EFFECT OF ENERGY CONSERVATION GUIDELINES ON COMFORT, ACCEPTABILITY AND HEALTH

A. Pharo Gagge and Ralph G. Nevins*
John B. Pierce Foundation
290 Congress Avenue, New Haven, CT

Abstract

Both the Winter and Summer Surveys in a New York government building validate the recommendations of ASHRAE STANDARD 55-74 that the optimum acceptable thermal environment, in which at least 80% of normally clothed men and women living in the United States and Canada would express thermal comfort, lies in the range 72^{o}-78^{o} (^{o}F) ET* (22.2^{o}-25.6^{o} C). The ASHRAE ET* is the dry bulb temperature of a uniform thermal environment at 50% rh with air movement in range 20-25 fpm (0.1-0.125 m/s) for sedentary man (1.-1.2 mets) while wearing an intrinsic thermal insulation of 0.6 Clo.

The FEA Summer Conservation Temperature limits of 78^{o}-80^{o} F (25.6^{o}-26.7^{o} C) can be made 80% acceptable (1) by use of light clothing with insulation less than 0.4 Clo, (2) by increasing the air movement above 50 fpm, (3) by reducing the relative humidity, or (4) by all. These FEA Guidelines, which require the elimination of thermostats and reheat processes, make (1) and (2) the more desirable approaches to 80% acceptability. In summer time heat, men tend to wear 50% more clothing (insulation) than women, while at work. In summer the practical minimum level of clothing insulation for men appears to be 0.4-0.5 Clo while for women, 0.2-0.3 Clo.

For the 68^{o}-70^{o} F (20^{o}-21.1^{o} C) FEA Conservation Guideline temperatures for winter, the 80% acceptability is possible for persons wearing 0.9-1.2 Clo insulation, provided proper care is made to cover legs with socks and trousers or wear dresses with stockings and with shoes without open toes.

Except for the seriously ill and those in hospitals, there appears to be no serious health hazard for properly clothed individuals due to exposure to the FEA Winter and Summer Guideline Temperatures.

For simple sedentary tasks, no decrements in performance can be expected for the FEA Guideline temperatures - winter or summer - as long as the applicable ASHRAE ET* falls within the 80% acceptability range defined by our Comfort Charts in terms of T_a, Clo, air movement and relative humidity. A loss of dexterity may occur when air temperature falls below 65^{o} F (18.3^{o} C). Decrements in the performance of simple manual and mental tasks may occur when the ASHRAE ET* rises above 90^{o} F (32.2^{o} C).

Comfort Charts are presented to show how various clothing insulations can be used to convert any combination of dry bulb temperature, relative humidity, air movement to an equivalent ASHRAE Effective Temperature ET*. From these charts the reader can recognize for himself additional strategies possible to meet the 72^{o}-78^{o} F (22.2^{o}-25.6^{o} C) ET* necessary for 80% acceptability.

Key Words: Effective Temperature (ET*), Clothing Insulation, Thermal Acceptability, Energy Conservation, Thermal Preference Survey, Winter Temperature Guidelines, Summer Temperature Guidelines

*late Fellow of the Pierce Foundation

CONSERVATION OF ENERGY BY REDUCING FUEL CONSUMPTION for heating during winter and for air conditioning during summer is an easy technical possibility when the living space is cooler than normal in the winter and warmer without humidity control in the summer. The question arises, how can these changes be accomplished without losing the general acceptability of such a working environment. Based on the combined advice of many professional organizations, assembled for a three day conference in November 1973 at Airlie House, Arlington, the Federal Energy Administration (FEA) introduced in summer 1974 their Guidelines for Comfort Conditions in Government Buildings and Homes in General. For winter, indoor temperatures were to be set at 68°-70° F (20-21.1° C) and for summer at 78-80° F (25.6-26.7° C). The summer setting would be accomplished without humidity control and reheat. These design values were chosen as being 6° F (3.3° C) above and below the optimum level of 75° F (23.9° C) currently set by ASHRAE Standard 55-74, Thermal Environmental Comfort Conditions for Human Occupancy.

In July 1974, the late Dr. Ralph Nevins, and the Pierce Foundation, were contracted by the FEA to initiate a series of laboratory tests and field surveys to determine occupant reaction to their proposed Guidelines. The complete report has been published (March, 1976)(1). In the present paper we will briefly summarize results and general implications of the two field surveys in a New York GSA multistory office building. My associate Dr. Richard Gonzalez is covering the laboratory tests associated with the present study and will present their behavioral implications. In the present paper we will summarize from a short literature survey the expected effect of the FEA Guidelines on man's health and performance. Finally we will present a series of working charts by which the reader can see how changes in humidity, ambient temperature, air movement, clothing habits and activity can attain environmental acceptability within the Guidelines as well as compliance with the ASHRAE Standard 55-74, which requires an Effective Temperature (ET*) that lies in range 72-78° F (22.2 -25.6° C).

THE SUMMER SURVEY OF THERMAL PREFERENCE

The summer survey of thermal preferences was made of typical groups of workers in the General Services Building, 26 Federal Plaza, New York City. Of the 46 floors in the GSA Building, the 23rd, 26th, 33rd and 39th floors were selected for the survey. Approximately 230 people were questioned twice; in all approximately 460 responses were obtained. During the distribution and completion of the questionnaires, the dry and wet temperatures, the air movement, and the Black Globe temperature were evaluated in each local area. From these four basic measurements and from the clothing insulation worn (as determined from the questionnaire) it was possible to describe quantitatively the thermal environment and to correlate these values with the thermal preferences presented. The outside weather data was taken from the daily weather records for the test period (1300-1500 EST) at Central Park. These records agreed well with casual readings in the shade at street level outside of the GSA Building itself.

During the survey period the outside weather temperature averaged 75.3° F (24° C); the average dew point was 61.4° F (16° C) which corresponded to an average humidity of 60% rh. The average dry bulb temperature indoors, was 74° F (23.3° C) with a dew point of 58° F (14.5° C) and relative humidity of 59%. The range of indoor temperatures surveyed extended from 72.5° F (22.5° C) to 78° F (25.5° C). Over half the responses were made at temperatures between 72° F and 75° F. Due to the generally pleasant outdoor weather conditions and an obvious lack of need for air conditioning indoors, none of the test conditions fell in the FEA Summer Guideline area.

For the survey group the average intrinsic <u>clo</u> was 0.45 for males and 0.35 for females. For both sexes the metabolic rate was estimated as 1 met. There were no significant relationships to age.

By using cross-correlation methods of analysis, the following significant observations were made:

A. Cross-Tabulations: <u>Temperature Sense</u> vs <u>Comfort Sense</u> (entire group)

	Comfortable			Uncomf.			V. Uncomf.		Totals	
	(Row %)	N	(Col %)	(Row %)	N	(Col %)	(Row %)	N	(Row %)	N
Cold		2	(1)		27	(21)		6		35
Cool		67	(22)		19	(15)		0	(28)	86
Slt. Cool		77	(25)		10	(8)				87
Neutral		117	(38)		7	(5)			(61)	124
Slt. Warm		36	(12)		32	(25)				68
Warm		7	(2)		31	(24)		3	(11)	41
Hot					3	(2)		4		7
Totals	(68)	310	(100)	(29)	129	(100)	(3)	13	(100)	452

The above table shows that:

(1) The % of those voting "Sl. Cool-Neutral-Sl. Warm" and of those voting "Comfortable" were essentially equal at 68%. Thus either grouping may be considered as a good index of acceptable.

