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NBSLD, Computer Program for Heating and Cooling Loads in Buildings

T. Kusuda

Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

November 1974

Final Report

Prepared for
Housing and Urban Development
451 7th Street, S. W.
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

U. S. DEPARTMENT OF COMMERCE

NBSLD

Computer Program for Heating and Cooling Loads in Buildings

National Bureau of Standards

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National Bureau of Standards

Preface

This document comprises the engineering manual for the computer program called the National Bureau of Standards Load Determination Program hereafter referred to as NBSLD. Presented herein are the algorithms for the exact calculation methodology that was developed in the Thermal Engineering Systems Section of the National Bureau of Standards to determine accurate heating and cooling loads for the thermal design of buildings. NBSLD, which is based upon the methodologies presented in this publication, has been available for some time for the purpose of evaluating various building constructions and systems. The program was originally developed as a research tool because none of the commercially available programs had features or the sophistication to enable the evaluation of unconventional designs. NBSLD has been an indispensable tool for studies of numerous HUD housing systems, constructions of the Defense Department and the General Services Administration where non-conventional design conditions had to be evaluated.

As the existence and the capability of NBSLD became known, numerous requests were made to NBS to release the program for public use. This publication is in response to that request. Hopefully, engineers will be able to adopt some of the computational schemes described in this publication to their own programs. A complete Fortran program is attached, although NBS does not claim that the program is optimum from the standpoint of the computer memory allocation or computational economy. It will take additional improvements before the program becomes optimum from those viewpoints. The program documentation is being made available at this time so engineers can use it for accurate load determination as they seek to conserve energy through improved thermal design of buildings. The author would appreciate receiving reader's comments with respect to the accuracy of this text.

It should be mentioned that some of the subroutine algorithms listed in this publication have already been published in the well known ASHRAE booklet entitled "Procedure for Determining Heating and Cooling Loads for Computerized Energy Calculations". These subroutines were compiled by the author who served as the chairman of the Subcommittee on Heating and Cooling Load Calculations of the ASHRAE Task Group on Energy Requirements for Heating and Cooling of Buildings. The ASHRAE publication, however, contains several critical errors, which have been corrected for use in this volume.

The author is greatly indebted to Dr. J. E. Hill for this thorough editing of the text, to Mrs. Sharon D. Crampton for her skill and patience in typing the manuscript and to Mr. F. J. Powell for his encouragement to produce the document.

Table of Contents

Page

1. Introduction 1

2. Fundamentals of Heating and Cooling Load Calculation . . . 3

   2.1 A Rigorous Method of Calculating Heating and Cooling Loads 5

   2.2 Approximate Methods of Calculating Heating and Cooling Loads 9

3. Unique Features of NBS Load Calculation Computer Program . . 15

4. General Description of NBSLD Subroutines 22

5. NBSLD Logic Diagram 31

6. References 33

7. Appendix A - ASHRAE Task Group Subroutine Algorithms

   CLIMAT - Weather data processing 1a
   SUN - Basic solar position data 6a
   CCF - Cloud cover factor 15a
   SOLAD - Solar radiation intensity 18a
   TAR - Glass transmission and absorption 22a
   SHG - Solar heat gain through a window 29a
   SHADOW - Sunlit area calculations 31a
   FIJ - Radiation heat transfer exchange factors 48a
   FI - Interior surface heat transfer coefficients 64a
   FO - Outside surface heat transfer coefficients 65a
   ACR - Air cavity heat transfer coefficients 68a
   XYZ - Conduction transfer functions 71a
   HEATW - Heat conduction through exposed surfaces 79a
   SCHEDULE - Internal heat generation 86a
   Fundamentals of Room Temperature and Cooling (Heating) Load Calculations 89a
   RMTMP - Exact room load calculation 94a
   ATTIC - Exact attic temperature calculation 108a
   IHG - Instantaneous heat gain concept 109a
   HLC - Heating/cooling load calculation by the transfer function method 115a
   RMRT - Transfer functions for the room temperature calculations 122a
   HEXT - Heat extraction rate calculation 128a
   INFIL - Building air exchange calculation 129a

Miscellaneous routines

DST - Daylight saving time indicator 144a
WKDAY - Day of week identifier 145a
HOLDAY - U. S. Holiday identifier 149a
PSY - Psychrometric calculations 150a

8. Appendix B - Weighting Factor Method for Calculating Heating and Cooling Loads and Space Temperature

9. Appendix C - NBSLD Data Forms

10. Appendix D - NBSLD Fortran Listing

11. ASHRAE Psychrometric Chart

NBSLD

National Bureau of Standards Heating and Cooling
Load Determination Program

T. Kusuda
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ABSTRACT

A comprehensive computer program called NBSLD, the National Bureau of Standards Load Determination program, has been developed at NBS to reflect the time change of the many building parameters which are pertinent to accurate estimation of energy usage for heating and cooling. Current status of heating and cooling load techniques is reviewed. Of general interest are unique features of NBSLD which are not available in existing computer programs. A summary of various subroutines of NBSLD is given along with the detailed procedures for them. These subroutines constitute the recommended subroutine algorithms of the ASHRAE Task Group on Energy Requirements. Complete Fortran listing of NBSLD and data preparation forms are given for those who wish to use the program. The NBSLD computation is on the basis of the detailed solution of simultaneous heat balance equations at all the interior surfaces of a room or space. Transient heat conduction through exterior walls and the interior structures is handled by using conduction transfer functions. The use of heat balance equations, although time consuming in calculation, can avoid the vagueness and uncertainties inherent in the more popularly used weighting factor approach.

In addition, it is more accurate for a specific building design.

Key Words: ASHRAE Task Group on Energy Requirements; conduction transfer functions; heating and cooling load; National Bureau of Standards Heating and Cooling Load Computer Program

1. Introduction

Numerous studies in recent years on the matter of energy shortage lead one to believe that the U. S. demand for energy will very shortly outstrip her power generating capacity and fossil fuel supply. According to a recent report of the Stanford Research Institute[1/], space heating and cooling for residential and commercial buildings amounts to approximately 20% of the total energy consumed in the United States, which was 60 trillion Btu per year in 1968. Moreover, recent and frequent blackouts and brownouts in the east coast region of the United States are good indications that the electric power demand for summer air conditioning exceeds for certain times, the capability of supply and distribution by the power companies.

It is in this context that new and accurate methodology for energy calculations is most crucial for the design and analysis of the performance of space heating and cooling systems. This is especially true in view of the fact that the current load calculation procedures could lead to the over-design of heating and cooling equipment and imprudent use of energy.

It is generally accepted that buildings can be designed to be energy effective if their thermal insulation is increased; window size, air leakage, and lighting levels decreased; shading devices properly installed; heating and cooling systems adequately designed, installed, and maintained; and their heat storage capability most fully utilized. These energy saving features, however, must be considered with reference to numerous constraints, such as added costs for material, construction and maintenance, conformance to local building codes, occupancy life styles, aesthetics, construction practices, and availability of equipment.

In spite of these constraints, there is sufficient engineering information and technical basis that exist today to warrant extensive studies on various design alternatives for heating and cooling the building to minimize the wasteful use of energy. Design and operation of heating and cooling systems based upon conventional steady-state calculations, for example, usually result in oversizing of equipment and overheating or cooling of the space to be controlled. An over-design system usually operates at lower efficiency and needs more material (consequently more energy) to produce it, thus creating a vicious cycle.

One effective way to design the heating and cooling systems which is optimum from the standpoint of energy consumption, peak power demand and many practical constraints mentioned above, is to study the building thermal performance by using accurate simulations. Because the use of computer simulations make it possible to evaluate the sensitivity of various design alternatives on the net energy usage, they can be a very effective tool in the design process. In order for such design studies to be conducted on the computer however, the computer program to be used should be very comprehensive and should indicate the proper response to the change of the many parameters which are pertinent to energy usage. The intent of this document is to present a more detailed calculation methodology than is generally used to make it possible for engineers to reduce the area of approximation, where this is considered desirable, by a rigorous computer simulation of building systems, which consider and take into account most of the variables that affect the building and system operation.

Refined and sophisticated calculation procedures unfortunately are both time consuming and expensive. Without the use of advanced computer methods, they are literally impossible. The development of such calculation procedures can only be justified on the basis that the more accurate calculation will result in overall savings in energy usage and owning and operating costs and consequently in total life cycle cost due to better design of the building systems, more precise sizing of the equipment, and more carefully controlled operation of the heating and cooling system. There are many indications that such a justification is well warranted.

2. Fundamentals of Heating and Cooling Load Calculation

Calculation of the energy requirements of the heating and cooling system of a building involves three major steps which may be carried out simply to achieve approximate results, or with increasing degrees of complexity and sophistication as more accurate and more refined determination of system performance is required. First, is the calculation of heat loss or heat gain to the space which is heated or cooled. Second, is the determination of the heating and cooling load imposed on the system. Third, is the calculation of the energy input to all of the system components to satisfy that load.

The ASHRAE Handbook of Fundamentals[2/] contains the basic information whereby the heating and cooling load of a building may be calculated. Customarily such load calculations are made for the so-called "design conditions" for sizing the equipment and developing the design of the heating and cooling system. However, the "design conditions" normally exist only for a very few hours, if at all, during a heating or cooling season. Consequently, the actual day-by-day and hour-by-hour heating and cooling load for energy consumption is quite different from that for the design condition. Thus the heating and cooling load calculation for the purpose of estimating "energy requirements" must reflect the actual weather conditions rather than a design condition.

Various methods have been developed in the past such as the "degree day" method or "bin" method for proportioning the design load, to obtain approximate monthly, daily, or hourly loads and consequently provide a basis for determining energy requirements. Insofar as such methods are based on valid approximation procedures and checked against actual operating experience, they provide the base for simplified determination of energy requirements acceptable for the needs of most engineers.

In this section a review of the rigorous methods of calculating heating and cooling loads by means of solving heat balance equations at all the interior surfaces of a room or space is given. Also described are approximate methods in which weighting factors are developed after the heat balance equations have been solved for one set of conditions. The NBSLD calculations follow the rigorous method while the ASHRAE Task Group procedures use the weighting factor method.

In NBSLD the transient heat conduction through exterior walls of the room or space is handled by using conduction transfer functions. The use of heat balance equations at the interior surfaces, although more time consuming, can avoid the vagueness and uncertainties inherent in the weighting factor approach. In addition, it is more accurate for a specific building design.

2.1 A Rigorous Method of Calculating Heating and Cooling Loads

A cooling (heating) load is of course the amount of energy that is transferred to (from) the room and simultaneously removed (added) by the conditioning equipment at any given time of interest. To calculate this quantity directly requires a rather laborious solution of energy balance equations involving the room air, surrounding walls, infiltrating and ventilation air, and internal energy sources. The principle of calculation can be demonstrated by considering a fictitious space that is enclosed by 4 walls, a ceiling and floor, and having infiltration air as well as normal internal energy sources. The six equations that govern energy exchange at each inside surface at a given time t are:

$$q_{i,t} = h_{ci} \, (t_{a,t} - t_{i,t}) + \sum_{\substack{j=1 \\ j \neq i}}^{m} g_{ij} \, (t_{j,t} - t_{i,t}) + RS_{i,t} + RL_{i,t} + RE_{i,t}$$

for i = 1, 2, 3, 4, 5, 6

where

m = number of surfaces in the space

$q_{i,t}$ = rate of heat conducted into surface i at the inside surface at time t

h_{ci} = convective heat transfer coefficient at interior surface i

g_{ij} = radiation heat transfer factor between interior surface i and interior surface j

$t_{a,t}$ = inside air temperature at time t

$t_{i,t}$ = average temperature of interior surface i at time t

$t_{j,t}$ = average temperature of interior surface j at time t

$RS_{i,t}$ = rate of solar energy coming through the windows and absorbed by surface i at time t

$RL_{i,t}$ = rate of heat radiated from the lights and absorbed by surface i at time t

$RE_{i,t}$ = rate of heat radiated from equipment and occupants and absorbed by surface i at time t

The equations governing conduction within the six slabs cannot be solved independent of the above equations since the energy exchanges occurring within the room affect the inside surface conditions which in turn affect the internal conduction. Consequently, one is faced with solving six equations simultaneously with the governing equations of conduction within six slabs in order to calculate the cooling load at time of interest ($Q_{L,t}$) which would be given by:

$$Q_{L,t} = \sum_{i=1}^{6} h_{ci} \, (t_{i,t} - t_{a,t}) + \rho \, C \, G_{L,t} \, (t_{o,t} - t_{a,t})$$

$$+ \rho \, C \, G_{v,t} \, (t_{v,t} - t_{a,t}) + RS_{a,t} + RL_{a,t} + RE_{a,t}$$

where

ρ = air density

C = air specific heat

$G_{L,t}$ = mass flow rate of outdoor air infiltrating into the space at time t

$t_{o,t}$ = outdoor air temperature at time t

$G_{v,t}$ = mass rate of flow of ventilation air at time t

$t_{v,t}$ = ventilation air temperature at time t

$RS_{a,t}$ = rate of solar heat coming through the windows and convected into the room air at time t

$RL_{a,t}$ = rate of heat from the lights convected into the room air at time t

$RE_{a,t}$ = rate of heat from equipment and occupants and convected into the room air at time t

A rigorous approach such as this for calculating cooling load would be practically impossible if it were not for the speed at which such computations can be done by modern digital computers. Even so, there are very few computer programs in use today where instantaneous cooling loads are calculated in this exact manner. The concept, however, has been presented previously by Stephenson and Mitalas[3/], and by Buchberg[4/].

Not to be ignored is the effect of air temperature deviation from some prescribed set point. This set point is the temperature for which the cooling (heating) load calculation is made and for which the design capacity of the cooling (heating) apparatus is usually selected. A recent study by Mitalas and Stephenson[5/] shows that actual heat extracted from the space is considerably smaller than the cooling load calculated on the basis of a constant space temperature. This is due to the thermal storage effect of the building structure and internal furnishings. Figure 1 shows a result from that study and as can be seen, the calculated cooling load peaks at values considerably higher than the measured heat extraction rate.

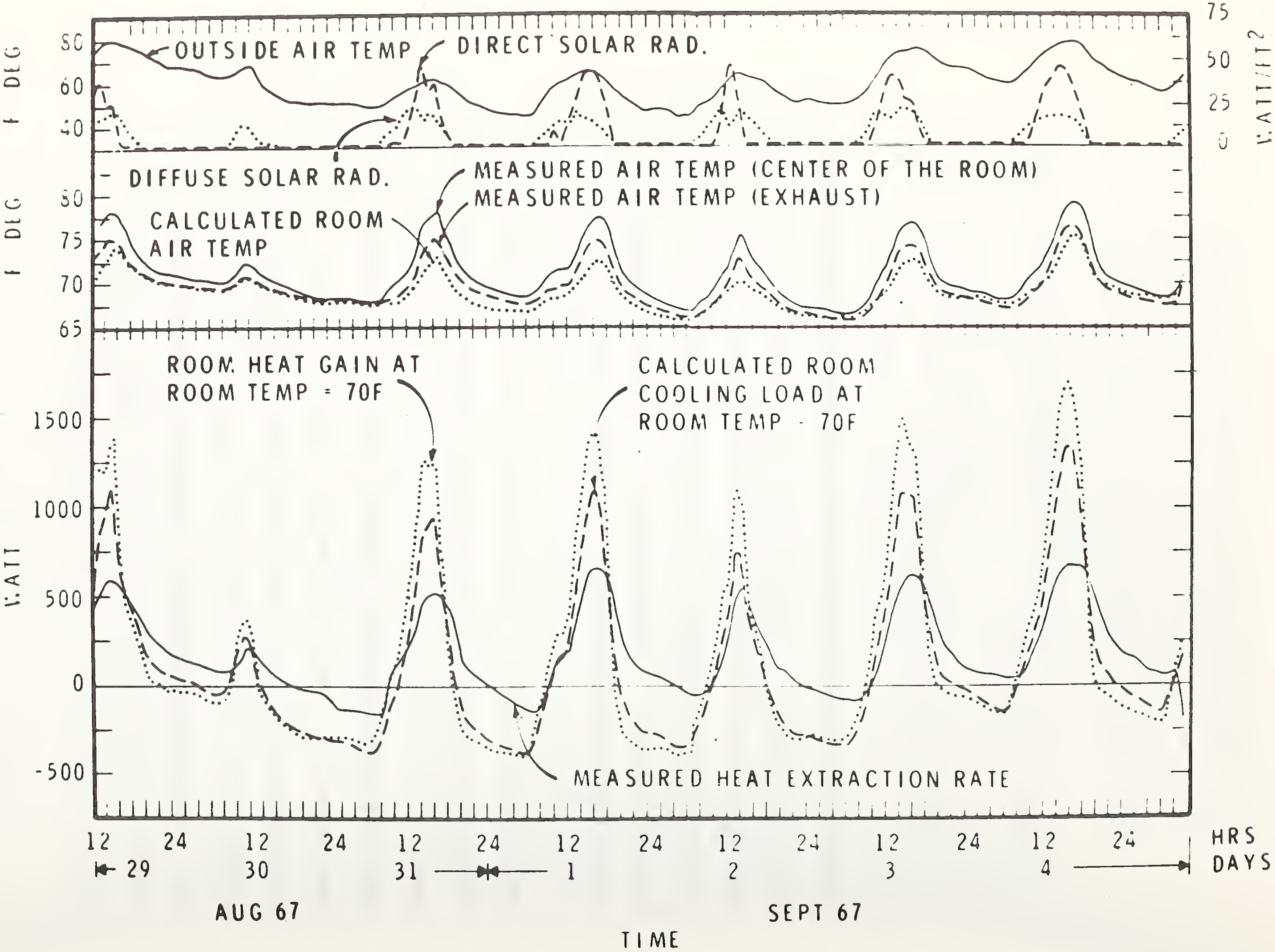

Figure 1 Measured and Calculated Thermal Performance in an Ottawa Office Building (Reference 4)

2.2 Approximate Methods of Calculating Heating and Cooling Loads

Since the exact solution technique is extremely time consuming especially for the calculations done for a period of 8760 hours (one year), the ASHRAE Task Group on Energy Requirements recommends a transfer function concept to simplify the calculation procedure. The transfer function concept was first introduced by Mitalas and Stephenson[3/] using what they called room thermal response factors. Their procedure is as follows: the room surface temperatures and cooling or heating load are first calculated by a rigorous method as described in the previous section for several typical constructions representing offices, schools and dwellings of heavy, medium and lightweight construction. In these calculations, the components such as solar heat gain, conduction heat gain, or the heat gain from the lighting, equipment, and occupants are simulated by pulses of unit strength. The transfer functions are then calculated as numerical constants which represent the cooling load (or heating) corresponding to the input excitation pulses. Once these transfer functions are determined for a number of typical constructions, they are assumed to be independent of input pulses and the determination of cooling loads (or heating) is possible without resorting to the rigorous calculations. The calculation required is, instead, simple multiplication of the transfer functions by a time-series representation of heat gain and the subsequent summation of these products, which can be carried out on a small computer with little effort.

Another way to shorten the computational effort for energy calculations is to determine regression parameters by fitting a simple algebraic equation to the results of rigorous calculations, which had been obtained not for an entire year but for a limited period in the year, such as for the months of January and/or July. Once this regression equation is determined with sufficient accuracy, an energy estimate is made by superimposing the weather conditions of the other months onto the relationships just determined.

An example of this approach is illustrated in Figure 2, which depicts the daily total heating and cooling load plotted against the daily average outdoor air temperature. This plot is a result of a lengthy rigorous calculation performed on a typical apartment in Jersey City using the annual hourly weather conditions that occurred in 1949. The straight lines superimposed on the figures were the least square regression lines that best fit the calculated loads for January and July. It was clear from this figure that the exact calculations for other months would not be necessary, at least for the purpose of determining daily loads, since the regression relationship determined from the January and July calculations were sufficiently accurate that they could be extrapolated to the remainder of the year.

Depending upon the type of building and its heating and cooling system, a good correlation such as illustrated in Figure 2 may not be possible. Figure 3 shows, for example, a similar plot for a test office building whose heating and cooling load were measured in a research project

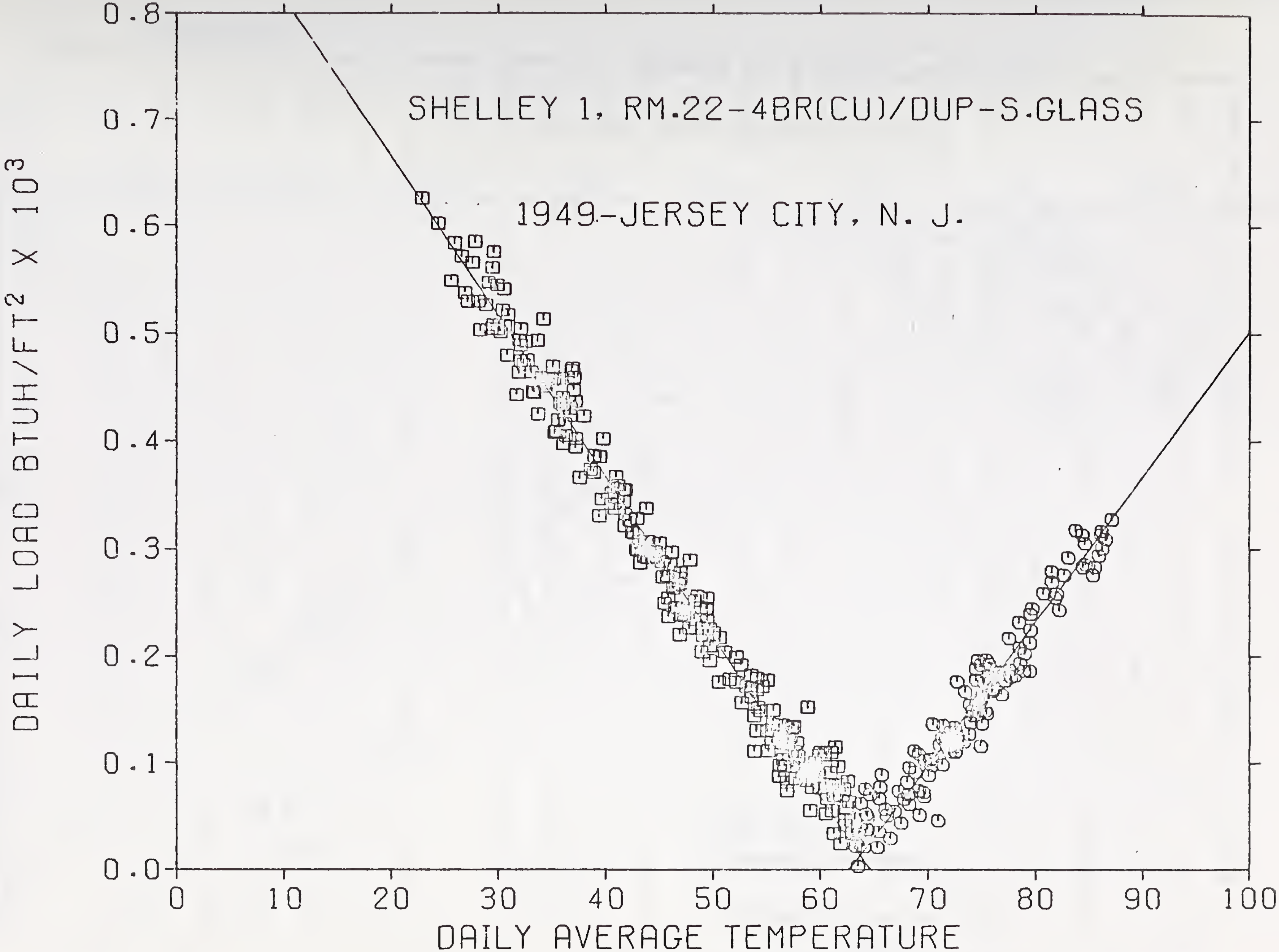

Figure 2 Calculated Daily Total Thermal Loads of a Jersey City Apartment Plotted Against Daily Average Temperatures

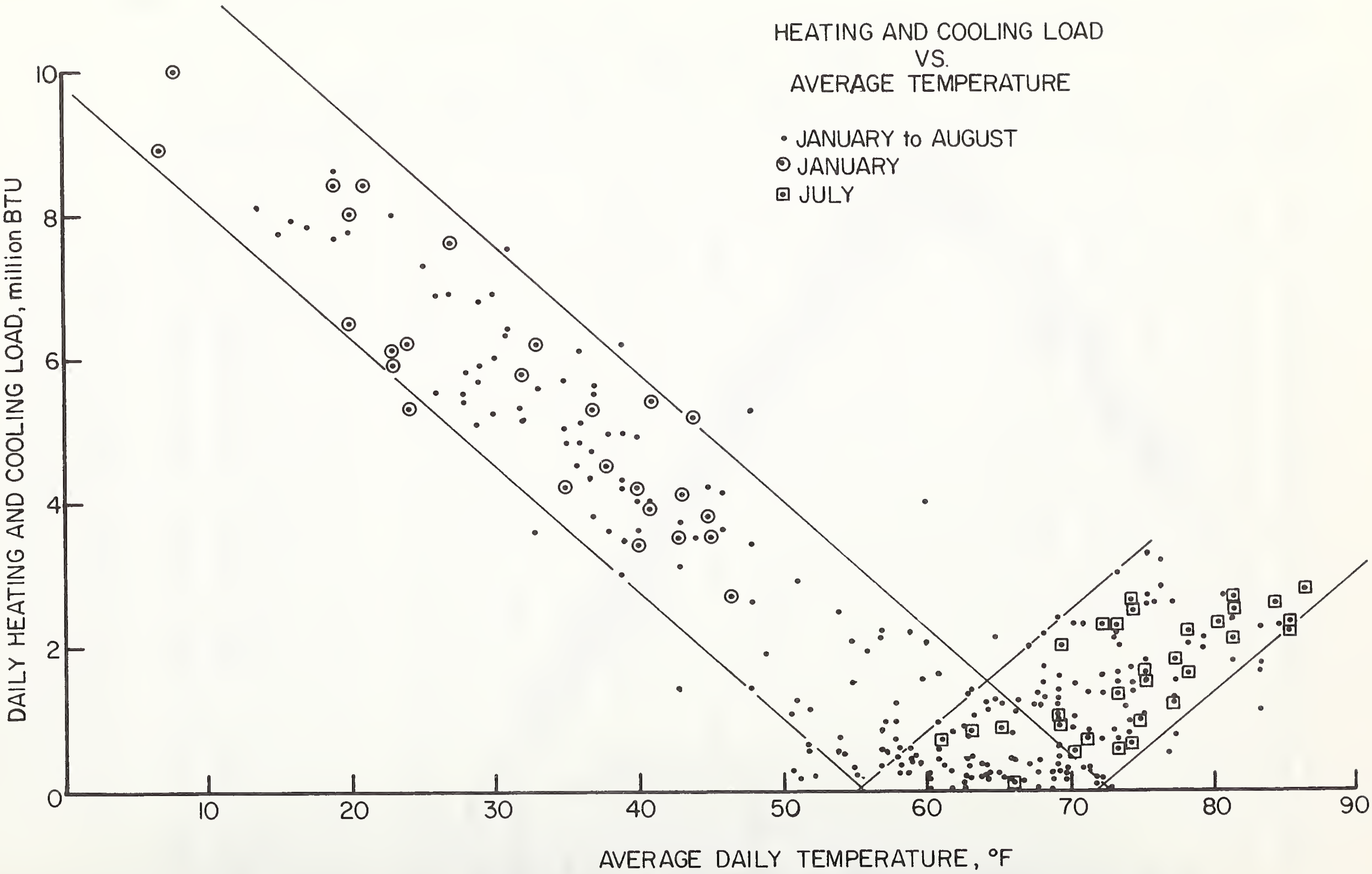

Figure 3 Measured Daily Total Thermal Loads of a Columbus Law Building Plotted Against Daily Average Temperatures

conducted by Ohio State University. The scatter appears considerably larger than the calculated relationship obtained in the Jersey City study. It is obvious that the thermal performance of commercial buildings are affected in a large way by the manner in which internal heat is generated in addition to the normal dependence on outdoor temperature. The inclusion of one or more additional statistical parameters dealing with these internal heat gains should improve the correlation.

Recently one additional method of predicting the heating and/or cooling load or the indoor temperature as a result of the excitation parameters such as outdoor temperature, solar radiation and internal heat generation has been demonstrated by Kusuda and Tsuchiya[6/] and further expanded by Kimura and Ishino[7/]. The method uses the concept of equivalent thermal mass of a building and attempts to fit the observed input and output data into a linear differential equation. The initial results are promising. Figure 4 shows a comparison of predicted and measured room temperature and heat extraction rate for a simple one room test building studied by Kimura and Ishino.

Calculated room temperature in Figure 4 is obtained by the transfer functions derived from the measured data of August 19, while the heat extraction was calculated by the transfer functions derived from the measured values of August 13. The good agreement indicated in Figure 4 implies that the detailed calculation is needed only for a limited number of days to derive accurate transfer functions based upon the equivalent thermal mass of the particular building under consideration.

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* Private communication with Professor C. F. Sepsey and J. Jones of the Ohio State University.

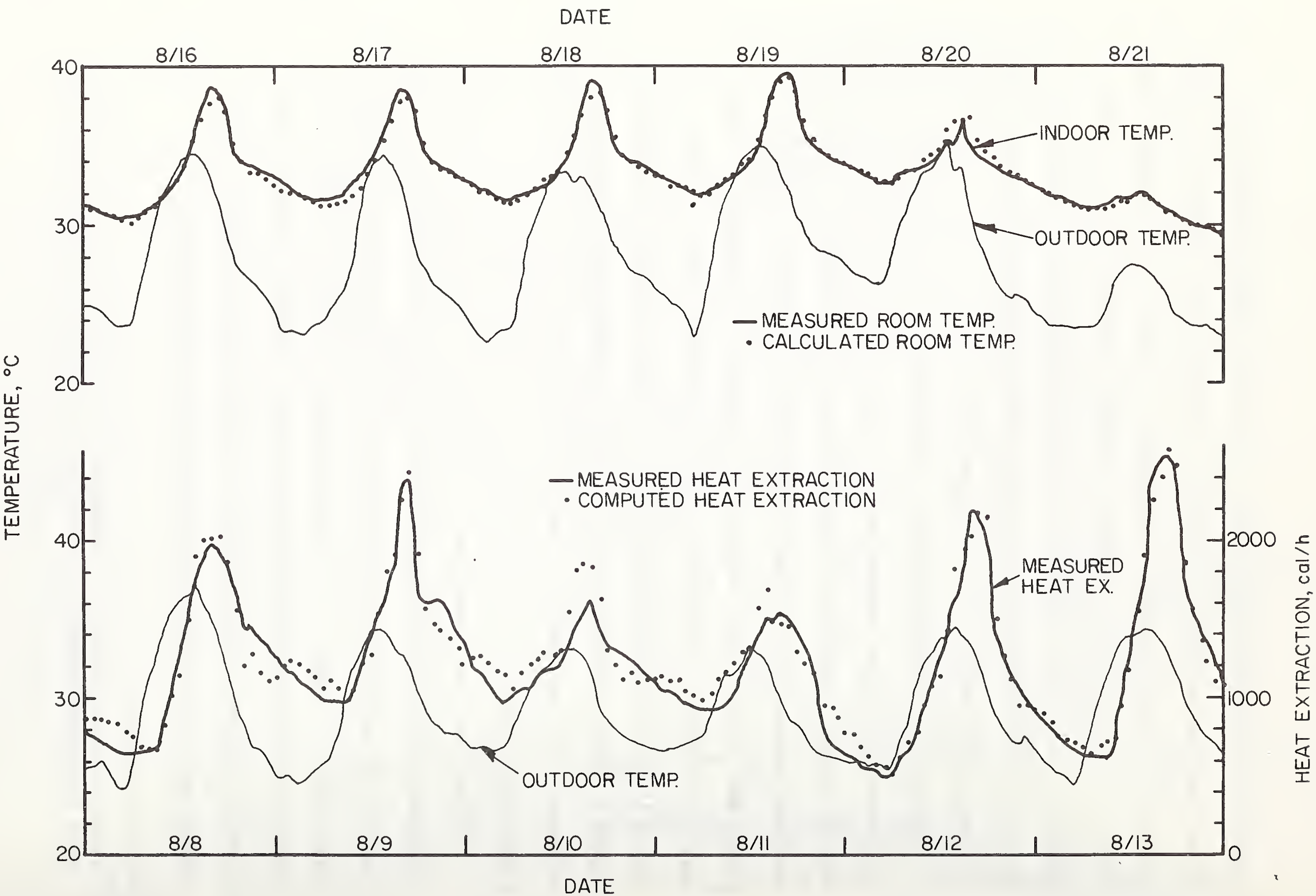

Figure 4 A Comparison of Measured and Calculated Thermal Performance of an Experimental Building (Courtesy of Professor K. Kimura)

3. Unique Features of NBS Load Calculation Computer Program

A comprehensive yet easy-to-use computer program for determining heating and cooling loads has been developed in the Thermal Engineering Systems Section of the Center for Building Technology at the National Bureau of Standards. This computer program is based upon extensive information accumulated over the past decades in various phases of building heat transfer problems, and is intended to be used for the design of equipment and air conditioning systems as well as for estimates of building energy requirements.

