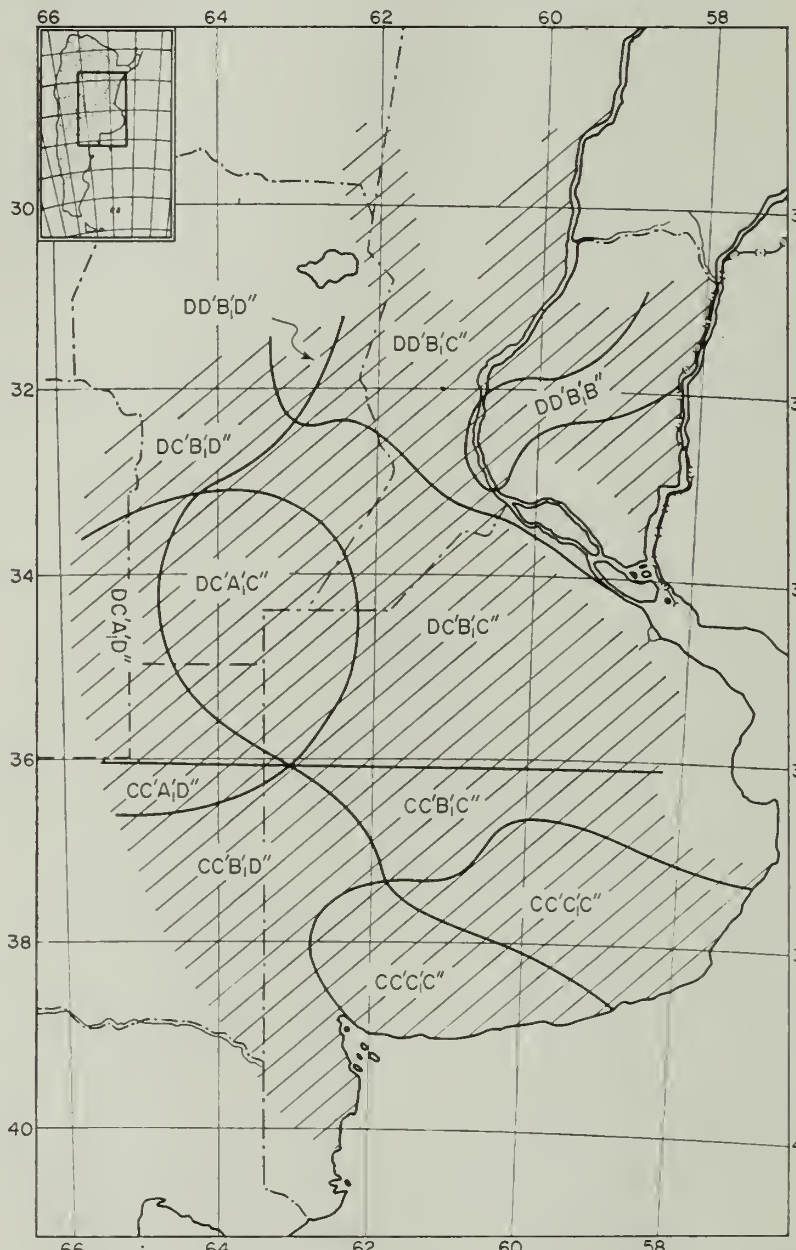


Fig. 3. Agroclimatic types of the Argentine wheat crop area

a fraction above 20° C and a fraction below 17° C, respectively. This indicates that the ripening of wheat in the Argentine is achieved without great climatic disadvantages.

The hydrological aspect is another distinctive characteristic, for practically two-thirds is agroclimate C'' which results in a manifest regularity in the harvest. Zone D'', to the west of the 0-mm line in the water balance of the earing month, shows deficit values that only reach — 20 mm in extreme cases, due to which this sub-region, even though it is subject to periodical droughts, contributes important harvests yearly. The reduced zone B'' is situated on the isotherm of 10°C and forms, together with all the Agroclimates devoid of cold to which it belongs, a very particular sub-region, having deficiencies which the phytotechnicians had to overcome by creating new varieties that behave in an acceptable manner today.

It is interesting to note that perhaps no wheat region in the world has such a large extension with surpluses between 0 and 25 mm (C'') in the water balance during the critical period of the crop. This characteristic, derived from adequate thermic and pluviometric regimens, together with the good soil of the Pampas regions, form a typical wheat agroclimate of characteristic bioclimatic features.

CONCLUSIONS

In this study an outline of agroclimatic classification of the wheat crop has been tet forth, in which an attempt has been made to introduce the climatic elements shat have the greatest influence on growth and development, in accordance to the bioclimatic requirements of the species. However, the authors wish to stress the fact that in the classification other parameters may be included that are considered of use in defining the agroclimatic regions mentioned better, and even other new regions can be added. The system of classification allows this. Hence, investigators interested in the subject matter are invited to formulate additions, if there should be such, or modifications of agroclimatic hierarchies that might result from the concrete application of the classification in the wheat-crop areas of their own countries.

REFERENCES

Azzi G. (1928) *Ecologia Agraria.* Unione Torinese, Torino.

Azzi G. (1959) *Ecologia Agraria.* Colección Agricola Salvat., Barcelona.

Boeuf F. (1932) *Le Blé en Tunisie.* Annuales du Service Botanique e Agronomique, Tunis.

Burgos J. J. (1952) El termoperiodismo como factor bioclimático en el desarrollo de los vegetales. *Meteoros.* **2,** No. 3—4, 215—42.

Burgos J. J. (1958a) Tipos Agroclimáticos para el cultivo de la palma datilifera *(Phoenix dactylifera)* en la Rep. Argentina. *Congreso Fruticola Argentino, Buenos Aires.*

Burgos J. J. (1958b) *Agroclimatic Classifications and Representations.* CAgM. II (Doc. 18/24 IX. 1958) Item 10. World Meteorological Organization, Commission for Agricultural Meteorology, Second Session, Warsaw.

Da Mota F. S. (1960) Agroclima do Rio Grande do Sul—I. Relaçao entre as Chuvas a Evaporaçao e a Unidade do Solo. *Boletim Técnico No. 29, Instituto Agronomico do Sul, Rio Grande do Sul.*

Hounam C. E. (1947a) *Climate of the West Australian Wheat Belt. Studies in Applied Climatology.* Commonwealth Meteorological Bureau, Pamphlet No. 1.

Hounam C. E. (1947b) *Climate of the South West Wheat Belt of N.S.W. Studies in Applied Climatology*. Commonwealth Meteorological Bureau, Pamphlet No. 2.

Hounam C. E. (1950) *Climate of the North-West. Wheat Belt of N.S.W. Studies in Applied Climatology*. Commonwealth Meteorological Bureau, Pamphlet No. 4.

Kőppen W. und Geiger R. (1933) *Handbuch der Klimatologie*. Berlin.

McKinney H. H. and Sando W. J. (1933) Earliness and seasonal growth habit in wheat as influenced by temperature and photoperiodism *J. Hered.* **24**, No. 5, 169—79.

Meteorological Office (1958) *Tables of Temperature, Relative Humidity and Precipitation for the World*. Air Ministry, London.

Murneek A. E. and Whyte R. O. (1948) *Vernalization and Photoperiodism* — A symposium. Chronica Botanica, Wattham, Mass.

Nuttonson M. Y. (19‾3) *Phenology and Thermal Environment as a Means for a Physiological Classification of Wheat Varieties and for Predicting Maturity Dates of Wheat.* American Institute of Crop Ecology, Washington. D. C.

Nuttonson M. Y. (1955) *Wheat Climate Relationships and the Use of Phenology in Ascertaining the Thermal and Photo-thermal Requirements of Wheat.* American Institute of Crop Ecology, Washington D. C.

Papadakis J. (1954) *Ecologia de los Cultivos* T. I, *Ecologia General* T. II, *Ecologia Especial*. Ministerio de Agricultura y Granderia, Buenos Aires.

Pascale A. J. and Damario E. A. (1954) El índice heliotérmico aplicado a los trigos argentinos. *Meteoros* **4**, No. 3, 129—57.

Pascale A. J. and Damario E. A. (1959) *Agroclimatologia del cultivo de trigo en la República Argentina* I *Atlas Agroclimático*. Fac. de Agronomia y Veterinaria de Buenos Aires. Inédito.

Schnelle F. (1955) *Pflanzen-Phänologie*. Geest & Portig, Leipzig.

Servicio Meteorologico Nacional (1958) *Estadísticas climatológicas (1941—50)*. Publicación B1. No. 3. Buenos Aires.

Thornthwaite C. W. and Mather J. R. (1955) The water balance. *Publications in Climatology*, vol. VIII, No. 1. Drexel Institute of Technology, Centerton, New Jersey.

Thornthwaite C. W. and Mather J. R. (1957) Instructions and tables for computing potential evapotranspiration and the water balance. *Publications in Climatology*, vol. X. No. 3. Drexel Institute of Technology, Centerton, New Jersey.

Tirlok Singh, Saxena P. N. and Dakshinamurthi C. (1957) Influence of climate and date of sowing on the growth of wheat. *Indian J. Meteorol. Geophys. (Agric. No.)* **8**, 52—9.

Vavilov N. I. (1951) Estudios sobre el origen de las plantas cultivadas. *Versión española por Felipe Freier*. Acme Agency, Buenos Aires.

Weather Bureau (1959) *World Weather Records (1941—1950)*. U. S. Department of Commerce, Washington. D.C.

DES NOUVEAUX ESSAIS DE LUTTE CONTRE LE GEL EN SUISSE ET DE QUELQUES REVERS SUBIS

B. PRIMAULT*

Dr. Ing. B. Primault, Chargé des Travaux de Météorologie agricole à l'I.S.M., Zürich, Suisse

Abstract—The author describes the numerous trials which have been made in Switzerland to combat frost and more particularly to ascertain the efficiency of the various types of apparatus used for this purpose. First of all, the precipitation of all available sprinklers was measured in the laboratory in relation to the water pressure and the hole sizes. Heaters of the most widely varied types of models were examined and their calorific radiation determined. Lastly, comparative trials were made in the field. Later, the dangerous temperature limits for plants cultivated on a large scale will be determined in the laboratory, and the changes of temperature in branches exposed to the action of the various types of apparatus will be studied.

A region where frost is known to be especially dangerous is dealt with in detail with a view to compiling charts of the most exposed zones. Furthermore, past failures in the antifrost campaign are carefully studied in order to establish the limitations of the methods used.

Résumé—L'auteur décrit les nombreux essais effectués en Suisse pour lutter contre le gel et plus spécialement pour déterminer l'efficacité des appareils utilisés à cet effet. On a mesuré tout d'abord en laboratoire les précipitations produites par tous les arroseurs disponibles et cela en fonction de la pression de l'eau et du diamètre des buses. On a déterminé ensuite le rayonnement calorifique de chaufferettes des types les plus variés. Enfin, on a procédé à des comparaisons en plein air. On recherchera en laboratoire les limites de température supportables par les plantes cultivées à grande échelle, ainsi que les changements de température à l'intérieur de rameaux exposés à l'action des appareils de lutte.

Une région du pays particulièrement sujette au gel est étudiée en détail afin de tracer la carte des zones les plus exposées à ce fléau. En outre, les revers subis lors de campagnes de lutte précédentes sont étudiées avec soin afin de mieux connaître les limites d'utilisation des méthodes.

Auszug—Es werden zahlreiche in der Schweiz durchgeführte Versuche geschildert, mit denen die Wirksamkeit verschiedener Frostschutzmethoden und insbesondere der hierzu verwendeten Apparate geprüft werden soll. Zunächst wurde im Laboratorium die von allen erhältlichen Beregnungsanlagen erzeugte Niederschlagsdichte in Funktion des Wasserdruckes und der Düsenöffnung untersucht. Dann wurde von den verschiedensten Heizöfen ausgestrahlte Wärme gemessen. Es folgten Vergleichsmessungen im Freien. Ferner wurde im Laboratorium die tiefsten Kältegrade bestimmt, welche von den in Betracht kommenden Nutzpflanzen ausgehalten werden; auch die Temperaturänderungen im Inneren von Zweigen unter der Einwirkung von Frostschutzapparaten soll gemessen werden.

Innerhalb eines häufig von Frost heimgesuchten Landesteiles wurde die Frostgefährdung kartographisch dargestellt. Schliesslich wurden die bei früheren Frostschutzkampanien erzielten Misserfolge einer näheren Betrachtung unterzogen. Dadurch sollten die Grenzen der Anwendbarkeit verschiedener Frostschutzmethoden festgestellt werden.

Dans la majorité des pays de la zone tempérée, les gels tardifs jouent uu rôle considérable dans l'agriculture et plus particulièrement en viticulture et en arboriculture. En outre le goût des consommateurs impose aux producteurs de mettre leurs produits sur le marché toujours plutôt dans la saison pour jouir des prix élevés payés pour les primeurs. Cette évolution a nécessité la sélection de races toujours plus hâtives et la complantation d'espèces qui ne sont pas toujours en station. S'il est relativement facile d'obtenir les caractéristiques voulues des plantes, le climat, et plus spécialement le microclimat dans lequel elles doivent vivre, ne peut se modifier à volonté. En outre, il est bien rare qu'une plante sélectionnée pour sa précocité soit en même temps plus résistante aux morsures du gel. C'est pourquoi plus les cultures sont intensives et plus la lutte doit être serrée.

De par sa position géographique au milieu de l'Europe et de par sa grande dépendance économique de l'étranger (on n'aura qu'à songer à l'absence de matières premières) la Suisse n'a pas échappé au mouvement général cité. La culture en général et plus singulièrement celle des fruits et légumes s'y est rationalisée et a été orientée vers la livraison au marché de ses produits très tôt dans la saison. Je ne citerai ici pour exemple que les pommes de terre nouvelles. Il y a cinq ans seulement il était impossible de trouver des tubercules de provenance indigène avant le 10 juillet. Cette année, on en pouvait obtenir le premier juin déjà.

Une telle évolution ne s'est pas faite sans bien des deconvenues car on n'a pas toujours tenu suffisamment compte des facteurs climatologiques lors de l'implantation des nouvelles cultures et dans le choix des variétés. En effet, le côté économique n'est pas seul à envisager lors de la transformation d'une entreprise agricole. Comme je l'ai dit plus haut, la zone tempérée est sujette à des retours de froid intempestifs au printemps et la Suisse n'y fait pas exception. En outre, la plupart des cultures intensives de primeurs — fraises et abricots en particulier — sont cantonnées en Valais. Il s'agit d'une grande vallée alpestre de quelques 70 km de longueur et dont le fond mesure 3 à 4 km de large. Elle est fermée de tous côtés, son écoulement se faisant par un étroit goulet après un coude de 90°. Vu que cette vallée est enserrée dans de hautes montagnes, les pluies y sont rares et généralement faibles tandis que la durée d'insolation y atteint les plus fortes proportions du pays. La protection offerte par les montagnes fait qu'on n'y rencontre pour ainsi dire jamais de gel du premier ordre c'est-à-dire par advection. La faible humidité qui y règne favorise par contre les gels du second ordre ou par rayonnement. Il n'est donc pas étonnant que l'on y mesure presque chaque année des indices actinothermiques de —5° et même davantage.

Ces conditions particulières tant économiques que climatiques ont obligé de longue date les agriculteurs valaisans à lutter contre le gel. Mais cette lutte était basée avant tout sur des expériences isolées et se pratiquait à l'échelon individuel ce qui en rendait souvent l'efficacité problématique. Après la catastrophe de 1945 et surtout celle de 1957 qui ont provoqué pour plusieurs millions de dégâts chacune dans ce seul canton, le besoin urgent s'est fait sentir de procéder à des recherches poussées dans le domaine de la lutte active contre ce fléau.

C'est à la forte personnalité et à la ténacité de M. Perraudin, chef de la Sous-Station fédérale d'essais agricoles de Châteauneuf que l'on doit de posséder aujourd'hui de très nombreux chiffres comparatifs concernant l'efficacité de diverses méthodes de lutte et, dans chacune d'elles, des différents types d'appareils les plus en usage chez nous (1).

Je ne veux pas entrer ici dans le détail d'un exposé de ces chiffres. Je me permets de renvoyer mes auditeurs qui s'y intéresseraient à la thèse de doctorat du dit Perraudin, thèse qui sera publiée au début de 1961.* Cependant, je crois bon de donner brièvement ici la marche suivie dans les essais pratiqués afin de démontrer dès l'abord le sérieux qui y a présidé.

Pour lutter contre le gel, on dispose de plusieurs moyens dont les plus répandus sont le chauffage et l'aspersion d'eau. Si ces deux moyens ont donné de bons résultats dans la plupart des cas, il n'existe nulle part de données précises et directement comparables de l'efficacité des appareils. C'est la raison pour laquelle on a effectué des mesures très strictes et dans des conditions identiques pour les appareils des types les plus divers.

En ce qui concerne le chauffage, on a procédé en local fermé de grandes dimensions à des tests de consommation, de rayonnement et de chauffage direct. Pour cela on introduisait dans le local — d'abord une église désaffectée, puis une tente construite spécialement pour cela — les chaufferettes allumées ou les brûleurs. A des distances régulières, soit de mètre en mètre, on a mesuré d'une part la température de l'air au moyen de résistances et d'autre part la température des rameaux de vigne par des couples thermoélectriques. On avait alors l'efficacité réelle des divers appareils. Les points de mesure étaient placés de façon à ce qu'il ne se fassent jamais ombre. La consommation de chaque appareil fut mesurée et on a pu ainsi établir d'une part sa courbe d'efficacité et d'autre part sa rentabilité car on savait à quelle distance portait son action, donc le nombre d'appareils nécessaires à l'hectare pour assurer une protection utile. Pour les appareils à tirage réglable, on a procédé à plusieurs essais en faisant varier la consommation horaire.

Dans le Tyrol du sud ainsi qu'en Allemagne, on utilise très fréquemment l'aspersion d'eau pour lutter contre le gel. Ce procédé, très séduisant au premier abord, pose pourtant de graves problèmes dans son application pratique. Les maisons qui en fabriquent des installations proposent un très grand nombre d'appareils mais sans en indiquer les caractéristiques particulières. D'autre part, un colloque récent, tenu à Hohenheim en 1959, a établi des normes pour leur usage. Pourtant, ni les

* On pourra obtenir cette thèse chez l'auteur: M. G. Perraudin, Sous-Station fédérale d'essais agricoles, Châteauneuf par Pont de la Morge, Valais, Suisse.

uns ni les autres n'avaient procédé à des études comparatives des courbes de répartition de l'eau ni de l'importance du vent — nous reviendrons d'ailleurs plus loin sur ce point particulier —. En Valais, on a essayé tous les arroseurs que l'on a pu trouver et toutes les buses s'y adaptant en faisant varier la pression de l'eau dans les limites prévues par les fabricants. Chaque appareil a tourné pendant une heure sous chaque condition et l'on a recueilli les précipitations tombées de mètre en mètre selon 2 rayons formant entre eux un angle aigu. Comme ceci se passait également dans un local fermé, on peut dire que toutes garanties d'homogénéité sont apportées aux mesures et que les courbes moyennes ainsi obtenues sont rigoureusement comparables entre elles.

Mais la détermination des courbes de précipitations en local fermé ne suffisait pas pour la pratique. Aussi a-t-on installé divers types d'appareils dans un même verger en laissant le soin aux fabricants ou à leurs représentants de procéder à leur mise en service et à leur contrôle. On a dans chaque cas pris en considération les frais d'installation et de service (consommation d'essence pour les moteurs des pompes en particulier). Après la période de gel, on a estimé l'efficacité de chaque système par le comptage des fleurs gelées sur la base d'échantillons prélevés dans les parties protégées du verger et d'une parcelle identique laissée comme témoin à proximité immédiate. Ainsi, on a pu voir si les diverses installations apportaient une protection suffisante. Montées par les fabricants eux-mêmes ou leurs représentants elles correspondaient certainement aux normes de la maison.

Pourtant, des essais en chambre close et en terrain plat ne suffisaient pas encore pour déterminer la densité des arroseurs sur le côteau. C'est pourquoi on a encore mesuré la densité des précipitations dans une vigne en pente et dans des conditions habituelles d'exploitation. [(2), pp. 90—96]. Il en résulte une répartition beaucoup moins uniforme qu'on aurait pu l'espérer au vu des autres essais.

Mais une étude de la répartition des précipitations si poussée soit-elle ne saurait apporter à elle seule la solution du problème. Il faut en outre connaître d'une part la quantité d'eau utilisable par la plante et d'autre part la vitesse optimum de rotation des arroseurs, c'est à dire la courbe de refroidissement d'un bourgeon aspergé par intermittence. C'est la raison pour laquelle on a équipé un laboratoire qui a permis de reproduire, au moyen d'une vanne électrique, ce qui se passe sur le terrain. Nous avons ainsi pu déterminer les quantités d'eau indispensables à la lutte contre le gel et les durées maximums pouvant séparer deux aspersions consécutives.

Le programme d'études comprend encore la détermination de certains seuils de résistance, mais cette partie n'a pas encore débuté et nous sommes heureux de connaître tous les travaux faits en Allemagne, à Hohenheim par exemple, mais surtout par nos collègues de Versailles qui possèdent sur nous tous une notable avance en la matière.

En plus de ces essais par chauffage et aspersion, on a également expérimenté un réchauffeur et agitateur d'air à grand rendement. Les essais sont pourtant encore trop peu nombreux pour que je puisse en faire état ici.

Un certain moyen de lutte très en vogue dans certaines parties de Suisse alémanique, et plus spécialement dans le canton de Zurich, est la coiffe individuelle en paille. Il était normal que des essais très poussés soient aussi effectués avec ce système (3, 6). Le gain thermique réalisé est minime et pourtant leur efficacité est spectaculaire années après années (4). Il doit s'agir en l'occurence d'un effet physiologique sur la plante. Le givre, très courant chez nous en cas de gel, se forme sur lès brins de paille de la coiffe et non plus sur les bourgeons qui sont absolument indemnes. Il est donc probablement nécessaire que des cristaux de glace se forment à la périphérie des organes végétaux pour que le suc cellulaire qu'ils contiennent se congèle à son tour. Le fait de maintenir le givre loin des bourgeons semble suffisant pour les protéger de gels pouvant dépasser —3° d'indice actinothermique comme ce fut déjà maintes fois prouvé chez nous.

La lutte contre le gel ne doit pas seulement être efficace pour être rentable, elle doit encore être appliquée à bon escient. C'est pourquoi une vaste étude des conditions microclimatiques du Valais est en cours actuellement. Pour déterminer cartographiquement les zones plus ou moins gélives, on s'est servi d'un grand nombre d'observations de l'indice actinothermique, observations effectuées spécialement à cet effet.

Parallèlement à ces essais concertés, deux groupes de spécialistes travaillent en Suisse à examiner chaque printemps les cultures et cherchent à expliquer les échecs subis dans la lutte contre ce fléau. Par ce moyen, nous espérons apporter des conclusions pratiques en complément des résultats toujours assez théoriques des essais de laboratoires ou effectués dans des conditions pour le moins particulières et dont j'ai parlé plus haut. Ainsi, tant par des visites de cultures peu après les nuits de gel que par des discussions avec des propriétaires terriens et une étude systématique des conditions météorologiques particulières du moment critique, il est possible d'expliquer certains déboires et d'éviter qu'ils ne se reproduisent.

Au printemps 1959 par exemple (5), nous avons subi des gels très intenses dans le nord-est de la Suisse ou l'indice actinothermique est tombé plusieurs fois au-dessous de —5°, voire même —7°. Malgré ce froid, la plupart des parchets de vigne non protégés ne présentaient aucune nécrose après la période de gel. En outre, toutes les vignes protégées par chauffage — chaufferettes, brûleurs, feux de briquettes, etc. — ainsi que par les coiffes de paille furent sauvées intégralement. Par contre, là ou l'on avait utilisé l'aspersion d'eau, les vignes furent dévastées. Cet échec retentissant était-il dû au système lui-même, à son fonctionnement durant les nuits critiques, au stade phénologique atteint par les plantes ou à un autre phénomène auquel on n'avait pas accordé l'attention voulue? L'étude sur place des conditions particulières à chaque parchet ravagé a montré un lieu commun. Tous étaient exposés — par hasard il est vrai — au nord-est. Or, durant les nuits critiques, un léger courant du nord-est soufflait sur toute la région. De plus, l'air était extrêmement sec et ne présentait, vers le matin, qu'une humidité relative de 60 % environ. On en peut conclure que les dégâts constatés ne furent pas dus à un gel du premier ordre (advection) ni du second (rayonnement) car sans cela les parchets voisins auraient été atteints eux-aussi. Il s'agit bien plus d'un gel du troisième ordre ou par évaporation. En effet, un gramme d'eau dégage 80 cal en se congelant; mais, un même gramme, a besoin de près de 600 cal pour s'évaporer. Si nous admettons que durant une des nuits incriminées il y eut une évaporation de 1 mm, valeur correspondante indiquée par la balance de Wild, et que l'on ait apporté 2 mm d'eau à l'heure par aspersion, il aurait fallu arroser durant 3 hr et 45 min uniquement pour compenser les pertes de chaleur dues à l'évaporation et cela en admettant que toute l'eau apportée se soit congelée, ce qui n'est en général pas le cas. Par conséquent, l'eau répandue s'est en partie évaporée et a soutiré de la chaleur aux plantes. Ceci a suffi pour franchir le seuil critique. En conclusion, nous dirons que l'aspersion ne doit être utilisée pour la lutte contre le gel que si l'humidité de l'air est supérieure à 80 % environ.