(2) Of those voting "Comfortable", there was a tendency to prefer parallel cool sensation over a warm one. This proved specially true both for females and for the 51-70 year age group. This asymmetry was not typical of a general population as most of the test conditions fell in temperature ranges expected for cool and comfortable.

B. Cross-Tabulation: Perspiration Sense vs Comfort Sense

	NONE		Slight	Moderate	Heavy	% with + PSENS		Total
		(Col. %)				Row %	Col. %	
Comf.	222	(78)	70	16	0	28	52	308
Uncomf.	58	(20)	42	27	2	55	43	129
Very Uncomf.	6	(2)	2	4	1	54	3	13
N (Row %)	285	(63)	114 (25)	47 (10)	3 (2)			450

The above table shows that:

(3) Although only about a third of the group stated they had a strong perspiration sense, this sense was associated with "warm" and "uncomfortable" votes.

C. Cross-Tabulation: Dry-Humid Sense vs Temperature Sense

	Very dry		Dry	Normal (Neutral)	Humid		Very Humid	Total
Cold	3		15	14	3		2	37
Cool	2	$\boxed{64}$	19	51	13	$\boxed{27}$	2	87
Slightly Cool	2		23	56	7			88
Neutral	3		23	83	13		1	123
Slightly Warm	3		14	11	37		1	66
Warm		$\boxed{23}$	5	7	23	$\boxed{72}$	6	41
Hot	1			1			5	7
Totals	14		99	223	96		15	449

$\boxed{\Sigma}$ Sum of observations

(4) In judging air quality, described by "Dryness" and "Humid", the former significantly correlated with a sense of "Cool" and the latter with a sense of "Warm".

D. Cross-Tabulation: Air Flow Sense vs Temperature Sense

Temp. Sense \ Air Flow Sense	Pleasant (with high air movement)	Neutral	Unpleasant (with low air movement)	Total
	N (row %)			
Cold-Cool Sl. Cool	86 (41)	62 (29)	64 (30)	212 (100)
Neutral	32 (26)	63 (51)	28 (23)	123 (100)
Sl. Warm-Warm-Hot	9 (8)	27 (23)	79 (69)	115 (100)
	127 (28)	152 (34)	171 (38)	450 (100)

(5) When air quality was judged by the "Pleasantness" of air flow sense, 66% of the group had a positive feeling divided between "Pleasant" and "Unpleasant". "Pleasant" was usually associated with "Cool" and "Comfortable" sensation and "Unpleasant" with "Warm" and "Uncomfortable" sensations.

E. Cross-Tabulation: Temperature Sense vs Air Temperature

	Cold	Cool	Sl. Cool	Σ Cool (Row %)	Neutral ΣN (Row %)	Σ Warm (Row %)	Sl. Warm	Warm	Hot	Total
≤ 22.5 (72.5°F)	13	13	10	36 (59)	18 (29)	9 (15)	5	2	2	63
22.7 22.5-22.9	6	21	12	39 (42)	30 (33)	33 (36)	15	7	1	92
23.2 23.0-23.4	7	19	26	52 (57)	24 (26)	16 (17)	9	7	0	92
23.7 23.5-23.9	4	11	8	23 (49)	11 (23)	13 (28)	8	4	1	47
24.2 24.0-24.4	0	4	7	11 (33)	7 (21)	15 (45)	6	8	1	33
24.7 24.5-24.9	0	2	6	8 (18)	14 (31)	23 (51)	13	10	0	45
25.2 25.0-25.4	0	0	2	2 (15)	4 (31)	7 (54)	3	2	2	13
≥ 25.0 (77°F)										
Col. Total (Row %) (% Total)	30 (8)	70 (18)	71 (18)	171 (45)	108 (28)	105 (27)	58 (15)	40 (10)	7 (2)	384

(6) Although the maximum probability of those voting both "Cool" and "Warm" occurring at 74.8° F (23.9° C), this temperature did not prove to be the temperature range where the greatest number voted "Acceptable" as judged by "Neutral" and "Comfort" sensations.

F. Cross-Tabulation: Comfort Sense vs Air Temperature

T_a	Comfortable	Uncomfortable	Very Uncomfortable	Total
	(Row %)			
$\leq$ 22.5	37 (60)	22 (35)	3 (5)	62 (100)
22.5-22.9	71 (76)	19 (21)	3 (3)	93 (100)
23.0-23.4	67 (72)	25 (27)	1 (1)	93 (100)
23.5-23.9	31 (62)	18 (36)	1 (2)	50 (100)
24.0-24.4	22 (67)	9 (27)	2 (6)	33 (100)
24.5-24.9	27 (59)	18 (39)	1 (2)	46 (100)
25.0-25.4	9 (69)	2 (15)	2 (16)	13 (100)
$\geq$ 25.5	0	0	0	0
Col. Total (% Total)	264 (68)	113 (29)	13 (3)	390

(7) The entire temperature range of the survey (72.5-77.9° F) or (22.5-25.5° C) was considered comfortable by 68% of those voting and lay, for the most part, on the cool side of the optimum, which would have been expected theoretically at 78° F (25.6° C) for the average clothing worn ($\approx$ 0.4 Clo).

WINTER SURVEY OF THERMAL PREFERENCE

The winter survey was made at the same building location (GSA Building, Federal Plaza, NYC) as the Summer (Task II). The last two weeks in January and the first week in February were chosen for the study. The questionnaire for Winter was essentially the same as that for Summer except for the additional interest in the effect of cold extremities. The sections of the building surveyed were the same as before. All instrumentation was identical to the previous study. The mode of the survey was slightly different in that half of the observations were made in the afternoon and the other half in the morning before lunch.

The number of questionnaires completed was 514 from a maximum of 262 individuals. The number retested was 125.

The outside weather conditions were ideal for the survey and typical for the New York area. The average outdoor temperature was 34° F; the lowest was 17° F and the warmest, 43° F. The outside vapor pressure ranged from 1.6 Torr to 7.1 Torr with an average of 3.6, which value corresponds to a dew point of 30° F.

Indoor temperature during the survey varied widely, due to the poor control of internal temperature by the building engineer. The average indoor temperature was about 77° F; 80% of the observations were evenly distributed over the 73° F-81° F range. The highest zone temperature observed was 84° F while the lowest was 71° F. Although the indoor temperatures were well above the FEA Guideline level of 68°-70° F (in spite of frequent complaints to the building engineer that the test areas were too warm), this relatively even temperature distribution from 73° to 81° made possible a significant statistical analysis of thermal responses over this range so that reasonable projections could be made towards both the FEA Guidelines for both Winter and Summer.

The average dew point temperature was 44° F, corresponding to an average indoor relative humidity of 30%. The average indoor air movement was about 30 ± 10 fpm.