The major reason why NBS developed this comprehensive program is that despite the existence of numerous load calculation programs currently available, most of them are not suitable for the analysis of building designs where non-conventional or innovative ideas on structures, heating and cooling systems and controls are employed. Some of the unique aspects of building and system design and operation that can be handled by or studied by using NBSLD are:

1. Inside-out construction of exterior walls where the thermal insulation is placed on the outside of the building shell as opposed to conventional walls having insulation on the inside. (These two walls could have the same U-value and yet their thermal response would be quite different.)
2. Effect of interior partition walls or floor-ceiling sandwich structures on the heat storage characteristics of the room,

3. Off-peak heating or cooling of buildings to shave the peak heating or cooling demand,
4. Evaluation of intentionally <u>undersized heating and cooling equipment</u> by calculating the room temperature and humidity deviations from a design setpoint. (The results would indicate whether or not the indoor conditions would remain within acceptable limits.)
5. Evaluation of <u>indoor thermal environment</u> of various zones during the intermediate season, such as spring and autumn, when the heating or cooling requirements for these zones may not be in phase with that of the building as a whole. (This would apply to a case where a two-pipe system would be installed for example. The central system for the entire building might be switched to heating in late autumn and yet some zones, particularly those facing south may still require cooling. NBSLD can be used to determine the indoor thermal conditions of unheated or uncooled rooms.)
6. Use of <u>solar energy</u> for heating and cooling buildings as it relates to the thermal storage characteristics of the building,
7. Use of <u>attic ventilation</u> to reduce the cooling load since NBSLD can accurately predict attic temperatures,
8. Accurate determination of the need for heating and air conditioning in <u>basement rooms</u>,

9. Design of heating and cooling systems and equipment on the basis of intermittent operation, such as the shutdown of air conditioning facilities during the nighttime or weekends,

10. Effective use of natural air conditioning such as ventilation, shading, increased ceiling insulation and the subsequent determination of the requirements for mechanical cooling,

11. Effective use of planned ventilation to minimize a building heating load during the winter season,

12. Accurate evaluation of indoor comfort conditions based upon air temperature, humidity and mean-radiant temperature,

13. Determination of the condition whereby moisture condensation takes place along interior surfaces of a building, and

14. The effect of interior furnishings of various simple shapes upon the heating and cooling loads.

Figure 5 depicts an overall calculation sequence to attain the hour by hour heating and cooling load of buildings. Shown in the double lined boxes are input data to be supplied whereas those in single lined boxes indicate calculations to be performed. The cycle indicators show the iteration cycles for the number of buildings, the number of rooms in a given building and the number of days for which the calculations are performed. More specific identification of the types of input data needed

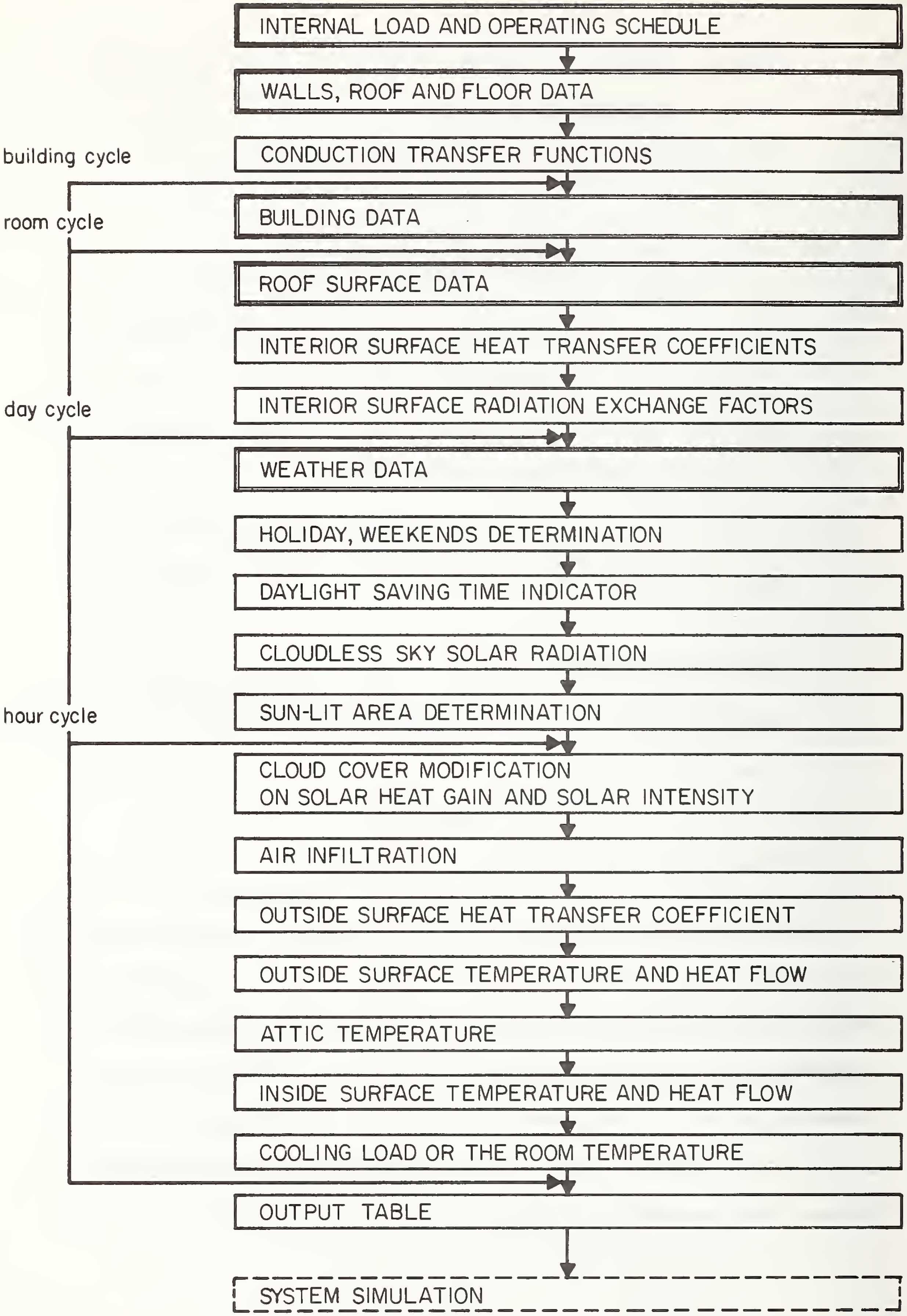

Figure 5 Calculation Sequence of NBSLD

INPUT - OPERATING DATA

- ELECTRIC POWER TO LIGHTS, WATTS PER SQUARE FOOT OF FLOOR (QLITY)
- HOUR BY HOUR LIGHTING SCHEDULE (QLITX)
- ELECTRIC POWER TO EQUIPMENT, WATTS PER SQUARE FOOT OF FLOOR (QEQPX)
- HOUR BY HOUR EQUIPMENT SCHEDULE (QEQUX)
- SUPPLY AIR RATE (CFMS)
- AIR LEAKAGE RATE (CFML)
- SUPPLY AIR TEMPERATURE (TS)

Figure 6

INPUT - BUILDING DATA

- ROOM NUMBER (ROOMNO)
- CEILING HEIGHT (H)
- ROOM LENGTH (L)
- ROOM WIDTH (W)
- NUMBER OF OCCUPANTS (QCU)
- OCCUPANT SCHEDULE (QOCUP)
- WINTER WINDOW OVERALL HEAT TRANSFER COEFFICIENT (UGLAS)
- GROUND FLOOR HEAT TRANSFER COEFFICIENT (UG)
- SUMMER INFILTRATION, AIR CHANGES PER HOUR (ARCHGS)
- WINTER INFILTRATION, AIR CHANGES PER HOUR (ARCHGW)
- TYPE OF HEAT TRANSFER EXPOSURES (ITYPE)
  -ROOFS-WALLS-WINDOWS-DOORS-FLOORS
- TYPE OF RESPONSE FACTORS TO BE USED (IRF)
  -HEAVY/LIGHT: ROOF, EXTERIOR WALLS, CEILING/FLOOR PARTITION
- U VALUE OF THE EXPOSURE (U) (ONLY WHEN RESPONSE FACTOR IS NOT CALCULATED)
- AREA OF THE EXPOSURE (A)
- ORIENTATION OF THE EXPOSURE (AZW) -N,E,S,W (ONLY FOR EXTERNALLY EXPOSED SURFACES)
- WINDOW SHADING COEFFICIENT (SHADE)
- SOLAR HEAT ABSORPTION COEFFICIENT FOR THE EXTERIOR SURFACE (ABSP)
- TIME INCREMENT OF TEMPERATURE DATA USED
- PROPERTIES OF BUILDING MATERIALS - THICKNESS - THERMAL CONDUCTIVITY - DENSITY - SPECIFIC HEAT
- NUMBER OF SURFACES IN EACH WALL (NS,NW,NN,NE)

Figure 7

INPUT - WEATHER DATA

- LATITUDE (LAT)
- LONGITUDE (LONG)
- TIME ZONE NUMBER (TZN)
- MONTH (MONTH)
- DAY (DAY)
- ELAPSED DAYS SINCE JANUARY 1 (ELAPS)

- MAXIMUM TEMPERATURE OF THE DESIGN DAY (DBMAX)
- DAILY TEMPERATURE RANGE OF THE DESIGN DAY (RANGE)
- DESIGN INDOOR TEMPERATURE CONDITION (DBIN)
- DESIGN OUTDOOR WET-BULB TEMPERATURE (WBMAX)
- DESIGN INDOOR WET-BULB TEMPERATURE (WBID)
- DESIGN WINTER OUTDOOR TEMPERATURE (DBMWT)
- DESIGN SUMMER GROUND TEMPERATURE (TG)
- DESIGN WINTER GROUND TEMPERATURE (TGW)

Figure 8

are listed in Figures 6, 7 and 8. The exact way the input data is put into the program is specified in Appendix C.

4. General Description of NBSLD Subroutines

In order to perform the chain of calculations depicted in Figure 5, a number of subroutines were developed at the National Bureau of Standards, the algorithms of which have already been published through the ASHRAE Task Group booklet entitled "Procedure for Determining Heating and Cooling Loads for the Computerized Energy Calculations". This booklet, however, contained several errors which have been corrected and is attached to this report as Appendix A. NBSLD incorporates most of the revised ASHRAE algorithms as they are written; however, some of them have been combined or split to fit the overall computational scheme in NBSLD. Listed below is a brief description of the NBSLD subroutines with their specific reference to the ASHRAE algorithms in parentheses.

1. ABCD, ABCDP, ABCD2, ABCDP2, DERVT, GPF, MULT, RESF, RESFX, RESPTK: These routines are parts of the conduction transfer functions calculation package and are needed for the accurate evaluation of thermal time lag, damping, heat storage in exterior facing surfaces as well as the internal furnishings. (XYZ)
2. AIRCON: This routine is used to determine instantaneous values of the physiological indices for the space being studied such as ASHRAE's New Effective Temperature, Predicted Mean Vote (Fanger), Heat Stress Index, KSU Index, Resultant Temperature, Operative Tempera-

ture, and Index of Thermal Stress (Givoni). - not included in the text

3. ATTIC: Attic space temperature and heat conduction through the ceiling into the room below are calculated by this routine for the vented or non-vented attics. (ATTIC)

4. CCM: This routine modifies the solar radiation computed for a cloudless sky by instantaneous cloud cover data. (CCF)

5. DPF: This routine calculates dew point temperature of atmospheric air when the partial vapor pressure is known. (PSY)

6. DST: This routine determines whether a given data is in a daylight saving time zone. The information is needed for the proper assignment of the energy usage schedule. (DST)

7. FCTR: This routine determines radiation exchange factors between any two surfaces which are part of a given room. For the room of six interior surfaces, for example, thirty radiation exchange factors are calculated. These factors are used in turn to determine the rate of heat exchange by radiation between all the interior surfaces. (FIJ)

8. F: This routine calculates radiation heat exchange factors (form factors) between two adjacent rectangular surfaces which are normal to each other, such as that between the floor and wall. (FIJ)

9. FO: This routine calculates the surface heat transfer coefficients for externally exposed surfaces from weather data. (FO)

10. GLASS: This routine calculates solar heat gain through glass when the shading coefficient, orientation, and type of glass are given. (SHG)

11. HOLDAY: This routine identifies the national holidays in the United States so that the proper holiday schedule can be used for the energy calculation. (HOLIDAY)

12. OUTSID: This routine calculates the outside surface temperature and heat gain into the wall or roof by taking into account solar heating, back radiation to the sky, convective heat loss to the ambient air and transient heat conduction within the wall or roof. (HEATW)

13. PSY1: This is a psychrometric routine that determines the thermodynamic properties of moist air when the dry-bulb temperature, wet-bulb temperature and barometric pressures are given. (PSY)

14. PSY2: This routine is similar to PSY1 except that the dew point temperature is required instead of the wet-bulb temperature. (PSY)

15. PVSF: This routine determines the saturated vapor pressure of atmospheric air as a function of temperature. (PSY)

16. RMTMP: This is the single most important subroutine of NBSLD since it determines the room temperature by solving matrix equations expressing a balance of heat gains, heat storage at the room surfaces, and cooling capacity of an air conditioning unit. However, the room temperature can be prescribed, in which case the routine will calculate the heating/cooling requirements to satisfy that prescribed temperature. (RMTMP)

17. ROOM: This routine reads in all the data required for the room heat transfer calculation such as dimensions, surface area, surface orientations, shading coefficients, surface solar absorptivity, etc.

18. SHG: This is the routine that calculates solar heat gain through glass. (SHG)

19. SOLVP: This routine solves the simultaneous linear algebraic equations that appear in RMTMP. (RMTMP)

20. SUN: Basic sun data such as solar angles, cloud cover, direct and diffuse radiation needed for solar heat gain and solar heating of the building exterior surfaces are calculated in this routine. (SUN, SOLAD)

21. TAR: This routine calculates transmission and absorption characteristics of glass. (TAR)

22. WBF: This is another psychrometric routine that calculates the wet-bulb temperature when the enthalpy of moist air and the barometric pressure are specified. (PSY)

23. WKDAY: This subroutine determines the day of week when the date and year are given. The information is needed for the proper selection of energy usage schedules which are dependent upon whether the day is a weekday or not. (WKDAY)

24. WD, WDX, DECODE, ERROR, WEATHE: The weather data tape 1440 supplied by the National Climatic Center, Asheville, N. C. is prepared in a format which cannot be readily applicable in most of the Fortran programs. These routines are therefore necessary to read the 1440 tapes and decode them into meaningful weather parameters, which in turn can be used by UNIVAC 1108 Fortran of the National Bureau of Standards. If there are some data which are unreasonable, the data will be replaced by the arithmetic average of two adjacent data by the ERROR routine. (CLIMAT)

All the subroutines in the program may be used to form a separate main program for a specific job. Following are sample usages of some of the subroutines.

1. Psychrometric Calculation

CALL PSY1 (DB, WB, PB, DP, PV, W, H, V, RH)

where inputs are DB = dry-bulb temperature

WB = wet-bulb temperature

PB = barometric pressure

outputs are DP = dew point temperature

PV = vapor pressure

W = humidity ratio

H = enthalpy

V = volume

RH = relative humidity

There is also a routine called PSY2 (DB, DP, PB, WB, PV, W, H, V, RH) in which the inputs are DB, DP and PB instead of DB, WB and PB. In many cases DB and RH are the inputs and the vapor pressure and dew point temperature or the wet-bulb temperature at standard barometric pressure are the outputs. A possible algorithm that could be desired, for example, might be:

```
PVS = PVSF (DB)
PV = PVS*RH/100
DP = DPF (PV)
Call PSY2 (DB, DP, PB, WB, PV, W, H, V, RH)
```

2. Solar radiation

Recently there has been increased interest in the application of solar energy for heating of hot water. SUN and GLASS routines should be valuable for evaluating various solar collectors at different locations in the United States at different times of the year. A sample use of these routines may be shown for a solar collector having the following characteristics (Figure 9)

location: latitude = 45°, longitude = 73°

azimuth angle = 0° south

tilt angle = 30° from horizontal surface

area = 500 ft^2

date = July 21

time = 4:00 p.m.

glass cover = double sheet - clear glass

U_R = overall heat transfer coefficient between the collector surface and the ambient, Btu/hr ft^2 °F*

U_W = overall heat transfer coefficient between the collector surface and water, which is being circulated under the collector plate, Btu/hr ft^2 °F

TWI = water temperature entering the collector, °F .

TWL = water temperature leaving the collector, °F

GPM = water circulation rate in gallons per minute

---

* When the collector temperature is less than 150 °F, the typical value of U_R for a flat black collector with double glass cover may be 0.75. The value increases to as much as 1.5 when the collector temperature is in the neighborhood of 300 °F. A special computer program is available for estimating the value of U_R for various types of collectors.

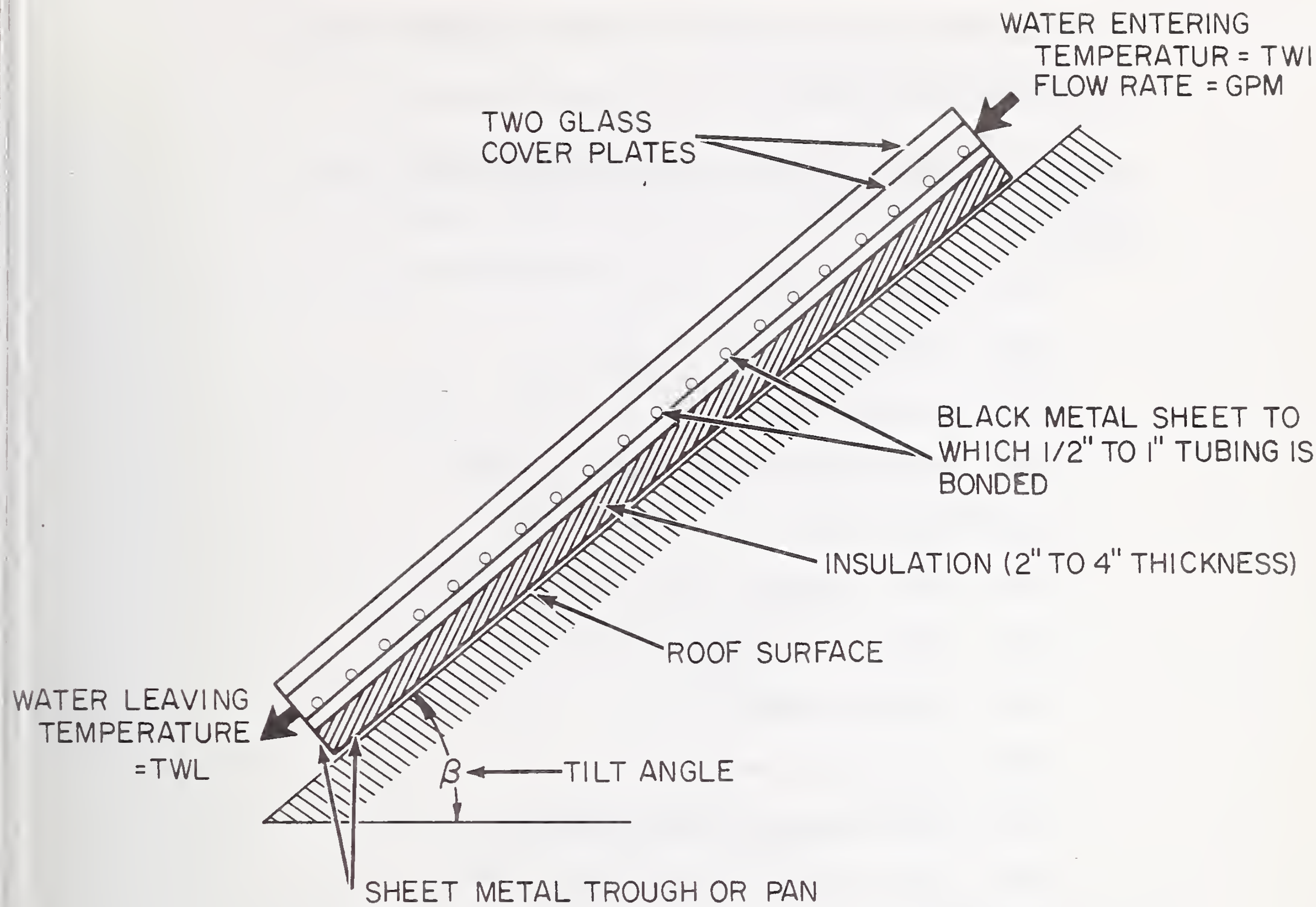

Figure 9 A Typical Flat Plate Solar Collector

It is assumed that the collector is well insulated around the edges and its bottom.

The algorithm for the use of SUN and GLASS routines would then be:

S(1) = LATITUDE = 30

S(2) = LONGITUDE = 73

S(3) = Time zone number = 5

S(4) = Elapsed days since January 1 = 202

S(5) = Time = 16

S(6) = IDST = daylight saving time index = 1

S(7) = Ground reflectivity = 0.2

S(8) = Clearness number = 1.0

S(33) = Cloud cover modifier = 1

S(9) = Azimuth angle of the collector = 0°

S(10) = Tilt angle of the collector = 30°

Call SUN

Call GLASS (SHDW, SHADE, GLASTP, GLAZE, SHG)

note: SHDW = sunlit area factor = 1

SHADE = shading coefficient = not applicable

GLASTP = 1/8" double strength glass (1)

GLAZE = double glazing (2)

SHG = solar heat gain - output

note: SUN and GLASS have S in common using the solar heat gain through the glass plate; the following calculation would be needed to estimate TS, collector surface temperature and TWL, leaving water temperature from the collector:

$$TS = \frac{U_R*DB + U_W*T_W + SHG}{U_R + U_W}$$

$$TWL = TWI + (TS - TWI)\ (1 - e^{-X})$$

$$\text{where} \quad X = \frac{U_W*A}{500*GPM}$$

5. NBSLD Logic Diagram

Figure 10 shows the way in which the various subroutines of NBSLD fit together in the usage of the program.

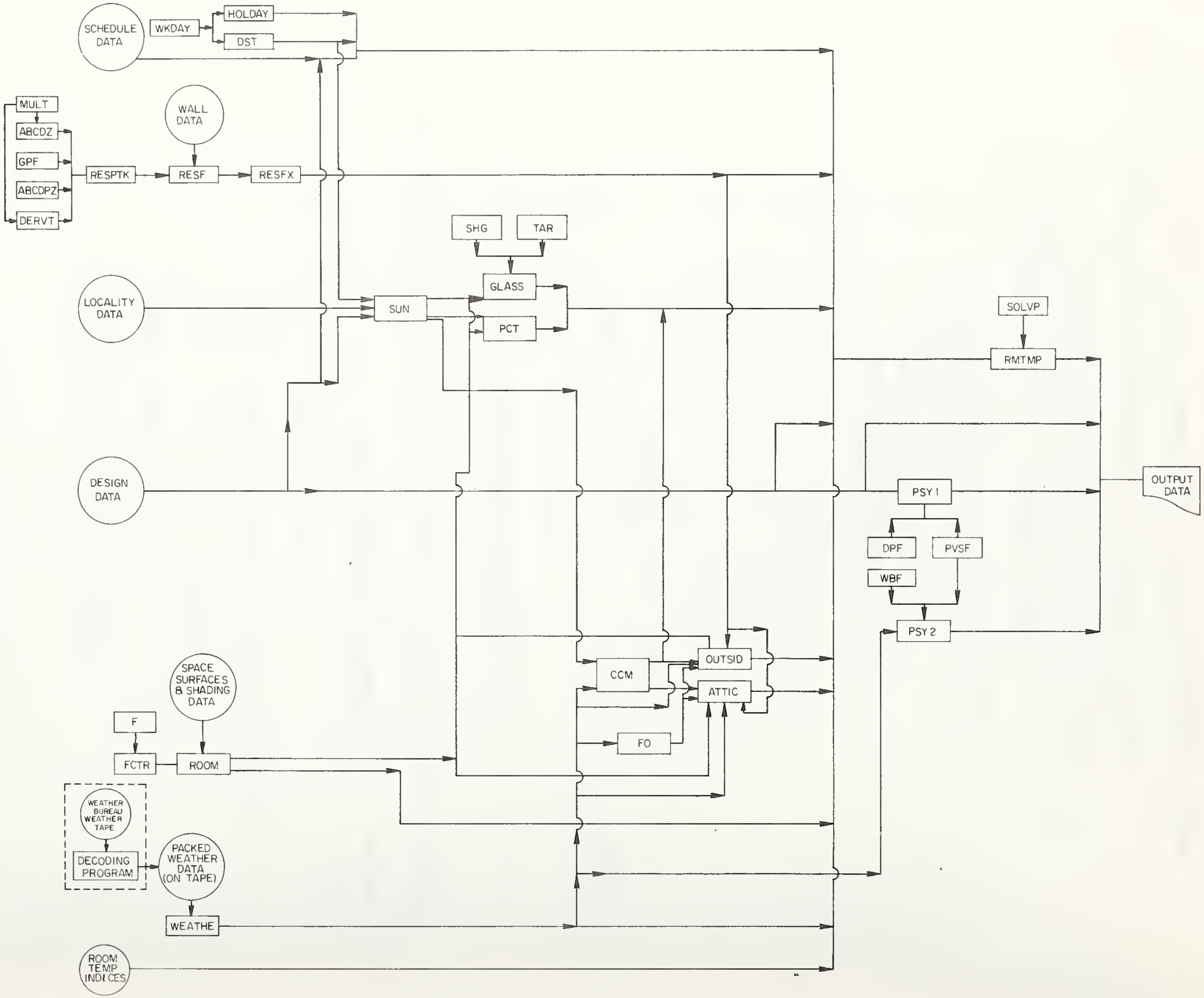

Figure 10 Interrelationship of Various Subroutines for NBSLD

6. References

1. "Pattern of Energy Consumption in the United States", Stanford Research Institute Report, pp. 6-7, January 1972.
2. "Heating Load" and "Air-Conditioning Cooling Load", ASHRAE Handbook of Fundamentals, Chapters 21 and 22, pp. 375-445, 1972.
3. Mitalas, G. P. and Stephenson, D. G., "Room Thermal Response Factors", ASHRAE Transactions, 1967, Vol. II, pp. III 2.1-2.10.
4. Buchberg, H., "Sensitivity of the Thermal Response of Buildings to Perturbations in the Climate", Building Science, Vol. 4, pp. 43-61, Pergamon Press, 1969.
5. Mitalas, G. P., "An Experimental Check on the Weighting Factor Method of Calculating Room Cooling Load", ASHRAE Transactions, 1969, pp. 222-232.
6. Kusuda, T., Tsuchiya, T. and Powell, F. J., "Prediction of Temperature by Using Equivalent Thermal Mass Response Factors", Proceedings of the 5th Symposium on Temperature, National Bureau of Standards, 1971.
7. Kimura, K. and Ishino, H., "Air Conditioning Load Calculation by the Equivalent Mass Weighting Factor Method for the Computerized Control", Proceedings of the Japanese Architectural Society, pp. 249-250, Kyushu meeting, October 1972 and Proceedings for the Second Symposium on the Use of Computers for Thermal Engineering Related to Buildings, COSTIC, 1974.

7. Appendix A

Subroutine Algorithms Prepared for the

ASHRAE Task Group on Energy Requirements

CLIMAT

A Procedure for Obtaining Climatic Weather Data

Climatic parameters needed for the hourly load calculations are:

DB:	Dry-bulb temperature, F
DP or WB:	Dew point or wet-bulb temperature, F
CT:	Cloud type
TC:	Total cloud amount
V:	Wind speed, knots
DIR:	Wind direction (clockwise from North), degrees
PB:	Barometric Pressure, in. Hg
ID:	Direct Solar Radiation, Btu per (hr) (sq ft)
$I_{d,sky}$:	Sky diffuse radiation, Btu per (hr) (sq ft)
$I_{d,ground}$:	Ground diffuse radiation, Btu per (hr) (sq ft)
Rain, Snowfall:	Precipitation data (Optional)

Hourly observations of these weather parameters for past years are available from the National Climatic Center either on magnetic tape or in card deck form. The hourly solar radiation data has been recorded for only approximately fifty stations throughout the United States (Table A-1). These data are, moreover, limited in their durations and completeness, and scarcely useful for the comprehensive energy analysis. On the other hand, the data series 144 includes the hourly observations of all of the parameters listed above except the solar radiation for more than 300 weather stations (Table A-2) covering a period of from ten to thirty years. Since the 144 series data are very much complete, it is recommended that hour by hour energy calculations be made with this series of data supplemented by simulated solar radiation data. A method for simulating solar radiation will be described later in this booklet.

Because of the specific coding scheme employed by the National Climatic Center for storing the hourly weather data onto the magnetic tapes, the 144 series is not directly usable by the standard Fortran programs. Different computing systems such as IBM 370, CDC 6600 and UNIVAC 1108 have their own decoding routines to read these tapes. Included in this section is a listing of a Fortran program which illustrates a decoding scheme required to make use of the weather tapes. This listing was prepared by Mr. McKay, Data Reduction Section, of the National Climatic Center, Asheville, North Carolina.

For further information on the procurement of weather tapes and possible assistance in decoding, the following office may be contacted:

Mr. G. McKay or D. Calloway
National Climatic Center
Applied Climatology Division
Federal Building
Asheville, North Carolina 28801
Tel. (704) 254-0961 x203

Table A-1 Solar Radiation Data

Albuquerque, New Mexico
Apalachicola, Florida
Barrow, Alaska
Bethel, Alaska

Bismark, North Dakota
Blue Hill/Milton, Massachusetts
Boston, Massachusetts
Brownsville, Texas

Canton Island
Cape Hatteras, North Carolina
Caribou, Maine
Charleston, South Carolina

Cleveland, Ohio
Columbia, Missouri
Dodge City, Kansas
El Paso, Texas

Ely, Nevada
Fairbanks, Alaska
Fort Worth, Texas
Fort Worth, Texas

Fresno, California
Grand Lake/Granby, Colorado
Great Falls, Montana
Hatteras, North Carolina
Inyokern, California

Lake Charles, Louisiana
Lake Charles, Louisiana
Lincoln, Nebraska
Lincoln, Nebraska

Los Angeles, California
Madison, Wisconsin
Matanuska, Alaska
Medford, Oregon

Miami, Florida
Nashville, Tennessee
New York, New York
Oak Ridge, Tennessee

Omaha, Nebraska (North Omaha)
Phoenix, Arizona
Riverside, California
Santa Maria, California

Santa Maria, California
Sault Ste. Marie, Michigan
Seattle, Washington
Sterling, Virginia

Tucson, Arizona
Upton, New York
Wake Island
Washington, D. C.