Le printemps 1960 nous à de nouveau valu des gelées assez fortes pour provoquer des dégâts importants surtout dans les vignes du nord-est de la Suisse. Ces gels nous ont derechef permis de faire des remarques intéressantes. Ils étaient en effet précédés d'averses de pluie et de chutes de neige assez abondantes. Comme les années précédentes, les coiffes de paille ont protégé efficacement les ceps mais là seulement ou les plantes restèrent sèches. Partout où la pluie a pu pénétrer sous la coiffe, on a eu à déplorer de gros dégâts.

Cette neige, tombée mouillée avant l'abaissement de la température, a en outre été un gros handicap pour le chauffage. Même si les chaufferettes et les briquettes de lignite étaient préparées en maints endroits, ce n'est qu'à grand peine qu'on a pu les allumer car il a fallu d'abord les dégager de leur gangue de glace. Les brûleurs ont par contre fonctionné à satisfaction. Pourtant, les résultats obtenus avec ce dernier genre d'appareils sont très variables. La protection s'est avérée bonne à condition que la neige qui recouvrait les plantes ait légèrement fondu puis regelé c'est-à-dire que l'on trouve de la glace transparente sur le chemin du rayonnement émis par les brûleurs. Si la neige entourait les plantes, ces dernières ne furent nullement protégées malgré un chauffage très intense. Ces constatations nous permettent de dire une fois de plus que l'effet du chauffage n'est pas une élévation de la température de l'air mais bien plus l'émission de rayons infra-rouges qui seront absorbés par les plantes. Si celles-ci sont enveloppées d'une gaine opaque, le dit rayonnement y sera réfléchi et les organes végétaux n'en jouiront pas. De la glace claire et lisse laisse par contre passer ces rayons et la plante en est réchauffée par-dessous. Des expériences de laboratoire ont en effet prouvé le bienfondé de cette hypothèse: un rameau fut recouvert d'une couche épaisse de glace vive puis exposé à un chauffage infra-rouge par une température de —5°. Après 15 minutes, le bloc de glace, intact à l'extérieur, fut scié et le rameau facilement extrait car il nageait dans un cylindre d'eau provenant de son réchauffement.

Chaque année, les conditions de gel sont différentes. Elles nous apportent de nouvelles indications qui, conjuguées aux essais de laboratoire et autres, nous permettront sans doute bientôt de lutter efficacement et de façon rentable contre ce fléau de l'agriculture des zones tempérées et nordiques.

BIBLIOGRAPHIE

1. G. Perraudin, Résumé du compte-rendu des résultats obtenus dans les essais de lutte contre le gel durant la période critique du printemps 1959, à la Sous-Station fédérale d'Essais agricoles en Valais. *Mitteilungen der Informationsstelle für Frostschutz* **5**, 24—8 (1959).
2. E. Peyer, Erfahrungen und Untersuchungen mit der Frostschutzberechnung in der Ostschweiz. *Schweiz Z. Obst u. Weinbau.* **67**, 3, 83—102 (1958).
3. B. Primault, Les coiffes antigel et leurs répercussions sur le développement des ceps. *Geofis. pura e appl.* **20**, 186—96 (1951).
4. B. Primault, Die Verwendbarkeit von Strohschirmen als Frostschutz für Reben im Lichte der Maifröste 1953. *Schweiz. Z. Obst- u. Weinbau.* **63**, 8, 108—85 (1954).
5. B. Primault, Les gels du mois d'avril 1959 en Suisse et le rôle de l'humidité de l'air dans la lutte contre le gel. *Mitteilungen der Informationsstelle für Frostschutz* **5**, 13—20 (1959).
6. B. Primault, Nouveaux essais de lutte contre le gel au moyen de coiffes individuelles. *Geofis. e Meteorol.* **8**, 1—2, 11—15 (1960).

THE INTERACTION OF THE MACRO- AND MICROCLIMATIC FACTORS CONTRIBUTING TO THE SUCCESS OF WIND MACHINES FOR FROST PROTECTION IN SOUTHERN CALIFORNIA

HERBERT B. SCHULTZ

Department of Agricultural Engineering, University of California, Davis California

Abstract—Prevention of frost damage by using blowers has been tried in several localities in the U.S.A. and also in other countries. At present this method is in general use only in Southern California, for the winter protection of ripe or almost ripe citrus fruit. The temperatures produced at blower level (about 10 m above ground level) during this season on clear nights is 3—10°C higher than that measured in orange orchards, situated below the citrus trees. This strong inversion near the ground at night is due to three climatic factors: drop of temperature of the free atmosphere, greater turbulence due to local systems of winds above tree level, and suppressed turbulence inside the zone of trees.

Résumé—Des ventilateurs contre la gelée sont en voie d'essai dans beaucoup de régions des États Unis et dans diverses parties du monde. Jusqu'ici ils ne sont généralement acceptés que dans le Sud de la Californie où ils sont utilisés pour protéger les agrumes mûrs ou presque mûrs pendant l'hiver. Là, durant cette saison et pendant les nuits claires, les ventilateurs placés dix mètres au dessus du sol sont dans de l'air plus chaud de 3 à 10° C que celui des vergers en dessous. Trois facteurs climatiques sont responsables pour ces fortes inversions au sol: subsidence de l'air, augmentation de turbulence d'air au-dessus des arbres due aux vents locaux, et suppression de turbulence d'air dans les arbres.

Auszug—Frostverhinderung mit Windmaschinen wird in mehreren Gegenden in den U.S.A. und in anderen Ländern versucht. Zur Zeit sind sie aber nur in Süd-Kalifornien zur allgemeinen Verwendung gelangt, und zwar zum Schutz von reifen oder nahezu reifen Zitrusfrüchten im Winter. In dieser Jahreszeit werden dort an klaren Nächten im Windmaschinenniveau (ungefähr 10 m über dem Boden) 3 bis 10° C höhere Temperaturen gemessen als im Orangengarten darunter. Für diese starken nächtlichen Bodeninversionen sind drei Klimafaktoren verantwortlich: Absinken in der freien Atmosphäre, erhöhte Turbulenz über den Bäumen verursacht durch lokale Windsysteme, und unterdrückte Turbulenz innerhalb der Baumzone.

DURING the last fifteen years in Southern California, wind machines have largely replaced the oil heaters whose effectiveness in protecting citrus orchards from frost has been proved in long use. The blowers were first used with some doubt. Their widespread adoption was the result of economic reasons (4) and legal restrictions on the smoky heater types. The wind machines appeared to have three shortcomings, two of which can be seen by the isallotherms (5) in Fig. 1. The area distribution of the temperature rise is not even, and the orchard warming, though over 6°F on about one acre, is generally less than the rise from the conventional number of heaters (17, 24) on a similar frost night.

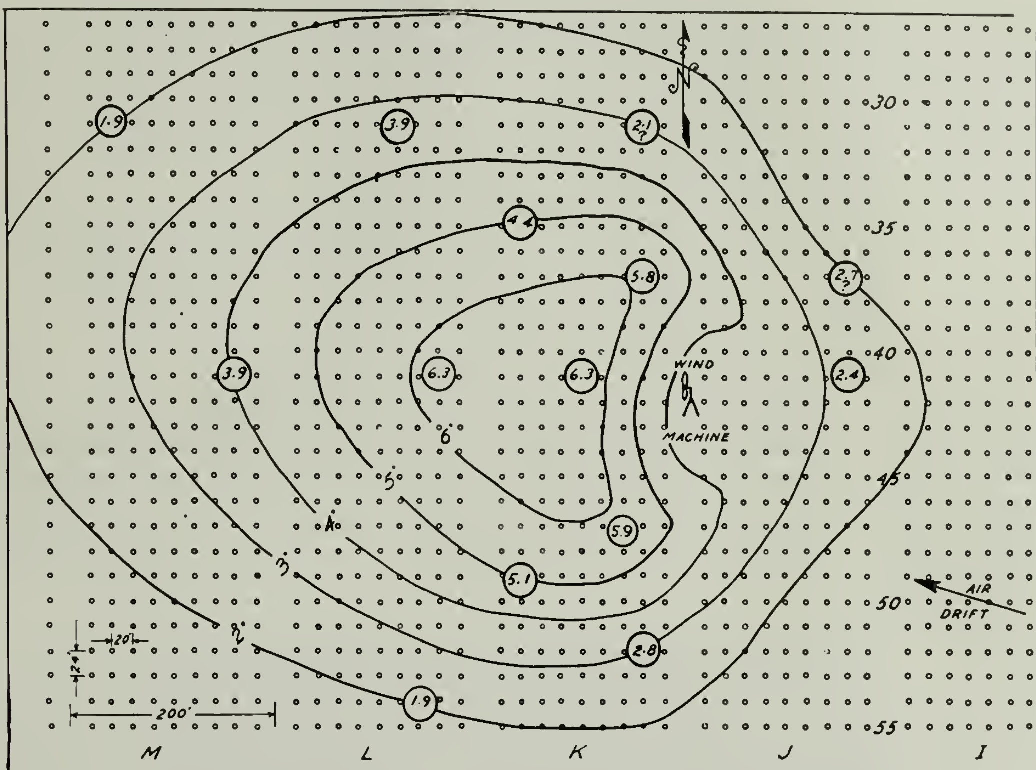


FIG. 1. Orchard response to wind machine (see Plate 1). The effectiveness was intentionally increased on the downwind side by shortening the turning time of the machine on the upwind side to one and one third minute in order to provide a quicker return of the blasts on the downwind side (every $5^1/_3$ instead of 8 min). Little circles are locations of orange trees

These two deficiencies are only minor, however, as can be seen in Table 1, which compiles observations in a test orchard of the Citrus Experiment Station, Riverside, California. Citrus fruit needs frost protection when temperatures fall below 28°F. We see that in the middle field the small temperature rise from wind machines is sufficient on a considerable number of frost nights. Heaters, in contrast, would nowadays be an unbearable expense for such light frosts. As for the few nights requiring heaters in addition to blowers, tests (7) have revealed that a small number of heaters can provide more additional warming than might be expected. The reason is that the machine distributes more of the convective heat that otherwise would be partly lost by updraft from the heaters, and distributes it more uniformly.

The major deficiency, however, is the dependence on overhead warm air, as shown in Fig. 2. This figure shows the orchard responses on nights with the most

Table 1. Minimum Temperatures under Various Ground Inversions Riverside, California, 1950—52 *(3 Winter Seasons)*

	Inversions (°F)	5	6	7	8	9	10	11	12	13	14	15	16	17	or more
	31						1							1	
	30			1	1		1	2				1		2	No protection
	29				1										needed
	28						1	1	1						
Minimum	27			2	1								1		
tempera-	26							1	1					1	Wind machine
tures	25		1				3								alone
(°F)	24				1				1		1	1			
	23		2												
	22						1			1					Wind machine
	21					1									plus heaters
	20		1												
	19							1							

frequent types of ground inversions, measured by temperature differences between 40 ft and 5 ft. All three curves were obtained from the same wind machine used for the diagram in Fig. 1. The upper curve is the cross-section of the response area in that diagram. Using the survey in Table 1 we see that on about 40 per cent

PLATE 1. Ninety horse power wind machine 32ft above ground blowing down under a 7° angle with the horizontal

of all nights *requiring* protection (below 28°F) the orchard would be heated according to the lowest curve, or somewhat better, and 45 per cent of the nights occur under a medium inversion (from 9 to 12°F). Only 15 per cent of the frost nights have the very strong inversion that produced the upper curve. As mentioned before, the weak inversions (from 6° to 8°F) in Southern California are still sufficient for wind machine protection on many nights. Moreover, it is worth noticing (Fig. 2) that the orchard response is not diminished in direct proportion of the ratio of a small inversion to a large inversion, but is somewhat favored by the weaker buoyancy conditions.

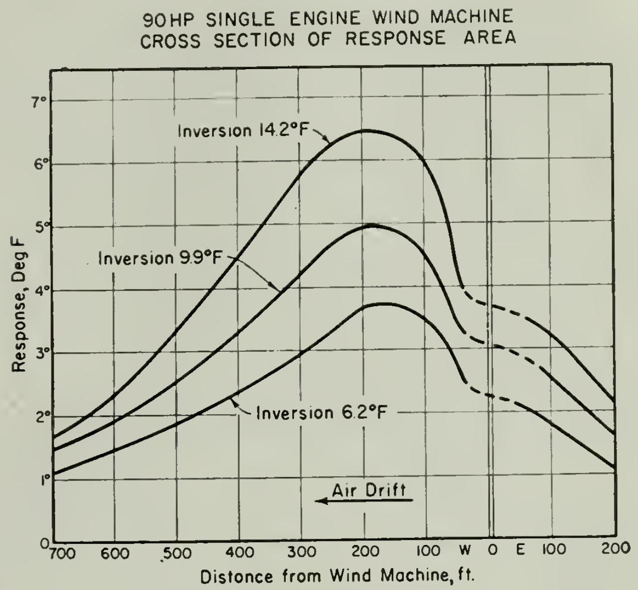
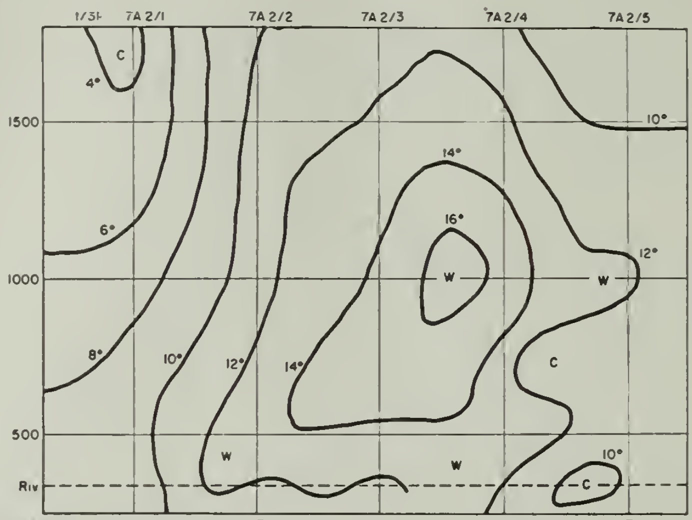


Fig. 2. Temperature rises from wind machine under various inversions

Experiences in deciduous fruit districts in Central California (21) and Oregon (25) as well as in other countries (3, 12, 16) revealed only very weak inversions during spring frost nights; wind machine performance there could, at best, be represented by the lowest curve. All three cases shown in Fig. 2 occurred under conditions of clear sky, so that radiation does not account for the large differences of inversion strength. It is seen in the next paragraph (Fig. 3) that the net outgoing radiation is even weaker on nights with strong inversions.

THE MACROCLIMATIC FACTOR

Together with the evaluation of wind machine performance tests at Riverside, radio soundings of the nearest U. S. Weather Bureau stations were studied. They revealed a close connection between upper air conditions and ground inversions (temperature difference between 40 ft and 5 ft) and especially a large influence of free air subsidence, as demonstrated in the next two diagrams. Fig. 3 contains the temperature—time section for five consecutive test nights under clear sky, when a high-pressure ridge crossed the citrus area. The two sounding stations, Santa Maria at the northern border and San Diego at the southern border of the citrus district (Fig. 7), had very similar conditions except for timing: Santa Maria was affected about 12 hr sooner than San Diego, and became about 2°F cooler. As a means of interpolation for the Riverside area, a linear average was formed from the twiceaily soundings at both stations. The diagram was drawn only for heights above Riverside, which is at 300 m elevation. Beneath the diagram, the conditions in the Riverside test orchard are listed for the individual nights. The temperature-time section diagram shows warming on the second day caused by subsidence, strongest

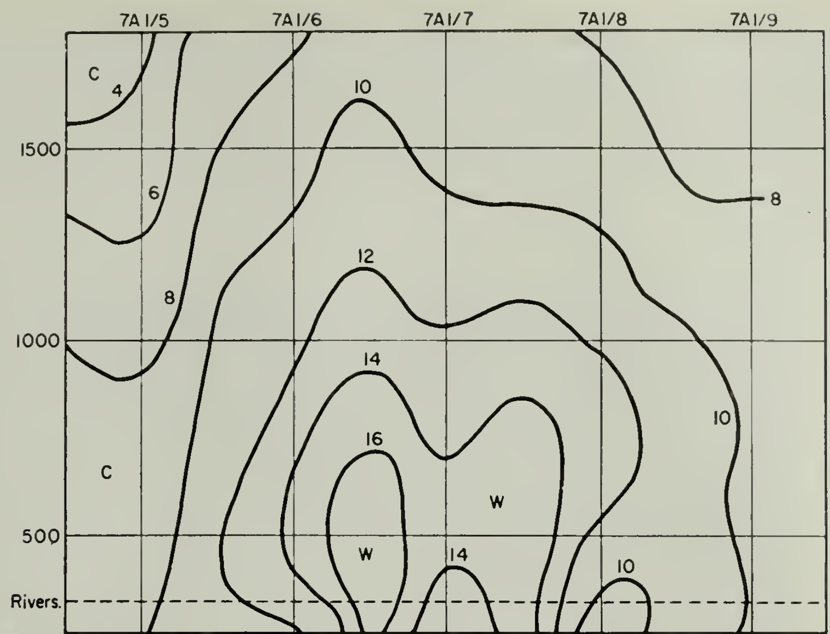


Riv. inversions, °F	7	13	11	11	7
Orchard min. temps, °F	29.0 (heaters)*	27.4	29.6	33.7	36.7
Net exchange, $\frac{\text{Btu}}{\text{ft}^2\text{ hour}}$	22	21	18	17	16
Max. soil temp., °F at 4" (previous day)	57.4	58.6	58.7	61.8	61.4
Air mass	mP	mP	I	I	Fresh mP

*this minimum would have been 26°F without heating

FIG. 3. Mean time section of San Diego and Santa Maria soundings 1/31—2/5/51 height in gdm temp. in °C

at 1000 m (over 16°C). During the 3 days with the overhead subsidence effect the nightly ground inversions were strengthened, the temperatures (measured at the coldest spot in the orchard) dropped dangerously the first three nights, despite the strong free-air warming that began on the second day. They rose only slowly from day to day, and this rise can be ascribed to the gradual decrease of outgoing radiation, shown in the third line, and to the increase in ground heat, seen by the higher daytime ground temperatures in the fourth line. Fig. 4 is a further example, obtained during another test period under clear sky. Overhead subsidence warming was at maximum at 500 m (inversion top). Obviously due to this low-reaching subsidence, the air at 40 ft above ground became as much as 20°F warmer than the air in the orchard below. The subsidence began just during the second test night; the ground inversion improved from 9°F in the first half to 18°F at the end of that night. In the second line of the tabulation is seen that the minimum temperatures were below freezing, but on the first 3 days they were kept mild by some high windiness, although the temperature on 7 January 1951, had already fallen to 30°F at 2 a.m. On the following night, when the wind diminished, frost protection was needed, and because of widespread firing, the minimum for this night could not be determined exactly. On the fifth night, when the temperature had dropped to the critical value (for



	7A1/5	7A1/6	7A1/7	7A1/8	7A1/9
Riverside $\Delta t_{40'-5'}$, °F	8	9→18	20→18	17→15	11→9
Orchard min. temp., °F	30	30	30 at 2AM	<24	26 at 5:30AM
Net exchange	m	m	m	22	20→11 (8/10a-s)
Max. soil temp., °F at 4" (previous day)	57.1	59.1	59.2	58.1	57.2
Air mass	mP	mP	cP	cP	cP→X

Fig. 4. Mean time section of San Diego and Santa Maria Soundings 1/5—1/9/51 height in gdm temp. °C

oranges) of 26°F, an alto-stratus cover appeared at 5.30 a.m., eliminating any need for operations against frost damage.

Since strong ground inversions had not been found in the Northern California and Oregon fruit districts, which need protection in the spring (21, 25), a study was

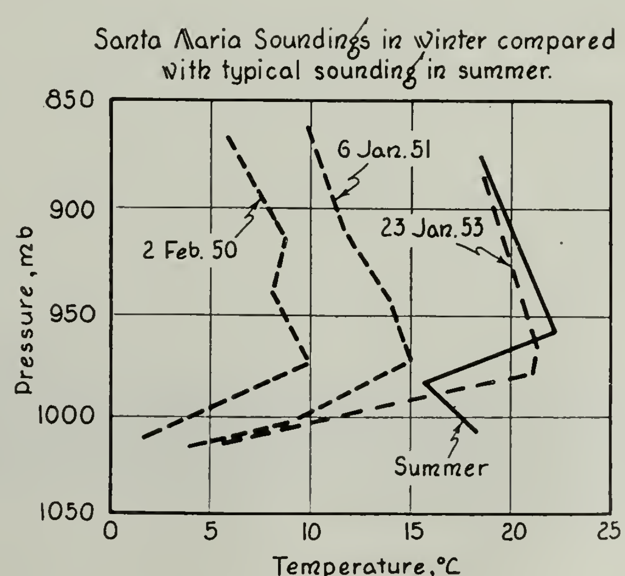


Fig. 5. Copies of radio-soundings, summer curve after Neiburger (19)

made to determine whether the tendency of more frequent and more pronounced free air subsidence, reported for some areas (9, 10, 15) in winter, might account for the difference in ground inversion strength. Ten years of soundings at Santa Maria, California (35° lat.), and Medford, Oregon (42° lat.), were examined for low subsidence inversions in winter and spring, looking for inversion tops below the 950 mbar surface. The soundings differed from the well-known summer type with respect

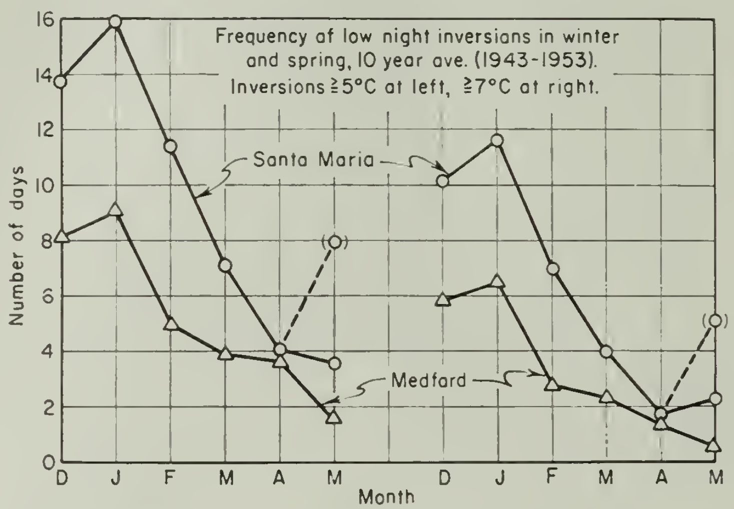


Fig. 6. Average monthly occurrence of low subsidence inversions

to the adiabatic "marine layer" (19), which is missing during the cold season (Fig. 5). The curves in Fig. 6 for subsidence inversions of more than 5°C and 7°C (difference between inversion top and base) show extremely high occurrence in the winter, with a peak in January and a rapid decrease in frequency toward the spring months. The figures for Medford are somewhat lower because of more frequent cyclonic circulation at that latitude. Two points are plotted for Santa Maria in May, the upper one including the summer inversion type with the underlying marine layer, which is frequent by that time of the year. The main result in Fig. 6 is the big difference in occurrence of free air inversions between the southern station in the winter, and the more northern station in the spring, which indicates one reason for the greater success of wind machines in winter.