The average intrinsic clothing insulation worn to work was 0.7 clo for men and 0.65 for women. These values are 50 % higher for men and 100 % higher for women than those observed during the Summer Survey. Thus people dress for work according to outside weather conditions rather than for the expected ideal office temperature or for their often overheated offices in the present building.

From a cross-correlation analysis, the observations with high significance were as follows:

G. Cross-Tabulations: Temperature Sense vs Comfort Sense

Both Sexes	Comfortable	Uncomfortable	Totals
	N (Col %)	N (Col %)	
Cool and Cold	63 (16)	33 (32)	86
Sl. Cool-Neutral-Sl. Warm	299 (76)	9 (9)	308
Warm-Hot	43 (8)	61 (59)	104
Totals	395	103	498

Males	Comfortable	Uncomfortable	Total
	N (Col %)	N (Col %)	
Cool and Cold	18 (10)	6 (16)	
Sl. Cool-Neutral-Sl. Warm	143 (81)	3 (8)	
Warm-Hot	16 (9)	29 (79)	
Totals	177	38	215

Females	Comfortable	Uncomfortable	Total
	N (Col %)	N (Col %)	
Cool and Cold	40 (19)	25 (40)	
Sl. Cool-Neutral-Sl. Warm	143 (68)	6 (9)	
Warm-Hot	27 (13)	32 (51)	
Totals	210	63	273

Age	Col. % Comfortable Age yrs.			Col. % Uncomfortable Age yrs.		
Group	<30	31-50	>50	<30	31-50	>50
Cool-Cold	18	15	15	52	10	41
Sl. Cool-Neutral-Sl. Warm	68	73	76	10	7	10
Warm-Hot	14	12	9	38	83	48

The above tables show:

(1) As high as 79% of all observations were in the "Comfort" category. This sense of comfort was primarily associated with a general neutral thermal sense. Of the remaining, who voted "Uncomfortable", a majority (91%) always associate their feelings with either a sense of coolness (32%) or warmth (59%).

(2) For both men and women, the trend above for "Comfort" was the same. However, for "Uncomfortable", men associate this feeling primarily with warmth, while women were equally divided between cool and warm.

	Comfortable		Uncomfortable	
While Air Flow SENSE was:	Pleasant	Unpleasant	Pleasant	Unpleasant
Col ΣN	274	20	107	80
	(Col %)	(Col %)	(Col %)	(Col %)
Cool-Cold	41 (15)	21 (30)	6 (20)	25 (31)
≈ Neutral	211 (77)	65 (15)	3 (60)	6 (8)
Warm-Hot	22 (8)	21 (55)	11 (20)	49 (61)
			Total (N)	481

(3) A cool air flow sense improved Comfort.

While Comfort was (below), Air Sense was:	Dry			Normal			Humid			Total		
	Row (%)	N	Col (%)									
Comfortable	(48)	193	(75)	(46)	186	(94)	(16)	24	(52)	(100)	403	(80)
Uncomfortable	(66)	66	(25)	(12)	13	(6)	(23)	22	(48)	(100)	100	(20)
Total	(51)	259	(100)	(39)	198	(100)	(10)	46	(100)	(100)	503	(100)

(4) A sense of air dryness in air quality could account for 66% of those voting uncomfortable and coolness.

Cross-Tabulation: Temperature Sense vs Air Temperature

All observations: Winter Study

Temp. Range °C	22.-22.9	23.-23.9	24.-24.9	25.-25.9	26.-26.9	27.-27.9	Total
No. Obs.	38	108	79	102	125	45	497
% Cool-Cold	37	28	24	17	14	0	
% ≈ Neutral (Acceptable)	63	70	67	66	55	24	
% Warm-Hot	0	2	9	17	31	76	

(5) The temperature range for maximum acceptability (i.e. those who do not vote "cool-cold" or "warm-hot"), is (72.5°-76° F) for men at 80% level and (72.5°-78° F) for women at 60% level. For maximum acceptance at 70%, the temperature range is 74°-77.7° which falls within temperature range for Comfort prescribed by ASHRAE Standard 55-74. This is illustrated in Figure 1 for all subjects.

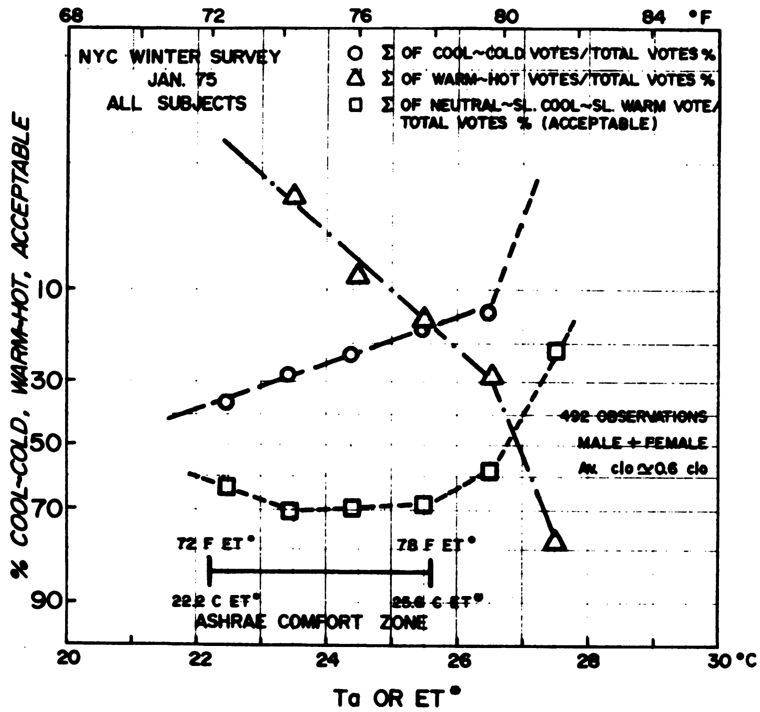


Figure 1. Percent thermal sensation vs T_a on probability coordinates - all subjects. Since average I_{clo} was 0.6 and humidity 40-50% RH, $T_a \cong ET^*$, by definition.

(6) The temperature range for 80% "Comfortable" is 71.5°-78°; for 90% comfortable, the range narrows to 74°-76°. The optimum temperature for Comfort is 75° F for our survey. In terms of ASHRAE ET* (i.e. equivalent temperature for 0.6 Clo and 50% rh), this optimum corresponds to 74° F. This is illustrated in Figure 2 for all subjects.