Table A-2

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ENVIRONMENTAL DATA SERVICE

Stations for which Local Climatological Data are issued, as of January 1, 1972

	ALABAMA
abc	Birmingham
abc	Huntsville
abc	Mobile
abc	Montgomery
	ALASKA
abc	Anchorage
abc	Annette
abc	Barrow
abc	Barter Island
abc	Bethel
abc	Bettles
abc	Big Delta
abc	Cold Bay
abc	Fairbanks
abc	Gulkana
abc	Homer
abc	Juneau
abc	King Salmon
abc	Kotzebue
abc	McGrath
abc	Nome
abc	St. Paul Island
abc	Shemya
abc	Summit
abc	Talkeetna
abc	Unalakleet
abc	Yakutat
	ARIZONA
abc	Flagstaff
abc	Phoenix
abc	Tucson
abc	Winslow
abc	Yuma
	ARKANSAS
abc	Fort Smith
abc	Little Rock
	CALIFORNIA
abc	Bakersfield
abc	Bishop
ac	Blue Canyon
ac	Eureka
abc	Fresno
abc	Long Beach
abc	Los Angeles Airport
ac	Los Angeles Civic Center
abc	Mt. Shasta
abc	Oakland
abc	Red Bluff
abc	Sacramento
abc	Sandberg
abc	San Diego
	San Francisco
abc	Airport
ac	City
abc	Santa Maria
abc	Stockton
	COLORADO
abc	Alamosa
abc	Colorado Springs
abc	Denver
abc	Grand Junction
abc	Pueblo
	CONNECTICUT
abc	Bridgeport
abc	Hartford
	DELAWARE
abc	Wilmington
	DISTRICT OF COLUMBIA
abc	Washington-National AP
abc	Washington-Dulles Int'l AP
	FLORIDA
ac	Apalachicola
abc	Daytona Beach
abc	Fort Myers
abc	Jacksonville
abc	Key West
ac	Lakeland
abc	Miami
abc	Orlando
abc	Pensacola
abc	Tallahassee
abc	Tampa
abc	West Palm Beach
	GEORGIA
abc	Athens
abc	Atlanta
abc	Augusta
abc	Columbus
abc	Macon
ac	Rome
abc	Savannah
	HAWAII
abc	Hilo
abc	Honolulu
abc	Kahului
abc	Lihue
	IDAHO
abc	Boise
abc	Lewiston
abc	Pocatello
	ILLINOIS
ac	Cairo
	Chicago
abc	Midway Airport
ab	O'Hare Airport
abc	Moline
abc	Peoria
abc	Rockford
abc	Springfield
	INDIANA
abc	Evansville
abc	Fort Wayne
abc	Indianapolis
abc	South Bend
	IOWA
abc	Burlington
abc	Des Moines
abc	Dubuque
abc	Sioux City
abc	Waterloo
	KANSAS
abc	Concordia
abc	Dodge City
abc	Goodland
abc	Topeka
abc	Wichita
	KENTUCKY
abc	Lexington
abc	Louisville
	LOUISIANA
abc	Alexandria
abc	Baton Rouge
abc	Lake Charles
abc	New Orleans
abc	Shreveport
	MAINE
abc	Caribou
abc	Portland
	MARYLAND
abc	Baltimore
	MASSACHUSETTS
abc	Boston
ac	Blue Hill Obs.
abc	Worcester
	MICHIGAN
abc	Alpena
	Detroit
abc	City Airport
abc	Detroit Metro AP
abc	Flint
abc	Grand Rapids
abc	Houghton Lake
abc	Lansing
ac	Marquette
abc	Muskegon
abc	Sault Ste. Marie
	MINNESOTA
abc	Duluth
abc	International Falls
abc	Minneapolis-St. Paul
abc	Rochester
abc	St. Cloud
	MISSISSIPPI
abc	Jackson
abc	Meridian
	MISSOURI
abc	Columbia
abc	Kansas City
abc	St. Joseph
abc	St. Louis
abc	Springfield
	MONTANA
abc	Billings
abc	Glasgow
abc	Great Falls
abc	Havre
abc	Helena
abc	Kalispell
abc	Miles City
abc	Missoula
	NEBRASKA
abc	Grand Island
ac	Lincoln
abc	Norfolk
abc	North Platte
abc	Omaha
abc	Scottsbluff
ac	Valentine
	NEVADA
abc	Elko
abc	Ely
abc	Las Vegas
abc	Reno
abc	Winnemucca
	NEW HAMPSHIRE
abc	Concord
ac	Mt. Washington
	NEW JERSEY
	Atlantic City
abc	Airport
a	State Marina
abc	Newark
ac	Trenton
	NEW MEXICO
abc	Albuquerque
ac	Clayton
abc	Roswell
	NEW YORK
abc	Albany
abc	Binghamton
	NEW YORK (Contd.)
abc	Buffalo
	New York
abc	Central Park
abc	J.F. Kennedy Int'l AP
abc	LaGuardia Field
abc	Rochester
abc	Syracuse
	NORTH CAROLINA
abc	Asheville
abc	Cape Hatteras
abc	Charlotte
abc	Greensboro
abc	Raleigh
abc	Wilmington
	NORTH DAKOTA
abc	Bismarck
abc	Fargo
abc	Williston
	OHIO
abc	Akron-Canton
	Cincinnati
ac	Abbe Obs.
abc	Airport
abc	Cleveland
abc	Columbus
abc	Dayton
abc	Mansfield
abc	Toledo
abc	Youngstown
	OKLAHOMA
abc	Oklahoma City
abc	Tulsa
	OREGON
abc	Astoria
abc	Burns
abc	Eugene
abc	Meacham
abc	Medford
abc	Pendleton
abc	Portland
abc	Salem
abc	Sexton Summit
	PACIFIC ISLANDS
abc	Guam
abc	Johnston
abc	Koror
abc	Kwajalein
abc	Majuro
abc	Pago Pago
abc	Ponape
abc	Truk (Moen)
abc	Wake
abc	Yap
	PENNSYLVANIA
abc	Allentown
abc	Erie
abc	Harrisburg
abc	Philadelphia
	Pittsburgh
abc	Airport
ac	City
abc	Scranton
abc	Williamsport
	RHODE ISLAND
ac	Block Island
abc	Providence
	SOUTH CAROLINA
	Charleston
abc	Airport
a	City
abc	Columbia
abc	Greenville-Spartanburg
	SOUTH DAKOTA
abc	Aberdeen
abc	Huron
abc	Rapid City
abc	Sioux Falls
	TENNESSEE
abc	Bristol
abc	Chattanooga
abc	Knoxville
abc	Memphis
abc	Nashville
	Oak Ridge
a	Area Stations
ac	City
	TEXAS
abc	Abilene
abc	Amarillo
abc	Austin
abc	Brownsville
abc	Corpus Christi
abc	Dallas
abc	Del Rio
abc	El Paso
abc	Fort Worth
ac	Galveston
abc	Houston
abc	Lubbock
abc	Midland
abc	Port Arthur
abc	San Angelo
abc	San Antonio
abc	Victoria
abc	Waco
abc	Wichita Falls
	UTAH
ac	Milford
abc	Salt Lake City
abc	Wendover
	VERMONT
abc	Burlington
	VIRGINIA
abc	Lynchburg
abc	Norfolk
abc	Richmond
abc	Roanoke
ab	Wallops Island
	WASHINGTON
abc	Olympia
abc	Quillayute Airport
abc	Seattle-Tacoma AP
abc	Spokane
abc	Stampede Pass
ac	Walla Walla
abc	Yakima
	WEST INDIES
abc	San Juan, P. R.
	WEST VIRGINIA
abc	Beckley
abc	Charleston
abc	Elkins
abc	Huntington
ac	Parkersburg
	WISCONSIN
abc	Green Bay
abc	La Crosse
abc	Madison
abc	Milwaukee
	WYOMING
abc	Casper
abc	Cheyenne
abc	Lander
abc	Sheridan

a. Monthly summary issued. b. Monthly summary includes available 3-hourly observations. Published if 5 or more available per day. c. Annual Summary issued.

Subscription Price: Monthly Local Climatological Data $2.00 per year including annual Summary if published. Single copy prices: 20 cents for monthly Summary; 15 cents for annual Summary. Back issues sell at single copy rates. Checks and money orders should be made payable to, and remittances and correspondence should be sent to the Superintendent of Documents, Government Printing Office, Washington, D. C., 20402.

USCOMM-NOAA-ASHEVILLE,N.C.-3-31-72--3000

```
      SUBROUTINE SIGNCK(IFLD,ISGN)
C     THIS SUBROUTINE WILL TEST ANY PSYCHROMETRIC WITH A SIGN
C     OVER UNITS POSITION READ AS A1 AND THE HIGH ORDER POSITION
C     AS AN I SPEC OF PROPER WIDTH.
C     THE SIGN SHOULD ENTER THE PARAMETER LIST AS ISGN,
C     THE REMAINING PORTION AS IFLD.
C     UPON RETURN FROM THIS ROUTINE, THE VALUE OF THE FIELD
C     WILL BE AN INTEGER WITH PROPER SIGN.
C     IT WILL BE THE USER RESPONSIBILITY TO CONVERT THIS TO REAL
C     FORM WITH PROPER DECIMAL ALIGNMENT.
C     INVALID CONDITION CAUSED IFLD TO BE SET TO 9999

      DIMENSION IP(10),MIN(10),NUM(10)
                                                         +
      DATA IP/'A','B','C','D','E','F','G','H','I','Ø'/
      DATA MIN/'J','K','L','M','N','O','P','Q','R','Ø̄'/
      DATA NUM/1,2,3,4,5,6,7,8,9, Ø /,IAST/'*'/
      IF (ISGN.EQ.IAST) GO TO 16
      DO 14 K=1,10
      IF(ISGN.EQ. IP(K)) GO TO 20
      IF(ISGN.EQ.MIN(K)) GO TO 22
14    CONTINUE
16    IFLD+9999
      RETURN
20    IFLD=IFLD*10+NUM(K)
      RETURN
22    IFLD= -(IFLD*10+NUM(K))
      RETURN
      END
```

An Algorithm to Find Solar Position, and Intensity of Direct Normal and Diffuse Radiation

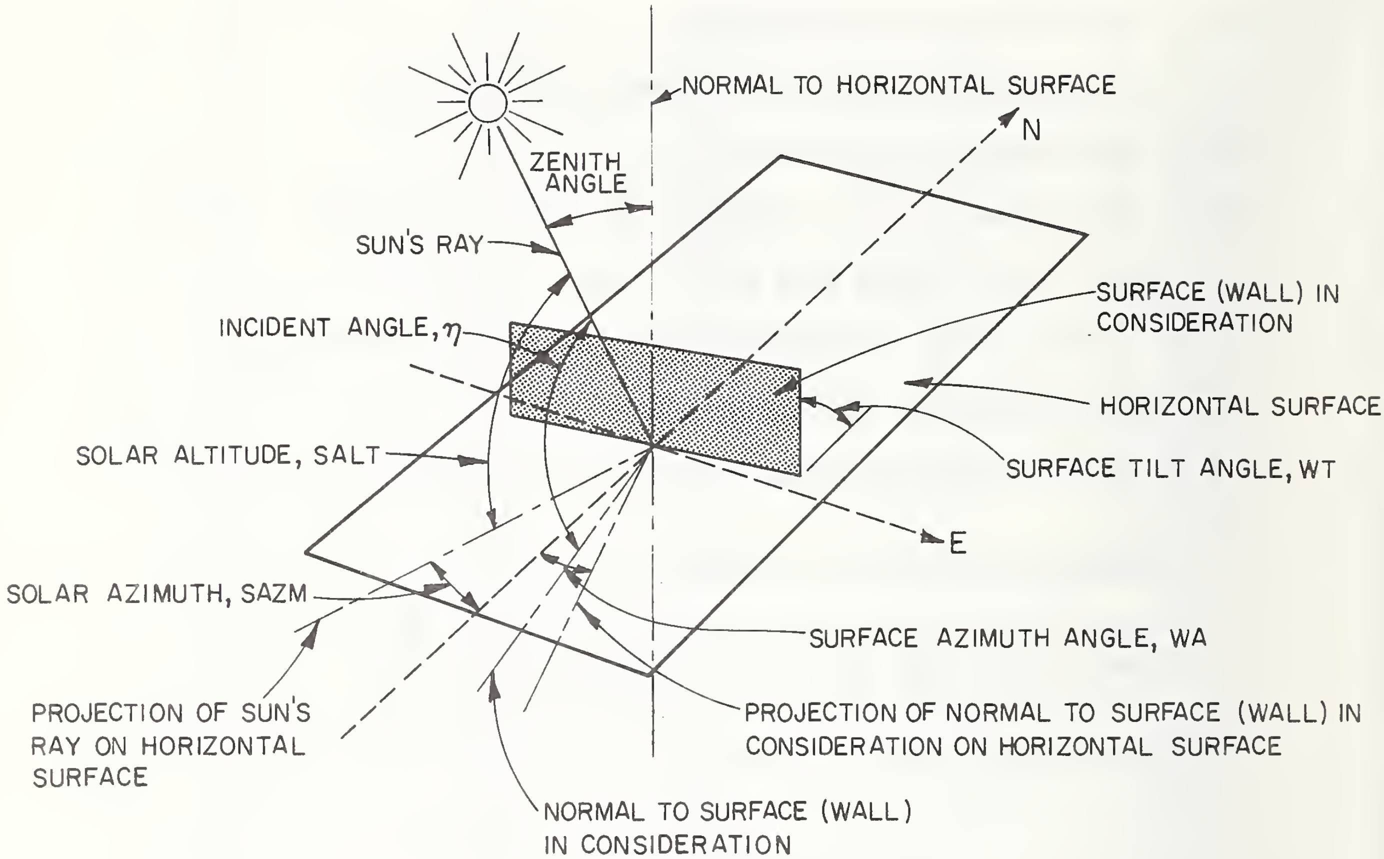

Figure A-1 Solar Angles for Tilted and Horizontal Surfaces

Figure A-1 DEFINITIONS OF SOLAR ANGLE

Data:

L: Latitude, degrees, $\begin{bmatrix} +\text{North} \\ -\text{South} \end{bmatrix}$

ℓ: Longitude, degrees, $\begin{bmatrix} +\text{West} \\ -\text{East} \end{bmatrix}$

TZN: Time zone number (hours behind Greenwich mean time), (see Figure A-3 and Table A-4)

d: Date, days (from start of year), (1 - 366)

t: Time, hours (after midnight), (0 - 24)

DST: Daylight saving time indicator (Output of DST), 0 for standard time and 1 for daylight saving time

ρ_g: Ground reflectivity

CN: Clearness number (see Figure A-4)

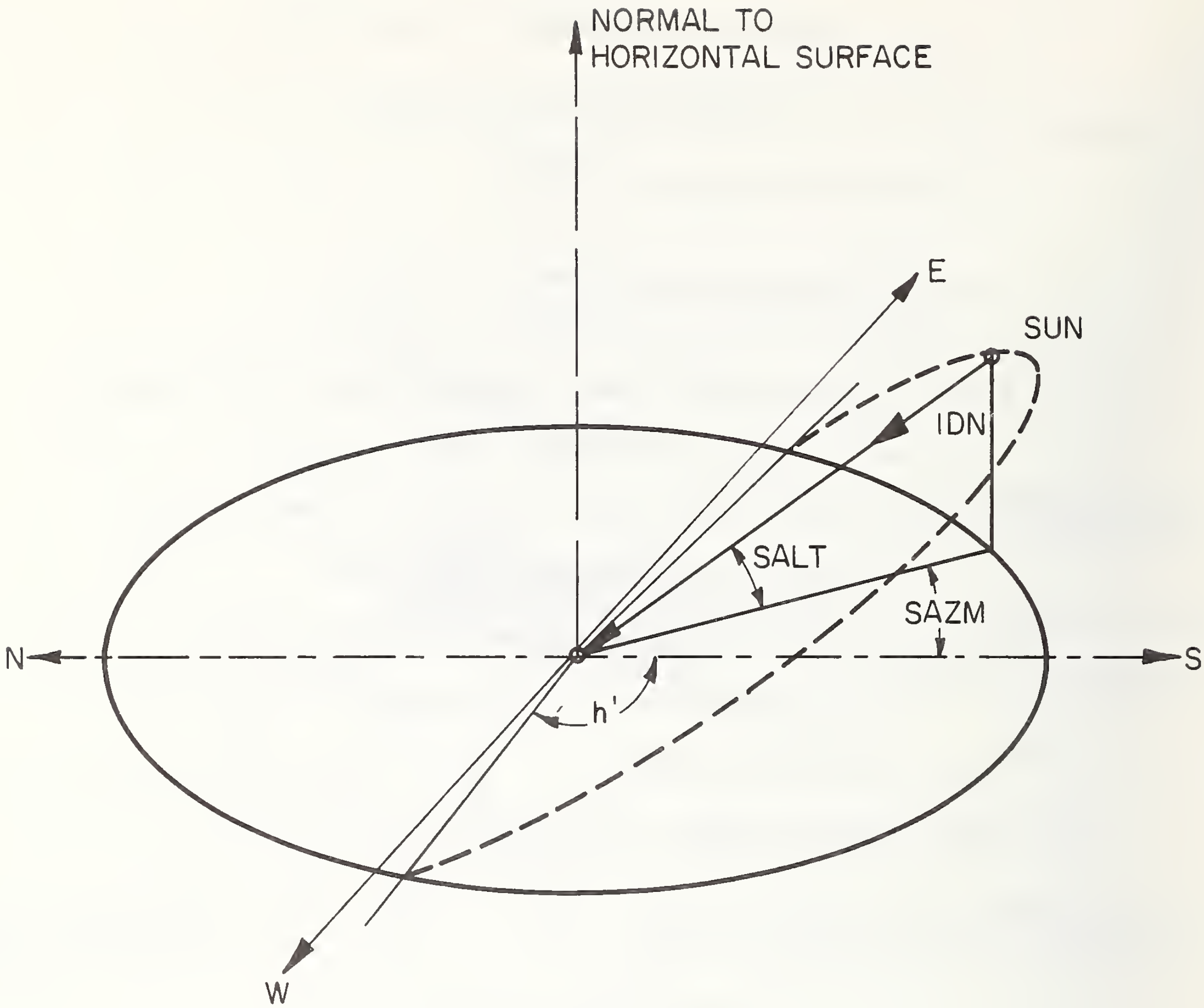

Figure A-2 Schematic Showing Apparent Path of Sun and Hour Angle

Figure A-3 Time Zones in the United States

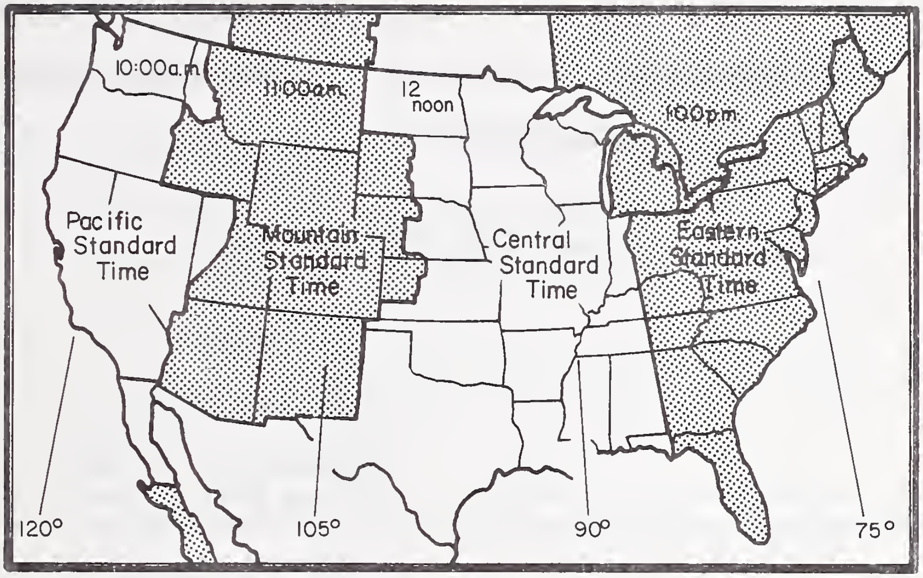

Table A-3 Time Zone Numbers in U. S. for Standard Time

TIME ZONE	TZN
Atlantic	4
Eastern	5
Central	6
Mountain	7
Pacific	8

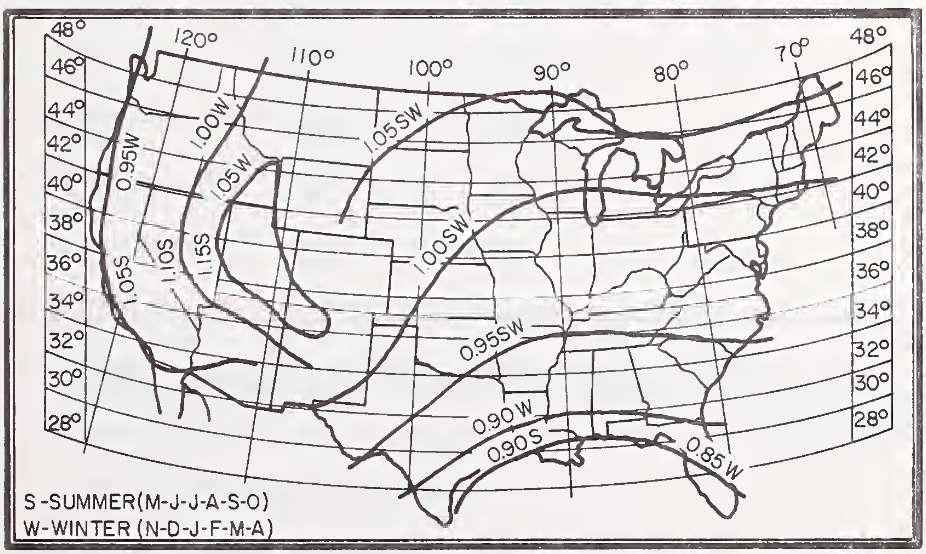

Figure A-4 Clearness Numbers of Non-Industrial Atmosphere in United States

Table A-4 lists, as function of date, five variables related to solar radiation. These variables are declination angle, δ; the equation of time, ET; the apparent solar constant, A; the atmospheric extinction coefficient, B; the sky diffuse factor, C.

TABLE A-4 VALUES OF δ, ET, A, B AND C*

Date	δ Degrees	ET Hours	A Btu Per (hr) (sq ft)	B Air Mass^{-1}	C
Jan. 21	-20.0	-.190	390	0.142	0.058
Feb. 21	-10.8	-.230	385	0.144	0.060
Mar. 21	0.0	-.123	376	0.156	0.071
Apr. 21	11.6	.020	360	0.180	0.097
May 21	20.0	.060	350	0.196	0.121
June 21	23.45	-.025	345	0.205	0.134
July 21	20.6	-.103	344	0.207	0.136
Aug. 21	12.3	-.051	351	0.201	0.122
Sept. 21	0.0	.113	365	0.177	0.092
Oct. 21	-10.5	.255	378	0.160	0.073
Nov. 21	-19.8	.235	387	0.149	0.063
Dec. 21	-23.45	.033	391	0.142	0.057

* Derived from the 1972 ASHRAE Handbook of Fundamentals, Table 1, p. 387, Chapter 22.

Calculation Sequence:

1. Determine δ, ET, A, B, and C from Table A-4

2. $h' = COS^{-1} (-TAN(L)*TAN(\delta))$ (see Figure A-2)

3. $Y = h'*12/\pi$

4. Sunrise time (SRT) and sunset time (SST) in hr

   $SRT = 12-Y-ET-TZN + \ell/15$

   $SST = 24-SRT$

5. Hour angle h in degrees

   $h = 15*(t-12+TZN+ET) - \ell$

   If /h/ > /h'/ skip all the remaining calculations in this sequence and set

   IDN = 0

   BS = 0

   BG = 0

6. Direction cosines of direct solar beam

   $COS(Z) = SIN(L)*SIN(\delta) + COS(L)*COS(\delta)*COS(h)$

   $COS(W) = COS(\delta)*SIN(h)$

   $COS(S) = (1-(COS(Z))**2 - (COS(W))**2)**0.5$

   If $Cos(h) > TAN(\delta)/TAN(L)$, COS(S) is positive

7. Solar altitude angle in radians

   $SALT = SIN^{-1} (COS(Z))$

8. Solar azimuth angle in radians

   $SAZM = SIN^{-1} (COS(W)/COS(SALT))$, if $COS(S) > 0$

   $SAZM = \pi-SIN^{-1} (COS(W)/COS(SALT))$, if $COS(S) < 0$

9. Intensity of direct solar radiation for a cloudless condition

   $IDN = A*CN*Exp(-B/COS(Z))$

10. Diffuse sky radiation (sky brightness) for a cloudless condition

$$BS = C*IDN/(CN)**2$$

11. Ground reflected radiation for a cloudless condition (ground brightness)

$$BG = \rho_g*(BS + IDN*COS(Z))$$

Calculation Modification for Southern Hemisphere:

The preceding algorithm is applicable to the northern hemisphere only. For buildings in the southern hemisphere, the following modifications are required.

1. Shift values of B and C in Table A-4 by six months. Values of δ, ET, A, B and C for the southern hemisphere are shown in Table A-5.

TABLE A-5 VALUES OF δ, ET, A, B and C FOR SOUTHERN HEMISPHERE

Date	δ Degrees	ET Hours	A Btu per (hr) (sq ft)	B Air Mass^{-1}	C
Jan. 21	-20.0	-.190	390	0.207	0.136
Feb. 21	-10.8	-.230	385	0.201	0.122
Mar. 21	0.0	-.123	376	0.177	0.092
Apr. 21	11.6	.020	360	0.160	0.073
May 21	20.0	.060	350	0.149	0.063
June 21	23.45	-.025	345	0.142	0.057
July 21	20.6	-.103	344	0.142	0.058
Aug. 21	12.3	-.051	351	0.144	0.060
Sept. 21	0.0	.113	365	0.156	0.071
Oct. 21	-10.5	.255	378	0.180	0.097
Nov. 21	-19.8	.235	387	0.196	0.121
Dec. 21	-23.45	.033	391	0.205	0.134

If $L \geq 0$ and if $\mathrm{Cos}(h) > (\mathrm{Tan}(\delta)/\mathrm{Tan}(L))$, Cos(s) is positive, and if $\mathrm{Cos}(h) \leq (\mathrm{Tan}(\delta)/\mathrm{Tan}(L))$, Cos(s) is negative.

If $L < 0$ and if $\mathrm{Cos}(h) \leq (\mathrm{Tan}(\delta)/\mathrm{Tan}(L))$, Cos(s) is positive, if $\mathrm{Cos}(h) > (\mathrm{Tan}(\delta)/\mathrm{Tan}(L))$, Cos(s) is negative.

An Algorithm for the Calculation of Cloudy Day Solar Radiation

This routine estimates the factor called CCF to modify the total solar radiation on a horizontal surface with the observed cloud cover data for a cloudy sky condition. The cloud cover observations are made every hour at major weather stations by experienced observers who estimate the amount of cloud on a scale of 0 to 10 and indicate the type of cloud in four different layers. Kimura and Stephenson[1/] analyzed 1967 Canadian data for observed solar radiation with respect to the cloud cover data, type of cloud, and the calculated solar radiation under a cloudless condition at the same solar time. Based upon their analysis, a comprehensive methodology was developed for calculating the cloudy day solar radiation. The value of CCF, Cloud Cover Factor, is first defined as follows:

$$CCF = ITHC/ITH$$

where

ITHC: Total solar radiation on a horizontal surface under a cloudy sky of given cloud amount and types of cloud

ITH: Total solar radiation calculated for a horizontal surface under a cloudless sky at the same solar hour as of ITHC

Data:

IS: Season index

CA_j: Cloud amount at the j-th layer, where j = 1, 2, 3, and 4

TOC_j: Type of cloud at the j-th layer, where j = 1, 2, 3, and 4

TCA: Total cloud amount

Calculation Sequence:

1. $X = (\Sigma CA_j)_{cirrus} + (\Sigma CA_j)_{cirrostratus} + (\Sigma CA_j)_{cirrocumulus}$

2. Cloud cover

   CC = TCA - 0.5*X

3. Cloud cover factor

   CCF = P + Q*CC + R*CC**2

   where P, Q, and R are found in the following table

Table A-6

Season	P	Q	R
spring	1.06	0.012	-0.0084
summer	0.96	0.033	-0.0106
autumn	0.95	0.030	-0.0108
winter	1.14	0.003	-0.0082

The value of P, which is essentially the cloudless sky factor, depends upon the proportion of direct to diffuse sky radiation in reference to the standard ASHRAE values published in the 1972 Handbook of Fundamentals. If the value of P is unity, this proportion of direct to diffuse solar radiation is such that the solar radiation evaluated for a horizontal surface under a cloudless sky should be equal to the value obtained by the method described in the 1972 ASHRAE Handbook of Fundamentals. If the value of P is different from unity, the direct to diffuse proportion is different from the standard values.

SOLAD

An Algorithm for Determining Diffuse and Direct Radiation Falling Onto a Surface

This routine determines the total as well as the diffuse and direct components of solar radiation incident on a given surface under either clear or cloudy sky by using the cloudless sky data calculated in the SUN routine and the cloud cover factor CCF calculated as described in the previous section.

Data:

- P: Cloudless sky factor shown in Table (A-6) in the CCF routine
- C: Standard diffuse sky factor shown in Table A-4 in the SUN routine
- CC: Cloud cover calculated in the CCF routine
- CCF: Cloud cover factor determined by the CCF routine
- WA: Azimuth angle of the surface under consideration in radians from south; + if west and - if east of south
- WT: Tilt angle of the surface under consideration in radians from the horizontal surface; zero for the horizontal surface and $\pi/2$ for the vertical walls.

COS(Z), COS(W), AND COS(S):

Direction cosines of direct radiation (Calculated in SUN)

IDN: Intensity of the direct normal solar radiation for a cloudless condition in Btu per (hr) (sq ft) (Calculated in SUN)

BS and BG: Diffuse radiation from the cloudless sky and that from ground in Btu per (hr) (sq ft) (Calculated in SUN)

SALT: Solar altitude angle in radians (Calculated in SUN)

Calculation Sequence:

1. Let X = SIN (SALT)

2. Y = 0.309 - 0.137*X + 0.394*X**2

3. K = X/(C+X) + (P-1)/(1-Y)

4. Direct radiation on a horizontal surface under a cloudless sky

   IDH = IDN*COS(Z)

5. Diffuse radiation on a horizontal surface under a cloudless sky

   IdH = BS

6. Total radiation on a horizontal surface under a cloudless sky

   ITH = IDH + IdH

7. Direct radiation on a horizontal surface under a cloudy sky

   IDHC = ITH*K*(1 - CC/10)

8. Direction cosines of normal to the surface under consideration (the surface has an azimuth angle of WA and a tilt angle of WT)

α = COS(WT)

β = SIN(WA)*SIN(WT)

γ = COS(WA)*SIN(WT)

9. Cosine of the incident radiation on the surface under consideration

COS(η) = α COS(Z) + β COS(W) + γ COS(S)

10. Direct radiation on a surface under consideration under a cloudless sky

ID = IDN*COS(η)

= 0 if COS(η) $\leq$ 0

11. Direct radiation on a horizontal surface under a cloudy sky

IDC = ID*IDHC/IDH

12. Diffuse radiation for a cloudless sky

Id = BS for the horizontal surface

Id = BS*Y + BG/2 for the vertical surfaces*

where Y = 0.55 + 0.437*U + 0.313*U**2

U = COS(η)

if U $\leq$ -0.2, Y = 0.45

13. Diffuse radiation upon a horizontal surface under a cloudy sky

IdHC = ITH*(CCF-K*(1 - CC/10))

---

* Diffuse radiation data for surfaces other than vertical and horizontal ones have not been analyzed sufficiently to date to provide a calculation procedure.