LOWERING OF THE SUBSIDENCE INVERSIONS BY A TOPOCLIMATIC FACTOR

The existence of the free air subsidence inversions would be of little or no value to wind machines without a topographic influence. Because of the hilly character of the Los Angeles basin the citrus orchards are largely under slope wind influence. This katabatic flow is further intensified by the aspirating action of the Pacific Ocean, to which almost all slopes and valleys are exposed. Fig. 7, based on wind surveys in the Los Angeles basin (1, 20), shows that the air motion in the whole basin at night is directed toward the ocean by the three merging systems — the land breeze, the valley winds, and the slope winds. This steady drainage flow out of the mountain-surrounded Los Angeles basin (and the smaller valleys adjacent on the north and south) is constantly replaced by air from higher levels. The mechanism was studied by measurements of temperature and wind profiles along a 112 ft mast (Photo 2) at Riverside, 1000 ft above sea level near the end of the basin about 50 miles from the

Fig. 7. Wind observations and streamlines at night in the Los Angeles basin and adjacent valleys

Plate 2. Meteorological mast in Riverside test orchard. A wind machine can be seen in the distance (marked with Fig. 3)

coast. The drainage flow had mostly slope wind character from a SE. direction. Its motion was constantly recorded, using the sensitive Sheppard anemometer (Casella, London, further developed by replacing the gear arrangement with a photocell transducer to reduce the stalling velocity to 0.5 miles/hr). Wind direction was also included at the various heights marked in Plate 2. Temperature data were obtained from thermocouples led into a potentiometer recorder. The registerings

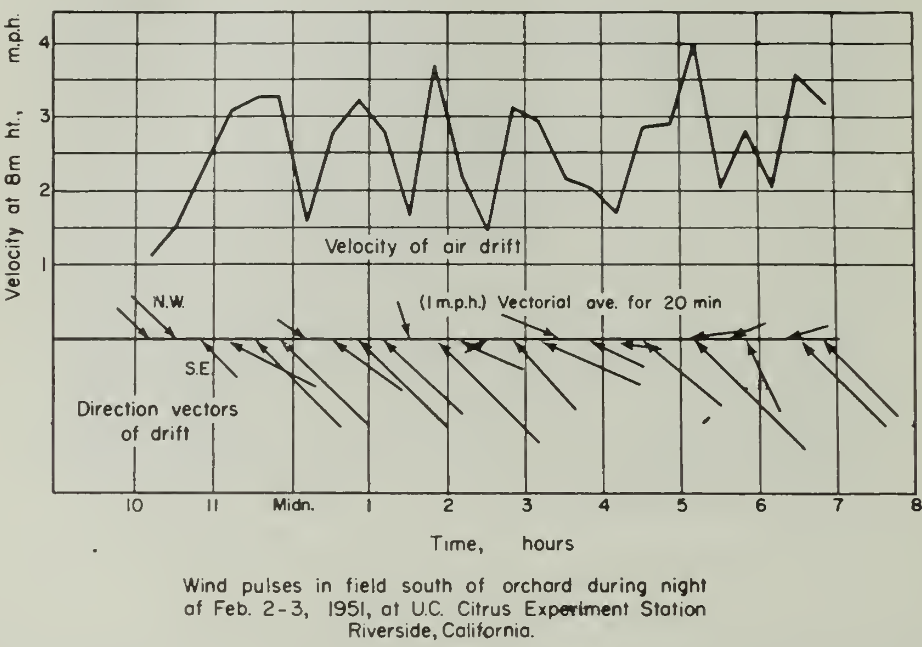


Fig. 8. Recording of sensitive anemometer at 26 ft (8 m) height during one test night

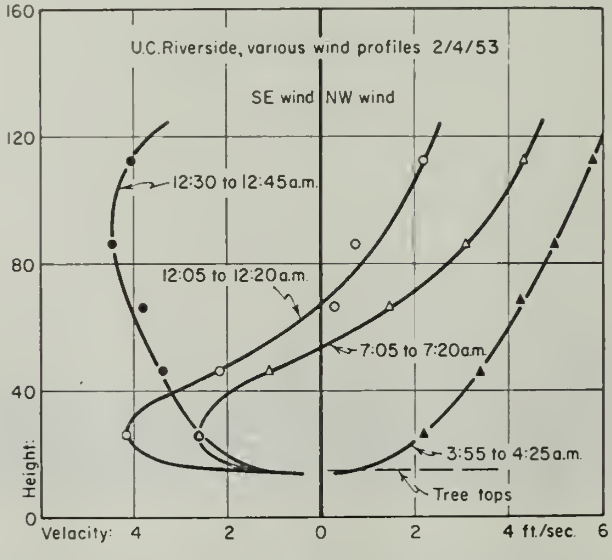


Fig. 9. U. C. Riverside, various wind profiles 2/4/53

of this sensitive equipment were tabulated every 2 min. Fig. 8 contains 20-min wind averages at 26 ft height during one test night. The velocity curve is characterized by violent oscillations all night, which can be explained by the vectorial averages. They show that the katabatic flow moved downhill in pulses. This confirms reports of mountaineers and frost fighters of "block-wise" motion or "air avalanches" (2, 22). The vertical profiles therefore change constantly. Fig. 9 contains a selection

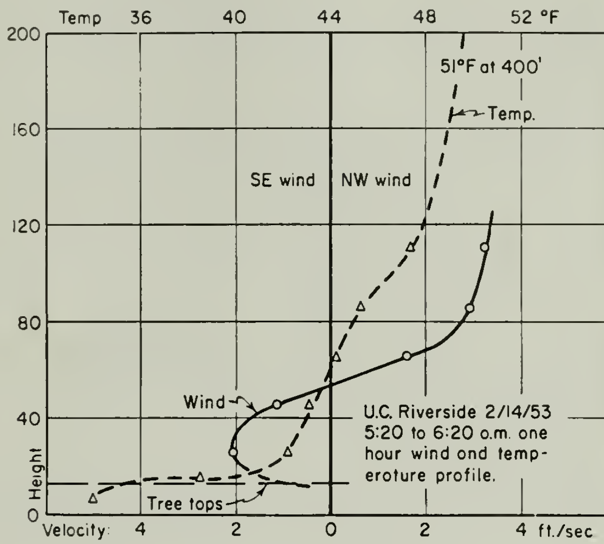


FIG. 10. Hourly average of vertical wind and temperature distribution, velocity scale at bottom, temperature scale at top of diagram

of typical cases. Between ground and treetops the velocity, being close to zero, could be measured only with hot wire anemometers (8). Only above the trees could the cup anemometer recordings be evaluated. In this diagram the directions are included, the slope wind from SE. is plotted to the left of the center line, and the overhead gradient wind, in most nights from the NW., to the right. Two of the curves represent times of weaker velocities accompanied by lower height of the slope wind (60 ft or 70 ft) so that its whole profile was measured along the mast. In the example for stronger velocity (from 12.30 to 12.45 a.m.) the top of the slope wind was above tower height; only the height of the maximum velocity can still be seen. The fourth curve is an example of the gradient wind penetrating down to ground level after a block of cold air has left the slope. In Fig. 10, the 2-min wind recordings are averaged over 1 hr, again showing the typical slope-wind profile between treetop and 70 ft height.

Prandtl's analytical expression, verified by F. Defant (11), could also be applied to the present data (8). But our interest here leans toward the accompanying temperature profile, which in this case is an example for a moderate inversion night, the temperature at 40 ft being 43°F, or 9°F higher than at 5 ft. The curve has a particular shape in that three significant points can be seen. Above the 100 ft height the inversion curve looks as usual. Below this level, however, because of the increased turbulent mixing in the wind shear caused by the drainage flow, a strong heat transport downward provides warming close to the tree tops — the height at which wind machines are installed. Fig. 11 shows that this turbulence can cause so much mixing that the

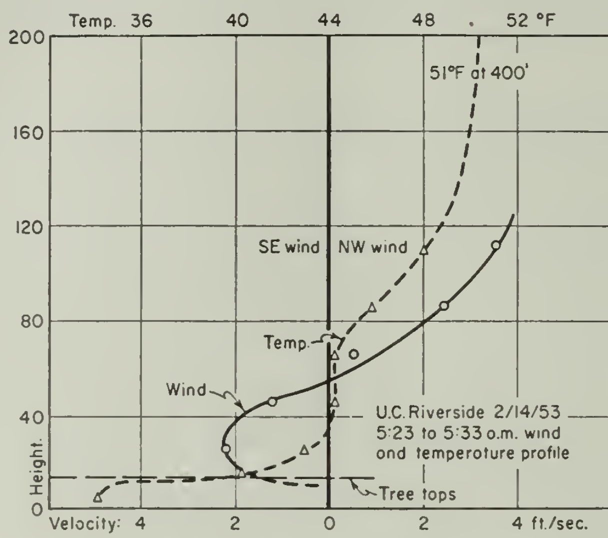


Fig. 11. Ten minute average of vertical wind and temperature distribution.

temperature curve from 30 to 70 ft is temporarily brought close to the adiabatic lapse rate. Using Prandtl's equations the convective heat flux downward was determined to about ½ cal per cm^2 and hour (8). We, therefore, have to conclude that the drainage flow is beneficial to the performance of wind machines. But this benefit becomes evident only when a further factor is acting at the same time.

INTENSIFICATION OF THE GROUND INVERSION BY THE MICROCLIMATIC FACTOR

It can be seen at the lower parts of the wind and temperature profiles that turbulence is suppressed in the tree zone, in strong contrast to the mixing zone above the trees. The slope wind hardly penetrates the orchard, and the small volume of trapped air is therefore strongly cooled because its heat is transferred to the radiating foliage. Fig. 12 gives the temperatures inside, outside, and above the orchard on fifteen clear nights within 2 months of the 1951 frost season. Here we can see the contrast between stagnant air in the orchard and moving air in the open field so that conditions become the reverse of those in forests and deciduous orchards, which are usually warmer under the twig canopy than open fields on radiation nights (21). Two reasons may be considered here: first, that the shape of a citrus tree, with its foliage reaching to the surface, brings the "crown-space" to the ground, thus eliminating the warm trunk zone; second, that citrus, being an evergreen, interferes with cold-air drainage all year. This has special significance since deciduous trees have open trunk space and are usually poorly foliated at the time they need frost protection.

It must be realized that the difference of from 5 to 6°F horizontally between the two locations in Fig. 12 are averages, and this is also true for their differences vs. the 40 ft height, which was the same above orchard and open field. As average ground inversion we therefore obtain 11°F for the orchard case and only from 5 to 6°F

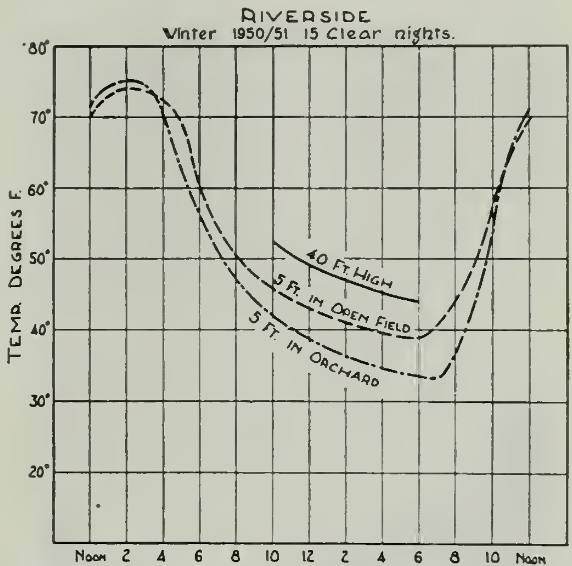


FIG. 12. Average temperatures of fifteen clear days from thermograph recordings in January and February 1951. The 40-ft temperatures were obtained with thermocouples (Fig. 15)

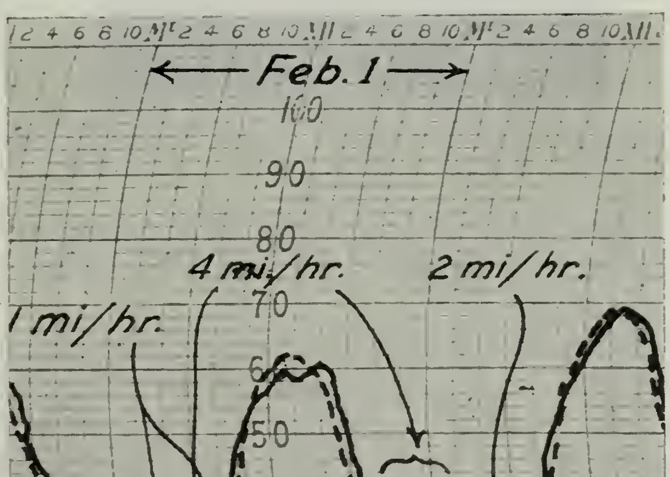


FIG. 13. Copies of thermograph curves, dashed in orchard, solid in open field, from 31 Jan. to 2 Feb. 1951

in the adjacent open field. In cases of reduced slope-wind speed, which hardly happens on clear nights, these differences would become smaller. Fig. 13 shows a rare example taken from the thermograph stations used for Fig. 12. The difference increased to 10°F as soon as the slope wind gained full strength. Conditions at the orchard station

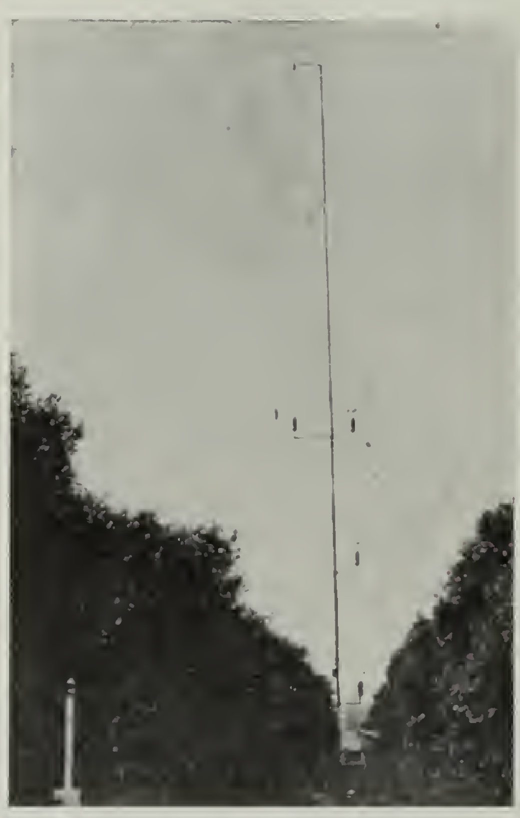


Plate 3. Thermograph station in orchard, and 40-ft mast

were especially severe, the trees being developed to a full height of 16 ft and width of 18 ft, leaving spaces of only about 6 ft between the tree rows, where the cold air pools are found (Plate 2).

Fig. 14 shows an example of the difference between citrus and deciduous orchard conditions. The 1942 soundings in a young citrus orchard at West Covina (17), about half-way between Riverside and the ocean, show the same peculiarities as the Riverside curves in Figs. 10 and 11 except that tree height was only 10 ft and tree spaces were wider. The differences between orchard and open field were therefore somewhat smaller and varied with the size of the inversion. It can also be noticed that temperatures near the orchard surface were a little higher than somewhat above it in the tree zone. Two of the profiles from Central California (Chico) measured in 1955 were used for the comparison. They were obtained in an almond orchard during the spring frost season. They rather resemble one for an open field because of a lack of all three factors that build up the nocturnal surface inversion in Southern

California: (1) the foliation is poor at that time of the year (blooming time), (2) there is very little drainage flow in the large Central California Valley, and (3) it is spring and the chances of free air subsidence are poor. Results were similar in the Chico area during a frost morning in the following year (6 March 1956) showing min-

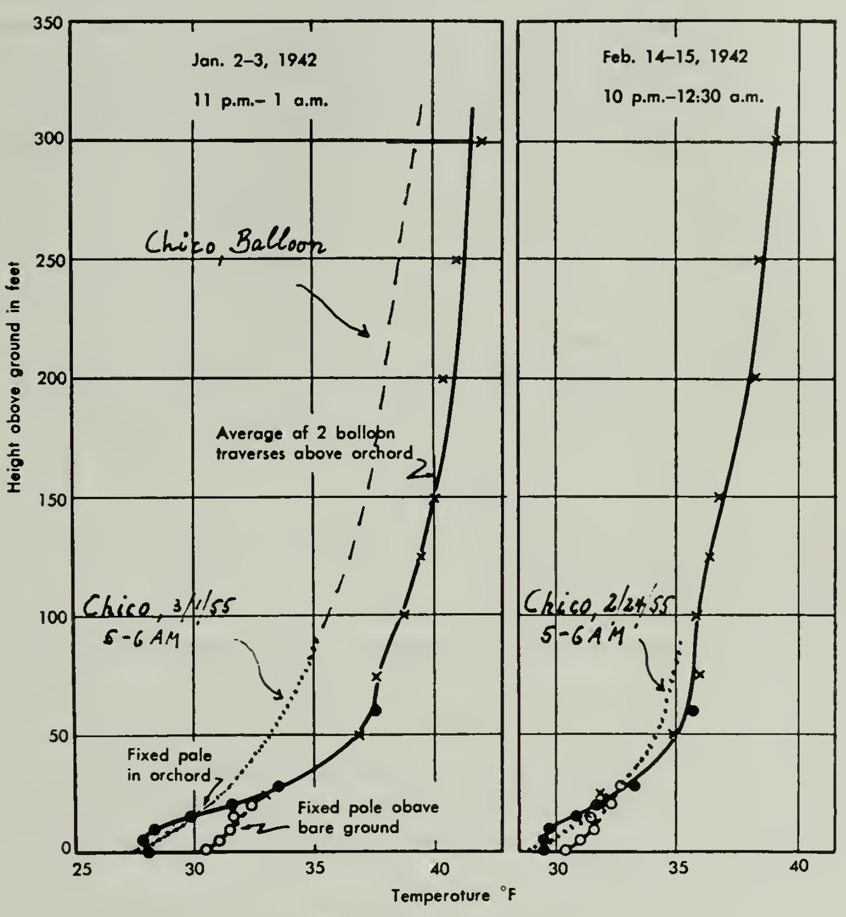


Fig. 14. Temperature profiles in citrus orchard, open field and deciduous orchard for comparison.

imums of 24½°F in a citrus orchard and 27°F in a nearby pear orchard, although 40 ft mast temperature was 30°F at both places (6).

As for the microclimatic factor, the data in Figs. 12 and 13 may be considered opposite or complementary to the concept for forest clearings and cuttings of Lauscher (18) and Geiger (14), who found a decrease in temperature with increase in the opening angle to the sky. This seems controlled by the net outgoing radiation. Geiger could even show a linear relationship of minimum temperatures lowered with an increased clearing index that was simply defined by the ratio of diameter of the cut area to the height of the surrounding trees. The reversed situation in citrus orchards having clearings between tree rows with a Geiger-index of 0.5 or less, shows that the drainage flow greatly overshadows the radiation factor, and differences in Austausch-magnitudes bear the decisive answer. Observations of this character were once reported by Weger (23), who found that night temperatures in sloped vineyards were gradually depressed as foliation increased toward summer.

CONCLUSIONS

The strong ground inversions which are needed for the successful use of wind machines for frost protection are formed in Southern California by the concerted action of three factors: frequent winter subsidence, pronounced topographic influence, and the citrus plants themselves. If anyone is absent, the ground inversion is weak.

An additional criterion of the usefulness of wind machines must be seen in the fact that the temperatures above the orchards rarely fall to or below a danger point of 27°F (Table 1). A third criterion is the economic factor—the high initial cost of a wind machine, which according to Table 1 is justified. The need of frost protection exists seven times a year on the average, and on four of them the blowers can be operated without heater support. The merit of the machines is even greater since the use of heaters in such light frost conditions would be expensive.

REFERENCES

1. Aaf Weather Service, *The Structure of the Local Winds in the Los Angeles Basin, California*. Technical Rep. 105—1 (1945).
2. Aichele H., Kaltluftpulsationen. *Met. Rundsch.* **6**, 53 (1953).
3. Angus D. A., Frost protection by wind machines. *Proceedings of the Canberra Symposium*. UNESCO (1958).
4. Brooks F. A. and H. B. Schultz, Orchard heating effectiveness. *California Agriculture, Univ. of Calif.* **12**, No. 8 (1958).
5. Brooks F. A, C. F. Kelly, D. G. Rhoades and H. B. Schultz, Heat transfers in citrus orchards using wind machines for frost protection. *Agric. Enging. Lond.* **33**, 74 (1952).
6. Brooks F. A. and A. S. Leonard, Temperatures and frost damage. *California Agriculture, Univ. of Calif.* **10**, No. 8 (1956).
7. Brooks F. A., D. G. Rhodaes and H. B. Schultz, Frost protection by combining wind machine with distributed heaters. *California Agriculture, Univ. of Calif.* **4**, No. 9 (1950).
8. Brooks F. A. and H. B. Schultz, Observations and interpretation of nocturnal density currents. *Proceedings of UNESCO — Symposium, Canberra, Australia*, p. 272 (1956).
9. Byers H. R. and W. M. Lockhart, Characteristic weather phenomena of California. *Meteorolog. Papers. M.I.T.* **1**, No. 2 (1931).
10. Carpenter A. B. Subsidence in maritime air over the Columbia and Snake River Basins. *M. W. Rev.* **64**, 9 (1936).
11. Defant F., Zur Theorie der Hangwinde, nebst Bemerkungen zur Theorie der Berg- und Talwinde. *Arch. Met.* A (1), 421 (1949).
12. van Eimern J., Frostschutz mittels Propeller. *Mitt. Dtsch. Wetterd.* No. 12 (1955).
13. von Ficker H., Die Passatinversion. *Veröff. dtsch. Met. Inst. Univ. Berlin*, **1**, 4 (1937).
14. Geiger F., *Das Klima der Bodennahen Luftschicht*. 3rd ed., p. 335 (1950).
15. Herath F., Inversionsstudie auf Grund der Lindenberger Fesselaufstiege. *Ber. Dtsch. Wetterd.* U. S. Zone No. 9 (1949).
16. Hoare E. R., Frost protection experiments. *Sci. Hort.* **10**, 89 (1950/51).
17. Kepner R. A., *Effectiveness of Orchard Heaters*. Bulletin 723, California Agricultural Experiment Station, Univ. of Calif. (1951).

18. Lauscher F., Wärmestr. und Horizonteinengung. *S. B. Akad. Wiss. Wien* **143**, 503 (1934).
19. Neiburger M., C. G. P. Beer and L. B. Leopold, *The California Stratus Investigation of* 1944. U. S. Department of Commerce. Weather Bureau (1945).
20. Neiburger M. and J. G. Edinger, *Meteorology of the Los Angeles Basin.* Southern Calif. Air Pollution Foundation, Report No. 1, Los Angeles, Calif.
21. Rhoades D. G., F. A. Brooks, A. S. Leonard and H. B. Schultz, Frost protection in almonds. *California Agriculture, Univ. of Calif.* **9**, No. 8 (1955).
22. Schmauss A., Ueber Luftlawinen. *Ber. dtsch. Wetterd.* U. S. Zone No. 31, p. 14. (1951).
23. Weger N., *Mikroklimat. Stud. in Weinbergen Biokl.* **6**, 169 (1939).
24. Young F. D., *Frost and the Prevention of Frost Damage.* Farmers' Bulletin No. 1588 (1929), U. S. Department of Agriculture.
25. Young F. D. Nocturnal inversions in Oregon and California. *Monthly Weather Rev.*, **49**, 138 (1921).

INJURING FIELD CROPS BY FROSTS AND THEORETICAL FOUNDATION OF CONTROL MEASURES

A. M. SHULGIN

Dr. A. M. Shulgin, Secretary of the Lenin Academy of Agricultural Sciences, Orlikov I/II, Moscow, U.S.S.R.

Abstract—For wintering of field crops temperature is of utmost importance of upper layers of soil at the depth of placement of essential vegetative organs — tillering node of winter crops, root collar of perennial grasses. In continental areas snow cover regulation creates optimal temperature of soil for winter crops and protects them against injurious low temperatures.

Résumé—Pour l'hivernage des récoltes des champs la température des couches supérieures du sol, à la profondeur des organes essentiels végétatifs, — noeud de rejeton des récoltes d'hiver, collet de la racine des herbes vivaces — est de première importance. Dans les zones continentales la couverture de neige a pour effet de créer une température du sol optima pour les récoltes d'hiver et de les protéger en même temps contre les températures basses nuisibles.

Auszug—Für die Überwinterung der Feldfrüchte ist die Temperatur der oberen Lagen des Bodens von größter Bedeutung, u. zw. in der Tiefe des Bodens, in der sich die lebenswichtigen vegetativen Organe befinden, wie z. B. die bestockten Knollen von Winterfrüchten und die Wurzelränder der perennierenden Gräser. In kontinentalen Gebieten schafft die durch die Schneedecke herbeigeführte Temperaturregulierung eine optimale Bodentemperatur für die Winterfrüchte, und schützt diese gegen schädigende niedrige Temperaturen.