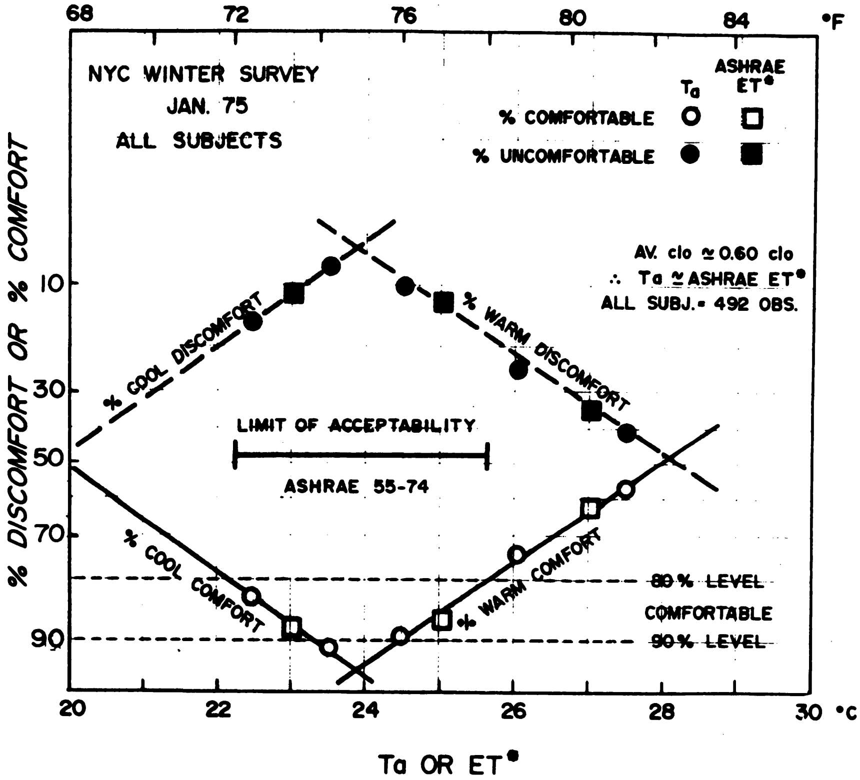


Figure 2. Percent comfort-uncomfortable sensation vs T_a on probability coordinates.

(7) The temperature range for Comfort found in the present survey matches the range for Comfort, prescribed by ASHRAE Standard 55-74.

HEALTH EFFECTS OF MODERATE THERMAL STRESS

The present phase of our FEA study on the effect of the Guidelines was a survey of the literature on the effects of moderate heat and cold stress.

The effects of moderate heat stress have received by far the greatest attention in the literature by clinicians, meteorologists, physiologists and statisticians. The most recent and perhaps now classical study was done by Lee and Henschel (1963)(2) on the effects of heat stress that might be encountered in fallout shelters - a great concern at that period of history. The conclusions of their study were clinical judgments for an abnormal minority of our population under heat stress well above moderate levels. A second now classical series of studies was the work of Burch and DePasquale (1962)(3) summarized in the book on the effects of air conditioning warm and humid chambers on the heart of normal and chronic patients. They did show that heart patients, who showed no deleterious health effects at 75°-76° F (23.9-24.° C) were selected for large exposures to 84°-86° F (28.9°-30° C), a level slightly above the FEA Guidelines.

There is very little in the literature on the effects of moderate cold, which can best be defined as occurring when skin temperature falls below 85° F (29° C). Extreme cold has long been an interest of the Armed Services, whose members must perform at temperatures well below freezing. The laboratory studies, to be reported by Dr. Gonzalez, are the best available for the lower Guideline temperatures (68°-70° F or 20°-21° C).

PERFORMANCE UNDER GUIDELINE TEMPERATURES

The earliest observations on the practical problem of performance of mental and physical tasks for working man appear to be those of Vernon (4) during the First World War. He equated accident frequency with atmospheric conditions (dry bulb temperature) in a munitions factory. For each work spell, the frequency of minor accidents was recorded. A rough calculation of the accident frequency showed that accident frequency was least among workers at shop temperatures of between 65 (18° C) and 69° F (20° C). For cooler ambient temperatures of less than 65° C (18° F) or higher ambient temperatures ≥ 69° F (21° C), the frequency of accidents increased.

The classic studies of Mackworth (1946)(5) and later Pepler (1965)(6) at Oxford were done specifically to quantify any deterioration in task performance as a function of warm ambient conditions. In the studies by Mackworth male wireless telegraph operators, in laboratory conditions, were studied. Their activity would be comparable to our everyday office work. Before the main study the men were acclimatized to heat at 95° F (35° C) for 3 hours a day, 5 or 6 days a week. The actual work procedure was for 3 hrs, at dry bulb temperatures of 85° (29.5° C) to 105° F (40.5° C) and wet bulb temperature 10° F (5.6° C) below DB, during which time 9 messages from a pool of 250 groups were transmitted at a speed of 22 words per minute. The subjects were dressed in gym shorts (approx. 0.1 Clo) and air velocity was at 100 fpm (0.5 m/s). The table below shows their averaged observed data.

Table 1. Average mistakes per hour.

Conditions						
	T_a °F (°C)	85 (29.4)	90 (32.2)	95 (35.0)	100 (37.8)	105 (40.5)
	Wet bulb °F (°C)	75 (23.9)	80 (26.7)	85 (29.4)	90 (32.2)	95 (35.0)
	RH%	63	65	66	68	69
Av. mistakes/subject per hour		12	11.5	15.3	17.3	94.7
Decrement in performance		0	0	30%	47%	700%

Mackworth's findings showed that increases in both dry bulb and wet bulb temperatures impaired the accuracy of the operators to record messages over the telephone and that decrements in task performance were primarily a function of the skill of the operator. Very skilled operators showed no significant mistakes until DB reached 100° F (38° C) and wet bulb was at 90° F (32° C).

By using the above tabulated basic data, plus the fact that the activity was about 1.1 met, which is typical of the metabolic rates for an office worker, his data have been standardized to the ASHRAE Effective Temperature ET* as shown in the following table.

ASHRAE ET* °F	°C	TSENS [1]	DISC [2]	(w) %	Av. mistakes/subj. per hour	Decrement in performance
74.0	(23.4)	-.1	0.1	6	12	0%
80.6	(27.0)	1.4	.4	13	11.5	0%
88.7	(31.5)	3.0	1.0	26	15.3	30%
98.6	(37.0)	4.6	2.3	51	17.3	47%
109.8	(43.2)	5.2	6.3	100	94.7	700%

[1] - 1 - Sl. cool; 0 - Neutral; 1 - Sl. warm; 2 - Warm; 3 - Hot; 4 - Very hot; 5 - Intolerable

[2] 0 - Comfortable; 1 - Sl. uncomfortable; 2 - Uncomfortable; 3 - Very uncomfortable

From the above studies of Mackworth it was clear that up to ET* levels of 80° F (26.7° C) no significant decrement of performance would be expected. The initial decrement could be expected for an average person as ET* rises above 82-84° F (28°-29° C) levels.

Decrements in performance toward the cold for a similar type activity as Mackworth's would depend primarily on the temperature of the fingertips and hands. The vertical finger skin temperature lies about 75° F (24° C) which would occur for normally clothed persons (0.6 ≈ 1 Clo) for ambient temperatures well below the guideline temperature of 68° F (20° C)

Our final conclusion was that the FEA Guideline temperatures for heat and cold should cause no significant drop in performance *per se*.

ROLE OF CLOTHING IN MEETING BOTH FEA ENERGY CONSERVATION GUIDELINES AND ASHRAE STANDARD 55-74.