14. Diffuse radiation on a surface under consideration

$IdC = Id*IdHC/IdH$

15. Total radiation upon a surface under a cloudy sky

$ITC = IDC + IdC$

When the cloud cover CC is zero,

$ITC = IT = ID + Id$

An Algorithm for Calculating Transmission, Absorption and Reflection Factors for Windows

Data:

Cos(η): Cosine of angle of incidence of direct solar radiation (Calculated in SUN)

$k*\ell$: Extinction coefficient [inches^{-1}] * thickness [inches]

NOTE: In some cases, glass manufacturers provide the value of transmission at normal incidence. In this case, using the curve given in Figure A-5, it is possible to obtain the value of $k*\ell$. The data for the curve are taken from reference 2.

Calculation Sequence:

A. Single-Pane Glass

1. Cosine of refraction angle

   COS(ξ) = SQRT (1 - (1-COS(η) ** 2)/n)

   where n = 1.520, which is the index of refraction for ordinary glass.

2. The fraction of radiation that is absorbed in a single pass through a sheet of glass of extinction coefficient $k*\ell$

   a = 1 - Exp (-$k*\ell$/COS(ξ))

3. Single glass air-glass interface reflectivity by the Fresnel's formula

vibration in parallel to the plane of glass

$r = (\mathrm{TAN}\ (\eta - \xi)) ** 2/\mathrm{TAN}\ (\eta + \xi)$

vibration in normal to the plane of glass

$r' = (\mathrm{SIN}\ (\eta - \xi)) ** 2/(\mathrm{SIN}\ (\eta + \xi)) ** 2$

4. Absorptivity for direct radiation

$A_\eta = 0.5 * (x + x')$

where $x = a * (1 - r) * (1 + r * (1 - a))/(1 - r * r * (1 - a) * (1 - a))$

$x' = a * (1 - r')\ (1 + r' * (1 - a))/(1 - r' * r' * (1 - a) * (1 - a))$

5. Transmissivity for direct radiation

$T_\eta = 0.5 * (y + y')$

where $y = (1 - r) * (1 - r) * (1 - a)/(1 - r * r * (1 - a) * (1 - a))$

$y' = (1 - r') * (1 - r') * (1 - a)/(1 - r' * r' * (1 - a) * (1 - a))$

6. Absorptivity and transmissivity for diffuse radiation

$$A_d = \int_0^{\pi/2} A_\eta\ \mathrm{SIN}\ (2\eta)\ d\eta$$

$$T_d = \int_0^{\pi/2} T_\eta\ \mathrm{SIN}\ (2\eta)\ d\eta$$

B. Double-Pane Glass

For the double-pane window, transmissivity and absorptivity for the outer and inner panes can be calculated separately first by using the single-pane procedure described above. Those calculated single glass properties can be designated here as follows:

A_1: Absorptivity of inner pane for direct radiation

A_2: Absorptivity of outer pane for direct radiation

T_1: Transmissivity of inner pane for direct radiation

T_2: Transmissivity of outer pane for direct radiation

A_{1d}: Absorptivity of inner pane for diffuse radiation

A_{2d}: Absorptivity of outer pane for diffuse radiation

T_{1d}: Transmissivity of inner pane for diffuse radiation

T_{2d}: Transmissivity of outer pane for diffuse radiation

1. Reflectivity of inner and outer panes

$$R_{1\eta} = 1 - A_{1\eta} - T_{1\eta}$$

$$R_{2\eta} = 1 - A_{2\eta} - T_{2\eta}$$

$$R_{1d} = 1 - A_{1d} - T_{1d}$$

$$R_{2d} = 1 - A_{2d} - T_{2d}$$

2. Absorptivity of the double-glazed system

a. Direct radiation

$$A_{\eta,outer} = A_{2\eta} * (1 + R_{1\eta} * T_{2\eta}/(1 - R_{1\eta} * R_{2\eta}))$$

$$A_{\eta,inner} = A_{1\eta} * T_{2\eta}/(1 - R_{1\eta} * R_{2\eta})$$

b. Diffuse radiation

$$A_{d,outer} = A_{2d} - (1 + R_{1d} * T_{2d}/(1 - R_{1d} * R_{2d})$$

$$A_{d,inner} = A_{1d} * T_{2d}/(1 - R_{1d} * R_{2d})$$

3. Transmissivity of the double

a. Direct radiation

$$T_{\eta} = T_{1\eta} * T_{2\eta}/(1 - R_{1\eta} * R_{2\eta})$$

b. Diffuse radiation

$$Td = T_{1d} * T_{2d}/(1 - R_{1d} * R_{2d})$$

Since the calculation of transmissivity and absorptivity are quite involved, they have been precalculated by Stephenson[3/] for various values of COS (η) and expressed as polynomial functions of COS (η). The polynomial coefficients are shown in Table A-3 for single and double glazed windows and the equations are as follows:

Single-pane, direct radiation transmission

$$T_{\eta} = \sum_{j=0}^{5} t_j * (\mathrm{Cos}\ (\eta) ** j)$$

Single-pane, diffuse radiation transmission

$$T_d = 2 * \sum_{j=0}^{5} t_j/(j + 2)$$

Polynomial representations of absorption factors for direct solar and diffuse radiation.

Double-pane, direct radiation transmission

$$A_{\eta,outer} = \sum_{j=0}^{5} a_{j,outer} * ((\mathrm{Cos}\ (\eta) ** j)$$

$$A_{\eta,inner} = \sum_{j=0}^{5} a_{j,inner} * ((\mathrm{Cos}\ (\eta) ** j)$$

Double-pane, diffuse radiation transmission

$$A_{d,outer} = 2 * \sum_{j=0}^{5} a_{j,outer}/(j + 2)$$

$$A_{d,inner} = 2 * \sum_{j=0}^{5} a_{j,inner}/(j + 2)$$

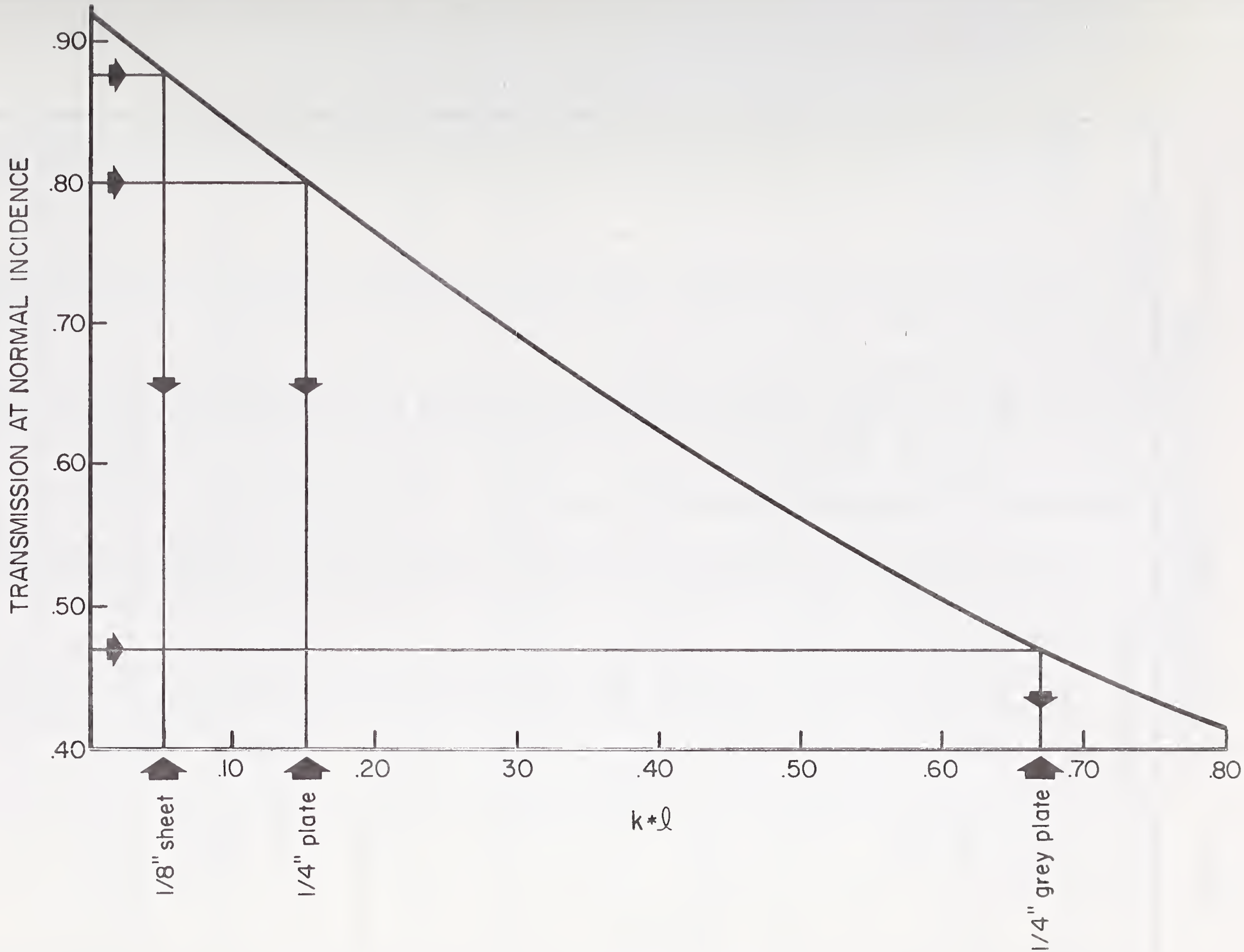

Figure A-5 Transmission at Normal Incidence Versus $k^*\ell$ for Single Sheet Glass

Table A-7 Polynomial Coefficients for Use in Calculation of Transmittance and Absorptance of Glass

k*ℓ	j	Single Glazing		Double Glazing		
		a_j	t_j	$a_{j,outer}$	$a_{j,inner}$	t_j
	0	0.01154	-0.00885	0.01407	0.00228	-0.00401
	1	0.77674	2.71235	1.06226	0.34559	0.74050
0.05	2	-3.94657	-0.62062	-5.59131	-1.19908	7.20350
	3	8.57881	-7.07329	12.15034	2.22366	-20.11763
1/8" Sheet	4	-8.38135	9.75995	-11.78092	-2.05287	19.68824
	5	3.01188	-3.89922	4.20070	0.72376	-6.74585
	0	0.01636	-0.01114	0.01819	0.00123	-0.00438
	1	1.40783	2.39371	1.86277	0.29788	0.57818
	2	-6.79030	0.42978	-9.24831	-0.92256	7.42065
0.10	3	14.37378	-8.98262	19.49443	1.58171	-20.26848
	4	-13.83357	11.51798	-18.56094	-1.40040	19.79706
	5	4.92439	-4.52064	6.53940	0.48316	-6.79619
	0	0.01837	-0.01200	0.01905	0.00067	-0.00428
0.15	1	1.92497	2.13036	2.47900	0.26017	0.45797
	2	-8.89134	1.13833	-11.74226	-0.72713	7.41367
1/4" Reg.	3	18.40197	-10.07925	24.14037	1.14950	-19.92004
Plate	4	-17.48648	12.44161	-22.64299	-0.97138	19.40969
	5	6.17544	-4.83285	7.89954	0.32705	-6.66603
	0	0.01902	-0.01218	0.01862	0.00035	-0.00401
	1	2.35417	1.90950	2.96400	0.22974	0.36698
	2	-10.47151	1.61391	-13.48701	-0.58381	7.27324
0.20	3	21.24322	-10.64872	27.13020	0.84626	-19.29364
	4	-19.95978	12.83698	-25.11877	-0.67666	18.75408
	5	6.99964	-4.95199	8.68895	0.22102	-6.43968
	0	0.01712	-0.01056	0.01423	-0.00009	-0.00279
	1	3.50839	1.29711	4.14384	0.15049	0.16468
	2	-13.86390	2.28615	-16.66709	-0.27590	6.17715
0.40	3	26.34330	-10.37132	31.30484	0.25618	-15.84811
	4	-23.84846	11.95884	-27.81955	-0.12919	15.28302
	5	8.17372	-4.54880	9.36959	0.02859	-5.23666
	0	0.01406	-0.00835	0.01056	-0.00016	-0.00192
	1	4.15958	0.92766	4.71447	0.10579	0.08180
	2	-15.06279	2.15721	-17.33454	-0.15035	4.94753
0.60	3	27.18492	-8.71429	30.91781	0.06487	-12.43481
	4	-23.88518	9.87152	-26.63898	0.02759	11.92495
	5	8.03650	-3.73328	8.79495	-0.02317	-4.07787
	0	0.01153	-0.00646	0.00819	-0.00015	-0.00136
0.80	1	4.55946	0.68256	5.01768	0.07717	0.04419
	2	-15.43294	1.82449	-17.21228	-0.09059	3.87529
50% Trans.	3	26.70568	-6.95325	29.46388	0.00050	-9.59069
H.A. Plate	4	-22.87993	7.80647	-24.76915	0.06711	9.16022
	5	7.57795	-2.94454	8.05040	-0.03394	-3.12776
	0	0.00962	-0.00496	0.00670	-0.00012	-0.00098
	1	4.81911	0.51403	5.18781	0.05746	0.02576
	2	-15.47137	1.47607	-16.84820	-0.05878	3.00400
1.00	3	25.86516	-5.41985	27.90292	-0.01855	-7.33834
	4	-21.69106	6.05546	-22.99619	0.06837	6.98747
	5	7.08714	-2.28162	7.38140	-0.03191	-2.38328

SHG

An Algorithm for Calculating Solar Heat Gain Through Windows

Data:

IDN:	Intensity of direct normal solar radiation, Btu per (hr) (sq ft), (Calculated in SUN)
BS:	Sky brightness, Btu per (hr) (sq ft), (Calculated in SUN)
BG:	Ground brightness, Btu per (hr) (sq ft), (Calculated in SUN)
$\cos(\eta)$:	Cosine of the angle of incidence of direct solar radiation, (Calculated in SUN)
FWS:	Form factor between the window and the sky*
FWG:	Form factor between the window and the ground*
RO, RA, RI:	Thermal resistances at outside surface, air space, and inside surface respectively, (sq ft) (hr) (F) per Btu
SLA:	Sunlit area factor (Calculated in SHADOW)
SC:	Shading coefficient if the window is shaded by drapes or blinds or if it has an inter-pane separation of more than 1 inch

---

* If more accurate data are not available, use FWS = FWG = 0.5.

NOTE: When the value of SC is given, these transmission and absorption factors should be for the standard 1/8" thick double strength glass (or $k*\ell = 0.05$ of TAR) regardless of the type of glass used.

T_η, T_d: Transmission factors for direct and diffuse solar radiation for windows (Calculated in TAR)

$A_{\eta,outer}$, $A_{\eta,inner}$, $A_{d,outer}$, $A_{d,inner}$: Absorption factors for direct and diffuse solar radiation through outer and inner window panes (Calculated in TAR), respectively

Calculation Sequence:

1. Inward flowing fraction of the radiation absorbed by the inner and the outer pane, respectively.

   NI = (RO + RA)/(RO + RA + RI)

   NO = RO/(RO + RA + RI)

2. Let

   $D = SLA*IDN*Cos(\eta)*(T_\eta + NO*A_{\eta,outer} + NI*A_{\eta,inner})$

   $d = (BS*FWS + BG*FWG)*(T_d + NO*A_{d,outer} + NI*A_{d,inner})$

3. Solar heat gain through window.

   If SC = 0, SHG = D + d

   If $SC \neq 0$, $SHG = (SC)*(D + d)_{k*\ell=0.05}$

SHADOW

A Brief Description of the Procedures for Calculating External Shadows on a Building

A major portion of the air conditioning load on modern commercial buildings comes from solar radiation. To improve the accuracy of load assessment, it is necessary to know how much of a building is shaded and how much lies exposed to the sun's rays.

A new technique developed by Groth and Lokmanhekim[4/] employs the representation of all architectural forms as a series of plane polygons. Even curved surfaces can be so represented. For example, a sphere may be approximated by the 20 sides of a regular icosohedron This approximation gives a maximum error of only 3% in the shadow area cast by the sphere.

The output of the algorithm is not only the sunlit area, but also a pictorial display of the shadows and the surface upon which they are cast.

Coordinate Transformation:

Designate the polygons which cast shadows as shading polygons (SP) and those upon which shadows are cast as receiving polygons (RP). The vertex coordinates of each RP, and its relevant SP's, are transformed from a base coordinate system, xyz, to a new coordinate system, x'y'z', with origin 0 attached to the plane of the RP. The first three vertices,

V_1, V_2, and V_3, of the RP being examined are used to define this new coordinate system. The x' axis passes through V_2 and V_3, while the y' axis passes through V_1. In order that the z' axis point outward from the surface, angle $V_1V_2V_3$ must be convex and the vertices must be numbered counterclockwise. The equation of transformation is written in matrix form as

$$\vec{x}' = A\ (\vec{x}-\vec{x}_0)$$

where

$$\vec{x}_0 = \vec{x}_2 + \gamma(\vec{x}_3-\vec{x}_2)$$

$$\gamma,\ \text{A Scaler} = (\vec{x}_1-\vec{x}_2)\cdot(\vec{x}_3-\vec{x}_2)/(\vec{x}_3-\vec{x}_2)\cdot(\vec{x}_3-\vec{x}_2)$$

$$\text{1st } \vec{\text{row}} \text{ of A} = (\vec{x}_3-\vec{x}_0)/\left|\vec{x}_3-\vec{x}_0\right|$$

$$\text{2nd } \vec{\text{row}} \text{ of A} = (\vec{x}_1-\vec{x}_0)/\left|\vec{x}_1-\vec{x}_0\right|$$

$$\text{3rd } \vec{\text{row}} \text{ of A} = \text{1st } \vec{\text{row}} \text{ of A x 2nd } \vec{\text{row}} \text{ of A}$$

Solar altitude, α, and azimuth, β, must also be transformed, into the solar direction vector, as

$$x_s' = \begin{pmatrix} \text{Sin}\beta \cdot \text{Cos}\alpha \\ \text{Sin}\alpha \\ \text{Cos}\beta \cdot \text{Cos}\alpha \end{pmatrix}$$

Clipping Transformation:

Any part of an SP whose z' is negative cannot cast a shadow on the RP. These "submerged" portions of the SP's must be clipped off, prior to projection, lest they project "false" shadows (see Figure A-6). This is done by finding, through linear interpolation, the points A and B, on the perimeter of the SP, which pierce the plane of the RP, and taking these points as new vertices. All submerged vertices are deleted. This results in a new polygon with line AB as a side, which will project only real shadows.

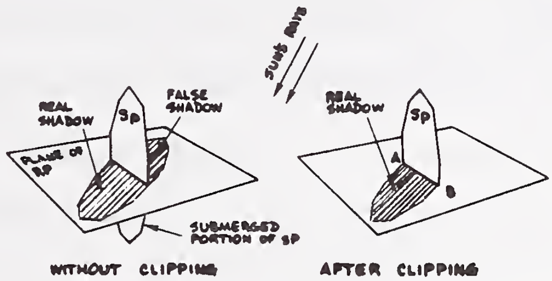

Figure A-6 Clipping

Projection Transformation:

To simulate the actual casting of a shadow, the following transformation projects, along the sun's rays, all the vertex points of the transformed and clipped RP's.

$$X = x' - \frac{x'_s}{z'_s} z'$$

$$Y = y' - \frac{y'_s}{z'_s} z'$$

Enclosure Test:

The coordinate, clipping and projection transformation have converted all RP and SP's in space into two dimensional figures in the RP plane. It remains only to find the points in the RP plane which lie inside the RP and inside one or more of the SP projections, i.e., points of the RP which are shaded. At this point, the two-space XY is divided into a grid and the center of each element of this grid is tested for enclosure by the RP and the SP projections. A point, P, whose coordinates are $X_P Y_P$, is inside of polygon $V_1, V_2, \ldots V_n$ if the following inequality holds.

$$\sum_{i=1}^{n} \Delta\theta_i \neq 0$$

The angular change, $\Delta\theta_i$, subtended at P by the ith side, and counted positive counterclockwise, is given by the following formulae.

$$\Delta\theta_i = \begin{cases} \theta_j - \theta_i & \text{if } |\theta_j - \theta_i| < 2 \\ \dfrac{(\theta_i - \theta_j)(4 - |\theta_j - \theta_i|)}{|\theta_j - \theta_i|} & \text{if } |\theta_j - \theta_i| \geq 2 \end{cases}$$

$$j = \begin{cases} i + 1 & \text{if } i < n \\ 1 & \text{if } i = n \end{cases}$$

$$\theta_i \sim \begin{cases} \dfrac{Y_i - Y_P}{X_i - X_P + Y_i - Y_P} & \text{in 1st quadrant} \qquad 1 + \dfrac{X_P - X_i}{X_P - X_i + Y_i - Y_P} \quad \text{in 2nd quadrant} \\[2ex] 2 + \dfrac{Y_P - Y_i}{X_P - X_i + Y_P - Y_i} & \text{in 3rd quadrant} \qquad 3 + \dfrac{X_i - X_P}{X_i - X_P + Y_P - Y_i} \quad \text{in 4th quadrant} \end{cases}$$

These approximate formulae, which express $\Delta\theta_i$ in right angles, replace the time-consuming square root and are cosine computer library routines. They have, by set theory, been proved adequate for the purpose.

Display Matrix and Sample Problem:

An alphameric matrix is created corresponding to the grid elements in the RP plane. A blank component represents a grid element either outside the RP or exposed to the sun. An asterisk component represents a shaded grid element or one on the RP's boundary. Grid elements shaded by a transmissive structure are randomly asterisked with a probability equal to the fraction of incident light stopped by the shading structure. Figure A-7 shows the solution of a typical problem involving a transmissive structure.

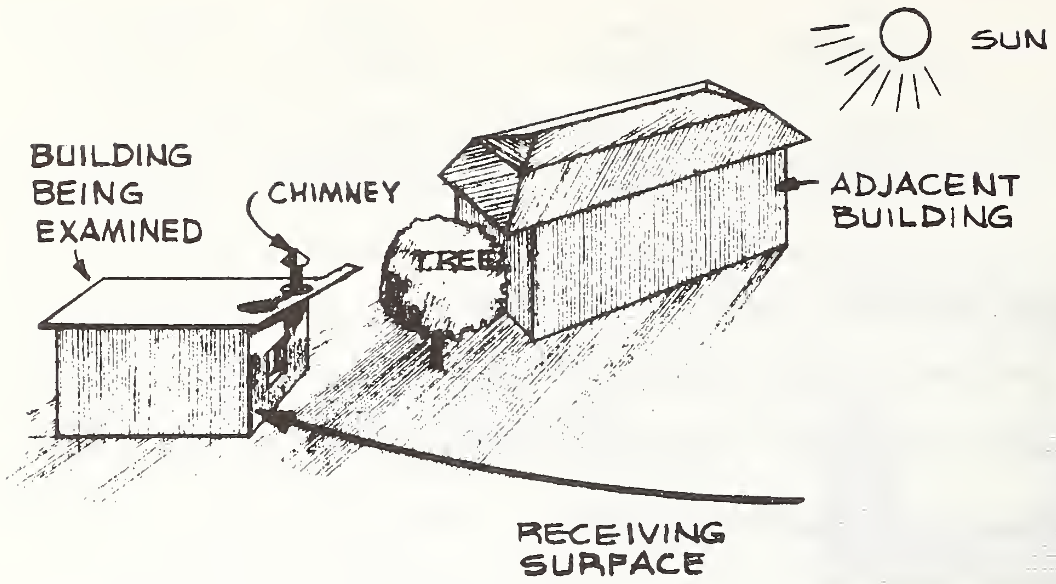

Figure A-7 The Computer Output of a Typical Problem

SHADOW 1*

An Algorithm to Find the Ratio of the Sunlit and Shaded Area of a Given Window Where the Shadows are Cast by Various Combinations of Overhang and Side Fins

Data: (Variable names corresponding to the FORTRAN listing included in this section. Right and left is determined facing the window from outside - see Figure A-8).

HT: Window height

FL: Window width

FP: Depth of the overhang

AW: Distance from top of the window to the overhang

BWL: Distance of the overhang extended beyond the left edge of the window

BWR: Distance of the overhang extended beyond the right edge of the window

D: Depth of vertical projection at the end of the overhang

FP1: Depth of the left fin

A1: Distance of the left fin extended above the top of the window

B1: Distance from the left edge of the window to the left fin

C1: Distance of the left fin stop short above the bottom of the window

FP2: Depth of the right fin

---

* This section was contributed by Tseng-Yao Sun; Ayres and Hayakawa, Los Angeles, California.

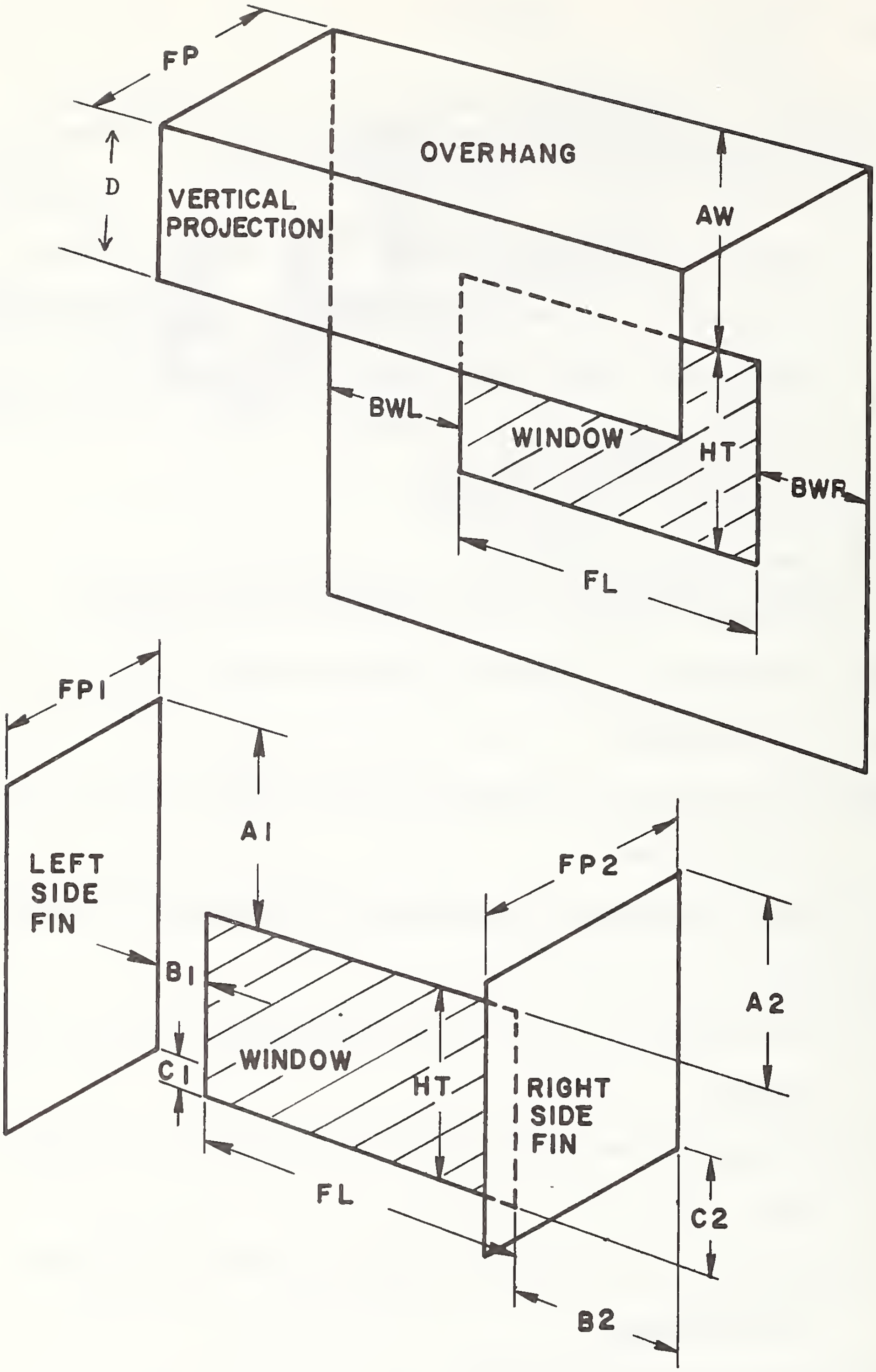

Figure A-8 Shadow 1 Input Data

A2: Distance of the right fin extended above the top of the window

B2: Distance from the right edge of the window to the right fin

C2: Distance of the right fin stop short above the bottom of the window

PHI: Solar azimuth angle

WAZI: Window azimuth angle

COSZ: Cosine of solar zenith angle

<u>Calculation Sequence</u>:

The principle calculation sequence of this subroutine is described in reference 5 and the principle output of the subroutine is the variable SHRAT--the shade ratio or ratio of sunlit area to the total window area. The treatment of shadow overlapping cast by various shading devices is not discussed in the reference but is included in the FORTRAN listing.

```
      SUBROUTINE SHADOW(SHDX,PHI,COSZ,SHRAT)
      DIMENSION SHDX(20)
      HT=SHDX(1)
      FL=SHDX(2)
      FP=SHDX(3)
      AW=SHDX(4)
      BWL=SHDX(5)
      BWR=SHDX(6)
      D=SHDX(7)
      FP1=SHDX(8)
      A1=SHDX(9)
      B1=SHDX(10)
      C1=SHDX(11)
      FP2=SHDX(12)
      A2=SHDX(13)
      B2=SHDX(14)
      C2=SHDX(15)
      WAZI=SHDX(16)
%     THIS PROGRAM CALCULATES SHADOW CAST BY OVERHANG AND SIDE FINS
%     PHI....SOLAR AZIMUTH ANGLE
%     COSZ...COSINE OF SOLAR ZENITH ANGLE
%     SHRAT..SHADE RATIO:RATIO OF THE SUNLIT AREA TO THE TOTAL WINDOW AREA
%     HT.....WINDOW HEIGHT
%     FL.....WINDOW WIDTH
%     FP.....DEPTH OF THE OVERHUNG
%     AW.....DISTANCE FROM TOP OF THE WINDOW TO THE OVERHUNG
%     BWL....DISTANCE OF THE OVERHUNG EXTENDED BEYOND THE LEFT EDGE OF THE WINDOW
%     BWR....DISTANCE OF THE OVERHUNG EXTENDED BEYOND THE RIGHT EDGE OF THE WINDOW
%     D......DEPTH OF VERTICAL PROJECTION AT THE END OF THE OVERHUNG
%     FP1....DEPTH OF THE LEFT FIN
%     A1.....DISTANCE OF THE LEFT FIN EXTENDED ABOVE THE TOP OF THE WINDOW
%     B1.....DISTANCE FROM THE LEFT EDGE OF THE WINDOW TO THE LEFT FIN
%     C1.....DISTANCE OF THE LEFT FIN STOP SHORT ABOVE THE BOTTOM OF THE WINDOW
%     FP2....DEPTH OF THE RIGHT FIN
%     A2.....DISTANCE OF THE RIGHT FIN EXTENDED ABOVE THE TOP OF THE WINDOW
%     B2.....DISTANCE FROM THE RIGHT EDGE OF THE WINDOW TO THE RIGHT FIN
%     C2.....DISTANCE OF THE RIGHT FIN STOP SHORT ABOVE THE BOTTOM OF THE WINDOW
%     WAZI...WINDOW AZIMUTH ANGLE
      SHRAT=1.
1103  A=AW
      H=HT
      GAMMA=PHI-WAZI
      COSG=COS(GAMMA)
      IF(COSG)100,100,104
100   SHRAT=0.
      GO TO 2000
104   CONTINUE
      SBETA=COSZ
      IF(SBETA)100,100,152
152   SING=SIN(GAMMA)
      VERT=SBETA/SQRT(1.-SBETA*SBETA)/COSG
      HORIZ=ABS(SING)/COSG
      TCETA=VERT/HORIZ
```

```
      IF(GAMMA) 155,154,154
%     -------SUN ON LEFT
154   B=BWL
      GO TO 156
%     -------SUN ON RIGHT
155   B=BWR
156   ARSHF=0.
      AREAV=0.
      ARSIF=0.
      AREAO=0.
      AREA1=0.
      ARSH1=0.
      FL3=0.
      H3=0.
      H1=H
      FL1=FL
      K=1
      L=1
      T1=FP*VERT
      FM1=FP*HORIZ
      IF(FP)37,37,153
153   T=T1
      FM=FM1
      AB=B*TCETA
      UG=(FL+B)*TCETA
      DE=(H+A)/TCETA
%     -------HORIZONTAL OVERHUNG "AREAO"
      IF(T-A)27,27,2
2     IF(AB-A)14,14,3
3     IF(DE-B) 12,12,4
4     IF(FM-B)11,11,5
5     IF(DE-(FL+B))8,8,6
6     IF(FM-(FL+B))9,7,7
%     -------HORIZ 9
7     AREAO=FL*(0.5*(AB+UG)-A)
      GO TO 37
8     IF(T-(H+A))9,10,10
%     -------HORIZ 7
9     AREAO=(T-A)*FL-((FM-B)**2)*TCETA*0.5
      L=2
      GO TO 21
%     -------HORIZ 8
10    AREAO=H*FL-(DE-B)**2*TCETA*0.5
      GO TO 37
%     -------HORIZ 3
11    AREAO=FL*(T-A)
      L=2
      GO TO 24
12    IF(T-(H+A)) 11,13,13
%     -------HORIZ 2
13    AREAO=H*FL
      GO TO 68
14    IF(UG-A)27,27,15
15    IF(DE-(FL+B))18,18,16
```

```
16      IF(FM-(FL+B))20,17,17
%       -------HORIZ 6
17      AREAO=(UG-A)**2/TCETA*0.5
        GO TO 37
18      IF(T-(H+A))20,19,19
%       -------HORIZ 5
19      AREAO=H+(FL-(A+0.5*H)/TCETA+B)
        GO TO 37
%       -------HORIZ 4
20      AREAO=(T-A)*(FL+B-FM*(1.+A/T)*0.5)
        L=2
%       -------VERT PROJ "AREAV"
21      FL3=FL+B-FM
        IF(T+D-(H+A))22,22,23
%       -------VERT 8
22      H3=D
        GO TO 3700
%       -------VERT 9
23      H3=H+A-T
        GO TO 3700
24      FL3=FL
        IF(T+D-(H+A))26,26,25
%       -------VERT 7
25      H3=H+A-T
        AREAV=H3*FL3
        GO TO 68
%       -------VERT 6
26      H3=D
        GO TO 3700
27      IF(T+D-A)37,37,28
28      IF(FM-B)34,34,29
29      IF(FM-(FL+B))31,37,37
31      FL3=FL+B-FM
        IF(T+D-(H+A))33,33,32
%       -------VERT 5
32      H3=H
        GO TO 3700
%       -------VERT 4
33      H3=T+D-A
        GO TO 3700
34      IF(T+D-(H+A))36,35,35
%       ------VERT 2
35      AREAV=H*FL
        GO TO 68
%       VERT 3
36      H3=T+D-A
        FL3=FL
3700    AREAV=FL3*H3
%       -------SIDE FIN AND SHORT SIDE FIN
%       -------SIDE FIN "AREA1" "ARSIF"
37      IF(GAMMA)66,68.74
74      FPF=FP1
        AF=A1
        BF=B1
```

```
      CX=C1
      GO TO 84
66    FPF=FP2
      AF=A2
      BF=B2
      CX=C2
84    IF(FPF)68,68,67
67    T=FPF*VERT
      FM=FPF*HORIZ
      AF1=AF
      IF(AREAO)73,73,88
%     -------TEST FOR OVERLAP OF FIN AND OVERHUNG SHADOW
88    AT=A+(BF-B)*TCETA
      IF(AT-AF)711,73,73
%     ------OVERLAP EXISTS..L=2 IF OVERHUNG SHADOW HAS HORIZ EDGE IN WINDOW
711   GO TO(621,712),L
%     ------TEST FOR TYPE OF OVERLAP
712   IF((FM-BF)-(FM1-B))621,622,622
%     ------SET L=1,SHADOW INTERSECT ON INCLINED EDGE OF OVERHUNG SHADOW
%     -------FIN SHADOW IS BELOW INCLINED EDGE OF OVERHUNG SHADOW
621   AF=AT
      L=1
      GO TO 73
%     -------L IS 2, HORIZ EDGE OF OVERHUNG SHADOW-PORTION ABOVE HORIZ EDGE
%     -------NOT IN OVERHUNG SHADOW IS FIN SHADOW
622   AREA1=FL*(T1-A)-AREAO
%     -------RESET TO CALC FIN SHADOW BELOW HORIZ EDGE OF OVHNG SHADOW
      AF=T1-A+AF1
      H=H+AF1-AF
%     ------SHADOW OF FIN (K=1 ON GLASS  K=2 ON VERT PROJ SHADOW)
73    AB=BF*TCETA
      UG=(FL+BF)*TCETA
      DE=(H+AF)/TCETA
      DJ=CX/TCETA
      IF(FM-BF)69,69,38
38    IF(AB-AF)39,50,50
39    IF(UG-AF)48,48,40
40    IF(T-AF)47,47,41
41    IF(UG-(H+AF))44,44,42
42    IF(T-(H+AF))91,80,80
%     -----FIN 9
80    AREA1=H*((AF+H*0.5)/TCETA-BF)+AREA1
      GO TO 58
44    IF(FM-(FL+BF))91,89,89
%     -------FIN8
89    AREA1=H*FL-(UG-AF)**2/TCETA*0.5+AREA1
      GO TO 58
%     -------FIN 7
91    AREA1=(FM-BF)*H-(T-AF)**2/TCETA*0.5+AREA1
      GO TO 63
48    IF(FM-(FL+BF))47,47,49
%     -------FIN 3
47    AREA1=H*(FM-BF)+AREA1
      GO TO 63
```

```
%       -------FIN 2
49      AREA1=H*FL+AREA1
        GO TO 58
50      IF(DE-BF)69,69,51
51      IF(UG-(H+AF))55,55,52
52      IF(T-(H+AF))93,94,94
%       ------FIN 6
94      AREA1=(DE-BF)**2*TCETA*0.5+AREA1
        GO TO 58
%       ------FIN 4
93      AREA1=(FM-BF)*(H+AF-(T+AB)*0.5)+AREA1
        GO TO 63
55      IF(FM-(FL+BF))93,99,99
%       -----FIN 5
99      AREA1=FL*(H-(BF+FL*0.5)*TCETA+AF)+AREA1
%       ------SHORT SIDE FIN "ARSH1","ARSHF"
58      IF(DJ-BF)69,69,59
59      IF(DJ-(FL+BF))61,61,60
%       -------SHORT 3
60      ARSH1=-FL*(CX-(BF+FL/2.)*TCETA)
        GO TO 69
%       -------SHORT 4
61      ARSH1=-(CX-AB)**2/TCETA*0.5
        GO TO 69
63      IF(DJ-BF)69,69,64
64      IF(DJ-FM)61,61,65
%       -------SHORT 2
65      ARSH1=-(FM-BF)*(CX-(T+AB)*0.5)
69      GO TO (77,76),K
76      ARSH1=-ARSH1
        AREA1=-AREA1
77      ARSHF=ARSHF+ARSH1
        ARSIF=ARSIF+AREA1
        GO TO(78,68),K
78      IF(AREAV)68,68,72
%       ------RESET PARAMETERS TO DEDUCT FIN SHADOW OVERLAP ON VERT PROJ SHADOW
72      K=2
        AREA1=0.
        ARSH1=0.
        BBF=BF
        BF=FM1-B+BF
        IF(BF)186,185,185
186     BF=BBF
185     IF(HT+A-T1-D)87,87,188
188     CX=CX-(HT+A-T1-D)
        IF(CX)85,87,87
85      CX=0.
87      AF=T1-A+AF
        H=H3
        FL=FL3
        GO TO 73
%       ------- SHADED AREA "ARSHA"
68      ARSHA=AREA0+AREAV+ARSHF+ARSIF
        SHRAT=(FL1*H1-ARSHA)/(FL1*H1)
```

```
      FL=FL1
 2000 CONTINUE
      RETURN
      END
```

An Algorithm to Determine Whether or Not a Given Window is Shaded by a Remote Object Such as an Adjacent Building

This algorithm is approximate and is applicable only where the window is relatively small in comparison to the shading object. Large windows may be subdivided into smaller segments for this consideration. The window is considered either completely shaded or completely in sun. Partially shaded window can be considered in either case depending on the location of the window reference point. Figure A-9 shows a typical window-shading object relationship.

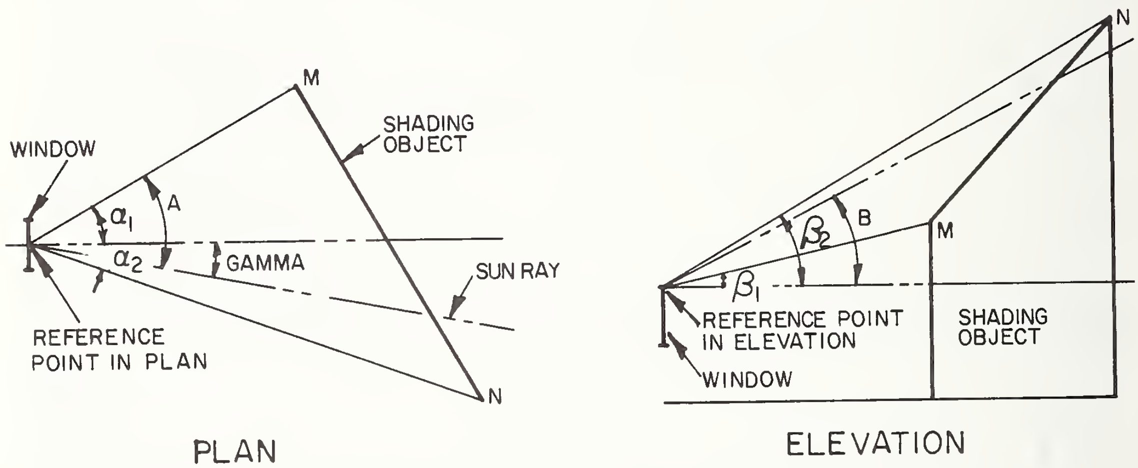

Figure A-9 A Typical Window-Shading Object Relationship

Note that the reference point can be located at any point on the window. Locating the reference point at the top of the window as shown in the elevation in Figure A-9 is slightly conservative as compared to if the reference point is located at the center of the window.

---

* This section was contributed by Tseng-Yao Sun; Ayres, Cohen and Hayakawa, Los Angeles, California.

Data:

$\alpha 1$, $\alpha 2$: Azimuth shadow limit angles. Right +, Left -

$\beta 1$, $\beta 2$: Altitude shadow limit angles

WAZI: Window azimuth angle

PHI: Solar azimuth angle

BETA: Solar altitude angle

Calculation Sequence:

This subroutine determines whether the window is sunlit or shaded for the given position of the sun.

1. Wall-solar azimuth angle

   GAMMA = PHI - WAZI

2. If GAMMA < $\alpha 1$ or GAMMA > $\alpha 2$, the window is in sun

3. If $\alpha 2$ > GAMMA > $\alpha 1$,

   A = GAMMA - $\alpha 1$

   B = $\beta 1$ + A*($\beta 2$ - $\beta 1$)

4. If BETA > B, the window is in sun. Otherwise, the window is in shade.

FIJ*

An Algorithm for Calculating Radiation Shape Factors Between Inside Surfaces of a Room

Definition of Room

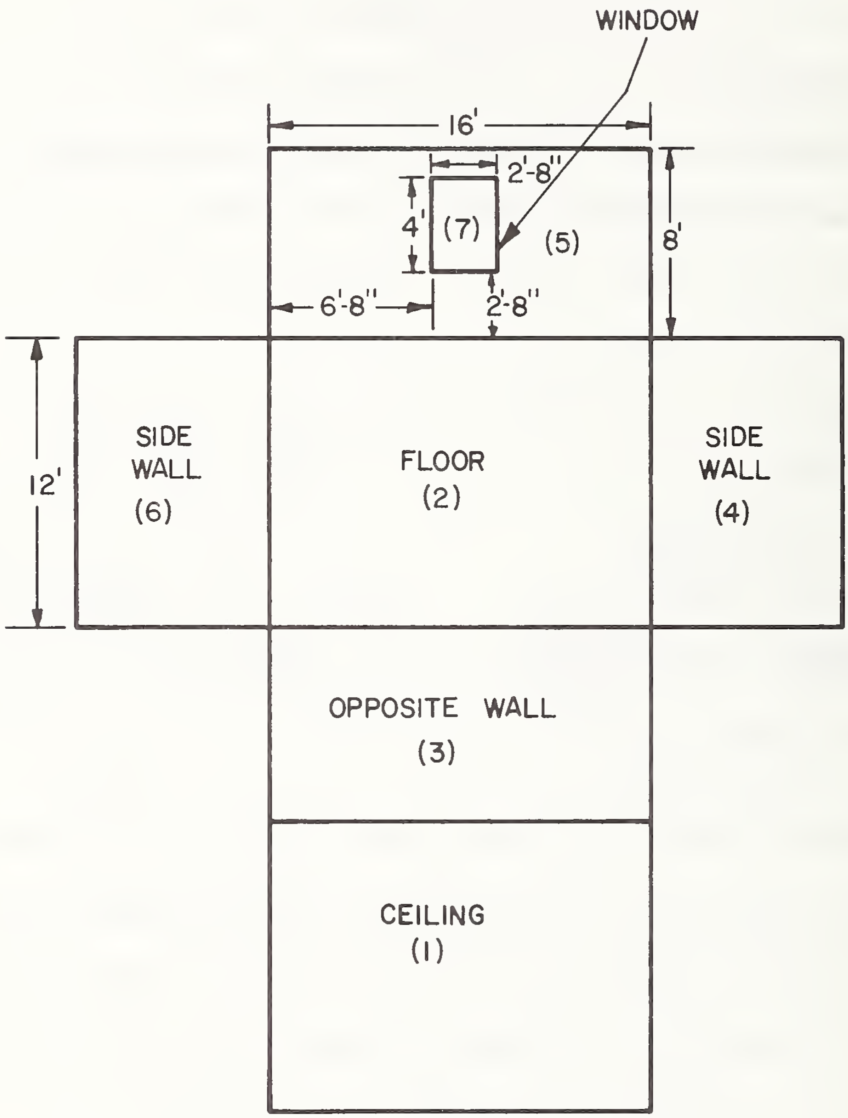

Figure A-10 Room Layout

---

* This section was contributed by D. M. Burch and B. A. Peavy; Thermal Engineering Systems Section, Center for Building Technology, National Bureau of Standards, Washington, D. C.

Data:

L: Length of room

W: Width of room

H: Height of room

A: Height of windows or doors

B: Width of windows or doors

C: Distance of left edge of window from left wall

D: Height of lower edge of window from floor

The primary variables determined by this subroutine are:

F_{m-n}: An array giving radiation shape factors between the various inside surfaces of a room

m,n =	1	Ceiling
	2	Floor
	3	Wall No. 1 (length by height)
	4	Wall No. 2 (side wall)
	5	Wall No. 3 (opposite wall)
	6	Wall No. 4 (side wall)
	7-14	Provision for windows and doors in walls

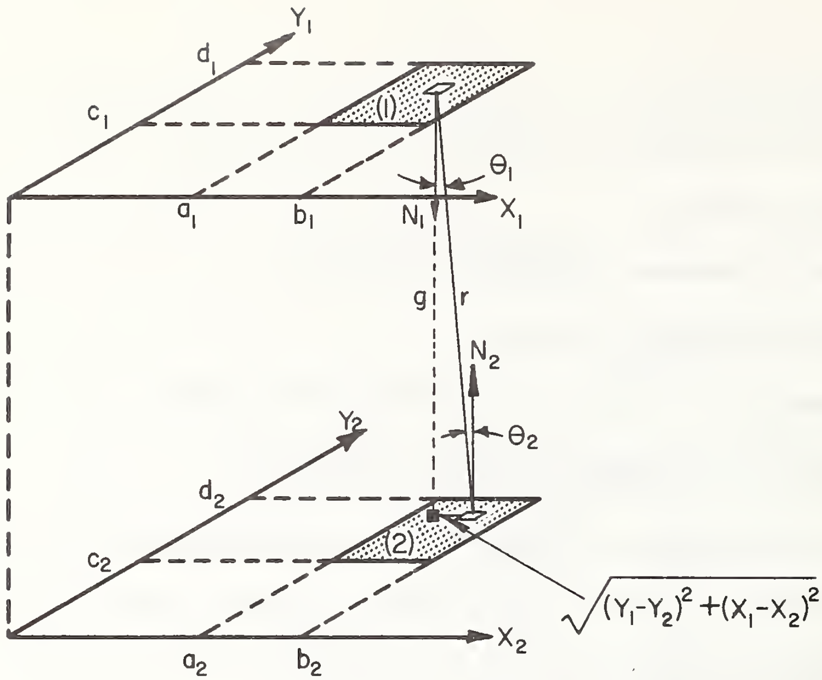

Figure A-11 Radiation Heat Exchange Between Ceiling and Floor Surfaces

Radiation shape factor, F_{1-2}, between two parallel room surfaces

$$2\pi(b_i-a_1)(d_1-c_1)F_{1-2} = [P(b_2-b_1)+P(a_2-a_1)][Q(c_2-c_1)+Q(d_2-d_1)-Q(c_2-d_1)-Q(d_2-c_1)]$$
$$+ [P(b_2-a_1)+P(a_2-b_1)][Q(c_2-d_1)+Q(d_2-c_1)-Q(c_2-c_1)-Q(d_2-d_1)]$$

where

$$P(Z_1)Q(Z_2) = Z_1W \tan^{-1}\frac{Z_1}{W} + Z_2V \tan^{-1}\frac{Z_2}{V} - \frac{G^2}{Z} \ln\left(\frac{W^2+Z_1^2}{W^2}\right)$$

$$V^2 = G^2+Z_1^2, \quad W^2 = G^2+Z_2^2$$

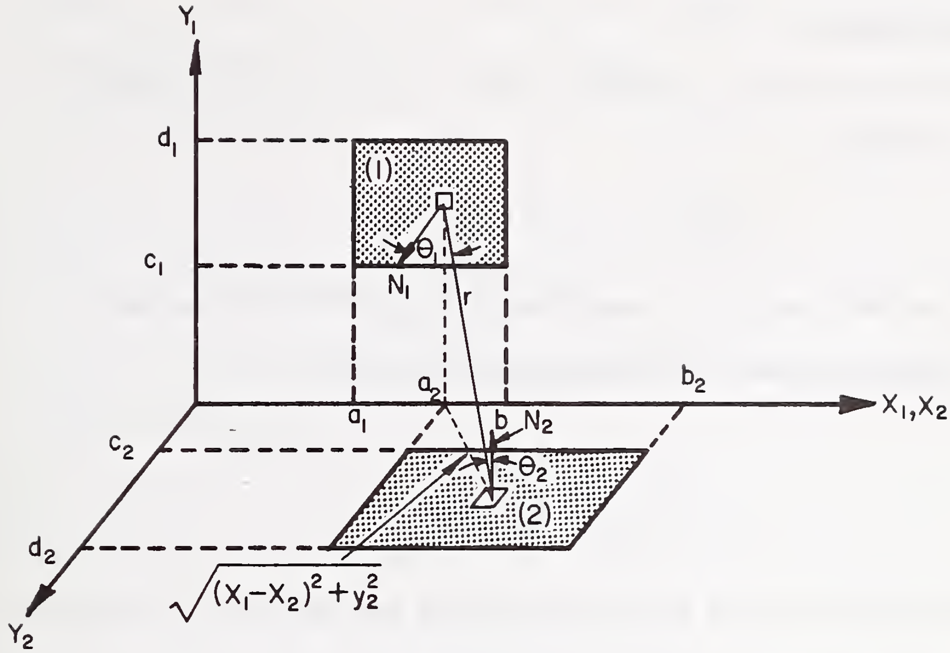

Figure A-12 Radiation Heat Exchange Between Wall and Floor Surfaces

Radiation Shape Factor, F_{1-2}, between two perpendicular room surfaces

$$2\pi(b_1-a_1)(d_1-c_1)F_{1-2}=[R(b_2-b_1)+R(a_2-a_1)][S(c_2-c_1)+S(d_2-d_1)-S(c_2-d_1)-S(d_2-c_1)]$$

$$+[R(b_2-a_1)+R(a_2-b_1)][S(c_2-d_1)+S(d_2-c_1)-S(c_2-c_1)-S(d_2-d_1)]$$

where

$$R(Z_1)S(Y_2+Y_1) = TZ_1 \tan^{-1} \frac{Z_1}{T} + \frac{1}{4} (Z_1^2 - T^2) \ln (T^2+Z_1^2)$$

$$T^2 = Y_2^2+Y_1^2$$

Calculation Sequence:

1. Determine areas of ceiling, floor, and walls (no windows or doors),

$$A_m, \; m = 1, 2, 3, 4, 5, 6$$

2. Calculate radiation shape factor F_{m-n} for these surfaces using equations, and reciprocal relation

$$F_{m-n} = \frac{A_n}{A_m} F_{n-m}$$

3. Determine area of windows and doors and subtract from pertinent wall areas to give net wall areas.

4. Calculate radiation shape factors from windows and/or doors to ceiling and/or floor using the above shape factor equations and the reciprocal relation. The radiation shape factors from a ceiling or floor surface to a window, door, or a wall area is given by

$$F_{m-n_k} = F_{m-n} - F_{m-n_1} - F_{m-n_2}$$

where k denotes the surface which is applicable for a receiving surface, A_n that has been subdivided into 2 or more surfaces.

5. Calculate radiation shape factors from windows and doors to walls using equations, above defined angle factor algebra and

$$A_{m_k} F_{m_k-n} = A_m F_{m-n} - A_{m_1} F_{m_1-n} - A_{m_2} F_{m_2-n}$$

which is applicable for a transmitting surface A_m that has been subdivided into 2 or more surfaces.