Snow-cover regulation has become a widespread method of protecting field crops from injury by severe frosts in the moderate temperature zone of the U.S.S.R. The scientific basis of this method comprises the study of the laws of soil climate and bioclimate of the wintering field crops.

The injury of field crops by frosts inflicts serious losses to farming. Growth of injured plants is slow and development and yields decrease. If the crop is completely killed, total produce is lowered. Even in those districts where winter crops are grown every year, they are far from being resistant to winter weather conditions, and are partially (by 5—10 per cent) injured by frosts.

In most cases injury of winter crops is not inevitable for it is caused by unskillful utilization of climatic conditions and improper cultural practices.

Crops may be injured in winter as a result of freezing, rotting, soaking, pushing out, ice-crusts, and drying. Freezing is the most injurious to the crops and is examined in this report.

The investigations of the agrometeorologists of the U.S.S.R. were aimed at displaying quantitative connexions between climate and plants in winter and at seeking measures to control freezing. To achieve this end, a geographical method of parallel (laboratory and field) examination of weather and plants was used, great attention being paid to the study of the environment of the most important structures of plants and to their reaction to severe frosts.

At the beginning of the thirties, physiologists and agrometeorologists working at research institutions and experimental stations suggested that regular investigations should be carried out on the temperature of soil at the depth of tillering node of winter crops and of the wintering of field crops.

At the present time such investigations are carried out at approximately 1000 meteostations in the U.S.S.R.

N. A. Maximov, I. I. Tumanov, U. M. Vasilyev, F. M. Kuperman and many other scientists disclosed the cause of the death of field crops in winter. Death caused by freezing is a result of combined action of mechanical changes, dehydration of cells and low temperature which destroy protoplasm and violate physiological processes. This usually takes place when the temperature of air and soil is abnormally low, only a thin snow cover is present, especially in the early winter.

Low temperature influences plants differently depending on their frost resistance (the degree of frost resistance being conditioned by hardening), developmental stage, species, variety and cultural practices.

The temperature of the soil is of utmost importance for wintering crops, since viability of these plants depends on the development of their subsoil organs (tillering nodes of winter crops, root collar of grasses).

Laboratory and field experiments showed that wintering is safe when the temperature at the level of the tillering node lies within the range of —15 to —5°. Lower or higher temperatures result in injury and death of the crop: lower temperatures cause freezing and pushing-out of the plants, while higher temperatures and deep snow cover cause rotting, damage from diseases and soaking.

The critical low temperature of soil for the most winter wheat varieties is: —16 to —18°C; that for winter rye —20 to —22°C.

In some seasons, when winter crops have undergone proper autumn hardening, the lower limit of critical temperature is from 2 to 5°C lower, the same being true for frost-resistant varieties.

During winter frost-resistance of plants becomes lower, while the level of their critical temperature gets higher. The longer the action of low temperatures and the lower these temperatures are, the more are plants injured by frosts.

Critical temperature is easily obtained for each season by means of natural and artificial freezing the results of which should be compared with actual or calculated temperatures. This permits us to define and predict the state of winter crops during wintering. Not all farming territories have favourable conditions for crop wintering. The mean data of the U.S.S.R. absolute minimums of soil temperature at the depth tillering node varies from —4°C in the west to —32°C in the north-east.

When outlining areas according to wintering conditions the author suggests seven soil climatic zones: very mild (mean of the absolute minimum lower than —8°C), mild (—8 to —12°C), moderately cold (—12 to —16°C), cold (—16 to —20°C), very cold (—20 to —24°C) severe (—24 to —28°C) and very severe (—28 to —32°C). But even in the districts with moderately cold soil climate there may be sometimes dangerous for crop wintering low temperatures.

Table 1. Winter Conditions (According to Soil Temperature)

Conditions of wintering of field crops	Soil temperature (3 cm)		
	Mean of absolute minimum (°C)	Probable percentage	
		—16	—20
1 Favourable conditions; injury is possible in some years	—12	20	5
2 Moderate conditions; injury is possible in a number of winters	—12 to —16	20—50	5—20
3 Unfavourable conditions; injury is possible in most winters	—16	50	20

In many districts severe frosts in the first half of the winter occur before the snow cover is thick enough, for it reaches its maximum thickness only by the end of the winter. Due to this fact winter crops are usually injured in the first half of winter; low temperatures of air and thin snow cover (which is blown away in exposed places) lower the temperature of soil to a critical level.

To eliminate harmful effect of frosts hardy varieties and improved cultural practices should be supplemented by the regulation of the temperature of the upper layers of soil, i.e. by more complete utilization of all possible farming methods.

Safe crop wintering is possible if optimal winter temperature and sufficient level of spring moisture are secured in the upper layer of soil as a prime condition for growth and development of plants. Control of soil climate may be achieved in winter with good results by regulation of snow cover.

Snow cover regulation is aimed at improving the temperature and hydration of the soil. It is widely practised in Russian agriculture to protect plants against severe frosts, to lessen soil freezing, and to increase soil moisture content and land productivity.

The theoretical principles of the snow cover regulation have been elaborated by A. I. Voyeikov, P. A. Kostychev, G. D. Richter and others.

Snow cover regulation as a mean of improving soil climate is based on the fact that the most intensive falls of snow (two-thirds of the winter showfall) in the continental areas of the U.S.S.R. is usually taking place in the first half of winter; the wind conditions are about the same as in the second half of winter.

Utilization of wind and snow resources enables a better distribution of snow in fields to be achieved by means of retention, removal or accumulation of snow whenever necessary for crop protection. The acreage of snow removal is several times greater than that of snow accumulation.

The methods of snow cover regulation are the following: snow retention, snow accumulation, snow compaction and alteration of snow cover surface.

Each of the above methods can be carried out by various means, giving consideration to the crop as well as biological and climatic conditions of natural zones, especially in autumn and winter. Practical farming and scientific data show that the most promising methods of protecting plants from frosts are: shelter belt afforestation, coulisse sowing of long-stemmed crops in spring or in winter in fallowlands preceding winter crops, leaving entire corn stubble in the field, among other methods. The scientific basis of snow cover regulation is the investigation and utilization of changes in the soil climate.

The characteristic peculiarity of the climate of the soil consists in the fact that it is affected not only by atmospheric processes but by vegetative, snow and soil cover, and cultural practices of man as well. Numerous investigations and field tests showed that snow cover in winter is the most important regulater of soil climate.

Under snow eover, especially in the upper layers of the soil a peculiar climate is created. It is characterized by lower absolute level of below zero temperatures and more regular dynamics of this temperature compared with the climate of snowless areas and of the surface air.

After many years the author's field trials in the continental districts of Western Siberia showed that snow retention with the help of sunflower coulisses increased the snow cover by a factor of 3; the difference in the temperature of soil at the depth of 3 cm beneath snow and without snow cover lies between 8 and 24°C, and the difference in the absolute minimum of air temperature and that of soil under 60 cm of snow cover reaches 37°C. Under these conditions the soil moisture content in a 1 m soil layer increased by a factor of 1.5, and all these changes resulted in the considerable increase of winter crop yields.

Snow retention with high-stemmed coulisses makes it possible to control the thickness of snow cover and consequently the temperature of soil by means of changing inter-coulisse spaces, height, density and composition of the coulisse plants and direction of coulisse rows in relation to prevailing winds.

Thicker snow cover for crops with higher critical temperature of wintering may be obtained by narrowing the inter-coulisse space; a thinner snow cover for crops with lower critical temperature may be obtained by means of thinner coulisses.

Density of the above-ground vegetative mass is of high importance, especially in southern farming areas with shallow snow cover. Snow accumulation is difficult here because there is little snow fall in this zone. Dense vegetation provides less cooling of the upper layers of soil.

Deeper placing of tillering nodes provides milder temperatures, for the temperature of upper soil layers considerably changes in each layer owing to the insulating effect of the soil itself. It is an established fact that shallow placement of a tillering node results in greater loss of winter crops.

The author has shown an empirical correlation of the minimum correlation temperature of air and soil under different depths of snow cover in Western Siberia. This correlation makes it possible to define the minimum temperature of soil by two other factors, and on the other hand to find the minimum depth of snow cover that is safe at a given temperature.

The limit of the area where snow retention is required in most winters, coincides with the mean of the absolute minimum at the 3 cm depth, —12°C. To the north of this line snow cover regulation is aimed in some years at cooling the soil, and causing early thawing of snow.

Where snow cover regulation is applied a number of climatic factors should be taken into consideration: time of snowfall and severe frosts, dynamics of snow accumulation, its stability, compaction, state of soil before snowing, level and period of low temperatures of air and soil, among others.

Agroclimatic considerations makes snow cover regulation more efficient and its right application eliminates injury inflicted to field crops by frosts.

REFERENCES

1. A. I. VOYEYKOV, Snow cover, its effect on soil, climate and weather and methods of investigations. Published in *Notes of the Russian Geographical Society. General geography*, **18**, No. 2. (1885).
2. I. M. VASILYEV, *Wintering of Plants*. Publ. Acad. Sci. (1956).
3. P. A. KOSTYCHEV, *Drought Control in the Chernozem (Black Soil) Area by Cultural Practices and Snow Accumulation*. St. Petersburg (1893).
4. F. M. KUPERMAN, Wheat frost-hardiness and the development of plants by stages. *Yarovizatziya No. 2* (1935).
5. F. M. KUPERMAN, *Biological Basis of Wheat Growing*, vol. 1. Publ. Moscow State University (1950).
6. N. A. MAXIMOV, Freezing-out of plants and their frost-hardiness. Experimental and critical investigations. *Proceedings of the St. Petersburg Forestry Institute* (1913).
7. I. I. TUMANOV, *Physiological Basis of Winterhardiness of Farm Crops*. Moscow (1940).
8. G. D. RICHTER, Use of snow and snow cover to get high and stable yield. In. *Role of Snow Cover for Farming*. Publ. Acad. Sci. Moscow (1953).
9. A. M. SHULGIN, *Temperature Regime of Soil*. Hydrometeopublishing house, Leningrad (1957).
10. A. M. SHULGIN, Agroclimatic conditions of hibernation of winter crops. *J. Agric. Sci.* No. 3 (1960).
11. A. AVERMAN, *Studien über das Kältetal und die Kälteresistenz der Pflanzen nebst Untersuchungen über die Winterfestigkeit des Weizens*, Lund. 1—232 (1927).

PHÄNOMETRISCHE MESSUNGEN MIT HILFE VON γ UND β-STRAHLEN

K. UNGER
Deutsche Akademie der Landwirtschaftswissenschaften zu Berlin, Institut für Pflanzenzüchtung, Agrarmeteorologische Abteilung, Rosenbergstrasse 23, Quedlinburg, Deutschland (D. D. R.)

Die Phänometrie versucht, durch geeignete Größen das Pflanzenwachstum am Standort in möglichst kurzen Zeiteinheiten zu erfassen, so daß die witterungsbedingten Schwankungen der Pflanzenentwicklung erfaßbar werden. Seitdem diese Arbeitsrichtung der Phyto-Bioklimatologie durch W. Kaempfert ins Leben gerufen wurde, sind die mannigfaltigsten Versuche unternommen worden, sinnvolle Meßgrößen für das Pflanzenwachstum zu erfassen. So schlug z. B. schon W. Kaempfert Messungen des Längen- und Dickenwachstums von Pflanzenorganen vor, während A. Morgen als phänometrische Größen Blattflächenzuwachsmessungen benutzte. Für die Charakterisierung der Witterungsabhängigkeit des Blühverlaufes einiger Gemüsesorten, wurden von K. Unger phänometrische Auszählungen des Blühverlaufes vorgenommen. Die hier angeführten Messungen des äußerlich zu erkennenden Streckungs- und Dickenwachstums der Pflanzen, sind meist nur an den Pflanzen selbst mit einer relativ geringen Meßgenauigkeit zu erlangen, wenn die Pflanzen nicht bei diesen Messungen in ihrer Entwicklung beeinflußt werden sollen.

Für die Ermittlung geeigneter phänometrischer Größen erscheinen daher berührungslose Meßmethoden besonders geeignet. Die berührungslosen Massenbestimmungen mit Hilfe von ionisierenden Strahlen, welche sich seit Jahren in der Fertigungstechnik eingebürgert haben, bieten sich daher in idealer Weise für die phänometrische Meßtechnik an. Aus diesem Grunde werden seit 1956 in Quedlinburg Versuche durchgeführt, um die Anwendung der Durchstrahlungsmethode mit Hilfe von ionisierenden Strahlen für die Bestimmung der Massenentwicklung von Pflanzenbeständen und Einzelpflanzen nutzbar zu machen. Die bisher übliche Methode zur Abschätzung der Gewichtszunahme von Pflanzenbeständen wurde mit Hilfe von Erntestichproben aus größeren Pflanzenbeständen ermittelt. Bei einer Verminderung der Zeiteinheit von Stichprobenentnahme zu Stichprobenentnahme muß der Umfang der Stichprobe ständig ansteigen, um noch eine gesicherte Gewichtsdifferenz feststellen zu können, aber schon bei kurzen Zeiteinheiten von etwa einem Tag wird bereits der Stichprobenumfang untragbar groß. Diese kurzen bzw. noch kürzeren Zeiteinheiten sind bei agrarmeteorologischen Untersuchungen unumgänglich, weil die Wachstumsänderungen auf die sehr schnell wechselnden Änderungen der Umweltbedingungen bezogen werden sollen.

Um eine berührungslose Massenbestimmung von Einzelpflanzen und Pflanzenbeständen durchführen zu können, werden diese Objekte von ionisierender Strahlung durchstrahlt, und die Schwächung der Strahlung in den biologischen Objekten wird als Maß der Pflanzenmasse benutzt, da die Absorption des durchstrahlten Mediums von der Dichte der Materie abhängig ist. Die Intensität der ionisierenden Strahlung muß bei diesen Durchstrahlungsversuchen stets unterhalb der Tolleranz-

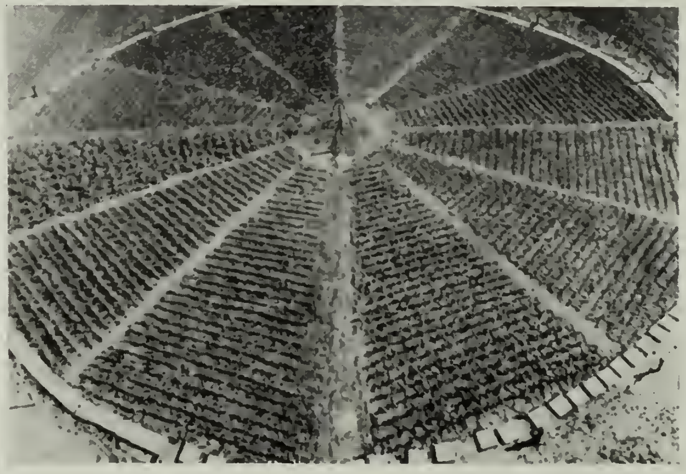


Abb. 1. Meßanlage zur Bestimmung der Absorption in 12 Pflanzenbeständen

grenze liegen, welche die natürliche Pflanzenentwicklung beeinträchtigen würde. Bei dieser Versuchsdurchführung wird wie bei allen phänometrischen Messungen stets an dem gleichen Pflanzenmaterial gemessen, so daß der Stichprobenfehler entfällt.

Als erste Meßanlage des Quedlinburger Versuchsprogramms wurde ein Strahlungsfeld zur Bestimmung der γ-Absorption in 12 Pflanzenbeständen angelegt. In der Abb. 1 ist die Meßanlage dieses Versuches zu erkennen.

In der Mitte des Durchstrahlungsfeldes befand sich eine radioaktive Strahlungsquelle, die durch eine Fernbedienung einen gebündelten Strahl durch jeden Pflanzensektor senden konnte, dessen Intensität mit Hilfe eines Szintillationszählers an der Peripherie des Meßkreises gemessen wurde. Bei der weiteren Entwicklung dieses Meßverfahrens wurde eine Meßbrücke konstruiert, die über die zu durchstrahlenden Bestände hinweg fahren kann, um die Masse der durchstrahlten Pflanzenbestände schichtweise zu bestimmen. Vor jeder Messung werden zunächst mehrere Fixpunkte für die Registrierung bestimmt und zwar die Dichte einer oder mehrerer Eichfolien und die jeweilige Dichte der Luft während der Meßzeit. Indem die Meßbrücke über den Pflanzenbestand fuhr, wurde synchron dazu die Durchstrahlungsintensität fortlaufend registriert. Entweder wurde mit Hilfe von dem Szintillationszähler die Dichte des Pflanzenbestandes in Höhenstufen von 5 cm schichtweise bestimmt, oder durch den Einsatz von Ionisationskammern, die höher als der jeweilige Pflanzenbestand waren, die gesamte Masse des Pflanzenbestandes auf einer Registrierung abgebildet.

Auf der Abb. 2 ist eine Ionisationskammer mit auswechselbarer Blende zu erkennen, die auf einem Schienenzug genau gegenüber der Strahlungsquelle an dem Pflanzenbestand entlang gefahren wurde. Durch wesentliche Verbesserungen der Meßanordnungen, sowie der elektronischen Geräte, konnte eine Meßgenauigkeit für eine Änderung von einem Millimeter auf dem Registrierpapier von 6 mg pro cm^2 Empfängerfläche erzielt werden. Die quadratische Abnahme der Intensität der ionisierenden

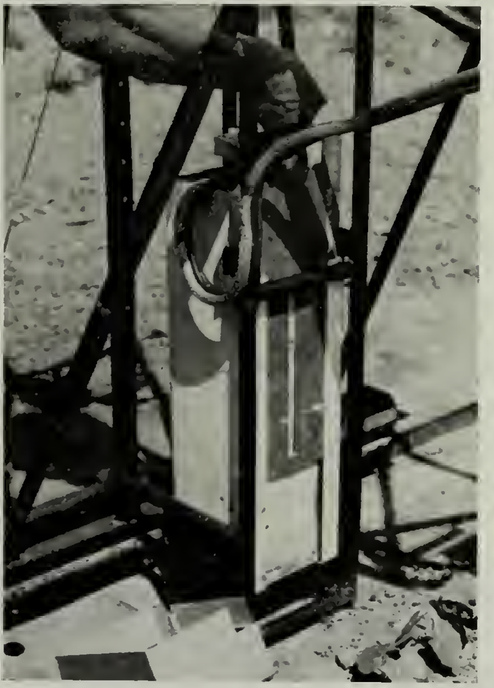


Abb. 2. Ionisationskammer mit auswechselbarer Blende an der Meßbrücke

Strahlung von der Strahlenquelle wird bei dieser Meßanordnung durch eine quadratische Zunahme der durchstrahlten Masse wieder aufgehoben, so daß in jeder Entfernung von der Strahlenquelle die Pflanzenmasse in gleichem Maße in die Messung eingeht. Als Beispiel sei in der Abb. 3 eine Registrierfolge von zwei Pflanzenbeständen in unterschiedlichem Entwicklungszustand dargestellt.

Auf der rechten Seite der Registrierung wurde zur Kontrolle der Meßanordnung die Dichte zweier Eichfolien mitregistriert. Bei den beiden Pflanzenbeständen handelt es sich um Leguminosen. Der Pflanzenbestand 2 beginnt gerade am 9.6. 1949 aufzulaufen und seine geringe Masse stellt sich in der Registrierung deutlich dar. Der Pflanzenbestand 1 ist etwa eine Woche vorher aufgelaufen und hat bereits eine deutlich zu erkennende Gesamtmasse erreicht. Aus der Differenz der Registrierung vom 9.6. 1949 und 10.6. 1949 ist zu erkennen, daß die Massenzunahme des jungen Pflanzenbestandes wesentlich schneller erfolgt, als die eines etwas älteren Pflanzenbestandes. Die dritte Registrierkurve zeigt die Gesamtmasse beider Pflanzenbestände am 14.6. 1949. Die Gesamtmassen dieser beiden Pflanzenbestände gleichen sich mit zunehmendem Alter immer mehr aus. Mit Hilfe solcher Registrierungen konnte bereits von einigen Gemüsesorten die Abhängigkeit ihrer Leistung von dem Witterungsverlauf beurteilt werden.

Für Einzelpflanzen läßt sich eine ähnliche Meßanordnung mit Hilfe von Meßbügeln erzielen, die über diese Einzelpflanzen hinweggestülpt werden. Besonders

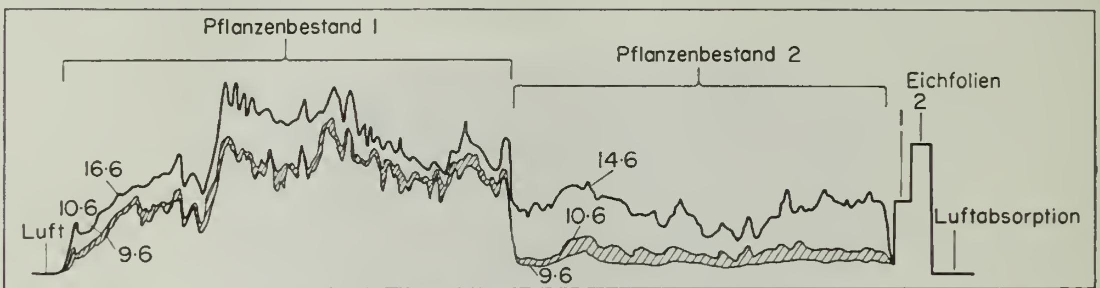


Abb. 3. Registrierung der Masse zweier Leguminosen — Pflanzenbestände am 9.6, 10.6. und 14.6. 1959

geeignet für solche Messungen sind z. B. Kopfsalat und Kopfkohl. Für diese Messungen wurden in Quedlinburg neue tragbare Impulsgeräte, teilweise auf Transistorbasis, entwickelt. Während als Strahlungsquellen für Pflanzenbestände nur die weitreichende γ-Strahlung langlebiger Strahlungsquellen, wie z. B. von ^{60}Co, ^{137}Cs und

Abb. 4. Aufsicht auf ein transportables Impulszählgerät

^{170}Tm benutzt werden kann, eignet sich für die Durchstrahlung von Einzelpflanzen teilweise auch relativ harte β-Strahlung, wie z. B. von ^{90}Sr besonders gut.

Auf der Abb. 4 ist ein transportables Zählgerät mit einer Dekadenzählröhrenendstufe und drei mechanischen Zähleinheiten zu erkennen. Die Zeitnahme des Zählgerätes erfolgte elektronisch. An diesem Zähler wurden mit ^{90}Sr geladene Meßbüge angeschlossen, um z. B. die Dichte von Salatköpfen oder Kopfkohl zu bestimmen

Damit erweist sich die berührungslose Massenbestimmung von Pflanzenbeständen und Einzelpflanzen mit Hilfe von γ- und β-Strahlen radioaktiver Strahlungsquellen als ein neues Hilfsmittel der Phänometrie, das uns ermöglicht, in kurzen Zeiteinheiten Gewichtsbestimmung von Pflanzenbeständen und Einzelpflanzen zu messen und zu registrieren, ohne auf die völlig unzureichenden Stichprobenmethoden, die sonst zur Gewichtsbestimmung benutzt werden, angewiesen zu sein. Die phänometrischen Unterlagen erlauben uns aber, mit Hilfe der parallel gemessenen mikrometeorologischen Werte einen weitgehenden Einblick in das bioklimatische Verhalten der Pflanzen zu gewinnen.

LITERATUR

1. Kaempfert W., Zur Phänometrie. *Wetter und Klima* **1,** 40—52 (1949).
2. Morgen A., Phänometrie des Pflanzenwachstums lebender Pflanzenblätter. *Wetter und Klima* **2,** 1/2 (1949).
3. Unger K., Zum Einfluß der klimatischen Standortfaktoren auf die Blühzeit und den Blühverlauf einiger Gemüseerbsensorten. *Z. Acker- u. Pflanzenb.* **102,** 69—80 (1956).
4. Unger K., Zur Anwendung der Durchstrahlungsmethode für phänometrische Messungen mit Hilfe von radioaktiven Strahlungsquellen. *Z. Angew. Meteorol.* **3,** 115—18 (1958).
5. Unger K., Die Anwendung radioaktiver Strahlungsquellen zur berührungslosen Massenbestimmung von Pflanzenbeständen und Einzelpflanzen am natürlichen Standort. *Züchter* **29,** 7, 289—93 (1959).