In reviewing, the ASHRAE Standard 55-74 (Thermal Environmental Conditions for Human Occupancy) describes the optimum "Comfort Envelope" as being the adjusted dry bulb temperatures falling within an envelope defined on a psychrometric chart by 71.6° F (21.9° C) and 77.6° F (25.3° C) at 14 Torr (1.9 kPa) and by 72.6° F (22.6° C) and 79.7° F (26.5° C) at 5 Torr (0.7 kPa). In terms of the new Effective Temperature (ET*), defined as the adjusted dry bulb temperature at 50% relative humidity, the optimum ET* range lies between 72° F (22.2° C)-78° F (25.6° C). Further this optimum range applies for normally clothed people while engaged in sedentary or near sedentary activities, such as light office work. The Federal Energy Conservation Guidelines for control of indoor environments in government office buildings require that dry bulb settings in the winter be within 68° F (20° C) - 70° F (21° C) and in the summer be 78° F (25.6° C) - 80° F (26.7° C). The feasibility of the higher guideline 80° F (26.7° C) - 82° F (27.8° C) has also been considered. Summer setting should be accomplished without humidity control and reheat. The question is now how do the Standard and Guidelines relate to each other.

The Pierce Laboratory's FEA survey of thermal preference in a typical government office building located in New York City during both the summer, 1974, and winter, 1975, produced two general observations. The first was that, during the winter, an acceptable environment (defined by Standard 55-74 as an expression of thermal comfort by 80% of those surveyed) occurred over the 72-78 ET* range and thus fell within the ASHRAE "Comfort Envelope." Further the average clothing insulation worn in winter was approximately 0.6 clo (intrinsic) for both males and females. The average activity was rated as sedentary office work and fell in range 1.0-1.2 mets (60-70 W/m^2). Air movement observed was within 20-30 fpm (0.10-0.15 m/s). A second general observation was that this same working population habitually clothed themselves for office work according to the season and outdoor weather conditions prevailing rather than for any expectation of the indoor climate, which was on an average 75° F (23.9° C) the year around. During the summer the average clothing insulation worn in New York was 0.4 clo; men wore a slightly higher value of 0.45 clo, compared to the women's 0.35 clo value. Adjusted dry bulb temperatures within 72-78° F range proved to be on cool side while wearing such light clothing during the summer.

Our laboratory study on FEA Winter Guideline Temperatures, which is being covered by my associate Dr. Richard Gonzalez today, shows that the 80% acceptability criterion was possible for groups of subjects exposed to 68° F (20° C), specially if they were given access to additional clothing insulation for comfort. In his study, the wearing of a clothing insulation of about 1.0 clo (intrinsic) proved sufficient to make 68° F (20° C) fall in the 80% acceptability range.

Our Summer Laboratory Study (also covered by Dr. Gonzalez) showed that, when light clothing insulation was worn, it fell in the range 0.3-0.5 clo, and thermal comfort was achieved by the majority of those tested up to 82° F (27.8° C).

Our studies on clothing requirements under FEA Temperature Guidelines Conditions indicate in general that there is a need to relate the equivalence of various levels of clothing insulation worn under various environmental conditions to the Comfort Envelope of ASHRAE Standard 55-74. For this purpose we have used the latest dynamic model of thermal regulation (7) to calculate ASHRAE ET*. The particular feature of this FORTRAN program is that the ET* can be calculated from the basic environmental conditions described by (1) activity (metabolism), (2) operative temperature or ambient air and mean radiant temperature, (3) room air movement, (4) ambient vapor pressure (or relative humidity) and (5) the intrinsic clothing insulation worn. The basic clothing and heat transfer conditions associated with the ASHRAE ET* are used as a standard for comparison. Any thermal environment can be described in terms of the temperature of a standard equivalent environment controlled at 50% relative humidity with air movement of 20-30 fpm (0.1-0.15 m/s) in which a sedentary subject (1-1.2 mets) wearing a standard 0.6 intrinsic clo would exchange the same amount of heat by radiation, convection and evaporation at the same thermal strain, as he would in the actual working environment, described by adjusted dry bulb or operative temperature, air movement and humidity and clothing insulation worn. See Appendix 1 for calculation of ET*.

The primary objective of this section is to show how clothing insulation worn can be used as a key parameter in choosing the proper combination of environmental factors that fit the ASHRAE ET* Comfort Envelope (72-78° F) as defined by ASHRAE Standard 55-74 and secondly to show what practical clothing strategies in conjunction with existing humidity and air movement are possible to make the FEA Winter-Summer Guideline Temperatures fit within the basic ASHRAE Comfort Envelope.

In Figs. 3-6, which are all applicable for sedentary activity, the upper and lower temperature limits for 80% acceptability have been drawn as horizontal lines at 72° F (22° C) and 78° F (25.6° C) ET* on the ordinate in accordance with Standard 55-74. The abscissa is ambient air temperature (T_a = MRT) or the adjusted dry bulb temperature. Our New York survey showed that 90% acceptability would fall within the ET* limits 74° F (23.1° C)-76.5° F (24.5° C). Each figure shows what clothing insulation will result in values of ASHRAE ET* that fall within the 80% acceptability ranges for the air movement and relative humidity indicated.

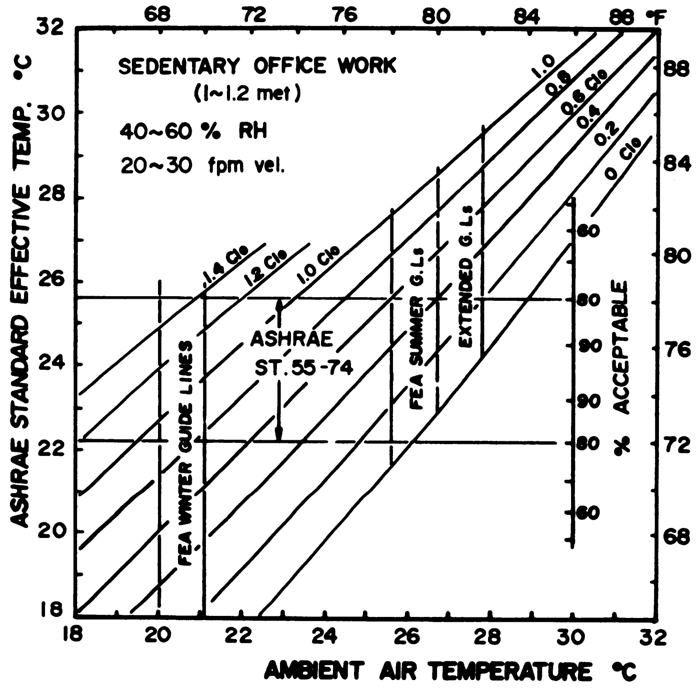


Figure 3. Relation of ASHRAE ET* temperature with varying clothing insulation for 40-60% relative humidity and 20-30 fpm. Note: Since by definition ASHRAE ET* describes the effective temperature as the dry bulb at 50% rh associated with 0.6 Clo and 20-25 fpm, the locus of ET* vs T_a for 0.6 Clo is always a straight line with unit slope.

Figure 3 relates ASHRAE ET* at normal humidity (50% RH) and air movement (0.1-0.15 m/s, 20-30 fpm), to the ambient air temperature or operative temperature (or adjusted dry bulb) for various Clo-levels. The 80% acceptability range of 72°-78° F is covered best by 0.6 clo (by definition). At the FEA Winter Guideline temperature of 68° F (20° C) an acceptable Clo range would be 0.9-1.5. At 72° F (22.2° C) the range of acceptable Clo is 0.6-1.2 clo; at 78° F (25.6° C) the acceptable clo range is 0.1 to 0.6 clo, at 82° F (27.8° C) the range of acceptable Clo narrows to 0-0.2 clo. For 0.4 clo the range of 80% acceptable extends from 74° F (23.3° C) to 80° F (26.7° C).