6. The resulting array F_{m-n} must be satisfied by the identity

$$\sum_{k=1}^{p} F_{m-k} = 1$$

where p is the number of surfaces visible to the transmitting surface A_m.

```
C      THIS PROGRAM DETERMINES THE RADIATION SHAPE FACTORS FOR A ROOM
C      OF ARBITRARY DIMENSIONS WITH THE PROVISION  FOR TWO WINDOWS OR
C      DOORS OF ANY SIZE AND POSITION ON EACH OF THE FOUR WALLS
C      INPUT TO THE PROGRAM IS READ IN FIELDS OF NINE AND FIRST CARD IS
C
C   LENGTH    WIDTH   HEIGHT
C
C      THIS CARD IS FOLLOWED BY FOUR CARDS GIVING PERTINENT DIMENSIONS
C      FOR WINDOWS AND DOORS - FIRST CARD IS FOR WINDOWS OR DOORS ON A
C      WALL DEFINED ON THE LENGTH OF ROOM - SECOND CARD ON WIDTH, ETC.
C      LEAVE SPACES BLANK IF THERE IS NO WINDOW OR DOOR
C
C        A        B        C        D        A        B        C        D
C        A        B        C        D        A        B        C        D
C        A        B        C        D        A        B        C        D
C        A        B        C        D        A        B        C        D
C
C WHERE  A=HEIGHT OF WINDOW, C=CORNER OF WALL TO LEFT EDGE OF WINDOW
C          B=WIDTH OF WINDOW, D=HEIGHT FROM FLOOR TO LOWER EDGE OF WINDOW
C      OUTPUT CONSISTS OF ASSIGNMENT OF NUMBERS TO THE VARIOUS SURFACES
C      OF THE ROOM
C
C     1     CEILING        LENGTH X WIDTH
C     2     FLOOR          LENGTH X WIDTH
C     3     WALL NO.1      LENGTH X HEIGHT
C     4     WALL NO.2      WIDTH X HEIGHT
C     5     WALL NO.3      LENGTH X HEIGHT
C     6     WALL NO.4      WIDTH X HEIGHT
C   7-14    WINDOW OR DOOR ON WALL NO.X
C
C   THIS IS FOLLOWED BY A PRINTOUT OF AN ARRAY OF RADIATION SHAPE FACTORS
      DIMENSION SF(14,14),A(8),B(8),C(8),D(8),S(14),X(5)
      DIMENSION IFIL(14),VF(14,14)
      REAL L
      READ(5,1)L,W,H
      READ(5,1)(B(I),D(I),A(I),C(I),I=1,8)
1     FORMAT(8F9.2)
301   FORMAT (6X,28H LEGEND FOR ROOM ARRANGEMENT/40H0ASSUME WALL NO. 1 I
     1S ON THE ROOM LENGTH/7H0M OR N/4H   1,6X,10H CEILING   ,F6.2,4H BY
     2,F6.2/4H   2,6X,10H FLOOR     ,F6.2,4H BY ,F6.2/4H   3,6X,10H WALL
     3NO.1,F6.2,4H BY ,F6.2/4H   4,6X,10H WALL NO.2,F6.2,4H BY ,F6.2/4H
     4  5,6X,10H WALL NO.3,F6.2,4H BY ,F6.2/4H   6,6X,10H WALL NO.4,F6.2
     5,4H BY ,F6.2)
403   FORMAT(I4,6X,15H   DOOR ON WALL,I2,4F11.2)
302   FORMAT(I4,6X,15H WINDOW ON WALL,I2,4F11.2)
303   FORMAT(6X,17H WINDOWS OR DOORS,13X,2H A,9X,2H B,9X,2H C,9X,2H D)
304   FORMAT(1H /8X,18H A - WINDOW HEIGHT/8X,17H B - WINDOW WIDTH/9X,48H
     1C - DISTANCE OF LEFT EDGE OF WINDOW TO LEFT WALL/8X,46H D - HEIGHT
     2 FROM FLOOR TO LOWER EDGE OF WINDOW)
      WRITE (6,301) L,W,L,W,L,H,W,H,L,H,W,H
      WRITE (6,303)
      K=7
      DO 305 I=1,8
      IF(D(I).LT.1.E-8) GO TO 305
      J=(I+1)/2
      IC=C(I)*100.
      IF(IC.EQ.0)GO TO 401
      WRITE(6,302)K,J,D(I),B(I),A(I),C(I)
      GO TO 402
401   WRITE(6,403)K,J,D(I),B(I),A(I),C(I)
402   CONTINUE
      K=K+1
```

```
305   CONTINUE
      WRITE(6,304)
      DO 26 I=1,8
      B(I)=A(I)+B(I)
26    D(I)=C(I)+D(I)
      S(1)=W*L
      S(2)=S(1)
      DO 15 I=1,8
      S(I+6)=(B(I)-A(I))*(D(I)-C(I))
      IA=S(I+6)
      IF(IA.EQ.0)S(I+6)=1.0E-08
15    CONTINUE
      DO 14 I=1,5
      VAR=L
      IF(I.EQ.2.OR.I.EQ.4)VAR=W
14    X(I)=VAR
      DO 25 I=1,4
      IW=(I-1)*2+7
25    S(I+2)=X(I)*H
      DO 2 I=1,14
      DO 2 J=1,14
2     SF(I,J)=0.0
      SF(1,2)=PF(0.0,L,0.0,W,0.0,L,0.0,W,H)
      SF(1,3)=AF(0.0,L,0.0,W,0.0,L,0.0,H)
      SF(1,4)=AF(0.0,W,0.0,L,0.0,W,0.0,H)
      SF(1,5)=SF(1,3)
      SF(1,6)=SF(1,4)
      SF(2,1)=SF(1,2)*S(1)/S(2)
      SF(2,3)=SF(1,3)
      SF(2,4)=SF(1,4)
      SF(2,5)=SF(2,3)
      SF(2,6)=SF(2,4)
      SF(3,1)=SF(1,3)*S(1)/S(3)
      SF(3,2)=SF(2,3)*S(2)/S(3)
      SF(3,4)=AF(0.0,H,0.0,L,0.0,H,0.0,W)
      SF(3,5)=PF(0.0,L,0.0,H,0.0,L,0.0,H,W)
      SF(3,6)=SF(3,4)
      SF(4,1)=SF(1,4)*S(1)/S(4)
      SF(4,2)=SF(2,4)*S(2)/S(4)
      SF(4,3)=SF(3,4)*S(3)/S(4)
      SF(4,5)=SF(4,3)
      SF(4,6)=PF(0.0,W,0.0,H,0.0,W,0.0,H,L)
      SF(5,1)=SF(1,5)*S(1)/S(5)
      SF(5,2)=SF(2,5)*S(2)/S(5)
      SF(5,3)=SF(3,5)*S(3)/S(5)
      SF(5,4)=SF(4,5)*S(4)/S(5)
      SF(5,6)=SF(5,4)
      SF(6,1)=SF(1,6)*S(1)/S(6)
      SF(6,2)=SF(2,6)*S(2)/S(6)
      SF(6,3)=SF(3,6)*S(3)/S(6)
      SF(6,4)=SF(4,6)*S(4)/S(6)
      SF(6,5)=SF(5,6)*S(5)/S(6)
      DO 250 I=1,4
      IW=(I-1)*2+7
250   S(I+2)=S(I+2)-S(IW)-S(IW+1)
      DO 3 K=1,4
      J=(K-1)*2
      DO 5 I=1,2
      N=I+J
      N6=N+6
      SF(N6,2)=AF(A(N),B(N),C(N),D(N),0.0,X(K),0.0,X(K+1))
      SF(N6,1)=AF(A(N),B(N),H-D(N),H-C(N),0.0,X(K),0.0,X(K+1))
```

```
      SF(2,N6)=SF(N6,2)*S(N6)/S(2)
5     SF(1,N6)=SF(N6,1)*S(N6)/S(1)
      SF(2,2+K)=SF(2,2+K)-SF(2,J+7)-SF(2,J+8)
      SF(1,2+K)=SF(1,2+K)-SF(1,J+7)-SF(1,J+8)
      SF(2+K,2)=SF(2,2+K)*S(2)/S(2+K)
3     SF(2+K,1)=SF(1,2+K)*S(1)/S(2+K)
      DO 8 K=1,2
      N=(K-1)*2
      SUM=0.0
      DO 6 J=1,2
      NJ=N+J
      NJ6=NJ+6
      SF(NJ6,K+4)=PF(A(NJ),B(NJ),C(NJ),D(NJ),0.0,X(K),0.0,H,X(K+1))
      SUM=SUM+S(NJ6)*SF(NJ6,K+4)
      DO 6 I=1,2
      NI=N+I+4
      NI6=NI+6
      SF(NJ6,NI6)=PF(A(NJ),B(NJ),C(NJ),D(NJ),X(K)-B(NI),X(K)-A(NI),C(NI)
     1,D(NI),X(K+1))
6     SF(NI6,NJ6)=SF(NJ6,NI6)*S(NJ6)/S(NI6)
      DO 7 I=1,2
      NI=N+I+4
      NI6=NI+6
7     SF(NI6,K+2)=PF(A(NI),B(NI),C(NI),D(NI),0.0,X(K),0.0,H,X(K+1))
      SF(N+7,K+4)=SF(N+7,K+4)-SF(N+7,N+11)-SF(N+7,N+12)
      SF(N+8,K+4)=SF(N+8,K+4)-SF(N+8,N+11)-SF(N+8,N+12)
      SF(N+11,K+2)=SF(N+11,K+2)-SF(N+11,N+7)-SF(N+11,N+8)
      SF(N+12,K+2)=SF(N+12,K+2)-SF(N+12,N+7)-SF(N+12,N+8)
      SF(K+4,N+7)=SF(N+7,K+4)*S(N+7)/S(K+4)
      SF(K+4,N+8)=SF(N+8,K+4)*S(N+8)/S(K+4)
      SF(K+2,N+11)=SF(N+11,K+2)*S(N+11)/S(K+2)
      SF(K+2,N+12)=SF(N+12,K+2)*S(N+12)/S(K+2)
      SF(K+2,K+4)=(X(K)*H*SF(K+2,K+4)-SUM)/S(K+2)
      SF(K+2,K+4)=SF(K+2,K+4)-SF(K+2,N+11)-SF(K+2,N+12)
8     SF(K+4,K+2)=SF(K+2,K+4)*S(K+2)/S(K+4)
      DO 9 K=1,4
      IT=K+3
      IF(K.EQ.4)IT=3
      IW=(K-1)*2
      SUM=0.0
      DO 10 I=1,2
      IK=IW+I
      IK6=IK+6
      SF(IK6,IT)=AF(C(IK),D(IK),X(K)-B(IK),X(K)-A(IK),0.0,H,0.0,X(K+1))
      SUM=SUM+S(IK6)*SF(IK6,IT)
      DO 10 J=1,2
      IM=J+IW+2
      IF(K.EQ.4)IM=J
      IM6=IM+6
      SF(IK6,IM6)=AF(C(IK),D(IK),X(K)-B(IK),X(K)-A(IK),C(IM),D(IM),A(IM)
     1,B(IM))
10    SF(IM6,IK6)=SF(IK6,IM6)*S(IK6)/S(IM6)
      DO 11 I=1,2
      IL=IW+2+I
      IF(K.EQ.4)IL=I
      IL6=IL+6
11    SF(IL6,K+2)=AF(C(IL),D(IL),A(IL),B(IL),0.0,H,0.0,X(K))
      IW7=IW+7
      IAC=IW7+2
      IWL=K+3
      IF(K.NE.4)GO TO 12
      IWL=3
      IAC=7
```

```
12    IK=K+2
      SF(IW7,IWL)=SF(IW7,IWL)-SF(IW7,IAC)-SF(IW7,IAC+1)
      SF(IW7+1,IWL)=SF(IW7+1,IWL)-SF(IW7+1,IAC)-SF(IW7+1,IAC+1)
      SF(IAC,IK)=SF(IAC,IK)-SF(IAC,IW7)-SF(IAC,IW7+1)
      SF(IAC+1,IK)=SF(IAC+1,IK)-SF(IAC+1,IW7)-SF(IAC+1,IW7+1)
      SF(IWL,IW7)=SF(IW7,IWL)*S(IW7)/S(IWL)
      SF(IWL,IW7+1)=SF(IW7+1,IWL)*S(IW7+1)/S(IWL)
      SF(IK,IAC)=SF(IAC,IK)*S(IAC)/S(IK)
      SF(IK,IAC+1)=SF(IAC+1,IK)*S(IAC+1)/S(IK)
      KAC=IK+1
      IF(K.EQ.4)KAC=3
      SF(IK,KAC)=(X(K)*H*SF(IK,KAC)-SUM)/S(IK)
      SF(IK,KAC)=SF(IK,KAC)-SF(IK,IAC)-SF(IK,IAC+1)
9     SF(KAC,IK)=SF(IK,KAC)*S(IK)/S(KAC)
      NP=0
      DO 52 I=1,14
      IB=SF(I,1)*1000.
      IF(I.EQ.1)IB=1
      IF(IB.EQ.0)GO TO 52
      NP=NP+1
      IFIL(NP)=I
52    CONTINUE
      DO 16 I=1,NP
      DO 16 J=1,NP
      NI=IFIL(I)
      NJ=IFIL(J)
16    VF(I,J)=SF(NI,NJ)
      WRITE(6,307)
307   FORMAT(1H /4X,44H ARRAY FOR SHAPE FACTORS FROM SURFACE M TO N/1H )
      WRITE(6,17)(I,I=1,NP)
17    FORMAT(4H M/N,I5,13I7)
      DO 18 I=1,NP
18    WRITE(6,19)(I,(VF(I,J),J=1,NP))
19    FORMAT(1X,I2,1X,14F7.5)
      STOP
      END
```

```
      FUNCTION PF(A1,B1,C1,D1,A2,B2,C2,D2,G)
C     THIS FUNCTION SUBPROGRAM CALCULATES THE SHAPE FACTOR FROM A
C     PLANE RECTANGULAR SURFACE TO ANOTHER PARALLEL PLANE
C     RECTANGULAR SURFACE.
      S=(B1-A1)*(D1-C1)
      IP=S*10.
      IF(IP.NE.0)GO TO 1
      PF=0.0
      RETURN
1     F=F1(B1,D1,B2,D2,G)-F1(B1,D1,B2,C2,G)
     1-F1(B1,D1,A2,D2,G)+F1(B1,D1,A2,C2,G)
     2-F1(B1,C1,B2,D2,G)+F1(B1,C1,B2,C2,G)
     3+F1(B1,C1,A2,D2,G)-F1(B1,C1,A2,C2,G)
     4-F1(A1,D1,B2,D2,G)+F1(A1,D1,B2,C2,G)
     5+F1(A1,D1,A2,D2,G)-F1(A1,D1,A2,C2,G)
     6+F1(A1,C1,B2,D2,G)-F1(A1,C1,B2,C2,G)
     7-F1(A1,C1,A2,D2,G)+F1(A1,C1,A2,C2,G)
      PF=F/(3.1415927*S)
      RETURN
      END
```

```
      FUNCTION F1(X1,Y1,X2,Y2,G)
      U=X2-X1
      V=Y2-Y1
      UU=SQRT(G*G+U*U)
      VV=SQRT(G*G+V*V)
      WW=(G*G+U*U+V*V)/(G*G+V*V)
      FI=U*VV*ATAN(U/VV)+V*UU*ATAN(V/UU)-G*G*LOG(WW)/2.
      F1=FI/2.
      RETURN
      END
```

```
      FUNCTION AF(A1,B1,C1,D1,A2,B2,C2,D2)
C     THIS FUNCTION SUBPROGRAM CALCULATES THE SHAPE FACTOR FROM A
C     PLANE RECTANGULAR SURFACE OF A ROOM TO ANOTHER PERPENDICULAR
C     PLANE RECTANGULAR SURFACE.
      S=(B1-A1)*(D1-C1)
      IP=S*10.
      IF(IP.NE.0) GO TO 1
      AF=0.0
      RETURN
1     F=F2(A1,C1,A2,C2)+F2(B1,D1,B2,D2)
     1-F2(A1,D1,B2,D2)-F2(B1,D1,B2,C2)
     2+F2(A1,D1,B2,C2)-F2(B1,D1,A2,D2)
     3+F2(A1,D1,A2,D2)+F2(B1,D1,A2,C2)
     4-F2(A1,D1,A2,C2)-F2(B1,C1,B2,D2)
     5+F2(A1,C1,B2,D2)+F2(B1,C1,B2,C2)
     6-F2(A1,C1,B2,C2)+F2(B1,C1,A2,D2)
     7-F2(A1,C1,A2,D2)-F2(B1,C1,A2,C2)
      AF=F/(3.1415927*S)
      RETURN
      END
```

```
      FUNCTION F2(X1,Y1,X2,Y2)
      U=X2-X1
      V=Y1**2+Y2**2
      IF(ABS(U**2+V).LE.1.0E-7) GO TO 1
      GO TO 2
    1 F2=0.0
      GO TO 3
    2 IF(V.LE.1.0E-7) GO TO 4
      GO TO 5
    4 F2=.5*U**2*LOG(U**2)
      GO TO 3
    5 F2=.5*(U**2-V)*LOG(U**2+V)+2*U*SQRT(V)*ATAN(U/SQRT(V))
    3 F2=F2/4.
      RETURN
      END
```

LEGEND FOR ROOM ARRANGEMENT

ASSUME WALL NO. 1 IS ON THE ROOM LENGTH

M OR N						
1	CEILING	16.00 BY 12.00				
2	FLOOR	16.00 BY 12.00				
3	WALL NO.1	16.00 BY 8.00				
4	WALL NO.2	12.00 BY 8.00				
5	WALL NO.3	16.00 BY 8.00				
6	WALL NO.4	12.00 BY 8.00				
	WINDOWS OR DOORS		A	B	C	D
7	WINDOW ON WALL 2		4.00	2.67	6.67	2.67
8	WINDOW ON WALL 3		4.00	2.67	6.67	2.67

A - WINDOW HEIGHT
B - WINDOW WIDTH
C - DISTANCE OF LEFT EDGE OF WINDOW TO LEFT WALL
D - HEIGHT FROM FLOOR TO LOWER EDGE OF WINDOW

ARRAY FOR SHAPE FACTORS FROM SURFACE M TO N

M/N	1	2	3	4	5	6	7	8
1	.00000	.36405	.18326	.11766	.16504	.13472	.01706	.01822
2	.36405	.00000	.18326	.12078	.16824	.13472	.01394	.01501
3	.27488	.27488	.00000	.12759	.15887	.13715	.00956	.01706
4	.26473	.27176	.19139	.00000	.16715	.09464	.00000	.01033
5	.27006	.27531	.17332	.12157	.00000	.14066	.01909	.00000
6	.26944	.26944	.18286	.08412	.17192	.00000	.01127	.01095
7	.30709	.25086	.11468	.00000	.21001	.10144	.00000	.01592
8	.32793	.27026	.20474	.08261	.00000	.09853	.01592	.00000

An Algorithm for Calculating Radiation Shape Factors Between Attic Surfaces Where the Attic Has a Gabled Room

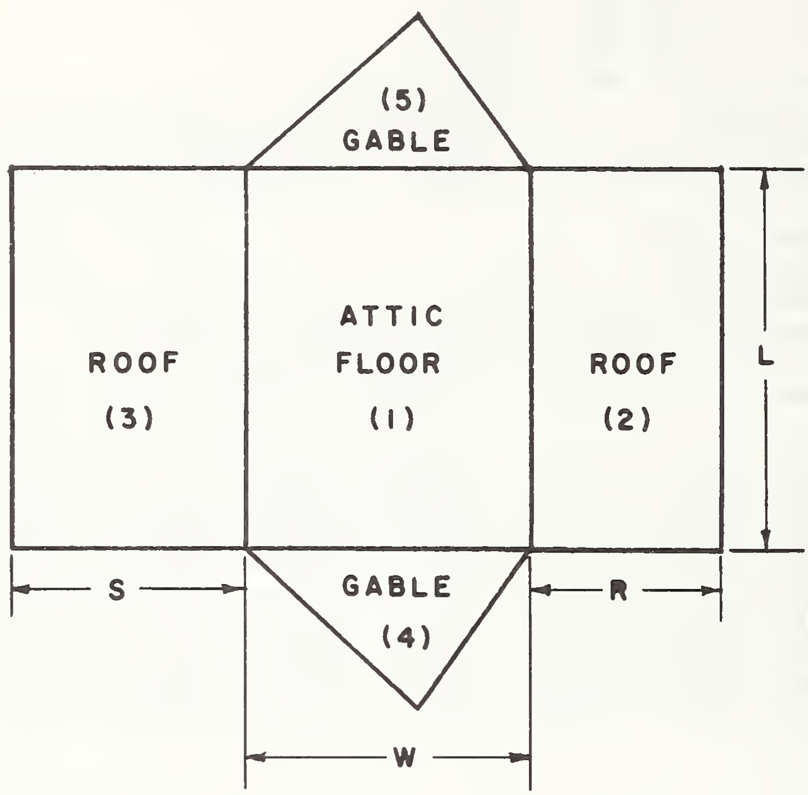

Figure A-13 Definitions of Attic Enclosure

Data:

L = Length of attic floor

W = Width of attic

---

* This section was contributed by B. A. Peavy and D. M. Burch, Thermal Engineering Systems Section, Center for Building Technology, National Bureau of Standards, Washington, D. C. 20234.

The primary variables determined by this subroutine are:

F_{m-n} = An array giving radiation shape factors between the various inside surfaces of an attic with a gabled roof.

m, n = 1 attic floor (1)

2 roof area (2)

3 roof area (3)

4 front gable (4)

5 rear gable (5)

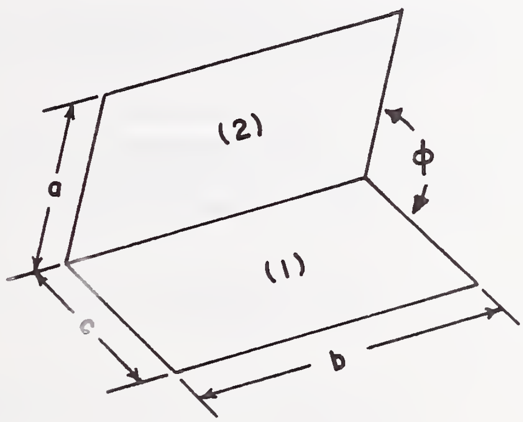

Figure A-14 Radiation Heat Exchange Between Two Adjacent Surfaces

$$X = \frac{a}{b},\ Y = \frac{c}{b},\ Z^2 = X^2 + Y^2 - 2XY \cos \phi$$

$$\pi Y F_{1-2} = -\frac{\sin 2\phi}{4}\left\{XY\sin\phi + \left(\frac{\pi}{2}-\phi\right)(X^2+Y^2) + Y^2\tan^{-1}\left(\frac{X - Y\cos\phi}{Y\sin\phi}\right) + X^2\tan^{-1}\left(\frac{Y - X\cos\phi}{X\sin\phi}\right)\right\}$$

$$+\frac{\sin^2\phi}{4}\left\{\left(\frac{2}{\sin^2\phi}-1\right)\ln\left[\frac{(1+X^2)(1+Y^2)}{1+Z^2}\right] + Y^2\ln\left[\frac{Y^2(1+Z^2)}{(1+Y^2)Z^2}\right] + X^2\cos 2\phi\ln\left[\frac{1+X^2}{1+Z^2}\right] + 2X^2\ln\frac{X}{Z}\right\}$$

$$+ Y\tan^{-1}\left(\frac{1}{Y}\right) + X\tan^{-1}\left(\frac{1}{X}\right) - Z\tan^{-1}\left(\frac{1}{Z}\right)$$

$$+\frac{\sin\phi\sin 2\phi}{2}X\sqrt{1+X^2\sin^2\phi}\left\{\tan^{-1}\left[\frac{Y(1+X^2\sin^2\phi)}{1+X^2-XY\cos\phi}\right]\right\}$$

$$+\cos\phi\int_0^Y\sqrt{1+\lambda^2\sin^2\phi}\left\{\tan^{-1}\left[\frac{X(1+\lambda^2\sin^2\phi)}{1+\lambda^2-\lambda x\cos\phi}\right]\right\}d\lambda \tag{1}$$

$$\sum_{m=1}^{5} F_{n-m} = 1 \tag{2}$$

$$F_{n-m} = \frac{A_m F_{m-n}}{A_n} \tag{3}$$

A_m is area of surface m

Calculation Sequence:

1. $X = R/L$, $Y = W/L$, $\phi_1 = \cos^{-1}\left(\frac{W^2 + R^2 - S^2}{2WR}\right)$

   Compute F_{1-2}, F_{2-1} [Equations (1) and (3)]

2. If $S = R$, $\phi_2 = \phi_1$, $F_{1-3} = F_{1-2}$, $F_{3-1} = F_{2-1}$, skip stage 3

3. $X = S/L$, $Y = W/L$, $\phi_2 = \cos^{-1}\left(\frac{W^2 + S^2 - R^2}{2WS}\right)$

   Compute F_{1-3}, F_{3-1} [Equations (1) and (3)]

4. $X = S/L$, $Y = R/L$, $\phi_3 = \pi - \phi_1 - \phi_2$

   Compute F_{2-3}, F_{3-2} [Equations (1) and (3)]

5. F_{m-4}, F_{m-5}, $m = 1, 2, 3$ [Equation (2)]

6. F_{4-m}, F_{5-m}, $m = 1, 2, 3$ [Equation (3)]

7. F_{4-5}, F_{5-4} [Equation (2)]

FI

An Algorithm for Approximating Inside Surface Heat Transfer Coefficients Tabulated in Table 1, Page 357 of the 1972 ASHRAE Handbook of Fundamentals

Data:

IDIR: Heat flow direction index

	1	Upward
	2	45° upward
IDIR =	3	Horizontal
	4	45° downward
	5	Downward

ε: Emittance of the surface

IV: Moving air index (IV = 0 corresponds to still air)

Calculation Sequence:

1. If IV = 0, $FI = h_c + 1.02*\varepsilon$

   where

	.712		1
	.682		2
h_c =	.542	for IDIR =	3
	.402		4
	.162		5

2. If IV $\neq$ 0, FI = 2.0 Btu per (hr) (sq ft) (F)

An Algorithm for Determining Outside Surface Heat Transfer Coefficient As a Function of Air Velocity and the Type of Surface Constructions

Data:

V: Wind velocity, knots (Determined in CLIMATE)

DIR: Wind direction (Determined in CLIMATE)

IS: Outside surface index

IS =
- 1 Stucco
- 2 Brick and rough plaster
- 3 Concrete
- 4 Clear pine
- 5 Smooth plaster
- 6 Glass, white paint on pine

WA: Wall azimuth angle, degree

Calculation Sequence:

1. Conversion of the unit of wind velocity from knots into mph.

   V' = 1.153*V

2. Outside surface heat transfer coefficient.

   FO = A*(V'**2) + B*V' + C

   where A, B and C are given in Table A-8

Table A-8

Value of Coefficients For Calculation of Outside Heat Transfer Coefficient

IS	A	B	C
1	0.0	0.464	2.04
2	0.001	0.320	2.20
3	0.0	0.330	1.90
4	-0.002	0.315	1.45
5	0.0	0.244	1.80
6	-0.00125	0.262	1.45

3. Relative wind direction to the wall surface.

RWD = WA + 180 - DIR

If $|RWD| > 180$, RWD = 360 - RWD

4. Conversion of the unit of wind velocity into m per sec.

VV = 0.51479*V

5. Air velocity close to wall surface

If $|RWD| < 90$ (windward)

VC = 0.25*VV for $VV > 2$

VC = 0.5 for $VV \leq 2$

If $|RWD| \geq 90$ (leeward)

VC = 0.3 + 0.05*VV

6. Convection component of the outside surface heat transfer coefficient.

FOC = 3.28*((VC)**0.605)*

---

* This equation was derived by K. Kimura based upon the recent data published in Reference 6.

ACR*

An Algorithm for Determining Thermal Resistance
Across the Air Cavity in Walls and Roofs

Data:

DT: Temperature difference across the air space, F

L: Thickness of the air space, in.

IDIR: Heat flow direction index

IDIR =
- 1 upward
- 2 45° upward
- 3 horizontal
- 4 45° downward
- 5 downward

ϵ_1, ϵ_2: Emittance of the surfaces facing the air cavity

ATC: Average temperature of the air cavity, F

Calculation Sequence:

1. Let x = Log (DT*(L**3))

   Then using the values for A_0, A_1, A_2, A_3, and A_4 which are given in Table A-9, calculate

   $$y = A_0 + A_1 * x + A_2 * (x ** 2) + A_3 * (x ** 3) + A_4 * (x ** 4)^{*/}$$

---

* This polynomial has been derived to represent experimental data presented in Figure 6 of reference 7 and shown here in Figure A-15.

Table A-9 VALUES OF A_0, A_1, A_2, A_3, and A_4 FOR CALCULATION OF RESISTANCE ACROSS THE AIR SPACE

IDIR	Range of DT*(L**3)	A_0	A_1	A_2	A_3	A_4
11	All the range	-1.5904	0.2824	0.0	0.0	0.0
22	$1 \leq$ DT*(L**3) ≤ 10	-1.7125	-0.0875	0.2437	-0.0420	0.0
	$10 <$ DT*(L**3) ≤ 100	-1.8546	0.3124	0.0	0.0	0.0
	$100 <$ DT*(L**3)	-1.7380	0.2910	0.0	0.0	0.0
3	$1 \leq$ DT*(L**3) ≤ 10	-1.7410	-0.0331	0.0198	-0.0146	0.0
	$10 <$ DT*(L**3) ≤ 100	1.0460	-3.4660	1.5482	-0.2669	0.01673
	$100 <$ DT*(L**3)	-0.2141	-0.6577	0.1693	-0.0095	0.0
4	$1 <$ DT*(L**3) ≤ 10	-1.7420	0.0163	-0.0409	0.0204	0.0
	$10 <$ DT*(L**3) ≤ 100	-6.5410	5.5710	-2.3690	0.4467	-0.0300
	$100 <$ DT*(L**3)	-0.1914	6.1610	-1.3390	0.1339	-0.0050
5	$1 <$ DT*(L**3) ≤ 10	-1.770	0.0	0.0	0.0	0.0
	$10 <$ DT*(L**3)	-1.745	0.0028	0.0029	0.0008	0.0

2. Let z = Exp (y)

   If $z > 0.3$ $\qquad h_c = z * (1 - 0.001 * (DT-50))/L$

   If $0.2 \leq z \leq 0.3$ $\qquad h_c = z * (1 + 0.00035 * (DT-50))/L$

   If $z < 0.2$ $\qquad h_c = z * (1 + 0.0017 * (DT-50))/L$

3. $h_r = 0.00686 * (((ATC + 460)/100) ** 3)$ **/

4. $RES = 1/(h_c + (1/(1/\epsilon_1 + 1/\epsilon_2 - 1)) * h_r)$

**/ This polynomial has been derived to represent the curve presented in Figure 5 of reference 7 and shown here in Figure A-16.

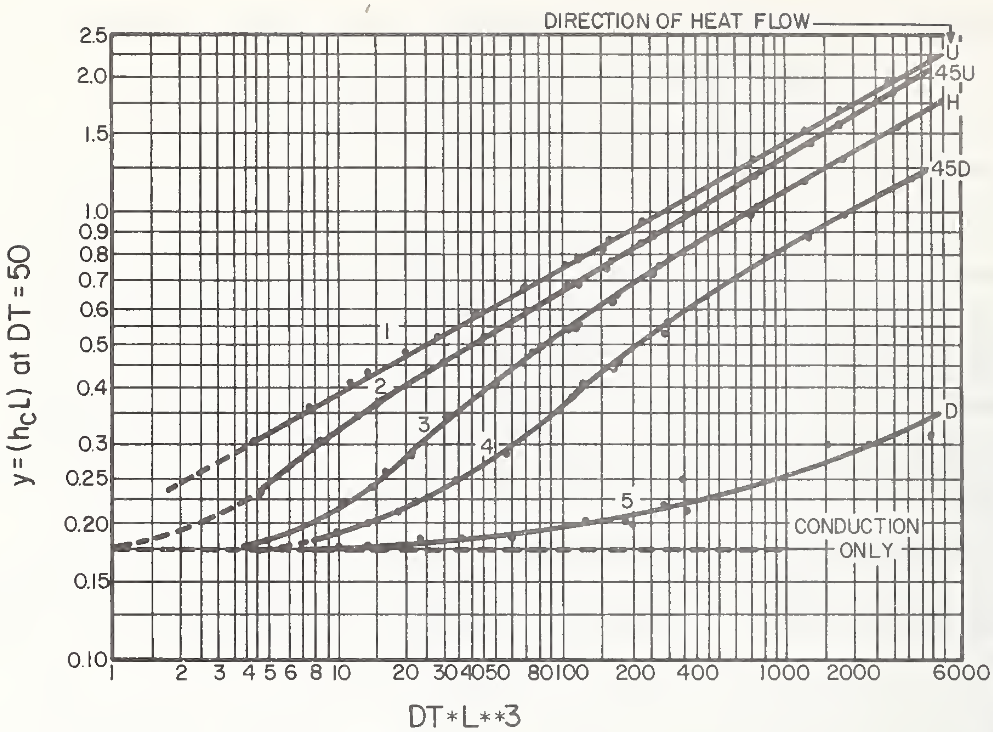

Figure A-15 Convection-Conduction Coefficient for Heat Transfer Across an Air Space for Five Orientations of the Air Space and Directions of Heat Flow

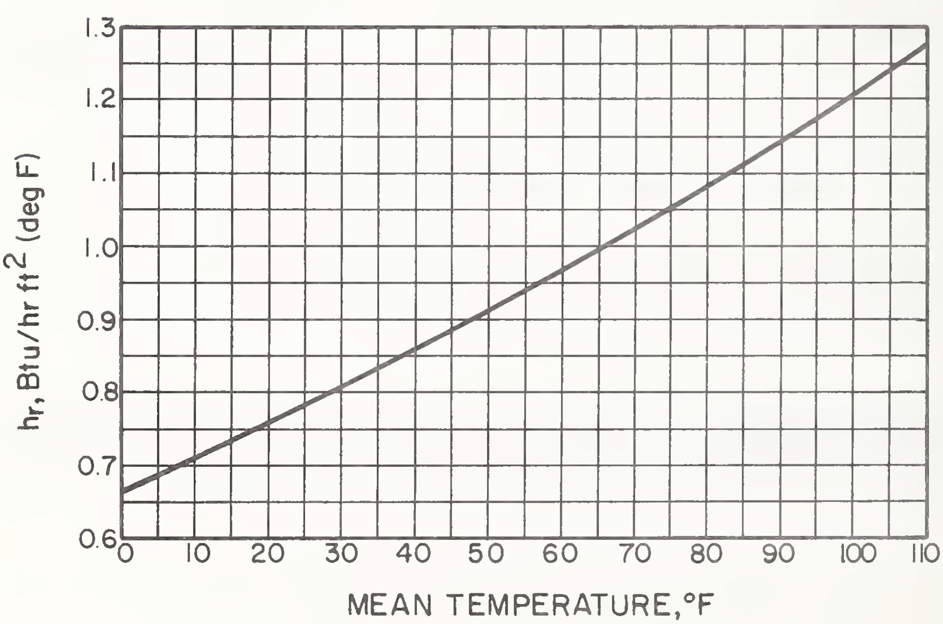

Figure A-16 Linear Radiation Coefficient for Heat Transfer Across an Air Space for a Radiation Interchange Factor

A Description of the Calculation Procedure for Transient Heat Conduction Using Conduction Transfer Functions

Conduction transfer functions are used widely and considered as a convenient and effective tool for the evaluation of transient heat transfer in building construction components. The conventional steady state heat transfer equation for calculating heat loss:

$$Q = U * (T_a - T_o) \tag{1}$$

where U: overall heat transfer coefficient of roof or wall

T_a: inside air temperature

T_o: outside air temperature

is not sufficient for evaluating transient heat transfer. This equation becomes invalid because the outdoor temperature T_o usually varies as affected by solar radiation, cloud cover and wind effect. The effect of the rapid change of the outdoor temperature will not be accounted for unless the structure is extremely lightweight, such as galvanized steel.

Approximate calculation for a more accurate determination of the instantaneous heat transfer can be made by replacing $T_a - T_o$ of equation (1) by a Total Equivalent Temperature Difference (TETD) which is usually precalculated for typical building construction components and takes into account the thermal storage effect. Although very useful, the TETD concept is only valid when the outside temperature T_o undergoes steady periodic changes. The TETD concept is therefore especially useful computing design heat transfer rates for the building where very warm or very cold conditions are assumed to occur for several successive days.

A more accurate formulation for conduction heat transfer from a room to randomly fluctuating outdoor conditions is to use the hourly history of temperatures in conjunction with Conduction Transfer Functions (CTF). For example, in calculating the energy transfer from a room at an inside surface, the equation would be:

$$Q_{i,t} = \sum_{j=0}^{N} X_j * T_{a,t-j} - \sum_{j=0}^{N} Y_j * T_{o,t-j} + R * Q_{t-1} \qquad (2)$$

where X_j, Y_j (for j = 0, 1, 2 ... N), and R are the Conduction Transfer Functions. In equation (2), $T_{o,t-j}$ and $T_{a,t-j}$ represent outdoor and room air temperatures respectively at jth hour prior to the time for which the value of Q_t is needed. And Q_{t-1} is the heat loss Q_t, from the room at the previous hour. By having a record of $T_{o,t-1}$, $T_{o,t-2}$, $T_{o,t-3}$ ... $T_{o,t-j}$; and $T_{a,t-1}$, $T_{a,t-2}$ ... $T_{a,t-j}$; it is possible to determine the instantaneous conduction transfer, provided that the values for X_j and Y_j, and R are available.

The number of terms involved for the calculation of Q_t (or the value of N in equation (2)) depends upon the type of roof or wall construction. Generally heavy constructions require a large value, although for most conventional constructions, it seldom exceeds 20. Stephenson amd Mitalas[8/] have shown that the value of N can be further decreased by employing more than one past record of Q_t (or Q_{t-j} with j being more than 1) in the following manner:

$$Q_{i,t} = \sum_{j=0}^{N'} A_j{*}T_{a,t-j} - \sum_{j=0}^{N'} B_j{*}T_{o,t-j} - \sum_{j=1}^{N} D_j{*}Q_{i,t-j} \quad (3)$$

where A_j, B_j, and D_j are the Modified Conduction Transfer Functions according to Stephenson and Mitalas[8/]. Table A-10 gives values of Conduction Transfer Functions calculated for a brick wall having an overall heat transfer coefficient of 0.418. In this table, the factors designated by Z_j and C_j are the additional transfer function to be used for evaluating the instantaneous heat loss $Q_{o,t}$ at the exterior side of the structure. The applicable equations for this side of the structure are then:

$$Q_{o,t} = \sum_{j=0}^{N} Y_j{*}T_{a,t-j} - \sum_{j=0}^{N} Z_j{*}T_{o,t-j} + R{*}Q_{o,t-1} \quad (4)$$

or

$$Q_{o,t} = \sum_{j=0}^{N'} B_j{*}T_{a,t-j} - \sum_{j=0}^{N'} C_j{*}T_{o,t-j} - \sum_{j=1}^{N'} D_j{*}Q_{o,t-j} \quad (5)$$

The table also shows that for the calculation of $Q_{o,t}$ the use of Stephenson type transfer functions would permit the reduction of N from 10 to N' = 4 with a corresponding increase of three terms in the past record of $Q_{o,t}$.