REPORTS OF CHAIRMEN OF SPECIALIZED WORKING GROUPS

AGROMETEOROLOGY

BERICHT ÜBER DIE VERHANDLUNGEN DER SPEZIELLEN ARBEITSGRUPPE AGRARMETEOROLOGIE

Chairman: Prof. A. MÄDE

An den Beratungen der speziellen Arbeitsgruppe „Agrarmeteorologie" nahmen etwa 40 Interessenten teil. Die Diskussionen wurden an den Nachmittagen des 6., 7. und 9. September durchgeführt.

In 10 einleitenden Berichten wurden einige der wesentlichen Probleme der agrarmeteorologischen Arbeit angeschnitten. Zuerst wurden die Beziehungen zwischen dem Witterungsablauf auf der einen Seite und dem Wachstum der Pflanzen und ihrer Ertragsleistung auf der anderen Seite diskutiert. Herr Robertson, Ottawa, Canada, stützte sich bei seinen Untersuchungen auf ein weiträumiges Beobachtungsnetz und konnte aus den unterschiedlichen klimatischen Bedingungen seiner Versuchsstationen den Einfluß der Temperatur und der Tageslänge auf den Ertrag darstellen. Herr Unger, Quedlinburg, Deutschland (D. D. R.), nutzte die Absorption von β- und γ- Strahlen zur fortlaufenden Bestimmung des Massenzuwachses aus und gewann auf diesem Wege phänometrisches Beobachtungsmaterial für die Beurteilung der Reaktion der Pflanzen auf die meteorologischen Bedingungen. Ergänzend dazu besprach Herr Pascale, Buenos Aires, Argentinien, Methoden der phänologischen Beobachtungen an landwirtschaftlichen Kulturpflanzen.

In einem zweiten Bericht wies Herr Pascale auf die Möglichkeiten zur Ausgliederung agrarklimatisch einheitlicher Gebiete in Südamerika hin. Für das Gebiet von Schottland gab Herr Fairbairn, Edinburgh, Gr. Britain, einen Überblick über die Einteilung Schottlands in Klimagebiete. Er benutzt dazu die Länge der Vegetationsperiode und die Höhe des Niederschlags während dieser Periode. Herr Koch, Jena, Deutschland (D. D. R.), demonstrierte den Einfluß des Windes auf das Wachstum der Waldbäume im Gebirge.

Die Beiträge der Herren Durand, Versailles, Frankreich, und Primault, Zürich, Schweiz, beschäftigten sich mit dem Frostproblem. Herr Durand besprach die Anwendung der im Laboratorium gewonnenen Erkenntnisse auf die Freilandbedingungen und Herr Primault gab einen Überlick über die umfangreichen Schweizer Versuche zur Frostschadenverhütung. An Hand von Untersuchungen über das Mikro- und Bioklima wies Herr Intribus, Zvolen, Tschechoslowakei, auf die Bedeutung der mikroklimatischen Forschung für die Wiederaufforstung stark zerstörter Gebiete hin.

Der letzte Bericht beschäftigte sich mit dem Problem der Waldbrandprognose, das in einer Arbeitsgruppe der Kommission für landwirtschaftliche Meteorologie der WMO untersucht wurde. Frau Pièslak, Warschau, Polen, berichtete über in verschiedenen europäischen Ländern auf diesem Gebiete vorliegenden Erfahrungen.

In der sehr regen Diskussion wurden die angeschnittenen Probleme durch die Mitteilung weiterer Erfahrungen ergänzt. Die Beratungen in der Arbeitsgruppe Agrarmeteorologie hatten das folgende Ergebnis.

(1) Die Kenntnisse über den Zusammenhang zwischen Witterung, Pflanzenwachstum und -ertrag sollten wesentlich erweitert werden. Es wird darauf ankommen, durch geeignete Untersuchungsmethoden zuverlässige biologische Beobachtungsreihen zu gewinnen, mit deren Hilfe der Einfluß von Wetter und Witterung auf die Entwicklung der Pflanzen quantitativ abgeschätzt werden kann. Es wird nicht immer nötig sein, moderne, umständlichere Verfahren, wie etwa den Einsatz von Strahlungsquellen zu verwenden, da auch die geschickte Anwendung einfacherer Methoden zu wertvollen Untersuchungsergebnissen führt.

(2) Die Ordnung des Klimamaterials der Archive der meteorologischen Netze wird durch die Erweiterung unserer Kenntnisse über die quantitativen Zusammenhänge zwischen Witterung und Ertrag wesentlich erleichtert. Diese quantitativen Zusammenhänge zwischen Witterung und Ertrag werden die Festlegung biologisch begründeter meteorologischer Grenzwerte zur Ausgliederung einheitlicher Gebiete für agrar- und forstwirtschaftliche Zwecke gestalten.

(3) Dem Problem der Frostschadenverhütung im Freiland sollte weiterhin besondere Beachtung geschenkt werden. Neben Untersuchungen an Pflanzen in der Nähe des Gefrierpunktes werden sorgfältige Analysen der meteorologischen Gegebenheiten in den gegen Frostschäden zu schützenden Gebieten die Auswahl der Frostbekämpfungsmethoden erleichtern.

(4) Die Nutzung mikro- und bioklimatischer Erkenntnisse können Wiederaufforstungsmaßnahmen wesentlich fördern und schließlich kann die Verbesserung der Waldbrandprognose in den europäischen Ländern zu einer wesentlichen Verminderung der Waldbrandschäden führen.

Die Diskussion ergab, daß trotz der ständigen Ausweitung unserer Kenntnisse über die Zusammenhänge zwischen meteorologischen und biologischen Komponenten die Agrar- und Forstmeteorologen zur Zeit nur einen Teil der ihnen gestellten praktischen Aufgaben lösen können. Eine wesentliche Verbesserung ist nur zu erwarten, wenn die Grundlagenforschung auf dem Grenzgebiet zwischen Meteorologie und Biologie mit größter Energie betrieben wird.

VORBEREITETE DISKUSSIONSBEITRÄGE

1. Robertson, Crop-weather (temperature and daylength) relationships.
2. Unger, Phänometrische Messungen mit Hilfe von Gamma- und Betastrahlen.
3. Pascale, Phenological observations on agricultural crops.
4. Pascale, World agroclimatic types of wheat crops.
5. Fairbairn, The growing season in relation to silviculture in Scotland.

6. Koch, Der Wind als wichtiger Faktor für das Wachstum von Waldbäumen im Gebirge.
7. Durand, Determination des seuils de résistance aux Gelées. Transposition aux conditions naturelles des résultats obtenues au laboratoire.
8. Primault, Rapports des nouveaux essais de lutte contre le gel en Suisse et de quelques revers subris.
9. Intribus, Untersuchungen über das Mikro- und Bioklima der zerstörten Gebiete der Slovakei bei ihrer Wiederaufforstung.
10. Piéslak, Die Methoden der Prognose der Waldbrandgefahr, angewandt in den Ländern Europas.

BERICHT DER SPEZIELLEN ARBEITSGRUPPE ÜBER LUFTVERUNREINIGUNG UND AEROBIOLOGIE

Chairman: Dr. KARL BISA

Unter Mitarbeit zahlreicher Forscher aus den verschiedensten Ländern der Erde wurden Themen der Luftverunreinigung und der Aerobiologie diskutiert. Die dabei aufgezeigten Schwerpunkte dieser Forschungsrichtung wurden näher fixiert und als Beschlußfassung folgende Punkte für die weitere Forschungsarbeit besonders aufgezeigt.

Unter Aerobiologie verstehen wir die Lehre und Forschung, die sich mit den Auswirkungen der in der Atmosphäre vorkommenden Aerosole auf Menschen, Lebewesen und Pflanzen befaßt. Die Aerobiologie hat die Anreicherung der Atmosphäre mit Schwebstoffen und Gasen zu identifizieren und ihre Auswirkungen zu erkennen und möglicherweise vorzubeugen. Eine Kenntnis der regionalen Aerosolklimata und der Diffusionsvorgänge ist erforderlich. Sie kann durch fortlaufende Messungen an zahlreichen typischen Schwerpunkten hergestellt werden. Die Auswertung dieser Ergebnisse mit synoptischer Anlehnung an die Forschungsarbeit angrenzender Disziplinen, insbesondere der Mikromorphologie der Atmosphäre, ist für die Kenntnis einer dynamischen Aerosolkontamination erforderlich.

Es ist experimentell erwiesen, daß eine Reihe von organischen, anorganischen und gasförmigen Reizstoffen in Spurenkonzentration von 10^{-7} bis 10^{-5} g/cm^3 sich mit Aerosolen verschiedener chemischer Konzentrationen so vereinigen können, daß eine erhebliche synergistische Intensivierung auftritt. Eine vordringliche Aufgabe besteht daher in der Erkundung von Gesetzmäßigkeiten, unter welchen solche Gase und Schwebstoffe durch ihre Assoziation eine synergistische Aktivierung vom physikalischen Standpunkt aus hervorrufen, in biologischem Sinne aber die Schädlichkeit eines einzelnen beteiligten Reizstoffes erheblich anwachsen lassen. Diese dringlich zu betreibende Grundlagenforschung läßt aber erst einen Einblick in die kinetischen Eigenschaften von Aerosolpartikeln in den Atemwegen von Lebewesen zu. Damit sind aber erst die Aussagen für Aerosoltoleranzgrenzen in der Atmosphäre und deren Festlegung in verschiedenen Bereichen sinnvoll.

Es ergibt sich, daß der bisherige Schwerpunkt der technischen Staubbekämpfung notwendigerweise in aerosologischer und besonders medizin-hygienischer Richtung ergänzt werden muß. Die Beseitigung oder Minderung industrieller Schwebstoffe gleicht der Beseitigung flüssiger oder fester Abfallstoffe.

Für die systematische Untersuchung dieser Frage legt die Arbeitsgruppe dem Executive Board folgende Standardisierungsvorschläge zum Zweck der Vergleichbarkeit einzelner Untersuchungen vor:

(1) Für die Meßmethodik von Gasen, flüssigen und festen Bestandteilen in der Atmosphäre. Dies betrifft die physikalischen Meßmethoden und die chemischen Verfahren. Die Fehlerbereiche der Methoden und Verfahren und damit die Grenzen der Anwendbarkeit — sind eingehend darzustellen.

(2) Für mikromorphologische Untersuchungen an Aerosolen sind standardisierte Testaerosole zu erarbeiten, die den Fachleuten vor ihrer allgemeinen Anwendung zur Diskussion gestellt werden.

(3) Die Relation und Identifizierung eines Aerosolsystems gegenüber biologischen Auswirkungen bedürfen möglichst einfachherstellbarer und leicht reproduzierbarer simulierter biologischer Standards. Wir müssen hierbei mindestens eine nachhaltige Unterstützung aus den Reihen der Mitglieder erwarten.

(4) Die Arbeitsgruppe legt Wert auf die Feststellung, daß die bioklimatische Forschung, insbesondere des von ihr vertretenen Schwerpunktes, als Grundlagenforschung in einfachsten Systemen bearbeitet werden soll. Die Mitglieder sind sich darüber klar, daß eine Kenntnis aerobiologischer Forschung auf Reaktionen in Lebewesen nicht ohne weiteres zulässig ist, und zu deren Sicherung vertiefter Einblicke in die Abläufe des atmosphärischen Aerosols bedarf.

(5) Die Arbeitsgruppe ist weiterhin der Auffassung, daß diese vordringlich zu betreibende Grundlagenforschung nicht allein zur Klärung des regionalen Klimas beiträgt, sondern für die Sicherung der biologischen Existenz unumgänglich notwendig ist.

Diesen Beschluß der Arbeitsgruppe und damit auch die mir gestellte Aufgabe lege ich in die Hände des Vorstandes zurück.

REPORT OF SPECIALIZED WORKING GROUP ON THE EFFECTS OF WEATHER AND CLIMATE ON FARM ANIMALS

Chairman: Dr. J. D. FINDLAY

THE Working Group was attended by thirty workers, and the discussions began with some considerations relative to the effect of cold on cattle and sheep.

Dr. M. A. McDonald (Canada) outlined some of his work on the effects of cold water on rumen activity in sheep and the effect of the ingestion of cold water on the body temperature. Rectal temperature fell by 1—2°C and took 2 hr to return to normal, after ingestion of cold water, while rumen temperature could be decreased to as low as 28°C by ingestion of cold water, taking 3 hr to return to its normal temperature.

Dr. C. M. Williams (Canada) discussed the effects of low fluctuating temperatures on beef steers. Dairy cattle and swine are normally housed during the extreme winter temperatures of Canada, of as low as —45°C. Beef cattle and sheep have only crude shelters and windbreaks. It was observed that open-fronted shelters, which are in common use, may be detrimental to the rate of gain of beef steers. This may be because the moisture content of the area increases during the night when temperatures are falling and the collection of moisture on the hair could reduce the insulating capacity. The bedding area of the shelter was shown to have an effect on the growth rate. If steers have a manure-pack to lie on, their growth rate may be 20 per cent greater than for steers obliged to lie on the ground.

Steers under sub-zero temperatures do not fulfill Adolph's hypothesis of "1 gram of water intake per Calorie of gross energy", but reduce water intake below this figure. Presumably evaporative losses are minimal, so upsetting the ratio. Water intake is related to air temperature, and feed intake is related to the water intake on the subsequent day, presumably exhibiting a time-of-passage effect.

Those steers receiving a greater cold stress had a smaller cross-sectional area of *the m. longissimus dorsi*, suggesting a low percentage of lean tissue in the carcass. Blood area levels rose in the cold stressed animal, as did erythrocyte and haematocrit values, while eosinophil counts fell in response to a cold stress.

In comparing the Hereford steers with Aberdeen Angus, Charbray & Hereford and Charolaise & Hereford cross-breeds, it has been observed that there are degrees of winter hardiness. A characteristic associated with winter hardiness, and perhaps the most critical, is the type of hair coat developed by the steer. Dr. Williams indicated that he had a psychrometric chamber large enough for one cow, and capable of maintaining temperatures as low as —3°C.

Dr. Whittow (U. K.) asked what the skin temperatures of the extremities were in Dr. McDonald's experiments, and Dr. McDonald replied that skin temperature of sheep drops a degree or two after the ingestion of cold water.

Dr. Bianca (U. K.) asked if the animals faced the wind or turned their back to it, and Dr. McDonald replied that this varied with species, and seemed to depend on the type of hair coat.

Sir John Hammond (U. K.) asked what was the rainfall in the area, as they had found within the U. K., that with iron roofs, condensation caused a reduction in fattening, due to drops of water on the skin. He found that the Hereford with a thick skin withstands such conditions better than, e.g., the Friesian which has a thin skin. Dr. Williams replied that only a small amount of rain and snow fell during his experiments.

Dr. Stegenga (Netherlands) remarked on the influence of the use of a blanket on gain of weight of cattle in autumn. In experiments in the Netherlands (Dr. Oosterlee) a non-waterproof blanket appeared to decrease the gain of weight of cows, while a waterproof blanket appeared to have the opposite effect.

Dr. R. E. McDowell (U. S. A.) maintained that in Southern U. S., in shelter studies with lactating dairy cattle, it was shown that when good quality feed is provided, shelter did not have a significant effect on summer or winter production, as compared with no shelter. A wind break reduced the variation in milk production and maintained a higher degree of feed efficiency than that obtained in an unprotected group of cattle.

Dr. J. C. D. Hutchinson (Australia), said that he had recently been measuring the thermal insulation of short lengths of fleece in a wind. Quite a moderate wind (11 miles/hr) is enough to reduce the insulation. The effect of the wind appeared to depend upon the angle of the fleece, the effect being small if the wind is parallel to the fleece surface. At narrow angles on the lee side, the insulation was as low as it was on the weather side. He also remarked that his colleague Dr. Tomaszewska has shown that extreme cold will increase skin thickness. A change begins within a few hours of exposure.

Dr. F. N. Marzulli (U. S. A.) remarked that in the Army Chemical Centre Laboratories in the U. S. A., they had observed that certain toxic substances penetrated the skin of goats more easily in summer than winter, under identical conditions of temperature and humidity.

Preliminary studies suggest that there may be an enlargement of the sebaceous glands during the summer, which may account for the results observed, if these glands permitted means of entry of such substances.

Dr. Findlay (U. K.) remarked that the only work he knew relative to seasonal changes in structures of the skin was some old work of Dempsey and Astwood.

Dr. Carter (U. K.) maintained that in relation to histological changes in the skin, two dominant factors must be considered: (a) the species, and (b) the nutritional status of the animals concerned, before the possible influence of non-biotic or physical variables on skin structures or activity could be assessed.

Seasonal histological changes in the skin are most likely first to reflect changes in the nutritional status of the animal, and it is most difficult to associate this with the effects of physical factors, such as temperature and light. Seasonal changes, in particular, histological details, such as hair growth, sebaceous and sweat glands may be observed in cattle. On the other hand, in some kinds of sheep, if the nutritional level is well controlled, it is difficult to analyse seasonal changes of any kind.

The group then considered some aspects of surface evaporation in cattle and other farm animals.

Dr. McDowell (U. S. A.) described his methods of measuring evaporative loss from the skin of cattle using sweat cup techniques with observation of the transferred moisture. He discussed some recent work on the use of the iontophoresis of formaldehyde into the skin to destroy the activity of the sweat glands. A 10 per cent solution of formaldehyde was used. He showed that the sweat glands were of some importance in heat loss in the cow. The distribution of sweat had been investigated by him and he had shown that the legs gave a small evaporative loss, dewlap intermediate, neck and body the highest. There was a large difference between individuals, but not between breeds, and one effect may mask the other. A highly technical discussion on sweat measuring techniques followed between Dr. McDowell and Mr. McLean (U. K.).

Dr. Primault (Switzerland) suggested that the variations found between animals of the same group might be related to weather fronts, in view of the permeability of the skin to certain chemicals, which has a relationship to cold and warm fronts, and it is possible that evaporation from the surface would be equally affected by such fronts, as may be indicated by the work of Lotmar.

Dr. McDowell (U. S. A.) agreed that the evaporative loss appeared to depend on the previous climatic treatment of the animal, but had no connection with the effect of cold and warm fronts.

Dr. Luck (U. K.) asked how many sweat glands per mm^2 were present in cattle skin, and Dr. Carter suggested there were about ten sweat glands per mm^2.

Mr. McLean (U. K.) spoke of his work on evaporative loss from cow skin and demonstrated the great importance of cutaneous evaporative loss in the heat regulation of the animal. Dr. McDowell commented that the rate of flow through the sweat cup may have to be modified, according to the animal and the site of the cup. He tended to use a high rate of flow, in order to make sure that all the moisture evaporated by the skin was picked up by the air stream.

Dr. Bligh (U. K.) discussed some work he had done recently on the sheep, in which very large rises of up to 50°C were obtained in the fleece, due to exothermic condensation of moisture from the sweat glands. He also showed that an injection of adrenaline appeared to cause the sweat glands of the sheep to function in a truly apocrine fashion, and when adrenaline was injected in very minute concentrations, similar heating effects were observed in the sheep, only explicable by the reaction of the sweat glands.

Dr. Carter (U. K.) stated that attention should be directed to variations in sweat gland number per unit area, in assessing comparative rates of moisture output per unit area of skin. In cattle this might range from levels of fifty per mm^2 at birth to about two per mm^2 at maturity. These general values should be recalled in comparing skin moisture output in cattle versus sheep.

Dr. Pullar (U. K.) demonstrated some recorder tracings taken from the gradient layer calorimeter, on the effect of shearing on sheep on the total heat loss at 10°C. Before shearing, the record of total heat loss has a "square wave" form. After shearing the record is very much smoother, the total heat loss going up by about 15 per cent. The evaporative loss falls by about 30 per cent, the increase in heat loss being due to an increase in heat loss by the "non-evaporative" routes. It is believed that the disappearance of the "square waves" may be due to the animal being in a vasodilated state.

Mr. McLean (U. K.) described some work in which he had shown that there appeared to be a step function in sweating from cows, when measured by capsule techniques which had very fast measuring capabilities, and that this might be related to the effects described by Dr. Pullar.

Dr. Hutchinson (Australia) said that the work described on the fleece of sheep reminded him of experiments which he had made with Dr. Deighton on the heat dissipation of cockerels in a direct calorimeter, when the birds made slight movements, such as shuffling on a perch, or stretching the neck to crow, there was increased heat dissipation. Similar results had been obtained by Hammel on dogs. Dr. Hutchinson had recently been measuring the effect of disturbance of the shorn fleece of sheep on its thermal insulation. There was no effect either in still air or wind, but with a longer fleece the effect began to show itself. None of these experiments involved hygroscopic effects.

Dr. Buettner (U. S. A.) reminded the group that measurement of the water loss of a body or a body area actually means a measurement of the difference of sweat output and water regain through the skin. The latter can reach 4 g/hr for one human foot.

Dr. J. S. Weiner (U. K.) asked what explanation Dr. McDowell had for the rather striking fall in surface water loss at high temperatures, and asked if this could be some form of fatigue. He asked whether it was a consistent finding.

Dr. Yeck (U. S. A.) described very broadly some of the work on evaporative loss in cattle which he had done, and stated that the purpose of most of this work was the establishment of optimum conditions of humidity and temperature for milk production. The meeting then discussed thermoregulation in the ox.

Dr. Ingram (U. K.) described experiments which he and Dr. Whittow had been performing using implanted hypothalamic heaters in the brain of the ox. He showed some recent findings which suggested that central control of thermal polypnea existed in the ox from temperatures in the region of 40—41°C, but that below these hypothalamic temperatures peripheral receptors appeared to play a predominant role.

Dr. Bligh (U. K.) described some recent work in which he had cooled the central temperature of the animal by the intravenous injection of cold saline. Mr. McLean remarked on some recent work he and his colleagues Drs. Ingram and Whittow had done showing that increased evaporative loss in the ox could be induced by hypothalamic heating and it was suggested that sweating also had a direct central control.

Dr. Hutchinson (Australia) pointed out that his colleague Dr. Waites found that heating the scrotum of the ram with hot air when the animal was in an environment of 15°C caused a sudden increase in evaporation of moisture from the scrotum, and this simultaneously caused panting of the animal. This resulted in a considerable fall in rectal temperature, which in rams is very close to the aortic temperature. This appeared to lend support to the response of the peripheral receptors of panting in the sheep, and was being further investigated by Dr. Waites, using preparations in which brain temperature can be simultaneously measured. The meeting then concluded.

A further meeting was held on the following afternoon, and at this further meeting some aspects of shelter on production in cattle, together with questions relative to the importance of the dewlap and the increased surface area to body weight ratio in exotic types of cattle in maintaining a high heat tolerance were discussed. The details of this meeting are not reported and none of the remarks of the speakers in the discussion were given to the Chairman for reproduction in the Report.

PROPOSED TERMS OF REFERENCE OF THE STANDING TECHNICAL COMMITTEE ON ENGINEERING BIOCLIMATOLOGY

Chairman: Prof. J. K. PAGE

At the London Congress of the International Society of Bioclimatology and Biometeorology held in September of 1960, the Executive Board of the Society agreed in principal to the formation of a permanent standing committee on engineering bioclimatology. The Working Group on urban bioclimatology, being the only group wholly concerned with engineering bioclimatology, agreed that their activities could be usefully absorbed into a wider group dealing with the environment in all engineered spaces like houses, ships, controlled environment rooms, motor transport, etc. In this wide field of endeavour, many of the biophysical problems are of the same order and the exchange of ideas on engineering aspects of biometeorology and bioclimatology should help advance the science of environmental bioengineering in all these fields. As Chairman of the Working Group on urban bioclimatology, I have taken the initiative in drawing up the attached proposed terms of reference for comment by members of the Executive Board and by other members of the society specifically interested in engineering biometeorology. The following persons have accepted on invitation to become members of the provisional standing committee on engineering bioclimatology: Professor Dingle, United States, Dr. R. G. Yeck, United States, and Professor Robinson, Israel. They will share with me the responsibility for assisting in the development of the work of the new standing technical committee until such time as a proper permanent comittee can be elected. The provisional committee would particularly welcome offers of assistance from other members of the I. S. B. B. with specific interests in this sphere of activity.

THE TERMS OF REFERENCE FOR THE STANDING TECHNICAL COMMITTEE ON ENGINEERING BIOCLIMATOLOGY & BIOMETEOROLOGY, PROPOSED ON 10 SEPTEMBER 1960, ARE AS FOLLOWS:

(1) The general objective of the Standing Technical Committee on engineering bioclimatology and biometeorology is the advancement of all aspects of engineering science which are primarily concerned with the biophysical environments in and around engineered objects. Working within the framework provided by I. S. B. B, the Standing Technical Committee on engineering

bioclimatology would deal not only with the environments in and around engineered objects but also with their conscious modification by suitable biological techniques. At a later step, the scope of the Committee's interests may be widened to cover engineering ecology. In accordance with the general policy of I. S. B. B, only engineered objects on the surface of the earth will be considered.