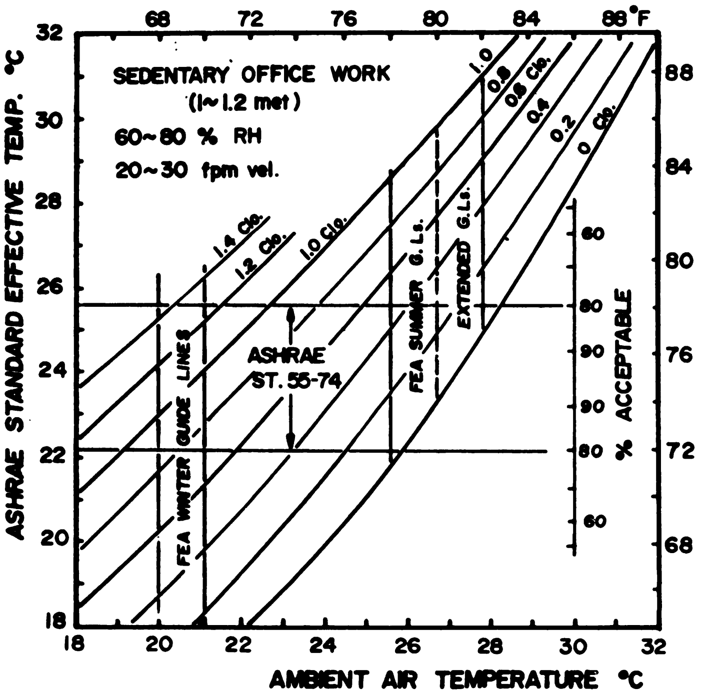


Figure 4. Relation of ASHRAE ET* to T_a with varying Clo insulation for 60-80% rh and other factors the same as in Figure 3. Note: Humidity is typical of summer indoors in NYC.

The conditions for high humidity and normal air movement, such as would occur in summer time, are illustrated in Figure 4. The acceptable clothing limits at 68° F (20° C) remain essentially unchanged over those in Fig. 3. At 80° F, the upper FEA Summer Limit, the acceptable Clo-range would be only 0-0.15 clo, which values are obviously impractical for daily wear. The temperature range for 80% acceptable with 0.6 clo narrows to 72-77° F (22°-25° C) and rises to 75-80° F (23.9-26.7° C).

Low humidities such as would occur indoors during winter time or in desert climates and with normal air movement are illustrated in Fig. 5. The acceptable Clo range for 68° F T_a is slightly higher (1.0-1.6 clo) than values for normal humidity in Fig. 2. A 0.3 clo ensemble would prove effective for the 78-80° F FEA Summer range but only marginally effective at 82° F.

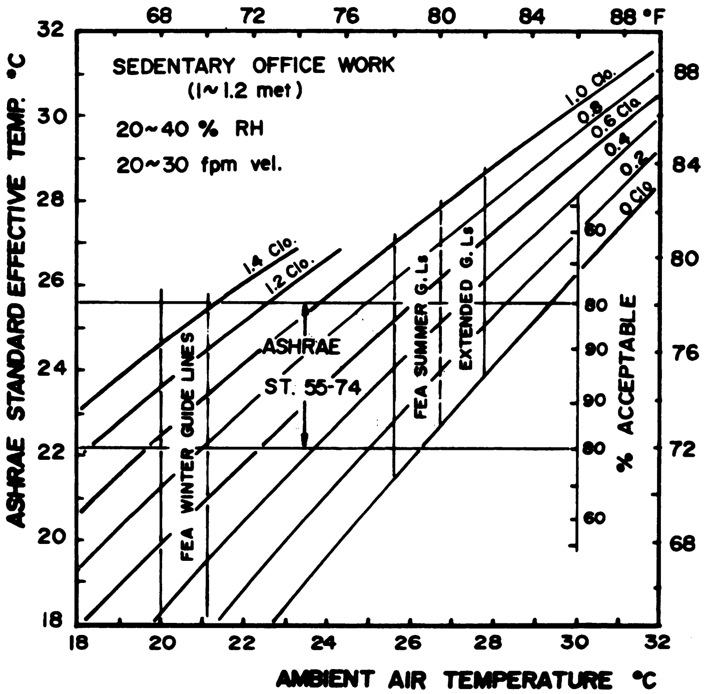


Figure 5. Relation of ASHRAE ET* to T_a with varying clothing insulation for 20-40% RH and other factors the same as in Figure 3. Note: Humidity is typical of winter indoors in NYC.

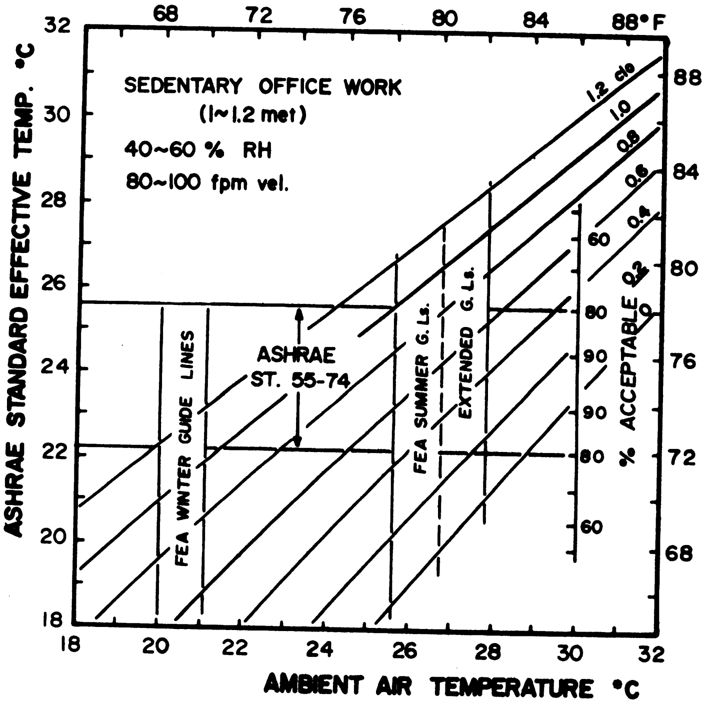
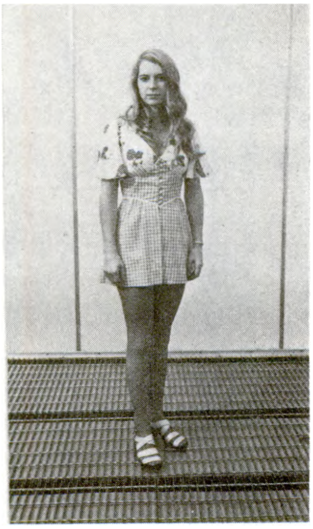
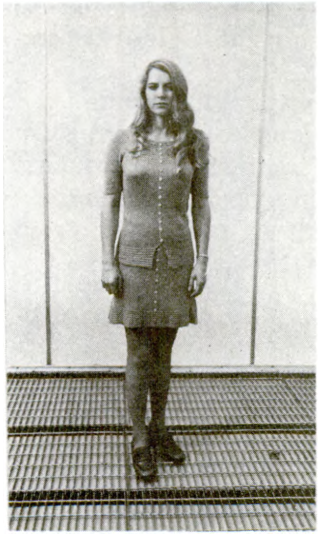


Figure 6. Relation of ASHRAE ET* to T_a with varying clothing for normal humidity and air movement in 80-100 fpm range. Note: Air movement typical under tropical ceiling fans.