Table A-10

Construction Data

	Thickness (f)	Thermal Conductivity Btuh/ft	Density lb/ft^3	Specific Heat Btu/lb °F	Thermal Resistance sq ft hr F/Btu
Inside Surface	0.000	--	--	--	.830
4-in common brick	0.333	.420	100.42	.220	.793
4-in face brick	0.333	.770	125.00	.220	0.432
Outside surface	0.000	--	--	--	.330
					2.385

Time increment: 1 hour

Overall heat transfer coefficient U = 0.418

Conduction Transfer Functions (CTF)

j	X_j	Y_j	Z_j	R
0	.9194	.0001	1.9833	0.8398
1	-.9391	.0080	-2.1785	
2	.0606	.0243	.1983	
3	.0153	.0186	.0387	
4	.0061	.0090	.0144	
5	.0026	.0039	.0060	
6	.0011	.0017	.0026	
7	.0005	.0007	.0011	
8	.0002	.0003	.0005	
9	.0001	.0001	.0002	
10	.0000	.0001	.0001	

Stephenson Type Transfer Functions

j	A_j	B_j	C_j	D_j
0	0.9194	0.0001	1.9833	1.000
1	-1.4128	0.0079	-3.2002	-1.3552
2	0.5785	0.0202	1.3942	0.4699
3	-0.0511	0.0064	-0.1448	0.0315
4	0.0007	0.0002	0.0024	0.0002

Data:

NL: Number of layers to be considered for the analysis of a given structure: the number of layers should include surface resistance or air cavity resistance if they contribute significantly to the overall heat transfer of that particular structure

K_i: Thermal conductivity of i-th layer in Btu per (hr) (ft) (F). This value is not needed for air cavities or for the surface resistance layers.

ρ_i: Density of i-th layer in lb per (cu. ft). This value is not needed for air cavities or for the surface resistance layers

C_i: Specific heat of i-th layer material in Btu per (lb) (F). This value is not needed for air cavities or for the surface resistance layers.

L_i: Thickness of the i-th layer in ft. This value is not needed for the air cavities or for the surface resistance layers.

RES_i: Thermal resistance of air cavities and surface resistance layers in (hr) (sq ft) (F) per Btu. This value is not needed whenever all of the remaining values such as K_i, ρ_i, C_i and L_i are given.

DT: Time increment for the conduction transfer functions in hr (usually one hour for the building heat transfer calculations).

Subscript i refers to i-th layer and it varies from 1 to NL.

The sequence of inputing the above property values for each layer is very important and must be consistent with the particular convention adopted for the specific calculation routine. The sequence must follow in order from the inside layer to the outside layer or vice versa. It should be noted that the inclusion of the surface thermal resistance as independent layers is optional depending upon the end use of the conduction transfer functions. If the inside surface temperature is to be computed as a balance of all the heat flow involved at that surface, the thermal resistance of the inside surface should not be included in the calculation of the conduction transfer functions. The same comment applies for the outside surface.

An algorithm for the calculation of the conduction heat transfer functions will not be given here, since it involves lengthy mathematical solutions to the standard transient heat conduction differential equation. Reference (9) provides an excellent background for this calculation. Several computer programs[10, 11] are available for the calculation of conduction transfer functions for multi-layer walls, roofs and floor constructions. The program developed by the National Research Council of Canada[10] requires the layer input to be placed in order from outside toward inside. It calculates the Stephenson type conduction transfer functions directly. The program of the National Bureau of Standards[11/] requires the input to be placed from the inside layer first and calculates the conduction transfer functions of plane, cylindrical and spherical walls. It also calculates the transfer functions for solid objects of plane, cylindrical and spherical shapes as well as the heat conduction systems involving semi-infinite solids, approximated by basement floors and underground constructions.

Under non-steady heat conduction, the heat lost from one side of a surface is not equal to the rate of heat entry at another side. Equations (2) and (3), however, must be valid also for the steady state heat transfer problems. One of the best ways to check the consistency of the conduction transfer functions is to use them in the solution of steady state problems and see if the following criteria is met: The room side surface temperature and the outdoor side surface temperature are maintained constant for many hours so that

$$TOS_t = TOS_{t-1} = \ldots\ldots \quad TOS_{t-N}$$

$$TIS_t = TIS_{t-1} = \ldots\ldots \quad TIS_{t-N}$$

$$QI_t = QO_t = QO_{t-1} = QI_{t-1}$$

Thus

$$QO_t = TIS_t * \sum^{N} Y_j - TOS_t * \sum^{N} Z_j + R * QO_t$$

$$QI_t = TIS_t * \sum^{N} X_j - TOS_t * \sum^{N} Y_j + R * QI_t$$

In order to satisfy these two equations simultaneously, it is necessary that

$$\sum^{N} X_j = \sum^{N} Y_j = \sum^{N} Z_j = U*(1 - R)$$

In fact, the conduction transfer functions of the sample wall shown in Table A-10 can be shown to satisfy this requirement

$$\sum X_j = \sum Y_j = \sum Z_j = 0.0668$$

and

$$U*(1 - R) = 0.418*(1 - 0.8398) = 0.0669$$

HEATW

An Algorithm for Calculating Transient Heat Conduction Through Opaque Walls or Roofs Using Conduction Transfer Functions

Data:

X_j, Y_j and Z_j for j = 0, 1, 2, ... N: Conduction transfer functions in Btu per (hr) (sq ft), (Calculated as outlined in XYZ for the system that excludes the inside and outside heat resistance layers)

R: Common ratio of the conduction transfer function (Calculated as outlined in XYZ),

$$R = \frac{X_{j+1}}{X_j} = \frac{Y_{j+1}}{Y_j} = \frac{Z_{j+1}}{Z_j} \text{ for } j \geq N$$

N: Number of the significant terms to be used for the conduction heat transfer calculation, (Calculated as outlined in XYZ)

FO_t: Outside surface heat transfer coefficient at time t, Btu per (hr) (sq ft) (F)

IT_t: Total solar radiation intensity on the outside surface at time t, Btu per (hr) (sq ft), (Calculated in SOLAD)

TIS_{t-j}: History of inside surface temperature at times t-1, t-2, ... and (t-N)th hour, F

TOS_{t-j}: History of outside surface temperature at times t-1, t-2, t-3, ... and (t-N)th hour, F

DB_t: Outdoor air dry-bulb temperature at time t, F

$HEAT_{t-1}$: Heat loss at the interior surface to the outdoor environment at the previous hour, Btu per (hr) (sq ft)

QO_{t-1}: Heat loss at the exterior surface to the outdoor environment at the previous hour, Btu per (hr) (sq ft)

a: Solar absorption coefficient at the exterior surface

α: Cosine of the angle subtended by a vertical line and the surface normal ... (Calculated in SUN)

TC_t: Total cloud amount ... (Calculated in CLIMATE)

TM: A reference temperature (usually the inside design temperature), F

Calculation Sequence:

A. Exterior walls and roof

1. The heat balance equation at the exterior surface is given by

$$QR_t + QA_t + QO_t - QS_t = 0$$

where

a) Incident solar radiation

$$QR_t = a*IT_t$$

b) Convection heat transfer from the outdoor air

$$QA_t = FO_t*(DB_t - TOS_t)$$

c) Conduction heat flow from the inside surface

$$QO_t = \sum_{j=0}^{N} Y_j*(TIS_{t-j}-TM) - \sum_{j=0}^{N} Z_j*(TOS_{t-j}-TM) + R*QO_{t-1}^{*}$$

d) Heat loss to the sky

$$QS_t = 2*\alpha*(10-TC_t)^{**}$$

2. Let

$$SUM1 = \sum_{j=0}^{N} Y_j*(TIS_{t-j}-TM) + CR*QO_{t-1}$$

$$SUM2 = \sum_{j=1}^{N} Z_j*(TOS_{t-j}-TM)$$

3. Outside surface temperature

$$TOS_t = (QR_t - QS_t + FO_t *DB_t + SUM1 - SUM2 + Z_0*TM)/(FO_t + Z_0)$$

4. Using this new TOS_t, the heat loss at the interior surface is then determined as follows:

$$HEAT_t = \sum_{j=0}^{N} X_j*(TIS_{t-j} - TM) - \sum_{j=0}^{N} Y_j*(TOS_{t-j} - TM) + R*HEAT_{t-1}$$

---

* Throughout this discussion a value of TM is always subtracted from the interior surface and exterior surface temperatures. This subtraction usually helps to minimize the digital errors which occur and are sometimes significant when a large number of numerical data are multiplied and added. Since $\sum_{j=0}^{N} X_j = \sum_{j=0}^{N} Y_j$, the net effect of the subtraction is zero.

** This expression was developed to yield a roof sky radiation of 20 Btu per (hr) (sq ft) for a cloudless condition, which was reported in reference (12).

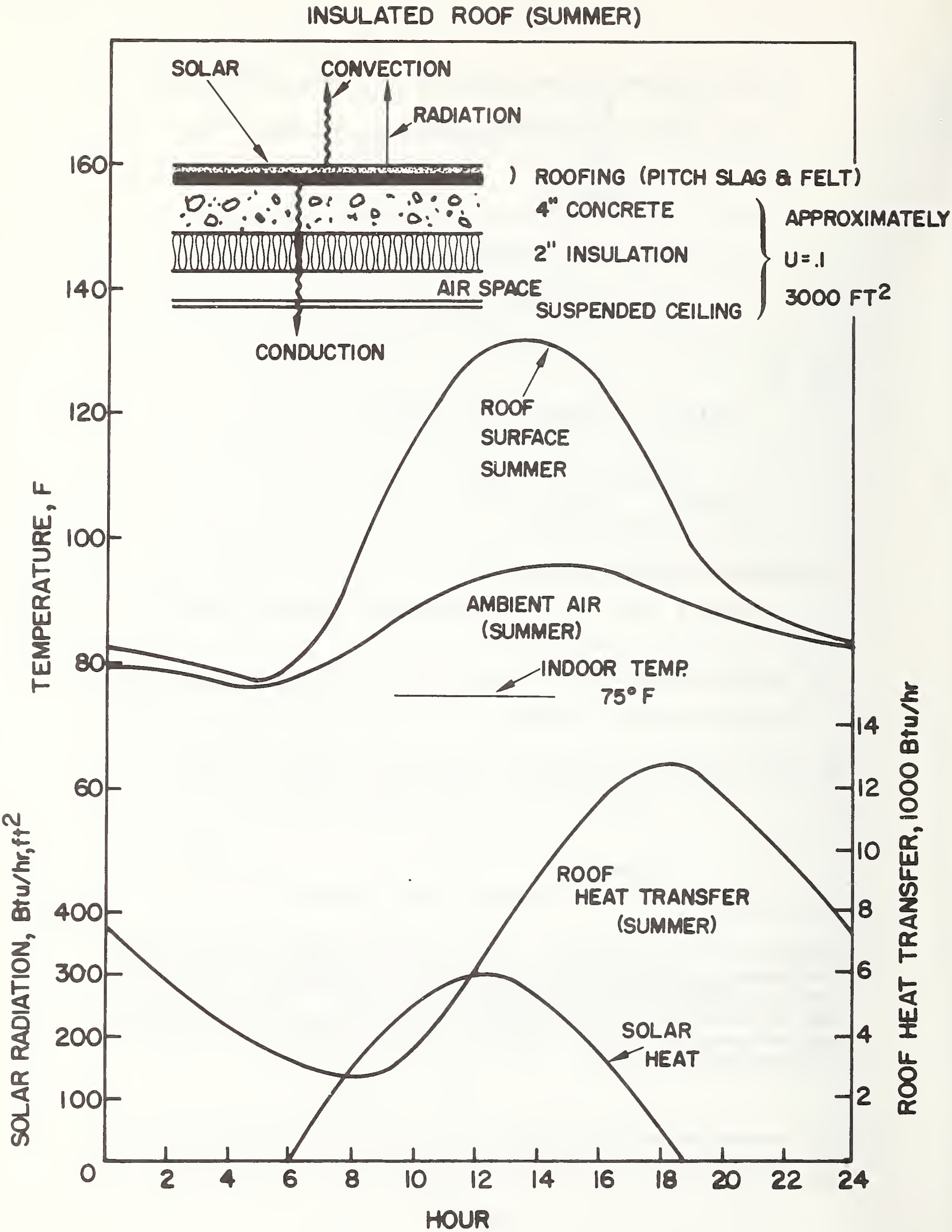

Figure A-17 Transient Heat Transfer in a Typical Roof

Table A-11

Layer No.	L(I)	K(I)	ρ(I)	C(I)	RES(I)	Description of Layers
1	0.	0.	0.	0.	2.04	Suspended Ceiling
2	.167	.025	13.	.320	0.	2-in. Insulation
3	.333	1.000	140.	.200	0.	4-in. Concrete
4	.031	.110	70.	.400	0.	3/4-in. Felt
5	.042	.830	55.	.400	0.	1/2-in. Pitch Slag

Time Increment DT = 1.

Conduction Transfer Functions

j	X_j	Y_j	Z_j	R
0	.21934	.00011	3.30513	.78793
1	-.25485	.00504	-4.27082	
2	.04650	.01060	.97885	
3	.00857	.00493	.00808	
4	.00224	.00140	.00104	
5	.00059	.00037	.00024	
6	.00016	.00010	.00006	
7	.00004	.00003	.00002	
8	.00001	.00001	.00000	
9	.00000	.00000	.00000	

Figure A-17 shows the energy balance that is involved in the above calculation sequence and the results of a typical calculation. Table A-11 gives the conduction transfer functions for the roof used in the calculations.

B. Interior walls and floor/ceiling sandwich

The calculation sequence for the partition wall and floor/ceiling sandwich is completely different from that of the exterior wall or roof. The difference is due to the fact that the air temperature at the exterior side of the construction can be assumed the same as at the interior side, at least for a climate controlled building. In order to take advantage of this fact, conduction transfer functions should be determined with the surface thermal resistance layer added at the exterior side of the structure. The heat loss through a partition wall is then calculated by

$$HEAT_t = \sum_{j=0}^{N} X_j*(TI_{t-j} - TM) - \sum_{j=0}^{N} Y_j*(TA_{t-j} - TM) + R*HEAT_{t-1}$$

where TA_{t-j} = room temperature at time (t-j)th hour

If the room temperature were maintained constant at TM, which is usually the case, the terms involving the Y_j's would then drop out of the equation.

C. Slab on grade floor

The heat loss to the ground through the floor on grade can be calculated by using conduction transfer functions determined on the basis of flooring, concrete, and 12 inches of ground layer

$$HEAT_t = \sum_{j=0}^{N} X_j*(TI_{t-j} - TM) - \sum_{j=0}^{N} Y_j*(TG - TM) + R*HEAT_{t-1}$$

Since usually TG is constant and

$$\sum_{j=0}^{N} Y_j = U_G*(1 - R),$$

then

$$HEAT_t = \sum_{j=0}^{N} X_j*(TI_{t-j} - TM) - U_G*(1 - R)*(TG-TM) + R*HEAT_{t-1}$$

The same method is applicable to a floor with a crawl space as long as the space is not vented. The conduction transfer functions for the floor with an unvented crawl space simply has an additional air resistance layer to account for the dead air space between the floor and the ground. In many cases it is safe to assume that TG = TM, and then the term involving U_G would drop out of the equation.

D. Floor over the vented crawl space

The floor over a vented crawl space can be treated in the same manner as an exterior wall or roof except that the solar radiation and sky radiation terms would not be included in the energy balance and that the outside surface heat transfer coefficient is replaced by a value similar in magnitude to the inside surface heat transfer coefficient. If the conduction transfer functions include the outside surface heat transfer resistance, the calculation is simply

$$HEAT_t = \sum_{j=0}^{N} X_j*(TI_{t-j} - TM) - \sum_{j=0}^{N} Y_j*(DB_{t-j} - TM) + R*HEAT_{t-1}$$

SCHEDULE

An Algorithm to Determine Heat Gains From Lighting, Equipment, Occupancy and Ventilation

Data:

1. Normalized 24 hour profiles (j = 1, 2, 3 ... 24) of operational schedules for weekdays (i = 1) and weekends and holidays (i = 2) are given for lighting, equipment use, occupancy, ventilation, indoor temperature setting, and humidity setting as follows:

   $QLITE_{i,j}$: Lighting schedules (fraction of some maximum)

   $QEQUP_{i,j}$: Equipment use schedules (fraction of some maximum)

   $QOCUP_{i,j}$: Occupancy schedule (fraction of some maximum)

   $QVENT_{i,j}$: Ventilation fan operating schedule (fraction of some maximum)

   $ROOMDB_{i,j}$: Space thermostat setting schedule

   $ROOMRH_{i,j}$: Space humidistat setting schedule

2. Maximum values of the parameters to be used with the schedules

   QLITX: Maximum electric power demand for lighting for the 24 hour period

   QEQUPX: Maximum electric power demand for appliances for the 24 hour period, KW

QOCUPX: Maximum number of equivalent sedentary adult occupants during the 24 hour period

QVENTX: Maximum amount of ventilation air supply during the 24 hour period, cu. ft per min.

QHTWTX: Maximum amount of hot water demand during the 24 hour period, gallons per hour

3. YEAR, MONTH AND DAY

These data are needed to determine whether the day is a weekday, weekend, or holiday, and whether the day falls within daylight savings time.

4. QOS(TA): Sensible heat loss of a sedentary adult at the room temperature TA, Btu per (hr) (occupant)

QOL(TA): Latent heat loss of a sedentary adult at the room temperature TA, Btu per (hr) (occupant)

WO(DB,WB): Humidity ratio of the outdoor air for a given outdoor air dry-bulb and wet-bulb temperature, lb of water vapor per (lb of dry air)

WI(TA,WGA): Humidity ratio of the indoor air for a given dry-bulb temperature and wet-bulb temperature, lb of water vapor per (lb of dry air)

QWT: Heat needed to generate one gallon of hot water, Btu per gallon of water

Calculation Sequence:

1. Determine the weekday indicator IWK from WKDAY

2. Determine the holiday indicator IHOL from HOLDAY

3. If IWK = 1 or 7 $\quad i = 2$

   If IHOL = 1 $\quad i = 2$

   Otherwise $\quad i = 1$

4. Heat generated from lights (for j = 1 ... 24), Btu per hr

   $QS_{i,j} = QLITX*3413*QLITE_{i,j}$

5. Heat generated from equipment and occupants, Btu per hr

   (for j = 1, 2 ... 24)

   Sensible heat

   $QS'_{i,j} = QEQUPX*3413*QEQUP_{i,j} + QOCUPX*QOS(TA)*QOCUP_{i,j}$

   Latent heat

   $QL_{i,j} = QOCUPX*QOL(TA)*QOCUP_{i,j}$ *

6. Heat gain due to ventilation air, Btu per hr

   Sensible heat

   $LEAK_{i,j} = QVENTX*C_p*60*(DB_j - ROOMDB_{i,j})*QVENT_{i,j}*\rho$

   Latent heat

   Determine WI_j from PSY using $ROOMDB_{i,j}$ and $ROOMRH_{i,j}$

   $LEAK'_{i,j} = QVENTX**60*(WO_j - WI_j)*1060*QVENT_{i,j}*\rho$

C_p and ρ on this page depict specific heat and density of air in the English units.

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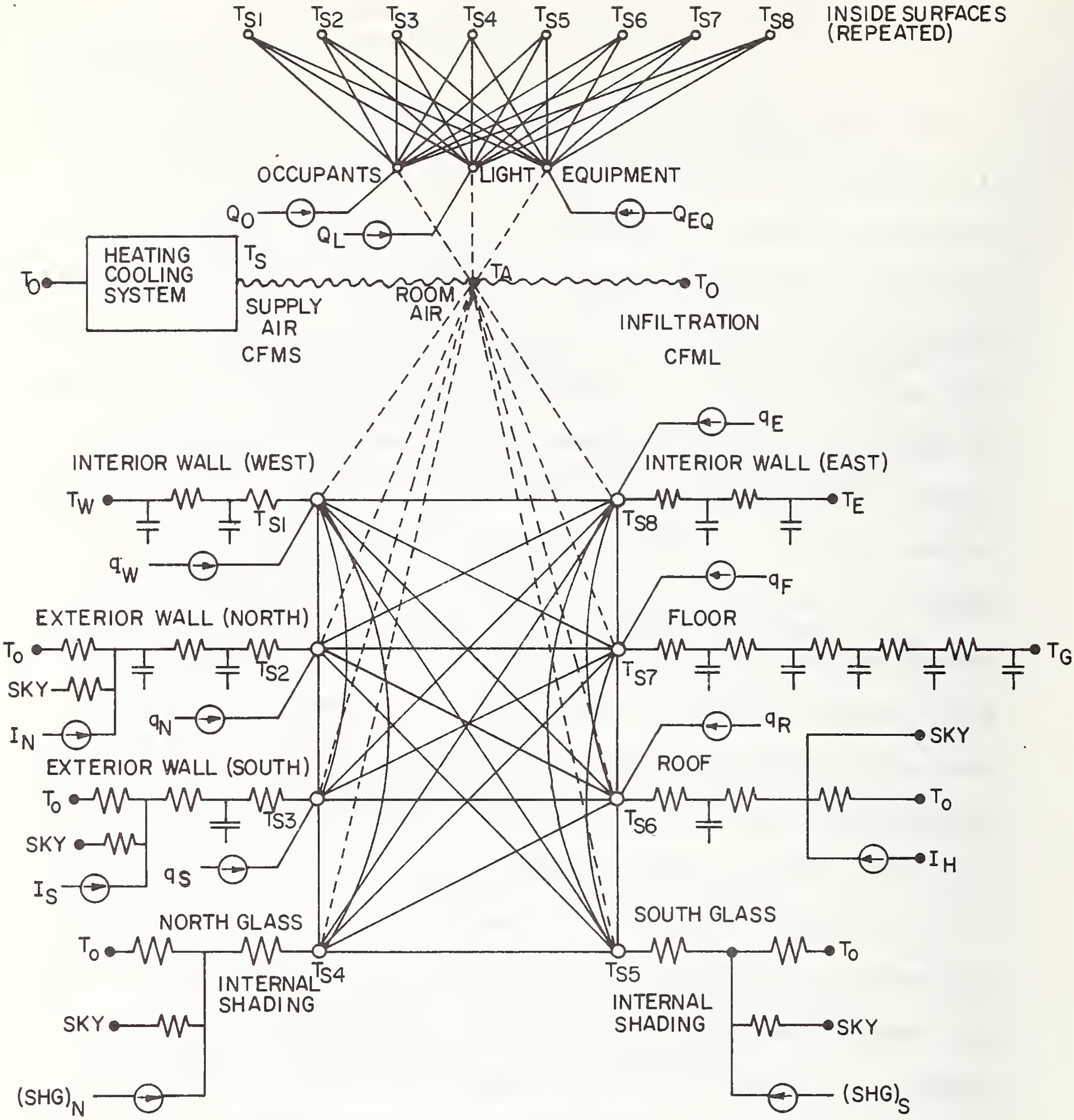
* It has been assumed that there is no latent portion of the equipment heat gain. There can be exceptions to this.

Fundamentals of Room Temperature and Cooling (Heating) Load Calculations

The basic energy transfer process that occurs in a room can best be illustrated by an electrical circuit network as shown in Figure A-18. The figure represents the phenomenon in a typical room having two exterior walls, each of which contains a window, and two interior partition walls, in addition to the roof and floor (see Figure A-19). Heat conduction paths through the walls, roof, and floor are depicted by resistance and capacitance circuits and these through windows are represented by resistance circuits, implying that the windows do not have significant thermal mass. Points T_{S1} through T_{S8} in Figure A-18 indicate interior surfaces of the walls, roof, floor and windows, all of which receive conduction heat through solid material, solar radiation (represented by $\ominus$ q) through transparent surface and long wavelength radiation from other solid surfaces indicated by solid lines connecting the surface nodes; and they lose heat to the room air (represented by a point called TA) by the convection process (dashed lines).

At the top of Figure A-18, the radiation heat exchange between the room surfaces, the surfaces of lighting fixtures, equipment such as business machines, and occupants is depicted. Also indicated in this same location is the convective heat exchange between these items and the room air. Actual heat or power input to these internal heat sources are indicated by $\ominus$ Q. Although not indicated in this figure, it is possible to represent the conduction heat gain from the inner core of lighting fixtures and equipment if they have sufficient thermal mass. This equipment could of course include the unit heaters or air conditioners



THERMAL RESISTANCE

THERMAL CAPACITENCE

THERMAL CURRENT SOURCE

Figure A-18 Analogous Electric Circuit for Heat Exchange Process in a Room

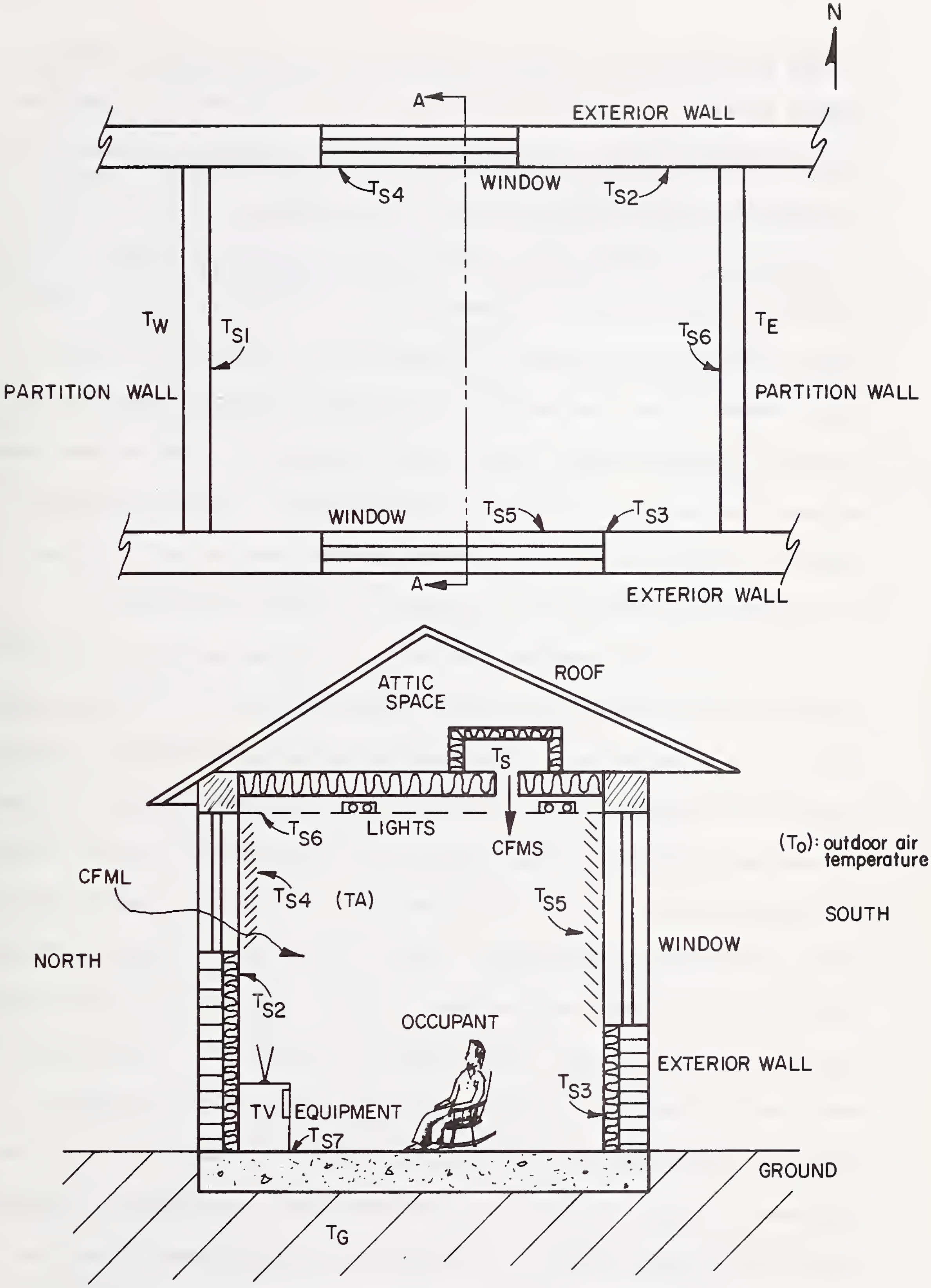


Figure A-19 Physical Model of a Typical Room Used in Figure A-18 if they are the part of the room heat exchange system. The room air changes energy with outdoor air or with the conditioned air from the central climate control system (or the forced ventilation system) and is depicted in this figure by lines $\overline{T_s T_a}$ and $\overline{T_o T_a}$. The heat exchange at the exterior surfaces with outdoor air, sky and sun (except for the partition walls and floor on grade) are also indicated using a normal design calculation procedure, the temperature or heat flow at the exterior sides of the room surfaces are usually available either by calculation or as input data. The exception occurs when two or more rooms adjacent one another are treated simultaneously. This latter case is commonly referred to as a "multi-room problem" and is very complex. No satisfactory solution for this case is presently available.

This electrical network problem can be solved and the corresponding calculation algorithm is called RMTMP (given in the following section). The solution can be obtained in two different modes: room temperature calculation mode or the room load calculation mode. The room temperature calculation mode requires the simultaneous solution of heat balance equations in order to determine all the surface temperatures together with the air temperature. On the other hand, the room cooling load calculation mode requires that the room temperature be prescribed and only the room surface temperatures are solved for. The convective heat exchange between the room air and the heat emitting surfaces is then the cooling load (or the heating load if the heat is lost to the surfaces). These two modes of computation can be combined to simulate the actual thermal behavior of a room and its environment where the temperature fluctuates. The floating temperature would be calculated as long as it remained between prescribed limits. A heating load would be computed when the room temperature fell to the lower limit and a cooling load would be calculated when the temperature rose to the upper limit. In this manner, the calculation of load and subsequent energy requirement would more closely correspond to actual building and system operation.

RMTMP

An Algorithm to Calculate Thermal Load or Room Temperature

This routine calculates heating and cooling loads or room temperature by solving heat balance equations involving each of the room surfaces. A room surface receives conduction heat flow through the solid wall, roof or floor material from behind, convection heat flow from the air and radiation heat flow from other surfaces and internal heat sources such as occupants, equipment and lighting fixtures.

Data:

NS: Total number of heat transfer surfaces contributing to the room heat balance

S_i: Area of i-th heat transfer surface, sq. ft., where $i = 1, 2, 3, \ldots NS$

$X_{i,j}$, $Y_{i,j}$ and $Z_{i,j}$:

Where $i = 1, 2, 3, \ldots NS$

$j = 1, 2, \ldots N_i$

Conduction transfer functions of i-th surface in Btu per (hr) (sq. ft.) ... (Calculated in XYZ). These conduction transfer functions are usually evaluated without the interior or room side surface thermal resistance. The thermal resistance layer of exterior surface is also omitted if the exterior surface temperature is to be computed as a result of a heat balance involving solar radiation, sky radiation and convective loss to the outdoor air.

N_i: Number of conduction transfer function terms to be used for the calculation of the i-th surface donduction heat gain

R_i: Common ratio for the conduction transfer function of the i-th surface

$TOS_{i,t-j}$*: for i = 1, 2, 3, ... NS and j = 0, 1, 2, ... N_i
Outside surface temperature history from present hour to that of N_i hours ago for i-th surface, F. (This information is available from HEATW routine.)

$TIS_{i,t-j}$: for i = 1, 2, 3, ... NS and j = 1, 2, 3, ... N_i
Inside surface temperature history from one hour ago to N_i hours ago for i-th surface, F. The present value (for j = 0) will be computed in this routine and stored for future use.