(2) The Committee will pursue these objectives by organising special subsessional meetings at future Congresses, and by encouraging the publication of suitable articles on engineering bioclimatology in the *Journal* of I. S. B. B. It will also suggest topics it considers suitable for discussion in the general sessions of future conferences for consideration by the Executive Committee of I. S. B. B. for possible inclusion in the programmes. (The provisional Committee took note of the absence of any papers on engineering bioclimatology and biometeorology in the main sessions of the 1960 Conference.)

(3) Enlarging on the above general objectives, the following specific tasks, possibly among others, would appear to confront the Committee.

(a) Liaison with the physiologists on the problem of transforming the basic results of physiological research into reasonably straight forward engineering design recommendations.

(b) Liaison with meteorologists and climatologists on the problems involved in the development of the science of engineering meteorology, both from the point of view of improving techniques of processing conventional meteorological data for bioengineering use, and also from the point of view of improving techniques of measurement of the physical characteristics of engineered environments. Special emphasis on microclimatological techniques is likely.

(c) Liaison with biological workers on the possibilities of improving the local climates surrounding engineered objects by biological, and as opposed directly physical techniques, e.g. the use of trees to shelter farmsteads, or to modify temperatures.

(d) Advising research workers in more purely biological fields about the types of environments likely to be encountered in various types of engineered spaces and suitable techniques of measurement for assessing the microclimates in such engineered spaces.

(e) Liaison with the Committee on solar radiation on the application of radiation data to bioengineering design problems.

(f) Consideration of the design problems encountered in constructing controlled environment rooms for different biological research purposes.

(4) Taking note of the resolution of the Davos meeting of the International Study Group on building and urban climatology to form a permanent Working Group with a Secretariate provided by C. I. B. (Conseil International du Batiment pour la Recherche, l'Etude et la Documentation) which wishes to form a liaison with I. S. B. B and the subsequent meeting of this working group in London in September 1960, the Technical Standing Committee

would have the responsibility for organizing the co-operation with the above group and for appointing any delegates to represent I.S.B. B on the above Working Group so as to assist in the liaison between the two international Groups.

IMPORTANCE OF PHYSICAL ENVIRONMENT IN CONDITIONING THE ORGANISM

Chairman: Prof. FRED. SARGENT, II

If serial measurements are made on a single living organism, no matter whether the determinations relate to the chemical properties of the blood, functions of important organs and systems, or to overt behavior, the values obtained vary, i.e. the measurements are not identical from one time to the next. The variability derives, fundamentally, from two sources: errors made in the measurements themselves and real changes in the organism which are sufficiently great to be detected in spite of instrumental or observational errors. The variability attributable to real changes in the organism might be thought of as *organismic variability*.

Now the statement that the organism exhibits temporal variability is certainly nothing new to a biologist. What is not so obvious to him are the complex causes of this variability. Perhaps they are spontaneous. Maybe they are "biological rhythms". On the other hand, they may reflect meteorological changes, seasonal variations, or cosmic events. Variations in activity or in eating habits may provoke them. Thus, the nature of organismic variability should be of primary concern to the bioclimatologist, for a basic assumption which he makes is that the temporal variability detected in an organism is caused by weather changes. In other words, he postulates that changes in the atmospheric environment condition the organism. To be able to justify or validate this assumption the bioclimatologist must be able to control all other factors which might cause organismic variability. To achieve this refinement of experimental control, he must possess expertness on the nature of all variations which living organisms exhibit.

Few investigators have concerned themselves with a systematic study of the variability of organisms. Those who have contributed most notably to the subject are H. Monod, E. Schreider, and R. J. Williams. Three fundamental facts stand out from their investigations. (1) Organisms are biochemical, functional, and behavioral individuals. That is, inter-individual variability is greater than intra-individual or temporal variability. (2) There is a significant rank-order correlation between inter-individual variability and intra-individual variability. (3) Whether one studies the individual organism or a group of organisms, there is an hierarchy of variability. In a general way, for example, the variability of the chemical composition of the blood is less than the variability of the functioning of homeostatic mechanisms (Sargent, Johnson, Wogan, Pandazi, *Klin. Wochenschr.* 37, 889, 1959).

The aim of the discussions of the Working Group was to begin a detailed consideration of the general question organismic variability in so far as it related to mesological theory (A. H. Koller, *The Theory of Environment*, 1918). Various aspects of this complex problem were reviewed by K. A. Provens, E. Wedler, J. P. Nicolas, and J. L. H. Sibbons. Their remarks are abstracted in the following paragraphs.

K. A. Provens (Oxford) critically examined previous work on the effects of heat on sensorimotor performance. It has been found that a number of tasks might be performed without significant impairment by acclimatized personnel in environmental conditions where the temperature did not exceed 85—90°F (E. T.), although an upper thermal limit for environmental comfort of 68°F (E. T.) has been suggested. Very little evidence is available on the effects of heat on unacclimatized subjects or on the performance of mental tasks or tasks demanding motor skill as distinct from physical effort. Other inadequacies and omissions of published studies were discussed and aspects of research urgently needing attention were emphasized.

E. Wedler (Berlin) emphasized the need for studies which segregated the effects of weather factors and non-meteorological factors of the environment which might affect reaction processes in the organism. Studies along such lines might provide a basis for estimating the relative importance of the physical environment in the conditioning of the organism. Although many have demonstrated statistically significant correlations between biological processes and the weather, the relative importance of the weather in the spectrum of mesological influences could not be determined from data now available.

J. P. Nicolas (Dakar) said that geographers usually consider climatology as an approach to the knowledge of a natural region; quite a few of them, however, focus attention on only the climatologic fact. When describing a tropical country one is obliged to look with much closer attention at the equilibrium which arises between atmosphere and living organisms, especially if one wants to achieve more than mere descriptions. To understand the environment, when geographical facts are unfolding, requires more than a simple analysis of the different factors representing the environment. It requires a synthetic view of the problem through an evolutionary process. At a long range changing climatic influences may be of great importance; but at a short range, cyclic evolution may explain many facts, provided that the environment be clearly defined.

A profound confusion exists in the notion of environmentalism not only in relation to studies of tropical zones but to geographical studies generally. The analysis of climate included in an ecological study searches for many environmental factors, independent of the living things studied. We know the efforts made by ecologists, but we want particularly to speak of biogeographers. Their way of thought is wrong. We suggest that there is no "climate" in the proper sense; there are only reactions of a physical state of atmosphere and a physiological state of living being. In other words, a system of energy balance takes place.

Now the living being has characteristics quite different according to its constitution, to its physiological functions, one of the most important being thermoregulation. The climatological analysis cannot be conducted the same way if the study bears upon a snail or a monkey. Even in the case of mammals it will be different for a man and a dog, in which there is no sweating. Therefore, the criteria of classifications, the cuts one has to make in the different series of basic elements in a bioclimatological investigation will have to be accorded to the particular subject. Furthermore, when one seeks a synthetic expression, being significant of the atmospheric conditions which are in balance with the biological equilibrium of the living group of animals or of plants, one has to employ a combination specifically fitted to the group.

Another cause of confusion is the difference in point of view of the workers who study the biological equilibrium in climatic changes. Those investigations are of paramount importance in our changing world where voyages are so fast, where peoples have to work in new environmental conditions with little time for acclimatization. They find a justification in mines, in submarine's microclimates, in jet pilot's physiology. But such investigations are not bioclimatology in the proper sense, they are studies of working environments. Usually investigators in those fields study extreme conditions, the stress. Nearer to the geographical preoccupations is the research done on deplaced people working in a petroleum field in the desert. But, if an annual cycle may be observed, if the environment is larger, we are usually concerned with quite particular psychological and sociological conditions of special significance, changing much the conclusions.

All these works are interesting, but the geographer has not to take cheese for chalk. The geographical expression of climatic influence either on animal or on man includes the time factor, a long duration of this influence covering several generations; a slow effect through years and centuries. We begin to be convinced of this in temperate zones, but not in tropical ones, because all the studies have been made by white men, for whom the climatic conditions approach, in many cases, the upper limits of tolerance. Now, the extreme conditions as we reproduce them in climatic chambers are, in fact, very rare in nature, and if they occur with a certain frequency in some places, no one can say if those conditions are really extreme for adaptated populations.

So, two main considerations have to accompany geographers in their bioclimatological investigations: First, climate has no significance in itself, but only in combination with a living being, whose physiological functions have to be well known. Secondly, duration of medium conditions are more important than extreme ones, all the more important as populations are adapted to those extreme conditions, and physiological investigations are not yet sufficiently advanced to be certain about racial differentiation.

At last geographers have to take in account the sociological and psychological factors changing the plain conditions dictated by the atmospheric complex. A typical effect of those factors is the spectacular changing of way of living of white people in tropics with housing amelioration and climatization.

All the experience acquired in the tropics lead me to express my wish that more observations would be made on the environmental complex, and that through a proper knowledge of the different factors challenging a biological equilibrium, climate be considered with more attention in respect of the living thing studied, for, as a general conclusion, this equilibrium is at last established between two energetical systems, atmosphere and life with all complications included in that word.

J. L. H. Sibbons (Sheffield) pointed out that many physiological indices and temperature scales were derived from indoor studies. They did not necessarily apply to outdoor meteorological situations. He discussed the problems of simulating indoors a realistic spectrum of radiation comparable to that experienced outdoors.

A. Stequet (Belgium) proposed that there should be a Joint Co-ordinating Committee on Antarctic physiological research comprised of representatives of all nations having an interest in Antarctica.

REPORT OF THE SPECIALIZED WORKING GROUP ON MICROCLIMATIC PROBLEMS IN BIOCLIMATOLOGY

Chairman: Dr. H. E. LANDSBERG

THE session of this Working Group took place on Thursday, 8 September 1960, in the afternoon. Dr. H. E. Landsberg (U. S. A.) acted as Chairman in the absence of Dr. C. H. Wyndham (South Africa) and Dr. E. T. Renbourn (U. K.) as Secretary for Mr. S. Minich (South Africa).

No special program had been planned in advance for the session. Rather a series of contributed papers submitted to the Congress were presented and discussed at this session.

At the outset the Chairman pointed out that there is no universally accepted definition for the scope of microclimatology. Although the term might imply, and has actually been used for, microscopic scales, in general it refers to the atmospheric environment near the ground. It involves the transformations of energy at or near the earth's surface. Hence radiation is one of the most important elements. The transfer of heat and momentum, of water vapor and suspensions, the differentiations caused by soil types, vegetation, and man-made stiuctures are all essential features of the microclimate, which is essentially governed by the rules of the aerodynamic boundary layer.

Reliable measurements are of great importance in this field. I. D. Wentzel of South Africa stressed this in the first paper, entitled "An instrument for the measurement of the humidity of air" which follows.

In the field of hygrometry the wet and dry bulb psychrometer is perhaps the instrument most commonly used as a standard of reference.

The evaluation of the vapor pressure of an air sample is based on the following equation:

$$e = e'_s - AP(t_{\mathrm{dry}} - t_{\mathrm{wet}})$$

where e = vapor pressure of air sample;
e'_s = saturation vapor pressure at the temperature of the wet bulb;
P = atmospheric pressure;
t_{dry} = dry bulb temperature;
t_{wet} = wet bulb temperature;
A = psychrometric constant.

Today the value of the constant as given in different publications varies between 3.27×10^{-4} and 3.88×10^{-4}.

The reason for this variation lies in the fact that any factor which causes the depression of the wet bulb temperature to be incomplete, has to be compensated for by the use of a higher psychrometric constant.

If, however, the true thermodynamic wet bulb temperature is known, the value of the psychrometric constant can be exactly calculated from basic physical principles. An instrument designed to fulfil this purpose is called the adiabatic saturator, and consists of a vacuum insulated glass tube, the inner walls of which have been silvered to reduce heat flow. As a further precaution the instrument is covered by a plastic insulating material, covered in aluminium foil.

A natural sponge, saturated with water is placed in the glass tube, called the mixing chamber. As the air is being drawn through the wet sponge, evaporation takes place and the air becomes saturated. The heat for evaporating the water is supplied by the air which cools down. As heat flow from outside is restricted, the process takes place adiabatically, and the temperature of the air at the back of the wet sponge is equal to the thermodynamic wet bulb.

When tested this instrument gave an accuracy of better than $\pm$ 0.1°F for dew point temperature. This is an absolute instrument and needs no calibration. The discussion brought out that while the instrument is fairly large in size, it has the advantage of accuracy. This is not the case for electrical hygrometers, which have unstable calibrations. Some dew cells have as low an accuracy as $\pm$ 4°F.

R. J. Bouchet (France) presented a paper on comparison of evaporation measured by a Piche evaporimeter in the shelter with the potential evapotranspiration (see abstract p. 6 of summaries of reports submitted to the Congress).

The discussion centered on the usefulness of various other methods for indicating evapotranspiration by evaporation measurements. For the Wild Scale seasonally variable coefficients appear and the usefulness of pan evaporation measurements for estimating evapotranspiration was doubted.

Professor W. Hesse (Germany) then stressed the need for a better methodology of microclimatic observations, especially where conditions within vegetation is being investigated. The need for comparative observations in the open and the availability of a climatic reference station was stressed (see abstract p. 7 of summaries of reports submitted to the Congress). Some important details are referred to in greater detail this author's paper, ,,Einfluss des Wärme- und Wasserhaushaltes auf das Pflanzenwachstum" *Ber. dtsch. Wetterd.* No. 51, 29—34 (1958).

Dr. H. B. Schultz (U. S. A.) in this paper showed the successes and limitations of wind machines for frost protection in Southern California (see abstract on p. 7 of summaries of reports submitted to the Congress). The limited applicability of the method was brought out in the discussion. Essential are macroclimatic conditions favorable to the formation of the strong inversions set forth in the paper. The final talk was given by Mr. G. W. Robertson (Canada), who presented a brief review of the microclimatic investigations underway in his country. The location of projects was pinpointed on a map. Among other things, the research directed toward the establishment of micro-environment of and around plant leaves is of great interest. The intimate relation to pest development was stressed. The interrelation between macro- and micro-climate is an important target of the investigations. The use of solar energy by the plant, too, is in the focus of attention.

In the ensuing general discussion a number of deficiencies in interdisciplinary communications were stressed. Principal among these is the need for interchange of information on microclimatic measuring techniques. Very important is the translation of meteorological measurements to meaningful quantities for plant, animal, and human physiology. Important lacunae of knowledge also exist in establishing the interplay of macro- and micro-climate. For example, how can microclimatic information be derived from the usual observations and how can short periods of microclimatic data be reduced to long series as available from climatic stations?

REPORT OF THE SPECIALIZED WORKING GROUP ON THERMOREGULATION

Chairman: Prof. H. HENSEL

LIST OF CONGRESS MEMBERS ATTENDING THE SPECIALIZED WORKING GROUP ON THERMOREGULATION

Dipl. Ing. F. W. Behmann
Dr. E. Betz
Dr. W. Bianca
Dr. J. Bligh
Prof. K. J. K. Buettner
Prof. R. A. McCance
Dr. H. B. Carter
Miss Dr. T. Chiemprasert
Dr. K. J. Collins
Dr. Th. R. A. Davis
Dr. M. A. McDonald
Dr. R. E. McDowell
Dr. F. L. Dunn
Prof. E. B. Edney
Dr. J. D. Findlay
Prof. F. E. J. Fry
Dr. E. M. Glaser
Dr. K. Golenhofen
Prof. J. Grayson
Dr. R. J. Hamburger
Dr. R. Hellon
Prof. H. Hensel
Dr. W. R. Henson
Prof. R. B. Hertzman
Dr. J. C. D. Hutchinson
Dr. D. L. Ingram
Capt. R. J. T. Joy
Dr. H. Jungmann
Dr. D. Mc. K. Kerslake
Prof. O. Ketusinh
Dr. A. Q. C. Klomp
Dr. Ch. S. Leithead
Prof. R. R. Lemaire
Dr. I. A. M. Lucas
Prof. C. P. Luck
M. J. R. McLean
Dr. W. Menger
Dr. L. E. Mount
Prof. D. Muecke
Dr. H. Pechert
Prof. J. P. Pichotka
Dr. E. T. Renbourn
Col. S. W. Ritchie
Prof. F. Sargent II
Dr. J. A. Sealander
Dr. J. Slomka
Prof. G. B. Spurr
Dr. M. Staquet
Prof. Th. Stegenga
Dr. S. W. Tromp
Dr. W. Undt
Dr. G. Voigt
Dipl. Ing. E. Wedler
Dr. W. H. Weihe
Prof. J. S. Weiner
Mr. J. D. Wentzel
Dr. H. G. Wenzel
Dr. G. C. Whittow
Prof. C. M. Williams
Dr. O. Wilson
Dr. R. G. Yeck

DISCUSSIONS

*I. Cold Acclimatization**

Comments on paper read by Dr. O. Wilson "Basal Metabolic Rate of 'Tropical' Man in a Polar Climate" (see p. 411).

M. A. MacDonald: Eskimos find that when living in unheated tents they are unable to maintain warmth on high protein diets composed of fish and caribou. They must resort to diets of a high fat content and its high caloric density. Even the high specific dynamic action of protein digestion is insufficient to achieve a feeling of body warmth.

A. B. Hertzman: Are the measurements of metabolic rate "spot checks"? Or do they cover a considerable period as during an entire night of sleep?

O. Wilson: The BMR measurements made in the Antarctic (1) were monthly "spot checks". They were made to determine whether or not there was a permanently increased level of BMR during the time in the Antarctic as a result of cold acclimatization. They were made in a neutral thermal environment (subjects comfortably covered with blankets). The resting metabolic rate determinations made on cold acclimatized Lapps during the Finmark study (2), on the other hand, covered a period of 8 or 9 hr. They were conducted during an entire night while the Lapps and unacclimatized control subjects slept or rested in the cold. O_2 and CO_2 determinations were made on 10-min samples collected every half or whole hour during this time.

REFERENCES

1. O. Wilson, Basal metabolic rate in the Antarctic. *Metabolism* **5**, 543 (1956).
2. K. L. Andersen, Y. Løyning, J. D. Nelms, O. Wilson, R. H. Fox and A. Bolstan, Metabolic and thermal response to a moderate cold exposure in nomadic Lapps. J. *Appl. Physiol.* **15**, 649 (1960).

E. T. Renbourn: Under what conditions did the subjects live in the Antartic? Did the indoor temperatures correspond to those in other latitudes?

O. Wilson: In contrast to the Americans and the Canadians in polar regions, who live in a subtropical indoor climate with about 25—30°C in the day-time (1) and around 24°C at night (2), the Europeans, especially the Scandinavians and the Britons (3, 4), definitely enjoy lower indoor temperatures. At our base, Maudheim, in the Antarctic the mean indoor temperature during the first year was 14.5°C

* The first paper presented during the Session on Thermoregulation was read by Th. R. A. Davis (See p. 206).

and during the second year was 13.5°C. Maximum day-time temperatures seldom exceeded 20°C, but night temperatures occasionally went below 0°C (5). Thus our indoor temperatures were constantly considerably lower than in corresponding American studies on BMR, but we probably wore more clothes indoors.

REFERENCES

1. A. C. Burton and O. G. Edholm, *Man in Cold Environment*. Edward Arnold, London (1955).
2. K. Rodahl, Nutritional requirements in cold climates. *J. Nutr.* **53**, 575 (1054).
3. J. M. Roberts, The Falkland Islands Dependencies Survey. *Brit. Med. J.* **2**, 863 (1949).
4. R. Goldsmith, Use of clothing records to demonstrate acclimatization to cold in man. *J. Appl. Physiol.* **15**, 776 (1960).
5. O. Wilson, Changes in body-weight of men in the Antarctic. *Brit. J. Nutr.* **14**, 391 (1960).

E. M. Glaser: It seems possible that apparent cold acclimatization may take place without much change of physiological function, merely because people become accustomed to the sensation of cold. This is probably a cerebral mechanism.

K. J. K. Buettner: I can confirm Glaser's statement of the physiological effect of cold extremities. Cold-adapted and unadapted people both had the same rather low peripheral skin temperature, especially of the feet during a winter field test. The unadapted person, however, could not sleep, while adapted people could.

Th. Stegenga: There are some indications at least in cattle, that day-length influences metabolic rate. Has Dr. Wilson payed attention to this possible influence of day-length differences in his examinations?

O. Wilson: Day-length varies considerably in the Antarctic. During the summer there is continuous daylight, which lasted for 2½ months in the region where we were stationed. During this period we were in the field travelling inland with sledges. Weather, radiation and show surface conditions often caused us to reverse day- and night-time. However, during this summer field period no BMR determinations were made. The BMR measurements were made during the autumn—winter—spring period. During the winter there was no daylight for 2½ months and much time was spent indoors. During this time working hours followed the normal day and night pattern. There was no correlation between BMR and sunshine hours during autumn and spring (1).

REFERENCE

O. Wilson, Basal metabolic rate in the Antarctic. *Metabolism* **5**, 543 (1956).

K. Golenhofen: Summary of the paper "Topographical Changes of Muscle Activity in Man during Cold Stress" (see p. 315): Scholander *et al.* (1) have shown that the cold acclimatization of white men is based mainly on changes in the regulation of heat production ("metabolic acclimatization") and not so much on "insulative acclimatization". (The special findings in Australian aborigines are not considered in this paper (2).)

During cold acclimatization the body learns to respond to cooling by increasing its heat production. Together with this thermoregulatory reaction there are also qualitative changes in the reactions. From animal experiments it is known that in

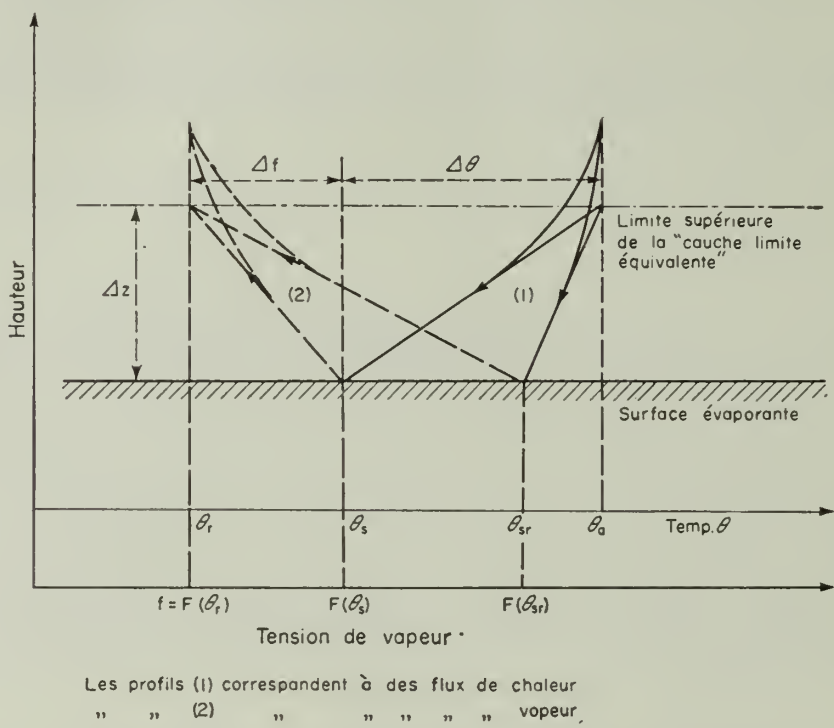


FIG. 1. Centralization of muscle activity in man during cooling. Action potentials of the muscle from the forearm *(Unterarm)*, calf *(Wade)* and thigh *(Oberschenkel)*. *Kühlung* (cooling): room temperature 10°C and cold wind, person uncovered and dressed only in bathing suit. *Kältezittern:* visible shivering (3)

metabolic acclimatization it is mainly the "non-shivering heat production" which is evident accompanied by a steady decrease in shivering.

In investigations with healthy subjects we found qualitative changes in the topography of shivering during prolonged cooling. Here the possible importance of such changes for cold acclimatization in man is discussed.

In the test (Fig. 1) the action potentials of the muscle were measured with needle electrodes in the forearm, calf and thigh (for details see (3, 4)). In the forearm the typical three-phase reaction described by Göpfert and Stufler (5) is to be seen: after an initial increase in activity there follows an adaptation (second phase). But this sequence is not uniform in all parts of the muscle system; rather there is a topographical differentiation. During the first phase, muscle activity is increased most in the forearm, less in the calf, and not at all in the thigh. This means that the distal parts of the muscle system are preferred in the initial phase.