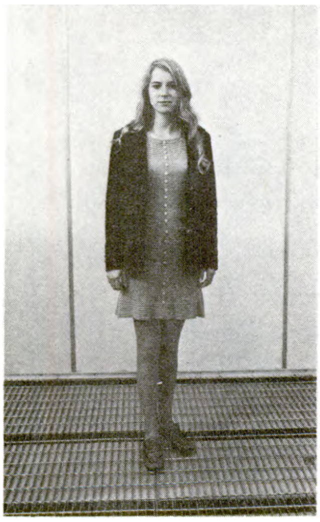
Figure 6 demonstrates how air movement (80 ≈ 100 fpm), for example, caused by ceiling fans such as used in the tropics, greatly improves Comfort and acceptability while wearing clothing in range 0.5 ≈ 0.8 clo within the FEA Summer Guideline temperatures.



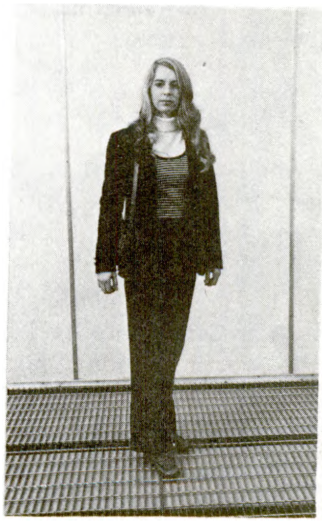
0.15 0.25 clo
Summer - FEA



0.4 0.5 clo
Summer - Normal



0.7 0.8 clo
Winter - Normal



0.9 1.1 clo
Winter - FEA

Figure 7. Clothing Ensembles for FEA Summer and Winter Guideline Temperature Ranges

B.

Figure 7 illustrates typical clothing combinations for both males and females that can be used to meet both the Guideline and ASHRAE Standard 55-74

From the accompanying figures it is clear that a proper choice of clothing insulation can make a wide range of ambient temperatures and air movements fit within the ASHRAE Comfort Envelope specified by Standard 55-74. The figures also show how habitual use of light clothing in summer and warmer clothing in winter allow readjustment of 80% acceptable ambient air temperature and still meet the 72-78° F ET* standard. Finally, these figures show why, as was the case for the old ASHVE Effective Temperature of Houghten and Yaglou (1923), clothing habits of the past caused the preferred ambient temperatures to be slightly higher in the summer than in the winter for the same optimum ET*.

ACKNOWLEDGMENTS:

The authors are indebted to many during the preparation of the above contract study. The New York surveys were accomplished under the direction of Professors Dorothy Cunningham and Paul Brandford of Hunter College, New York City. The statistical evaluation of these surveys was done by Professor Brandford. The evaluation of clothing and its significance was primarily the work of Dr. Y. Nishi, now at Hokkaido Institute of Technology, Japan. Through the course of this study we must acknowledge the valuable guidance and advice of Dr. R. R. Gonzalez, Dr. B. Wenger and Dr. J. A. J. Stolwijk of our Laboratory, Dr. P. O. Fanger of the Technical University of Denmark, and Dr. R. F. Goldman, the Chairman of TC 2.1, Physiology and Human Environment of the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

BIBLIOGRAPHY:

1. Gagge, A. P. and R. G. Nevins. Effect of Energy Conservation Guidelines on Comfort, Acceptability and Health. Final report of Contract #CO-04-51891-00 of Federal Energy Administration, March, 1976.

2. Lee, D. H. K. and A. Henschel. Evaluation of Thermal Environment in Shelters. Report prepared for Office of Civil Defense under contract No. OCD-OS-62-100. U. S. Dept. of Health, Education, and Welfare, Public Health Service, Division of Occupational Health, 1963.

3. Burch, G. E. and N. P. DePasquale. Hot Climates, Man and His Heart. Springfield, Ill.: Thomas, 1962.

4. Vernon, H. M. In: Basic Principles of Ventilating and Heating. By T. Bedford, Lewis & Co., 1948.

5. Mackworth, N. H. Effects of heat on wireless operators' hearing and recording Morse Code messages. Brit. J. Ind. Med. 3: 143-158, 1946.

6. Pepler, R. D. Performance and well-being in heat. In: Temperature, its Measurement and Control in Science and Industry. Vol. 3, Part 3. J. D. Hardy, ed. Reinhold Publ. 1965, pp. 319-336.

7. Gagge, A. P., Y. Nishi and R. G. Nevins. The role of clothing in meeting FEA energy conservation guidelines. ASHRAE TRANSACTIONS 82 (II), 1976.

APPENDIX 1

Annoted FORTRAN Program for Calculation of ASHRAE ET*

The present program is designed to calculate the ASHRAE ET* when the following basic factors are known and evaluated:

TA	-	ambient air or dry bulb temperature	C
TR	-	the mean radiant temperature	C
VEL	-	room air movement	$m \cdot s^{-1}$
RH	-	relative humidity	as fraction
CLO	-	intrinsic insulation of clothing worn	clo
ACT	-	level of activity in met units	met
(ACT = ACT*58.2 in $W \cdot m^{-2}$ in program)			
WK	-	work accomplished	$W \cdot m^{-2}$

The above factors are defined by READ and DO statements.

The basic physiological terms used to describe the regulatory model are as follows. Secondary definitions will occur in the program itself.

TSK	=	mean skin temperature	C
TCR	=	internal body temperature	C
SKBF	=	skin blood flow	$liters \cdot m^{-2} \cdot h^{-1}$
REGSW	=	regulatory sweating	$g \cdot m^{-2} \cdot h^{-1}$

The following function relating saturation vapor pressure SVP in Torr to temperature T in C is used. The function is known as the Antoine Equation.