At the beginning of the third phase there was a similar topography of muscle reaction. But with continued cooling, especially when visible shivering began, the thigh muscle was activated, accompanied by a decrease of activity in the more distal muscles. This "centralization" of muscle activity is more econimical for temperature regulation of the deeper parts of the body. It is possible that this form of reaction is preferred during cold acclimatization, but this question cannot be answered on the basis of present experimental findings.

REFERENCES

1. P. F. Scholander, H. T. Hammel, K. Lange Andersen and Y. Løyning, Metabolic acclimatization to cold in man. *J. Appl. Physiol.* **12,** 1—8 (1958).
2. P. F. Scholander, H. T. Hammel, J. S. Hart, D. H. LeMessurier and J. Steen, Cold adaptation in Australian aborigines. *J. Appl. Physiol.* **13,** 211—18 (1958).
3. K. Golenhofen, Zentralisation der Muskelaktivität bei Abkühlung des Menschen. *Pflüg. Arch. ges. Physiol.* **266,** 665—8 (1958).
4. K. Golenhofen, Die Reaktionen der menschlichen Muskulatur in Kälte und Affekt unter dem Gesichtspunkt der Thermoregulation. *Arch. phys. Ther.* **11,** 45—58 (1959).
5. H. Göpfert and R. Stufler, Die Vorstadien des Kältezitterns bei geringer Abkühlung des Menschen. *Pflüg. Arch. Ges. Physiol.* **256,** 161—180 (1952).

K. Golenhofen: I should like to ask Dr. Davis how he has measured shivering, and in which areas of the body.

Th. R. A. Davis: Measuring shivering by the EMG oscillograph is only marginally better than watching a man shivering. We have measured shivering by electronically integrating the muscle action potentials obtained from electrodes placed on the thighs and the upper arm. This is really a summation of all the electrical activity received in successive integrals of time and is the product of amplitude, duration and frequency of muscle action potentials. It is therefore only necessary to know the slope and the time in order to determine the total quantity of the electrical activity per unit of time at any period of the experiment.

J. C. D. Hutchinson: I should like to mention that my colleague Dr. Tomaszewska (1) had observed extinction of shivering in sheep exposed to cold (0—5°C) with intermittent wind (5—10 miles/hr) for 21 days. During the first week the animals shivered vigorously and constantly, when the wind was blowing. During the last two weeks the shivering was only intermittent.

REFERENCE

M. Tomaszewska, *Proc. Austr. Soc. Anim. Prod.* Vol. 3 (1960).

J. Grayson: May I mention some relevant data obtained on the highly anaesthetized rat by Dr. Mendel and me. In this animal the liver produces about 95 times as much heat as muscle per unit mass of tissue. Brain is an even more effective heat producer. I wonder, therefore, how much heat muscle at rest really contributes.

J. S. Weiner: How does Dr. Davis reconcile his views with the findings of Malcolm Brown? In their studies of cold acclimatization of Eskimos and Europeans, Brown and his colleagues found a consistent increase in hand blood flow but this would appear not to be the case in the experiments reported by Dr. Davis.

Th. R. A. Davis: Our experiments were carried out as far as we could judge with no change in physical fitness and always our subjects were measured under standardized conditions. Shivering, for instance, changed only in relation to the standard cold exposure chosen. There is no doubt that if our standard stress was changed to more severe conditions shivering would have been re-elicited. Our failure to discover changes in peripheral temperature may have been due to the lack of change in physical fitness. In this respect, Adams has demonstrated that peripheral and rectal temperature change on exposure to a standardized cold stress as a result of changing physical fitness in the absence of cold acclimatization. Also it should be realized that most of the experiments which have appeared to demonstrate changes in peripheral cooling were performed with much longer periods of cooling than in the studies reported here. Any changes in peripheral temperatures we observed were not undirectional and were quite inconsistent. Statistical analyses on the paired data basis produced no significance except in one or two areas which were not the same areas from one experiment to another.

E. M. Glaser: The suggestion that increased blood flow is observed during cold acclimatization may be only a sign of improved physical fitness, cannot apply to my experiments (1), in which people were subjected to cold conditions and took as much exercise as they had been used to before. These people showed an increase of blood flow after only 3 days at 4°C, and this was statistically significant, though I cannot tell how important this was physiologically. These experiments were some of the first to provide evidence of acclimatization to heat and to cold could both be present within a period of a few days.

K. J. K. Buettner: The individual tendency of subjects to have a different degree of homeothermy might be useful for investigation of the principles involved.

O. Wilson: I think that the changes in shivering found by Dr. Davis and Dr. Joy are very important findings and will be a great help in understanding the process of cold acclimatization. You have shown in day-time studies that shivering on exposure to a standard cold test decreases markedly as a result of acclimatization. In my opinion this is even more important during the night and therefore night time studies should be carried out. In the light of your findings I should like to make a comment on the role of metabolic rate and shivering in acclimatization to cold. The aim of adaptation is to produce a beneficial change in the response of the subject. The effect of acclimatization to cold therefore should be to allow: (a) a greater degree of working *effeciency in the day*, and (b) a greater amount of *rest in the night*.

(a) In the *day* an increased metabolic rate is needed to compensate for the increased heat loss and to keep warm for greater efficiency. This metabolic increase appears mostly as a result of muscular work and other activities. Vascular and other adaptive changes may help to increase the efficiency of manual work in cold. If the metabolic rate is not raised enough by work you may need an additional heat production by shivering. In acclimatization there will be a change in the rate and type of shivering.

(1) Shivering will be more easily abolished or suppressed for a certain period in the cold, and will allow critical work to be done more efficiently, although stored heat will be lost.

(2) It will be found that shivering is easier. Shivering will feel less unpleasant and is more easily resorted to when body heat is required.

(3) There will probably be a greater heat producing effect due to shivering. Shivering not only helps one to *keep warm* but also to *get warmer*. This may perhaps be a combined effect of shivering heat production and the "non-shivering" heat production (from the liver or the muscles).

(b) To be able to rest at *night* shivering has to be abolished or suppressed to a minimum, and a low resting metabolic rate will result. Judging from studies made in native people adapted to the cold (Australian aborigines and nomadic Lapps) (1—3) the requirements for rest and sleep in the cold are: (1) abolished gross shivering, which will result in (2) a loss of stored heat with a considerable body cooling and (3) a normal (or slightly raised) resting metabolism; (4) in order to meet a minor increase in cold stress without waking up some additional extra heat might be produced by an acclimatized individual during sleep. This extra heat is not provided by an increased BMR because acclimatization to cold does not raise BMR in man (4). Only indirectly may BMR be increased as an after-effect of hard work or a large meal. The source of the extra heat might be an increased muscular tension, or there might be a slight shivering compatible with sleep. There are indications that sleep is possible with concomitant shivering (5—7).

From what I have said it is evident that in studying acclimatization one of the most important things is to find out what keeps a person from sleeping in the cold. In order to be able to sleep in the cold one must be acclimatized. The three main factors are probably: (1) shivering, (2) cold extremities, (3) the rate of body cooling or the temperature gradient between the skin and the ambient surrounding. Gross shivering makes sleep impossible. In acclimatized persons shivering can be abolished. Cold extremities keep unadapted persons awake because of the uncomfortableness and probably because of a sense of danger. In acclimatizing this sense of danger will be lessened, and one can certainly get used to sleeping with cold feet. Judging from our study of cold acclimatized nomadic Lapps (3), I am inclined to think that the temperature gradient between the skin and the ambient surroundings (i.e. rate of heat loss from skin surface) is responsible for the onset of shivering and the impairment of sleep. The acclimatized person will tolerate a greater gradient than the unacclimatized and will be able to sleep with a greater heat loss and body cooling. But if the gradient increases above a person's degree of acclimatization he will wake up and start to shiver before his rectal and skin temperatures have been lowered appreciably. This was demonstrated by one of our Lapp subjects. He slept with a normal resting metabolic rate and with considerable body cooling and a lowered rectal temperature during a cold stress (room temperature 0°C), which kept the control subjects awake. The controls shivered and raised their metabolic rate and did not allow their rectal temperature to fall very much. When this Lapp subject was exposed to an increased cold stress (room temperature —7°C), which increased his skin—air temperature gradient, he woke up, shivered and could not sleep. He behaved like the controls did at 0°C, raising his resting metabolic rate and keeping his rectal temperature higher. This happened before his rectal and skin temperatures had begun to fall appreciately. Therefore it is not the level of the rectal temperature itself nor the rate of fall in the rectal temperature that induces shivering, nor is it the level of skin temperature or the gradient between the rectal and the skin. Neither does it seem to be the rate of skin cooling, as this does not seem to increase very much as the ambient temperature decreases below 5°C (7).

In view of this there are some important questions to be answered:

(1) What induces shivering?

(2) What keeps an acclimatized person from shivering during rest and sleep? Is it a conscious process that allowes him to go to sleep, or is it an unconscious process which abolishes shivering during sleep?

(3) How can one learn to abolish shivering?

(4) Can one learn to shiver during sleep?

REFERENCES

1. P. F. Scholander, H. T. Hammel, J. S. Hart, D. H. LeMessurier and J. Steen, Coldadaptation in Australian aborigines. *J. Appl. Physiol.* **13**, 211 (1958).
2. H. T. Hammel, R. W. Elsner, D. H. LeMessurier, H. T. Andersen and F. A. Milan, Thermal and metabolic responses of the Australian aborigine exposed to moderate cold in summer. *J. Appl. Physiol.* **14**, 605 (1959).
3. K. L. Andersen, Y. Løyning, J. D. Nelms, O. Wilson, R. H. Fox and A. Bolstad, Metabolic and thermal response to a moderate cold exposure in nomadic Lapps. *J. Appl. Physiol.* **15**, 649 (1960).
4. O. Wilson, Basal metabolic rate of "tropical" man in a polar climate. This volume, p. 411.
5. P. F. Scholander, H. T. Hammel, K. L. Andersen and Y. Løyning, Metabolic acclimatization to cold in man. *J. Appl. Physiol.* **12**, 1 (1958)
6. L. Irving, K. L. Andersen, A. Bolstad, R. Elsner, J. A. Hildes, Y. Løyning, J. D. Nelms, L. J. Peyton, R. D. Whaley, Metabolism and temperature of Arctic Indian men during a cold night. *J. Appl. Physiol.* **15**, 635 (1960).
7. K. L. Andersen, Tilpassing til kulde. *Nord. Med.* **64**, 994 (1960).

G. C. Whittow: I should like to ask Dr. Wilson and Dr. Davis whether there was cold vasodilatation in the extremities of their subjects.

O. M. Wilson: In our Finmark study of cold acclimatized Lapps the cold vasodilatation in the hand was also investigated (1). Three groups were studied: nomadic Lapps, North Norwegian fishermen used to working with bare hands in ice cold sea water, and unacclimatized controls. The cold vasodilatation was observed: (1) by measuring the blood flow of the hand with a plethysmograph at 2—5°C, and (2) by immersing the hand in a stirred ice and water mixture for half an hour and recording the changes in skin temperature with thermocouples.

In all three groups the hand in the ice water cooled to the same degree (approx. 1.5°C). When cold vasodilatation had set in and was fully established the hands of the cold acclimatized Lapps and fishermen were not warmer than the hands of the unacclimatized controls (approx. 7.5—8°C), nor was there a difference in blood flow or heat elimination. An important difference, however, was the earlier onset of the cold vasodilatation in the hands of the Lapps and fishermen. In these subjects the cold vasodilatation and also the increase in blood flow started after about 5 min, but in the controls it took place later. The mean duration of the initial vasoconstriction in the controls was about 9 min. The Lapps and fishermen also seemed to suffer less from pain and cold in the hands during the vasoconstriction.

REFERENCE

J. Krog, B. Folkow, R. H. Fox and K. L. Andersen, Hand circulation in the cold of Lapps and North Norwegian fishermen. *J. Appl. Physiol.* **15**, 654 (1960).

A. B. Hertzman: Surface, oral and rectal temperatures may be considered as numerical indices of the effects of acclimatization processes but not as controlling the latter. Possibly only hypothalamic temperature may be pertinent to the regulation mechanism (1).

REFERENCE

Benzinger, *Proc. Acad. Sci.* **45**, 645 (1959).

G. C. Whittow: In the standing, conscious animal (bull calf) shivering starts in the femoral region which is warmer than more peripheral leg muscles.

II. Heat Acclimatization

Comments on the paper read by Prof. R. Lemaire, "Influence de l'Humidité" de l'Ambiance sur la Température Cutanée Moyenne" (see p. 330.)

D. Mc. K. Kerslake: We have performed experiments similar to those of Prof. Lemaire but at ambient temperatures of 36 and 40°C. A similar fall in skin temperature was observed in most body regions, with rising humidity, but the sensation was definitely one of increasing warmth. The skin temperature reached a minimum at a humidity depending on the body region concerned, and above about 30 mm Hg absolute humidity, the temperature of all skin regions rose with further increase in humidity.

III. Thermoregulation Mechanisms

Introduction by Prof. Dr. H. Hensel "Electrophysiology of Thermoreceptors in the external skin".

Whereas well defined cold receptors connected with myelinated *A*-fibres could be found in the tongue of the cat, no specific cold or warm *A*-fibres were detected

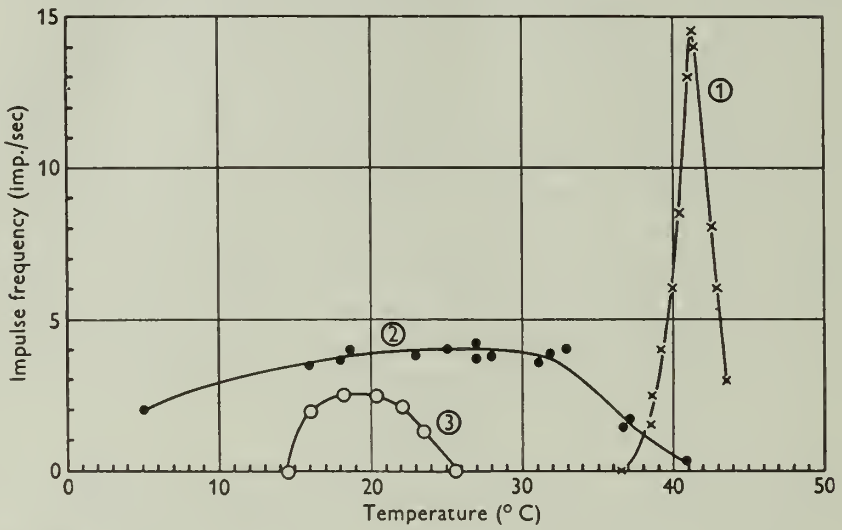


FIG. 1. Steady discharge frequency of three single *C*-fibres as a function of constant skin temperature. (1) Fibre excited by warming, fibre no. 8. (2) Fibre excited by cooling, fibre no. 1. (3) Fibre excited by cooling, fibre no. 3 (3)

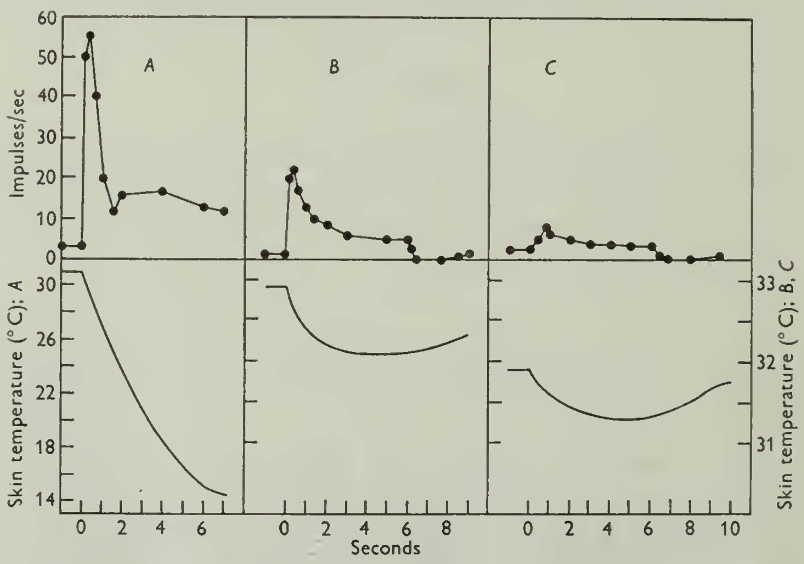


FIG. 2. Impulse frequency of a single cold fibre when cooling and warming the skin (fibre no. 3). The conduction velocity of the fibre was 1.5 m/sec. The left-hand temperature scale refers to *A*, and the right-hand scale to *B* and *C* (3)

in the cat's external skin. Besides specific mechanoreceptors, non-specific A fibres were found which were excited by physiological cooling as well as by mechanical stimulation in the physiological range (1). Since vasomotor reflexes can be elicited by cooling or warming the limb of the cat (2), the possibility of specific cold or warm

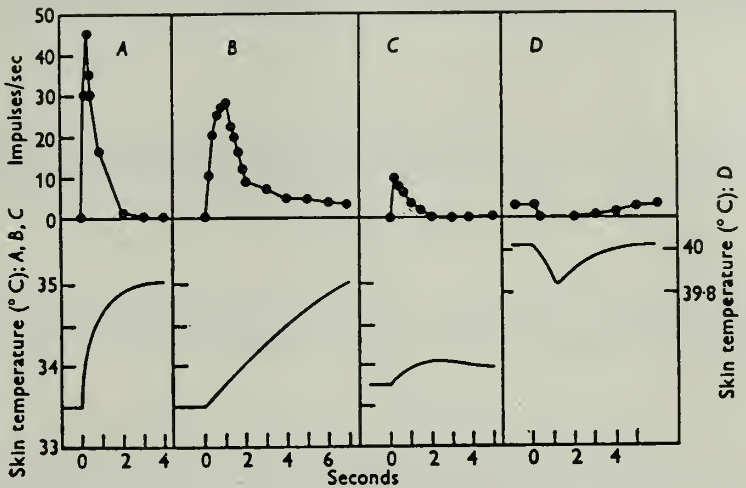


Fig. 3. Frequency of the discharge of impulses in a single C fibre (fibre No. 7), from a warm receptor, during cutaneous temperature changes. The left-hand scale applies to A, B and C and the right hand scale to D (3)

impulses in the group of non-myelinated C-fibres was investigated. Records from single C-fibres in the saphenous nerve revealed numerous specific cold and warm fibres (3). The C-cold receptors showed a steady discharge at constant skin temperatures (Fig. 1). The thresholds of these receptors for mechanical stimulation were high. The maximum of the steady discharge was between 16 and 27°C for the cold fibres and above 41°C for the warm fibres. Starting from indifferent temperatures of about 33°C cooling by 0.2°C or less was sufficient to excite the most sensitive cold fibres, whereas the warm fibres were excited by the same amount of warming. The dynamic sensitivity of some fibres was 30 imp/sec per °C, which is as great as both the sensitivity of the most sensitive cold fibres in the cat's tongue and the temperature sense in man. Rapid cooling caused an overshoot in frequency in the cold fibres (Fig. 2) whereas warming led to a transient inhibition (false start). The opposite behaviour was seen in the warm fibres (Fig. 3).

Recently we were able to record also from single cutaneous afferent fibres in conscious human subjects (4). Besides a great number of highly specific mechanoreceptors, we found several non-specific A-fibres excited by cooling as well as by pressure and one A-fibre which showed very much the same behaviour as that of the specific A-cold fibres in the cat (Fig. 4). At constant temperatures below 38°C, a constant discharge was seen, with a maximum of 12 imp/sec below 20°C. Sudden cooling led to a high increase in frequency with a dynamic sensitivity of 45 imp/sec per °C, whereas warming caused a transient inhibition of the steady discharge.

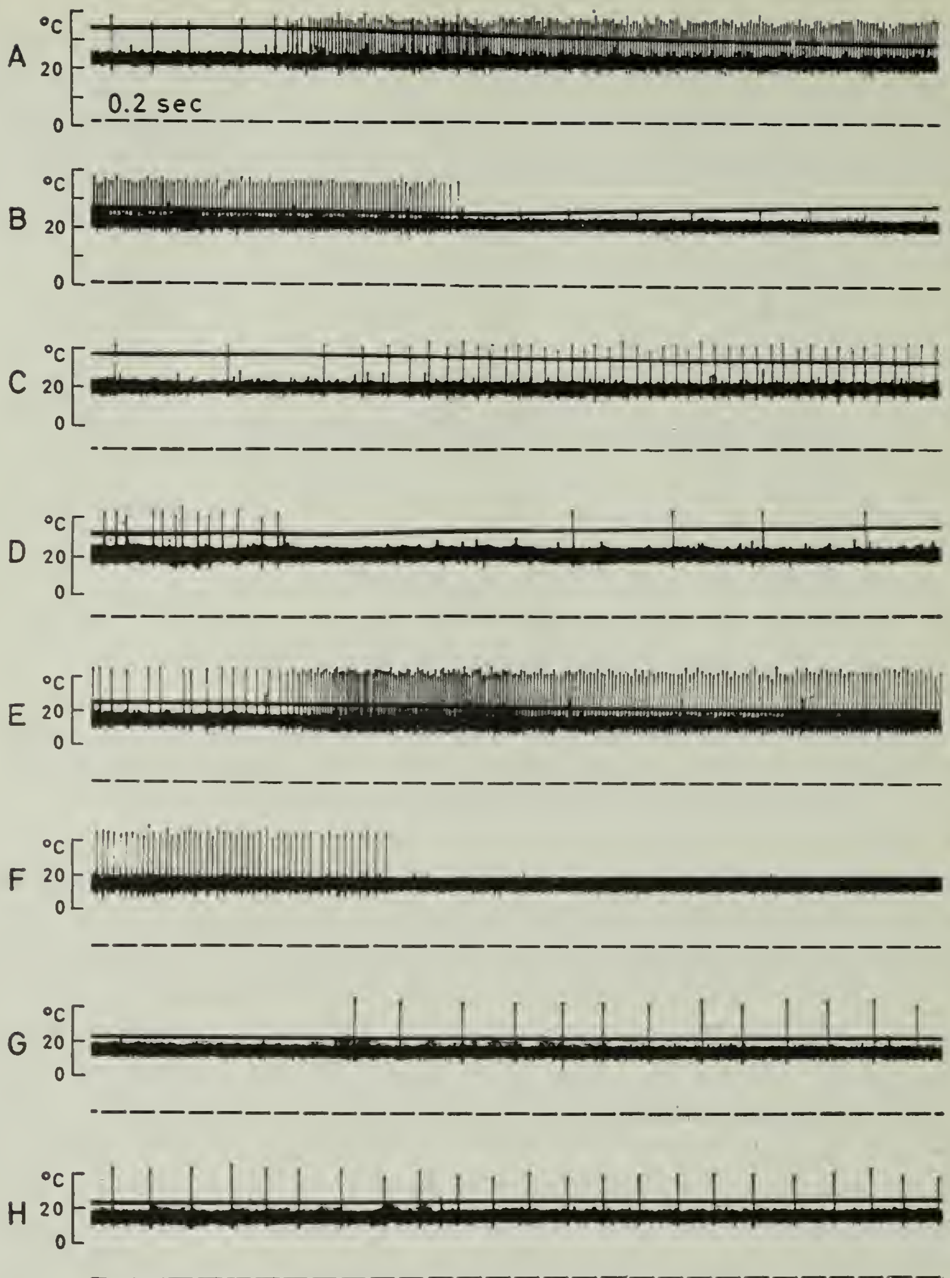


FIG. 4. Afferent impulses in single "cold" fibre (no. 18a) and temperature during cutaneous thermal stimulation. *A*, start of cooling from 34 to 26°C. *B*, start of rewarming. *C*, start of cooling from 38 to 35°C. *D*, start of rewarming. *E*, start of cooling from 24 to 16°C. *F*, start of rewarming, *G*, 13 sec after rewarming has started. *H*, continued from record *G* (4)

REFERENCES

1. I. WITT and H. HENSEL, Afferente Impulse an der Extremitätenhaut der Katze bei thermischer und mechanischer Reizung. *Pflüg. Arch. ges. Physiol.* **268**, 582—96 (1959).
2. H. W. KUNDT, K. BRÜCK and H. HENSEL, Hypothalamustemperatur und Hautdurchblutung der nichtnarkotisierten Katze. *Pflüg. Arch. ges. Physiol.* **264**, 97—106 (1957).

3. H. Hensel, A. Iggo and I. Witt, A quantitative study of sensitive cutaneous thermoreceptors with *C* afferent fibres. *J. Physiol.* **153,** 113—126 (1960).
4. H. Hensel and K. Boman, Afferent impulses in cutaneous sensory nerves in human subjects. *J. Neurophysiol.* **23,** 564—578 (1960).

R. R. Lemaire: In a constant temperature does it exist a constant frequency in response of thermal receptors?

H. Hensel: Yes. At constant temperatures, there is a steady discharge, the frequency of which is a function of temperature.

A. B. Hertzman: What is your impression of the relation of these receptors to temperature regulation in view of Benzinger's position denying their importance in the regulation of sweating.

H. Hensel: As yet we have no direct knowledge of the importance of these receptors for the sweating response. But there is clear experimental evidence that reflex vasodilatation occurs in the cat's ear during heating a limb, even if the recorded hypothalamic and rectal temperature is dropping at the same time. So the dilatation must be peripheral in origin (1).

REFERENCE

1. H. W. Kundt, K. Brück and H. Hensel, Hypothalamustemperatur und Hautdurchblutung der nichtnarkotisierten Katze. *Pflüg. Arch. ges. Physiol.* **264,** 97—106 (1954).

J. S. Weiner: That *C*-fibres may be concerned in temperature regulation as well as in thermal sensory reception is suggested by the neural organization of axon reflex sweating. We have found that the afferent pathway for axon-reflex sweating behaves as receptors do in general (excitation by nicotine, inhibition to hexamethonium and curarine). The nerve fibres concerned in axon-reflex sweating are unmyelinated, probably *C*-fibres.

D. Mc. K. Kerslake: Could the rate of discharge of the receptors be related to receptor temperature and rate of change of temperature without recourse to further derivatives or functions of time?

H. Hensel: Yes. The behaviour of the impulse frequency can be described by temperature and its first derivatives of time.

Comments by E. Betz on "Heat Production during Local Cooling of the Hypothalamus in Unanaesthetized Cats".

Krüger *et al.* (1) have shown that local cooling the anterior hypothalamus caused constriction of the ear vessels and a slight change in rectal temperature. Continuing these investigations, we analysed the variations of heat production during hypothalamic cooling (2). The nnanaesthetized cat was enclosed in a gas-tight container of plexiglass with double walls, through which water of various temperatures could be circulated. The interior was ventilated by 6 l./min of fresh, dried air. The air

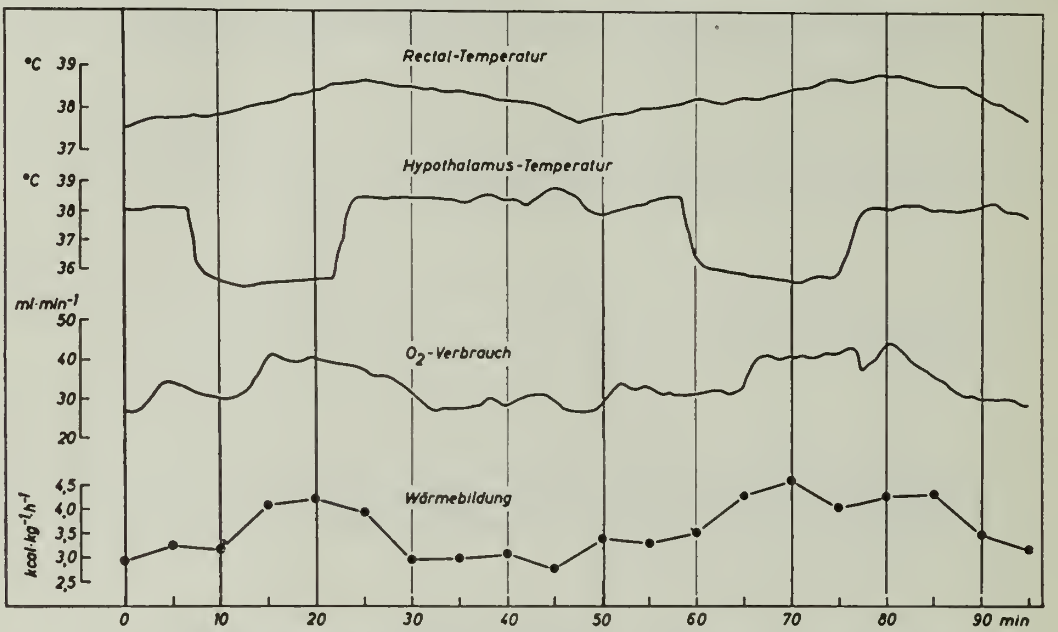


FIG. 1. Cooling of the anterior hypothalamus. Temperature of the respiration box 21°C. Increase of energy metabolism and rectal temperature

temperature was equal to the water temperature. The air was analysed continuously for oxygen and carbon dioxide. A water-perfused thermode was implanted in the frontal part of the hypothalamus and fixed by four screws onto the skull. The total flow through the needle was about 30 ml./min. Besides this we recorded the blood flow in the ear with a heated thermocouple and the rectal temperature with thermocouples.

At inside temperatures of from 20 to 30°C, cooling of the hypothalamus caused a rise of energy metabolism of from 5 to 35 per cent (average 11 per cent) in thirty-eight experiments with five different cats. The increase of heat production began a few seconds after the onset of cooling.

Fig. 1 shows two cooling tests.

Cooling the hypothalamus was accompanied by a rise in metabolism of about the same amount in each test. At low ambient temperatures, higher increases of metabolism were recorded during cooling. At environmental temperatures of from 5 to 15°C in the box, the metabolic increase during hypothalamic cooling reached an average of 27 per cent (19—38 per cent). The initial value before cooling was also higher, according to the low ambient temperature.

At high ambient temperatures the increase of metabolism was very small, and at 35°C, no rise of heat production could be seen while cooling the hypothalamus.

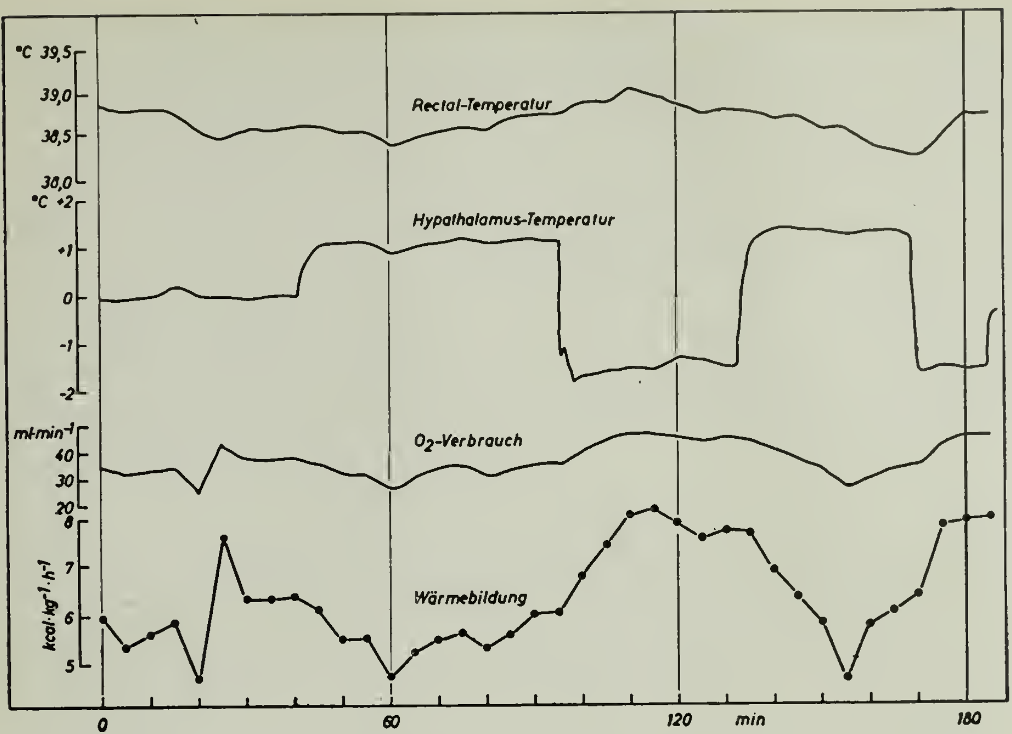


Fig. 2. Hypothalamic cooling at 8° C ambient temperature. Higher initial values and higher increases of metabolism.

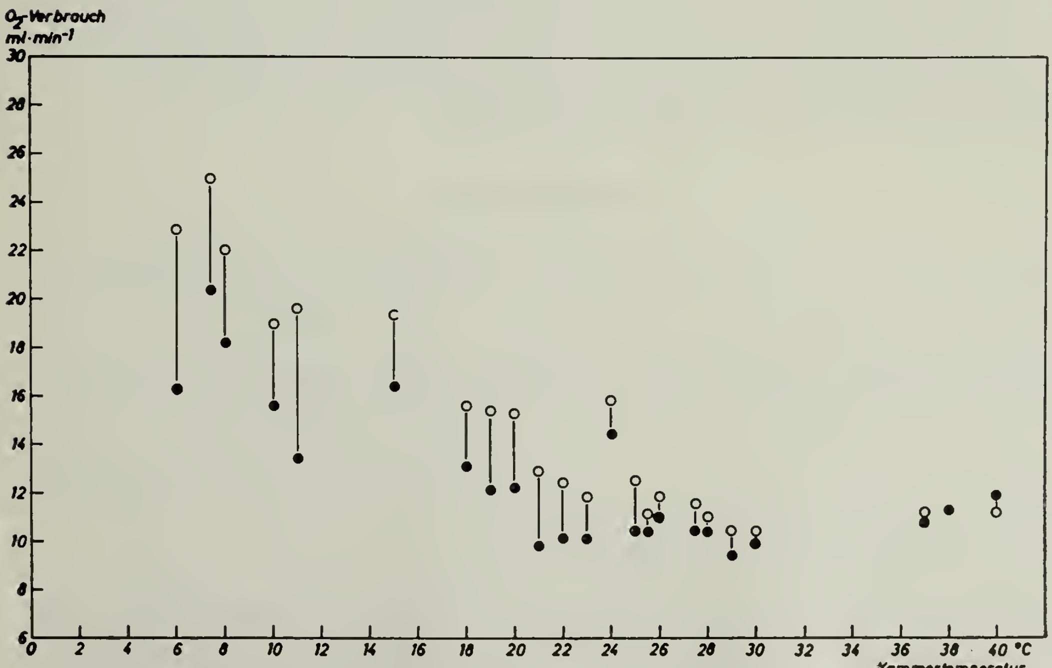


Fig. 3. Increase of O_2 consumption during hypothalamic cooling as a function of ambient temperature. Solid circles: O_2 consumption before hypothalamic cooling; open circles: O_2 consumption during hypothalamic cooling.

The variations of heat production were influenced by the motor activity of the cat. Therefore we selected for our figures only such experiments in which the animals were quiet or sleeping. The summary of these investigations is shown in Fig. 3.

At cold temperatures, the ear vessels were already constricted before the hypothalamus was cooled, so that no further constriction could follow. At high environmental temperatures, no constriction of the ear vessels was seen, corresponding to the behaviour of the energy metabolism.

The changes in rectal temperature during hypothalamic cooling were similar to those during the decrease of the environmental temperature. This result was already shown by Krüger *et al.* (1) in the cat and confirmed by Hammel *et al.* (3) in the dog. However, we were unable to reach a rise in rectal temperature by more than 1.5°C above the initial value, and an increase of 0.5°C was often seen. It seems remarkable that heating the anterior hypothalamus in a period of rising heat production, for example at the beginning of an experimental fever, had no essential influence on the course of the rectal temperature. When cooling was extended over a longer period, a constriction of the ear vessels but not a correspondingly constant increase of heat production could be seen.

In conclusion, local heating or cooling of the anterior hypothalamus in unanaesthetized cats was followed by a rise in O_2 consumption, the amount of which was dependent on the environmental temperature. The cats which were kept in a respiration box at from 5 to 10°C showed a higher increase of heat production during hypothalamic cooling than those in a warm environment. An increase in rectal temperature and a constriction of the ear vessels was also seen. The rectal temperature did not rise by more than 1.5°C. The findings suggest that the regulation of temperature is determined by afferents from cutaneous thermoreceptors as well as from thermosensitive structures in the hypothalamus.

REFERENCES

1. F. J. KRÜGER, H. W. KUNDT, H. HENSEL and K. BRÜCK, *Pflüg. Arch. ges. Physiol.* **269,** 240 (1959).
2. E. BETZ, K. BRÜCK, H. HENSEL, I. JARAÍ and A. MALAN, *Pflüg. Arch. ges. Physiol.* **272,** 76(1960).
3. H. T. HAMMEL, J. D. HARDY and M. M. FUSCO, *Appl. J. Physiol.* **198,** 481 (1960).

TH. R. A. DAVIS: What do you think is the mechanism raising the metabolism during the period of hypothalamic cooling?

E. BETZ: It can hardly be doubted that in the experiments demonstrated local changes of temperature in the hypothalamus caused the thermoregulatory reaction. It cannot be decided whether there are structures in the brain which are similar to peripheral thermoreceptors or whether the hypothalamic temperature does influence the synaptic transmission in this region. The increase of metabolism during the cooling of the hypothalamus is seen, however, only in unanaesthetized animals, for Brendel and Usinger (1) did not observe any increase in heat production when cooling the brain by lowering the temperature of the carotid blood in anaesthetized dogs.

REFERENCE

1. Brendel and Usinger, *Pfüg. Arch. ges. Physiol.* **270**, 73 (1959—1960).

R. R. Lemaire: What is the precise point where you placed the "thermodes"?

E. Betz: The thermodes were placed in the frontal part of the hypothalamus 1 mm right or left of the canalis centralis.

E. T. Renbourn: When immersed in a hot bath the oral temperature (thermocouple) rises as fast or faster than rectal temperature (thermocouple) and can sometimes reach a level 1—2.5°F above the rectal. What is the mechanism?

In a cold bath, where marked shivering occurs, sweating was seen on the forehead, palms and axillae. (This was repeated by Glaser.)

E. M. Glaser: Dr. Renbourn has asked for an explanation of this phenomena. I found in 1949 (1) that the oral temperature could rise above the rectal temperature and I suggested that this may be simply a matter of cool blood from the periphery and warm blood from the deep tissues, being differently distributed. Dr. Lee and I (2) found sweating during cooling and we suggested that sweating of the face, the palms, soles and axillae could be a non-specific central nervous effect, unconnected with thermal sweating, and probably due to overflow of sympathetic stimulation.

REFERENCES

1. E. M. Glaser, *J. Physiol.* **109** (1949).
2. E. M. Gaser and Lee, *J. Physiol.* **122** (1953).

C. P. Luck: Evidence of spinal mechanism in sweating in response to thermal peripheral receptor stimulation. Axon-reflex level? Isn't it possible that sweating is primarily a way of keeping the hydration of the skin surface — only secondarily a thermal affair.

G. C. Whittow: When Dr. Betz cooled the anterior hypothalamus and failed to induce shivering was the animal's skin vasoconstricted or vasodilated?

E. Betz: Indifferent ambient temperatures in all animals cooling of the anterior hypothalamus was followed by a vasoconstriction at least of the ear vessels. In already vasoconstricted skin (low environmental temperature) no change of blood flow could be measured. At environmental temperatures which already caused a vasodilatation, cooling of the hypothalamus led only to a slight vasoconstriction in the ear vessels.

Comments on the paper by R. Lemaire "Mécanisme Physiologique de la Tachycardie due à la Chaleur" (see p. 323).

D. Mc. K. Kerslake: How fast does the rectal temperature of a dog fall if the arterial flow is stopped completely?

E. T. Renbourn: In different parts of the intestine dogs show different temperature changes after a meal. This suggests that care must be taken in interpreting rectal temperature in terms of heat balance.

Ch. S. Leithead: Dr. Renbourn rightly emphasizes the importance of emotional factor in relation to responses of the body to whatever stress is being measured — in this case, heat. Some years ago I studied twenty-four men newly arrived from the United Kingdom in the summer heat of the Middle East. Fourteen of these subjects had never been outside England before, whereas the remaining ten had served in the tropics during the last war. Between the two groups there were no observable differences of blood pressure and pulse-rate responses to postural change or to exercise but subjective feelings of giddiness and faintness were confined to these subjects who had not been abroad before.

My experience of heat illness leads me to the belief that in syndromes of water and salt deficiency and of thermoregulatory failure, emotional factors are not of mportance, and there I must disagree with Dr. Renbourn.

IV. Sweating

Introduction by F. Sargent II "Comments on Hidromeiosis (Sweat Gland Fatigue)."

Sweat gland fatigue is but one of several disturbances of the eccrine sweat gland. It is characterized by a progressive depression of sweating and a concurrent increase in the sodium and chloride content of the sweat in the absence of mechanical occlusion of the duct by miliaria. Since it has not been proven that fatigue of the gland actually causes the decline, the term really begs the question. My colleague at the University of Illinois, Professor of Classics, Dr. John L. Heller, suggested *hidromeiosis* as an objective and dynamic term by which to identify this progressive depression of rate of sweating.

In so far as depression of total body sweating is concerned, the natural history of hidromeiosis exhibits the following features. (1) The decline is more likely to occur when ambient conditions demand maximal or submaximal rates of sweating. (2) Men doing physical work exhibit the depression more readily than sedentary subjects. (3) Humid ambient conditions provoke the decrement more readily than do dry ones. (4) Hidromeiosis occurs more regularly in the climatic chamber than in the field. These features, it must be noted, are not uniquely determining; hidromeiosis has been observed among sedentary subjects sweating moderately under dry conditions in the field. Furthermore, there is evidence that dehydration may accelerate the process, and acclimatization to heat may retard it; these features are not, however, so clearly established as the four listed above.

Several physicians have proposed that the anhidrosis of heatstroke develops as a consequence of hidromeiosis. Recently Bannister, Sargent and Johnson have described cases of clinically total anhidrosis among dehydrated young men without hyperpyrexia. Whether this condition represents a prodroma of heatstroke cannot be determined from the data in hand. One differential sign may be failure of cases suffering from heatstroke to exhibit the outburst of sweating following oral ingestion of water. The cases of apyrexial anhidrosis of Sargent and Johnson did show this phenomenon; those of Bannister did not. Duration of anhidrosis, however, may be the basis for these differences.

An interesting but unconfirmed finding is Hearne's report that cases of heat stroke do not sweat when given doses of pilocarpine sufficient to provoke profuse salivation.

The general conclusion which impresses itself on a reviewer of the literature on sweating is that there is great need for a systematic and critical study of the determining conditions for hidromeiosis. Several hypotheses may be offered within this framework for systematic investigation. (1) When first stimulated many physiological processes overshoot and then adjust at some point of equilibrium. The rise and fall of the time-curve of sweating may merely be an example of this general phenomenon. (2) Hidromeiosis may follow from an adaptation with the reflex arc of thermal sweating. (3) Hidromeiosis may develop because of hydration of the skin and mechanical occlusion of the poral duct. (4) Hidromeiosis may occur because there is "fatigue" within the reflex arc, either centrally in the hypothalamus or peripherally at the neuroglandular junction. Finally, it would be useful to establish whether hidromeiosis is the result of a decrement in the output of sweat per gland or merely the result of a decrease in the number of active sweat glands, the output per gland remaining constant. Evidence on this point would elucidate the hypotheses suggested above.

A. B. Hertzmann: With reference to Randall's demonstration of thermoregulatory sweating in spinal man, using a very sensitive sweat print technique, evidence is decisive in favour of such sweating (see *Fed. Proc.* **17,** 144, 1958).

In bathtub experiments chilling of the lower extremity increased oral temperature and elicited shivering, and the sudden increase in water temperature elicited sweating, cutaneous vasodilatation and fall in oral temperature (experiments not published).

Ch. S. Leithead: Fixed observation on young servicemen in Bahrein last year demonstrated reduction in sweating with water depletion *(Lancet* ii, 114, 1960).

Dehydration then becomes one of the many factors which can lower sweat rates› and one condition which must obviously predispose to heatstroke. Nevertheless the anhidrosis due to dehydration, and that due to "sweat-gland fatigue", seem quite different from the anhidrosis of heatstroke. In heatstroke the anhidrosis appears to be absolute, and invariably remains for 2 or 3 days after successful treatment of the hyperthermia.

A. B. Hertzmann: Sweating and dehydration *(U. S. Armed Forces Medical J.* May 1960): Progressive dehydration in a climatic chamber (Temperature, 110°F, vapour pressure, 24 mm Hg) elicited progressive rise in skin and oral temperatures without a decrease in sweating. Failure of the latter to rise with increase of body temperature was considered as evidence of a decreasing reactivity of the sweating mechanism, possibly due to rising osmotic pressure of the body fluids.

F. Sargent: Oral temperatures of healthy young men: I studied 100 healthy young men (17—19 years old) during 6 weeks of a midwestern summer. The men were subjects of an investigation of survival rations. Once a week between 7 a.m. and 10 a.m. oral temperatures were taken for 5 min after 1 hr of reclining. During the first 2 weeks eighty-eight of the men were on a standard adequate diet and were all engaged in the same amount of daily physical work. In this period the frequency distributions of oral temperature were normal. Only one reading in 172 observations exceeded 100°F:

No.	Oral temperature (°F)	
	Mean ∓ s. d.	Range
First control week, 87	97.6 ± 0.6	96.5 — 99.9
Second control week, 85	97.7 ± 0.6	96.0 — 100.4

The fact that Dr. Renbourn's observations were made in the afternoon and early evening may account for this high frequency of oral temperatures in excess of 100°F.

REPORT OF SPECIALIZED WORKING GROUP ON TROPICAL BIOCLIMATOLOGY

Chairman: Dr. E. M. GLASER

1. *First Report of the Committee for Tropical Bioclimatology*

The Secretary, Mr. J. P. Nicolas, presented the report. He said that the report was an attempt to record what was going on in tropical bioclimatology all over the world, but that not enough was known because many institutions had failed to reply when they had received questionaries about their work. The meeting agreed that this was still a very valuable report, and that the permanent chairman and the secretary should be thanked for their good work.

Ways were discussed for obtaining more information about work related to life in the tropics. It was agreed that the collection and spreading of such information was a useful task for the Committee and it was also agreed that research should be included which is not primarily bioclimatological but which is connected with bioclimatology either through its techniques or through its implications. The following agreed to collect information and to send it to the secretary:

Dr. Th. R. A. Davis, on medical and veterinary work in North America;
Dr. J. D. Findlay, on veterinary work in the British Commonwealth;
Mr. B. Givoni, on all kinds of work in Israel;
Dr. E. T. Renbourn, on physiological work in the British Commonwealth;
Prof. J. P. Pichotka, on medical and veterinary work in Germany and Eastern Europe.

2. *Definition of Tropical Bioclimatology*

At the suggestion of Professor A. B. Hertzman it was agreed to interpret this term with some latitude, leaving it to experience what should and should not be the Committee's concern.

3. *Definition of Climate*

There was a long discussion on what climate meant to people living in it. It was pointed out in several ways that heating, cooling of air, and clothing, allowed many people to live in a comfortable tropical microclimate all the time, but that many others are exposed to a number of stresses, which may or may not be entirely climatic. Also, even the most civilized of men may find themselves without their comforts at times. It seemed reasonable to conclude that environments should be defined precisely in terms of atmospheric conditions, clothing, etc., and that other factors should be stated, such as ability to overcome heat stress, nutrition, social factors, etc.

4. *Problems to Be Studied*

After discussion it was agreed that the Society and its Committee should not normally suggest specific problems for study, but that it might be proper from time to time to define fields worthy of increased attention.

5. *Exchanges between Tropical and Non-tropical Laboratories*

Though it was accepted that much research is best carried out under controlled conditions in large centres of research which are often in temperate zones, there was equally strong agreement that ideas for research and the application of results need a good understanding of life in the tropics, including influences which are not entirely climatic. It was agreed to recommend the institution of a scheme whereby junior research workers could visit laboratories in the tropics, for periods of 1—2 years and senior workers make shorter visits of 4—10 weeks. Professor Grayson agreed to provide facilities in Ibadan, Nigeria, for suitable senior or junior men at the Department of Physiology in Ibadan, and Mr. Nicolas suggested that Dakar might also be a good place to visit. The committee agreed to ask the Society whether the Society would consider it one of its tasks to obtain funds for such exchanges, and the acting chairman agreed to explore means of obtaining such funds in England. Implied in the above proposals is the possibility of visits by research workers in tropical laboratories to climatic research centres elsewhere.

It was also pointed out that several direct exchange schemes already exist and that those working for government establishments in Britain, France and the United States can often arrange work in the tropics without difficulty. However, the proposed scheme would be world-wide and co-ordinated.

SUBJECT INDEX