SVP(T) = EXP(18.6686-4030.183/(T+235.))

```
C   STEADY STATE CHARACTERISTICS OF MODEL AT THERMAL NEUTRALITY
      TTSK=34.0
      TTCR=36.6
      ALPHA=0.1
      TTBM=ALPHA*TTSK+(1.-ALPHA)*TTCR
      CSW=200.
      CSTR=0.5
      CDIL=150.

C   INITIAL CONDITIONS-PHYSIOLOGICAL THERMAL NEUTRALITY
      TSK=TTSK
      TCR=TTCR
      TBM=ALPHA*TSK+(1.-ALPHA)*TCR
      SKBFN=6.3
      SKBF=SKBFN
      EV=0.1*ACT

C   CLOTHING AND ENVIRONMENTAL HEAT TRANSFER FACTORS AT SEA LEVEL
C   CHCA IS EFF. CHC DUE TO ACT IN STILL AIR (TREADMILL WALKING)
      CHCA=5.66*(ACT/58.2-0.85)**0.39
C   CHCV IS FUNCTION OF ROOM AIR MOVEMENT (VEL)
      CHCV=8.6*VEL**0.53
      IF(CHCV-CHCA) 4,4,5
  4   CHC=CHCA
      GO TO 6
  5   CHC=CHCV
  6   CONTINUE
```

```
C  CHC VALUE FOR STILL AIR IS 3.0 AT SEA LEVEL
 7     IF(CHC-3.) 8,9,9
 8     CHC=3.0
 9     CONTINUE
       FACL=1.+0.15*CLO
       CHR=4.7
       CTC=CHC+CHR
       TO=(CHR*TR+CHC*TA)/CTC
       CLOE=CLO-(FACL-1.)/(0.155*FACL*CTC)
       FCLE=1./(1.+0.155*CLOE)
       FPCL=1./(1.+0.143*CHC*CLOE)
C  TIME OF EXPOSURE SET AT ONE HOUR
       TIM=0.
       TIME=1.

C  SIMULATION OF BODY TEMPERATURE REGULATION - START OF REG. LOOP
 100   CONTINUE
       CLOE=CLO-(FACL-1.)/(0.155*FACL*CTC)
       FCLE=1./(1.+0.155*CTC*CLOE)
       TCL=TO+FCLE*(TSK-TO)
       CHR=4.*5.67E-8*(((TCL+TR)/2.+273.2)**3)*0.725
       CTC=CHR+CHC
       TO=(CHR*TR+CHC*TA)/CTC
       ERES=0.0023*ACT*(44.-RH*SVP(TA))
       CRES=0.0014*ACT*(34.-TA)
C  HEAT FLOW EQUATION AT SKIN SURFACE
       DRY=FCLE*CTC*(TSK-TO)
       ESK=EV-ERES
       HFSK=(TCR-TSK)*(5.28+1.163*SKBF)-DRY-ESK
       HFCR=ACT-(TCR-TSK)*(5.28+1.163*SKBF)-CRES-ERES-WK
C  AVERAGE MAN 70KG, 1.8 SQ.METER
       TCSK=0.97*ALPHA*70.
       TCCR=0.97*(1.-ALPHA)*70.
       DTSK=(HFSK*1.8)/TCSK
       DTCR=(HFCR*1.8)/TCCR
       DTIM=1./60.
       DTBM=ALPHA*DTSK+(1.-ALPHA)*DTCR
       TIM=TIM+DTIM
       TSK=TSK+DTSK*DTIM
       TCR=TCR+DTCR*DTIM
C  DEFINITION OF REGULATORY CONTROL SIGNALS
       SKSIG=TSK-TTSK
       IF(SKSIG) 10,10,15
 10    COLDS=-SKSIG
       WARMS=0.
       GO TO 20
 15    COLDS=0.
       WARMS=SKSIG
 20    CRSIG=TCR-TTCR
       IF(CRSIG) 30,30,35
 30    COLDC=-CRSIG
       WARMC=0.
       GO TO  40
 35    WARMC=CRSIG
       COLDC=0.
 40    CONTINUE
```

```
C  CONTROL SKIN BLOOD FLOW
      STRIC=CSTR*COLDS
      DILAT=CDIL*WARMC
      SKBF=(SKBFN+DILAT)/(1.+STRIC)
C  RELATIVE WT. OF SKIN SHELL TO BODY CORE VARIES WITH SKBF
      ALPHA=0.04415+0.351/(SKBF-0.014)
C  DEFINITION OF CONTROL SIGNALS FOR SWEATING
      TBM=ALPHA*TSK+(1.-ALPHA)*TCR
      BYSIG=TBM-TTBM
      IF(BYSIG) 50,50,55
 50   COLDB=-BYSIG
      WARMB=0.
      GO TO 60
 55   WARMB=BYSIG
      COLDB=0.
 60   CONTINUE
C  CONTROL OF REGULATORY SWEATING
      REGSW=CSW*WARMB*EXP(WARMS/10.7)
      ERSW=0.68*REGSW
      EMAX=2.2*CHC*(SVP(TSK)-RH*SVP(TA))*FPCL
      PRSW=ERSW/EMAX
      PWET=0.06+0.94*PRSW
      EDIF=PWET*EMAX-ERSW
      EV=ERES+ERSW+EDIF
      IF(EMAX-ERSW)  70,70,75
 70   EV=ERES+EMAX
      ERSW=EMAX
      EDIF=0.
      PRSW=1.
      PWET=1.
 75   CONTINUE
      IF(TIM-TIME) 100,110,110
 110  CONTINUE
C  END OF REGULATORY LOOP
```

At the end of exposure TIME, all the basic physiological terms listed above are now evaluated for activity and environment defined above. The state of thermal equilibrium (STORE) and the skin heat loss to the environment (HSK) now follow:

```
C  CALCULATION OF HEAT STORAGE
      STORE=ACT-WK-CRES-EV-DRY
C  CALCULATION OF SKIN HEAT LOSS( HSK )
      HSK=ACT-ERES-CRES-WK-STORE
C  CALCULATION OF ASHRAE STANDARD EFFECTIVE TEMPERATURE - SET
C  DEFINITION OF ASHRAE STANDARD ENVIRONMENT
      CHRS=CHR
C  CHCS IS CHCA VALUE FOR ACT SELECTED IN STILL AIR
      CHCS=CHCA
      CLOS=0.6
      FACLS=1.09
      CTCS=CHRS+CHCS
      CLOES=CLOS-(FACLS-1.)/(0.155*FACLS*CTCS)
      FCLES=1./(1.+0.155*CTCS*CLOES)
      FPCLS=1./(1.+0.143*CHCS*CLOES)
C  STANDARD ACTIVITY POINT
      TACTS=TSK-HSK/(CTCS*FCLES)
C  AT START OF ITERATION
      SET=TACTS
```

```
C  DEF. OF SET IS SOLUTION OF HEAT BAL. EQ. WHEN ERROR=0.
 200  ERROR=HSK-CTCS*FCLES*(TSK-SET)-PWET*2.2*CHCS*FPCLS*(SVP(TSK)
     X-0.5*SVP(SET))
      IF(ERROR)210,220,220
 210  SET=SET+0.1
      GO TO 200
 220  CONTINUE
```

For the present analysis, the following printout is useful.

```
      WRITE(1,4000)TA,CLO,ACT,PWET,EMAX,TSK,TCR,TBM,HSK,DRY,EV,STORE,SET
 4000 FORMAT(13F7.2)
```

END of program

The above program applies for sea level conditions and may be used to develop psychrometric tables for clothed subjects in heated, ventilated and air-conditioned environments encountered in normal engineering practice and for prediction of comfortable-acceptable environments, when basic indoor temperatures are determined by a Building Simulation Program such as the National Bureau of Standards NBSLD.

For Fig. 3-6 the following common inputs were used:

ACT = 1.1 mets for sedentary office work
WK = 0. $W \cdot m^{-2}$
TIME = 1. hour
TA = TR = TO ^{o}C

Other environmental factors used are indicated on the figures themselves.