TA_t: Air temperature of the room at time t, F

DB_t: Outdoor air temperature at time t, F

TS_t: Supply air temperature from the central system at time t, F

H_i: Inside surface convection heat transfer coefficient for i-th surface, Btu per (hr) (sq. ft.) (F)

---

* Subscript t refers to the present time t and t-j refers to the present time minus j hours.

$F_{i,k}$: Radiation heat exchange view factor between the i-th surface and k-th surface

$$F_{i,i} = F_{k,k} = 0$$

E_i: Emissivity of the i-th surface

$R_{i,t}$: Radiant heat flux impinging upon i-th surface at time t from various sources, which include solar radiation, radiation from lights, occupants and equipment, Btu per (hr) (sq. ft.)

$Q_{i,t}$: Heat conducted into i-th surface at time t, Btu per (hr) (sq. ft.)

GL_t: Mass air flow rate due to air leakage at time t, lb per hr

GS_t: Mass air flow rate of the supply air from the central system at time t, lb per hr

QEQUP: Internal heat generated from equipment such as business machines and computers, Btu per hr

QOCPS: Internal heat (sensible) generated from occupants (a function of room air temperature), Btu per hr

QLITE: Heat from lights, Btu per hr

RE: Fraction of internal heat gain from equipment that can be assumed to be convective

RO: Fraction of internal heat gain from occupants that can be assumed to be convective

RL: Fraction of heat gain from lights that can be assumed to be convective

$SHG_{i,t}$: Solar incident radiation on i-th surface at time t, Btu per (hr) (sq. ft.)

Calculation Sequence:

1. Heat balance equation at the i-th surface at time t

$$Q_{i,t} = \sum_{j=0}^{N_i} X_{i,j} * TIS_{i,t-j} - \sum_{j=0}^{N_i} Y_{i,j} * TOS_{i,t-j} + R_i * Q_{i,t-1}$$

$$= H_i * (TA_t - TIS_{i,t}) + \sum_{k=1}^{NS} G_{i,k} * (TI_{k,t} - TI_{i,t}) + R_{i,t}$$

where $G_{i,k} = 4 * E_i * F_{i,k} * (TA_t + 460) ** 3 * 0.1714 * 10 ** -8$

$$R_{i,t} = SHG_{i,t} + \frac{((1-RE)*QEQUP + (1-RO)*QOCPS + (1-RL)*QLITE)}{\sum_{i=1}^{N_s} S_i}$$

2. Heat balance for the room air

$$\sum_{i=1}^{N_s} S_i * (TIS_{i,t} - TA_t) + GL_t * C_p * (DB - TA_t) + GS_t * C_p *$$

$$(TS_t - TA_t) + QEQUP * RE + QOCPS * RO + QLITE * RL = 0$$

where C_p is the specific heat of air in Btu per (lb) (F)

The values of GS_t and TS_t, supply air flow rate and its temperature, are the link between the load calculation and the system simulation. (More detailed explanation of this aspect is given in the final portion of this section.)

3. Assigning matrix elements for i = 1, 2, 3, ... NS and for k = 1, 2, 3, ... NS

$$A_{i,i} = X_{i,1} + H_i + \sum_{k=1}^{NS} G_{i,k}$$

$$A_{i,k} = -G_{i,k} = A_{k,i} = -G_{k,k}$$

$$A_{i,NS+1} = -H_i$$

$$B_i = -\sum_{j=1}^{N_i} X_{i,j} * TIS_{i,t-j} + \sum_{j=0}^{N_i} Y_{i,j} * TOS_{i,t-j} - R * Q_{i,t-1} + R_{i,t}$$

$$A_{NS+1,k} = S_k * H_k$$

$$A_{NS+1,NS+1} = -(GL_t + GS_t) * C_p - \sum_{k=1}^{NS} H_k * S_k$$

$$B_{NS+1} = -QEQUP*RE + -QOCPS*RO - QLITE*RL - GL_t*C_p*DB_t - GS_t*C_p*TS_t$$

4. Using these matrix elements, the following NS+1 equation should be solved simultaneously for $TIS_{i,t}$ (i = 1, 2, ... NS) and for TA_t

$$\begin{bmatrix} A_{1,1} & A_{1,2} & A_{1,NS+1} \\ A_{2,1} & A_{2,2} & A_{2,NS+1} \\ & & \\ & & \\ A_{NS,1} & A_{NS,2} & A_{NS,NS+1} \\ A_{NS+1,1} & A_{NS+1,2} & A_{NS+1,NS+1} \end{bmatrix} * \begin{bmatrix} TIS_{1,t} \\ TIS_{2,t} \\ \\ \\ TIS_{NS,t} \\ TA_t \end{bmatrix} = \begin{bmatrix} B_1 \\ B_2 \\ \\ \\ B_{NS} \\ B_{NS+1} \end{bmatrix}$$

5. When the value of TA_t has been specified, as in the case of a controlled condition, the following NS equations should be solved instead of the NS+1 equations given above.

$$\begin{bmatrix} A_{1,1} & A_{1,2} & \cdots & A_{1,NS} \\ A_{2,1} & A_{2,2} & & A_{2,NS} \\ & & & \\ \cdots\cdot & & \cdots\cdot & \\ A_{NS,1} & A_{NS,2} & & A_{NS,NS} \end{bmatrix} * \begin{bmatrix} TIS_{1,t} \\ TIS_{2,t} \\ \\ \cdots\cdot\cdot \\ TI_{NS,t} \end{bmatrix} = \begin{bmatrix} B'_1 \\ B'_2 \\ \\ \\ B'_{NS} \end{bmatrix}$$

where

$$B'_i = B_i - A_{i,NS+1} * TA_t$$

6. Calculate the sensible load by

$$QLS_t = \sum_{i=1}^{N_s} S_i * (TIS_{i,t} - TA_t) + GL_t * C_p * (DB_t - TA_t)$$

$$+ QEQUP * RE + QOCPS * RO + QLITE * RL$$

In this expression, QL is a cooling load if positive and it is a heating load if negative. This is the heat picked up by the room air (or that lost by the room air) which has to be removed (or added) by the central air conditioning system.

Note that for ordinary load calculations, GS_t and TS_t are not used as long as the following condition is satisfied:

$$|QLS_t| \leqq |GS_t * C_p * (TA_t - TS_t)| \ldots \text{Maximum capacity}$$

of the heating or cooling system

In other words, the desired or prescribed room temperature can be maintained as long as the calculated load is less than the maximum capacity of the central system. When the above condition is not satisfied because of the inadequate values for either the air supply rate or the supply air temperature, the room temperature used for the load calculation is no longer valid. The calculation must then be revised, first calculating the room temperature as outlined in 3 above.

7. Latent Load

If moisture condensation and absorption by room walls, or drying of the wall panels can be neglected, the latent load is the same as the latent heat gain or loss, provided the following condition is met:

$$QLL_t \leqq GS_t * \lambda * (WA - WS), \text{ where } \lambda = \text{latent heat of vaporization} \approx 1061 \text{ Btu per lb of water}$$

In other words, the desired moisture level can be maintained as long as the latent load of the room or the building is less than the capacity of the central system to remove (add) water vapor. When the above condition is not satisfied because of the inadequate air flow rate of the air supply system or the value of WS, the room humidity ratio would change according to

$$WI = \frac{GS_t * WS + GL_t * WA + QLL/\lambda}{GS_t + GL_t}$$

This equation becomes inderminate when there is no air supply or air leakage to or from the room. Theoretically the room relative humidity would reach 100% soon after the air supply or air leakage is stopped provided normal internal sources were still present. Under those conditions, seasonal value of WI to be used would be that corresponding to the dew point temperature which would be approximately equal to the average wall surface temperature of the space.

The most important application of RMTMP is for taking into account some of the performance characteristics of the room's (or space's) heating and cooling systems where the evaluation of heating and cooling load is linked to the system capacity. Presented in this section is a sample algorithm to illustrate how RMTMP can be used to account for the type of occupancy, temperature control scheme, and the system capacity. In this illustration, the heating/cooling load will be set equal to the maximum capacity of the system when the calculated load at a given time is greater than the maximum system capacity. The space or room temperature is then calculated on the basis of net load, which is the difference between the calculated load at a given design temperature and the maximum system capacity. If, on the other hand, the space temperature falls within the prescribed upper and the lower limits, the load is set equal to zero. The same procedure is applied to the latent load calculation. The details of the algorithm is depicted in the flow diagram (Figure A-20). The nomenclature for the figure is given in Table A-12.

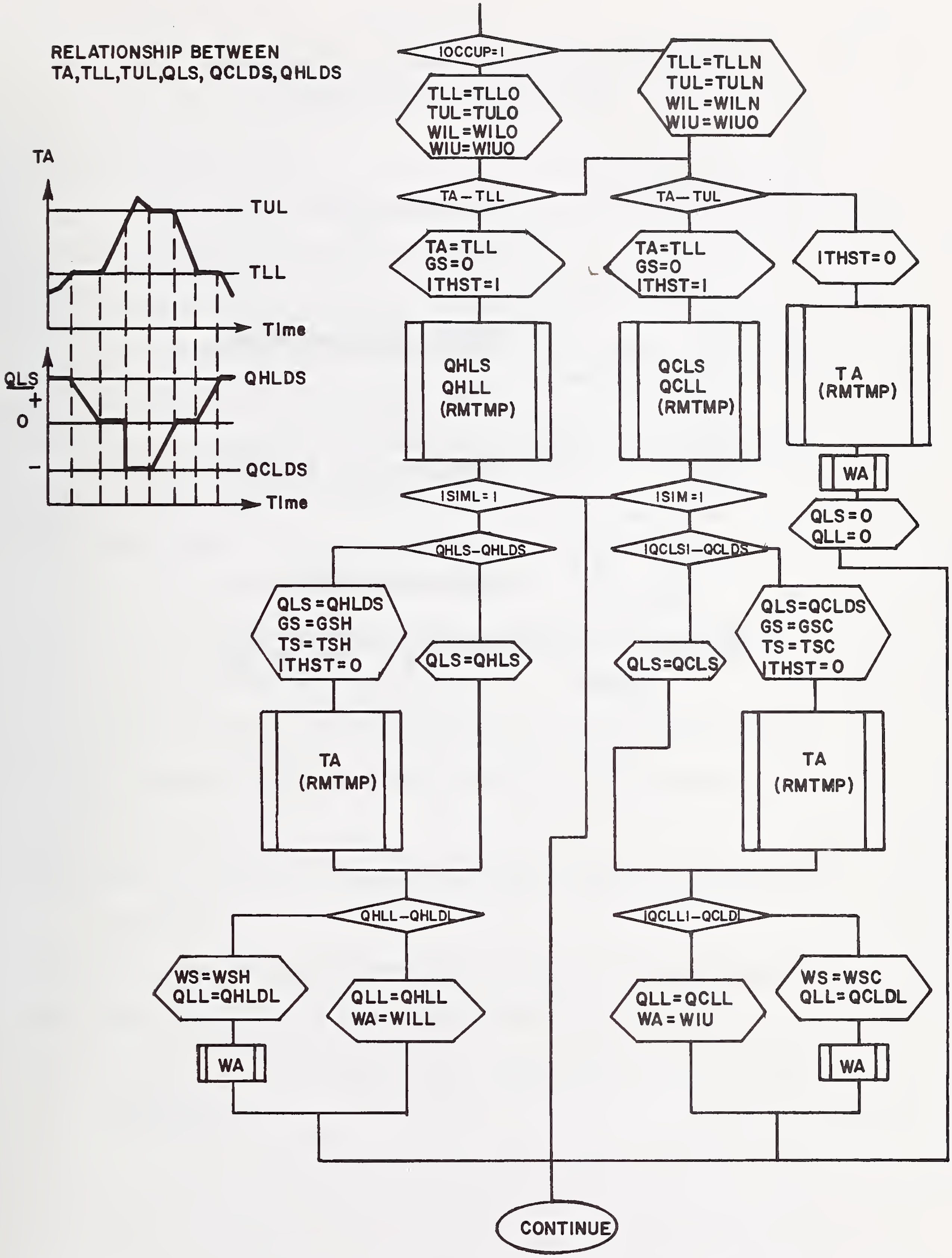


Figure A-20 Flow Diagram of the Room Temperature and the Room Thermal Load Calculation Steps

Symbols used in the flow diagram, Figure A-20

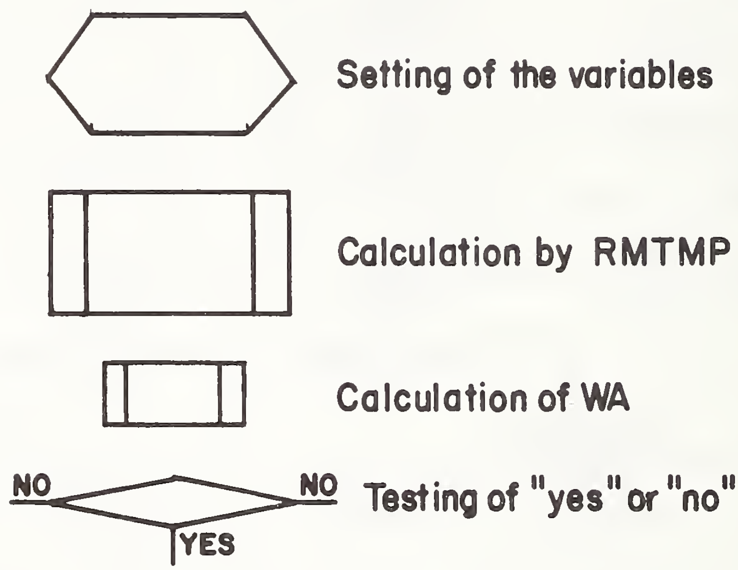


Table A-12

Nomenclature for Figure A-20

IOCCUP: Occupancy index

1 if during the occupied period

0 if during the unoccupied period

ISIML: System capacity consideration index

1 if the calculated load is to be compared with the maximum capacity of the system

0 if the load is to be estimated without regard to the installed system capacity

ITHST: Room temperature control index

1 if a space temperature is prescribed at a given level and the heating and cooling load is to be calculated to meet this prescribed condition

0 if the space temperature is to be determined as a balance between the required load and the available capacity of the system

TLL: The lower limit of temperature, below which heating must be supplied

TLLO: The lower limit of temperature during the occupied period

TLLN: The lower limit of temperature during the unoccupied period

TUL: The upper limit of temperature, above which cooling must be provided

TULO: The upper limit of temperature during the occupied period

TULN: The upper limit of temperature during the unoccupied period

WIL: The lower limit of humidity ratio, below which the room requires humidification

WILO: The lower limit of humidity ratio during the occupied period

WILN: The lower limit of humidity ratio during the unoccupied period

WIU: The upper limit of humidity ratio, above which the room requires dehumidification

WIUO: The upper limit of humidity ratio during the occupied period

WIUN: The upper limit of humidity ratio during the unoccupied period

GS: Mass flow rate of air from the supply system

GSH: Maximum mass flow rate of air from the supply system during heating

GSC: Maximum mass flow rate of air from the supply system during cooling

TS: Air temperature of the supply air system

TSH: Maximum temperature of air from the supply system during heating

TSC: Minimum temperature of air from the supply system during cooling

WS: Humidity ratio of the air from the supply system

WSH: Maximum humidity ratio of air from the supply system during a period when heating and humidification occur

WSC: Minimum humidity ratio of air from the supply system during a period when cooling and dehumidification occur

C_p: Specific heat of air

λ: Latent heat of vaporization

QHLDS: Maximum system capacity for heating, Btu per hr

$$QHLDS = GSH * C_p * (TSH - TA)$$

QHLDL: Maximum system capacity for humidification

$$QHLDL = GSH * \lambda * (WSH - WA)$$

QCLDS: Maximum system capacity for cooling, Btu per hr

$$QCLDS = GSC * C_p * (TA - TSC)$$

QCLDL: Maximum system capacity for dehumidification

$$QCLDL = GSC * \lambda * (WA - WSC)$$

The primary variables that are determined by this mode of calculation are:

QHLS: Sensible heating load of the space

QHLL: Latent heating load of the space

QCLS: Sensible cooling load of the space

QCLL: Latent cooling load of the space

TA: Space temperature

WA: Space humidity ratio

ATTIC

A Description of the Load Calculation for an Attic Space

In many cases the heating and cooling load in an attic space is affected strongly by the manner in which the attic conditions are maintained. The non-ventilated attic space may be treated as a simple air space within a roof structure and accounted for in the calculation of the conduction transfer functions. Where the attic space is ventilated during the summer to take advantage of the resulting natural cooling effect of the outdoor air, it has to be treated somewhat differently. Since it is reasonable to assume that the radiation heat exchange between the underside of the roof surface and the attic is as significant as the ventilation air rate in determining the attic thermal condition, RMTMP should be used. No additional algorithms are then required since all aspects covered in RMTMP apply directly to the attic heat transfer calculation. Of course, the solar radiation through windows, and internal heat gain from lighting and occupants would most likely be omitted. The floor should be treated as having its exterior surface exposed to the environmental conditions of the room below. The heat loss at the "exterior" surface of the floor then becomes the heat gain to the room beneath the ceiling.

FIJ 1 outlines the calculation procedure for obtaining the necessary shape factors where the attic has a gabled roof.

An Algorithm to Calculate Instantaneous Heat Gain of a Space at Time t

Data:

Windows:

NY: Number of windows

AY_k: Area of each window, sq ft

UY_k: Overall heat transfer coefficient for each window, Btu per (hr) (sq ft) (f)

SHG_k: Solar heat gain through each window, Btu per (hr) (sq ft) (Calculated in SHG)

Exterior Walls and Roofs:

NX: Number of exterior walls and roofs

AX_k: Area of each exterior wall and roof, sq ft

$HEAT_k$: Heat gain through each exterior wall and roof, Btu per (hr) (sq ft) (Calculated in HEATW) where k = 1, 2, ... NX

Lights:

NS: Number of different types of lights

QS_k: Power input to each type of light, Btu per hr where k = 1, 2, ... NS

Internal Heat Source Other than Lights:

NS': Number of different types of internal sensible heat sources other than lights

QS'_k: Heat generation from each internal sensible heat source, where $k = 1, 2, \ldots NS'$

NL: Number of different types of internal latent heat sources

QL_k: Latent heat gain from each internal latent heat source, Btu per hr, where $k = 1, 2, \ldots NL$

Inside Doors:

ND: Number of inside doors

AD_k: Area of each inside door, sq ft

UD_k: Overall heat transfer coefficient of each inside door, where $k = 1, 2, \ldots ND'$

Outside Doors:

ND': Number of outside doors

AD'_k: Area of each outside door, sq ft

UD'_k: Overall heat transfer coefficient of each outside door, Btu per (hr) (sq ft) (F), where $k = 1, 2, \ldots ND'$

Partitions:

NP: Number of partitions which separate the space from other spaces at different temperatures

AP_k: Area of each of these partitions, sq ft

UP_k: Overall heat transfer coefficient for each of these partition walls, Btu per (hr) (sq ft) (F) where k = 1, 2, ... NP

Underground Walls:

NG: Number of underground walls

AG_k: Area of each underground wall, sq ft

UG_k: Overall heat transfer coefficient of each underground wall, Btu per (hr) (sq ft) (F), where k = 1, 2, ... NG

Underground Floors:

NGF: Number of underground floors

AGF_k: Area of each underground floor, sq ft

UGF_k: Overall heat transfer coefficient of each underground floor, Btu per (hr) (sq ft) (F), where k = 1, 2, ... NGF

Internal Infiltration:

NLK: Number of internal air leakage sources

$LEAK_k$: Air leakage from each source, cfm (Calculated in INFIL), where k = 1, 2, ... NLK

External Infiltration:

NLK': Number of external air leakage sources

$LEAK'_k$: Air leakage from each external source, cfm (Calculated in INFIL), where k = 1, 2, ... NLK'

Temperatures:

TA_k: Dry-bulb temperature of each adjacent space, F, where k = 1, 2, ... ND, NP or NLK

DB: Outside air dry-bulb temperature, F (Obtained from CLIMATE)

TG: Average ground water temperature at half underground basement depth, F

TGW: Ground water temperature, F

TZ: Space dry-bulb temperature, F

Humidity Ratios:

WA_k: Humidity ratio of adjacent space, lb water per lb dry air, where k = 1, 2, ... ND, NP or NLK

WO: Outside air humidity ratio, lb water per lb dry air (Calculated in PSY)

WZ: Space humidity ratio, lb water per lb dry air

The following heat gains are calculated in this subroutine:

HEATG or HEATG': Total hourly solar heat gain through windows, Btu per hr

HEATK: Total hourly heat gain through exterior walls and roofs, Btu per hr

HEATIS: Total power input to lights, Btu per hr

HEATDP: Total sensible heat gain due to heat transfer through doors, partitions, underground walls and floors, and internal heat sources other than lights, Btu per hr

HEATVS: Total hourly sensible heat gain due to infiltration, Btu per hr

HEATL: Total hourly latent heat gain due to infiltration and internal heat sources, Btu per hr

<u>Calculation Sequence</u>:

1. $$\text{HEATG or HEATG}' = \sum_{k=1}^{NY} AY_k * SHG_k$$

2. $$\text{HEATX} = \sum_{k=1}^{NX} AX_k * HEAT_k$$

3. $$\text{HEATIS} = \sum_{k=1}^{NS} QS_k$$

4. $$\text{HEATDP} = \sum_{k=1}^{ND} AD_k * UD_k * (TA_k - TZ) + \sum_{k=1}^{ND'} AD_k' * UK_k' (DB-TZ)$$

$$+ \sum_{k=1}^{NY} AY_k * UY_k * (DB-TZ) + \sum_{k=1}^{NG} AG_k * UG_k * (TG-TZ)^{*}$$

$$+ \sum_{k=1}^{NGF} AGF_k * UGF_k * (TGW-TZ) + \sum_{k=1}^{NP} AP_k * UP_k * (TA_k - TZ)$$

$$+ \sum_{k=1}^{NS'} QS'_k$$

5. $$HEATVS = 1.08 * \left(\sum_{k=1}^{NLK} LEAK_k * (TA_k - TZ) + \sum_{k=1}^{NLK'} LEAK'_k * (DB-TZ)\right)^{**}$$

6. $$HEATL = 4775 * \left(\sum_{k=1}^{NLK} LEAK_k * (WA_k - WZ) + \sum_{k=1}^{NLK'} LEAK'_k * (WO-WZ)\right)$$

$$+ \sum_{k=1}^{NL} QL_k^{**/}$$

---

* The values of UG given in the 1972 ASHRAE Handbook of Fundamentals are based on TGW. A program for calculating basement wall losses using TC has been developed at the National Bureau of Standards. When using present ASHRAE values for UG, use TGW instead of TG.

** The coefficients 1.08 and 4775 in these equations are valid for the standard air density. If desired, they can be adjusted to actual conditions by multiplying both of them by $\frac{\rho}{0.075}$, where ρ is the actual density of the air expressed in lb per cu ft.

A Simplified Procedure for Obtaining Approximate Cooling Load by the Use of Weighting Factors

The procedure presented here was developed by Mitalas and Stephenson of National Research Council of Canada[13, 14] in order to expedite the otherwise complex and time-consuming solution of the heat balance simultaneous equations. The rigorous solution similar to that described in RMTMP was first obtained for typical rooms in commercial buildings with pulse type excitations that simulate various heat gains. The solution for these pulse excitations were then converted into new types of transfer functions called Weighting Factors. Weighting Factors developed for typical office spaces of light, medium, and heavy constructions are shown in Tables A-13, A-14, and A-15 for solar heat gain with no internal shading devices; heat gain conduction through interior and exterior structure components, solar heat gain with interior shading devices and all internal sources except lighting; and the heat gain due to lighting. By multiplying these Weighting Factors to the history of respective heat gains in a convolution scheme, similar to the way the conduction transfer functions are multiplied to the temperature history, it is possible to calculate an approximate cooling load.

Data:

AG_j for j = 0, 1, 2 ... MG and BG_j for j = 1, 2, 3 ... MG'

Weighting Factors for the solar heat gain HEATG (no internal shading devices)

AX_j for j = 0, 1, 2 ... MX and BX_j for j = 1, 2 ... MX'

Weighting factors for

HEAT: Conduction heat gain

HEATG: Solar heat gain where there are internal shading devices

HEATDP: Heat gain due to air leakage and internal sources except lighting

AIS_j for j = 0, 1, 2 ... MIX and BIS_j for j = 1, 2, 3 ... MIS'

Weighting factors for the heat gain from lighting HEATIS

In order to make use of the weighting factor concept, it is necessary to have previous values of heat gains as well as values of cooling loads. By denoting the cooling load due to HEATG as HLCG, due to HEATX, HEATG', and HEATDP as HLCX and that due to HEATIS as HLCIS, the following set of the previous data are needed:

$HEATG_{t-j}$	for j = 0, 1, 2 ... MG
$HEATX_{t-j}$; $HEATG'_{t-j}$; $HEATDP_{t-j}$	for j = 0, 1, 2 ... MX
$HEATIS_{t-j}$	for j = 0, 1, 2, 3 ... MIS
$HLCG_{t-j}$	for j = 1, 2, 3 ... MG'
$HLCX_{t-j}$	for j = 1, 2, 3 ... MX'
$HLCIS_{t-j}$	for j = 1, 2, 3 ... MIS'

Calculation Sequence:

1. Using the Weighting Factors* given in Tables A-13, A-14, and

* The Weighting Factors given in Tables A-13, A-14, and A-15 are for typical office construction. They are obtained using the method described in Appendix B.

A-15 and factor Fc defined by equation "d", calculate load components corresponding to the heat gains.

a. $$HLCG_t = Fc \sum_{j=0}^{MG} AG_j*HEATG_{t-j} - \sum_{j=1}^{MG'} BG_j*HLCG_{t-j}$$

b. $$HLCX_t = Fc \sum_{j=0}^{MX} AX_j*(HEATX_{t-j} + HEATG'_{t-j} + HEATDP_{t-j}) - \sum_{j=1}^{MX'} BX_j*HLCX_{t-j}$$

c. $$HLCIS_t = Fc \sum_{j=0}^{MIS} AIS_j*HEATIS_{t-j} - \sum_{j=1}^{MIS'} BIS_j*HLCIS_{t-j}$$

The coefficients given in Tables A-13, A-14, and A-15 are for the case where all the heat gain energy appears eventually as cooling load. In most cases, a fraction of the input is lost to the surroundings. This fraction depends on the thermal conductance between the room air and the surroundings. One estimate of this fraction Fc, is given by

d. $Fc = 1 - 0.02\ K_T \ldots$

for the range $1.0 > Fc > 0.7$

where $$K_T = \frac{1}{L_F}(U_{window} A_{window} + U_{exterior\ wall} A_{exterior\ wall}{}^{*} + U_{corridor\ wall} A_{corridor\ wall})$$

---

* A U*A product should also be included for walls that adjoin unconditioned spaces even though the walls are not exterior ones.

L_F = Length of room exterior perimeter

U = U value of the room enclosure element

A = Area of the room enclosure element

2. Hourly load

a. Sensible load

$$SCL_t = HLCG_t + HLCX_t + HLCIS_t + HEATVS_t$$

b. Latent load

$$= HEATL_t$$

Table A-13

WEIGHTING FACTORS FOR HEATG

	Weighting Factor Symbol	Heavy* Structure	Medium* Structure	Light* Structure
MG = 1	AG_0	0.187	0.197	0.224
	AG_1	-0.097	-0.067	-0.044
MG' = 1	BG_0	1.00	1.00	1.00
	BG_1	-0.91	-0.87	-0.82

* Heavy Structure - 6" concrete floor slab, 6" concrete exterior wall, approximately 130 lb of building material per sq. ft. of floor area.

Medium Structure - 4" concrete floor slab, 4" concrete exterior wall, approximately 70 lb of building material per sq. ft. of floor area.

Light Structure - 2" concrete floor slab, exterior frame wall approximately 30 lb of building material per sq. ft. of floor area.

Table A-14

NORMALIZED WEIGHTING FACTORS FOR HEATX + HEATG' + HEATDP

	Weighting Factor Symbol	Heavy Structure	Medium Structure	Light Structure
MX = 1	AX_0	0.676	0.681	0.703
	AX_1	-0.586	-0.551	-0.523
MX' = 1	BX_0	1.00	1.00	1.00
	BX_1	-0.91	-0.87	-0.82

Table A-15

WEIGHTING FACTORS FOR HEATIS

	Weighting Factor Symbol	Heavy Structure	Medium Structure	Light Structure
	Fluorescent fixtures recessed into a suspended ceiling, ceiling plenum not vented.			
	AIS_0	0.00	0.00	0.00
MIS = 2	AIS_1	0.53	0.53	0.53
	AIS_2	-0.44	-0.40	-0.35
	* Fluorescent fixtures recessed into a suspended ceiling, return air through ceiling plenum.			
	AIS_0	0.00	0.00	0.00
MIS = 2	AIS_1	0.59	0.59	0.59
	AIS_2	-0.50	-0.46	-0.41
	Fluorescent fixtures recessed into a suspended ceiling, supply and return air through fixtures.			
	AIS_0	0.00	0.00	0.00
MIS = 2	AIS_1	0.87	0.87	0.87
	AIS_2	-0.78	-0.74	-0.69

* Manufacturer's data sheet must be consulted to obtain the fractions of light input energy that are picked up by the room air and by ventilation air in the ceiling plenum.

Table A-15 continued

	Weighting Factor Symbol	Heavy Structure	Medium Structure	Light Structure
	Incandescent lights exposed in the room air.			
	AIS_0	0.00	0.00	0.00
MIS = 2	AIS_1	0.50	0.50	0.50
	AIS_2	-0.41	-0.37	-0.32
	The "BIS" Coefficients.			
MIS' = 1	BIS_0	1.00	1.00	1.00
	BIS_1	-0.91	-0.87	-0.82

An Algorithm For Calculating Weighting Factors for Space Air Temperature

This algorithm provides a sample calculation method for obtaining the weighting factors for deviation of space temperature from the design value; the value at which the space heating/cooling loads are obtained for by the HLC routine.

This general algorithm illustrated here is for a space enclosure surrounded with spaces on both sides as well as above and below that are thermally at the same conditions. The space enclosure consists of an external wall, interior partition walls, corridor partition wall, ceiling, floor, furnishings, an outside door and a window.

Data:

AF: Floor area, sq. ft.

AC: Ceiling area, sq. ft.

AP: Interior partition wall area, sq. ft.

AK: Corridor wall area, sq. ft.

AW: Exterior wall area, sq. ft.

AG: Window glass area, sq. ft.

AD: Door area, sq. ft.

AFN: Internal furnishings area, sq. ft.

BF_j, CF_j, DF_j: Transfer functions for floor, Btu per (hr) (sq. ft.) (F), (Calculated in XYZ)

BC_j, CC_j, DC_j: Transfer functions for ceiling, Btu per (hr) (sq. ft.) (F), (Calculated in XYZ)

BK_j, DK_j: Transfer functions for corridor wall, Btu per (hr) (sq. ft.) (F), (Calculated in XYZ)

BP_j, CP_j, DP_j: Transfer functions for interior partition walls, Btu per (hr) (sq. ft.) (F), (Calculated in XYZ)

CW_j, DW_j: Transfer functions for exterior walls, Btu per (hr) (sq. ft.) (F), (Calculated in XYZ)

CD_j, DD_j: Transfer functions for outside door, Btu per (hr) (sq. ft.) (F), (Calculated in XYZ)

CFN_j, DFN_j: Transfer functions for internal furnishings, Btu per (hr) (sq. ft.) (F), (Calculated in XYZ)

where $j = 0, 1, \ldots, M$

UG: Heat transmission coefficient of window glass, Btu per (hr) (sq. ft.) (F)

CFM: Rate of air flow through the room, cu ft per min. (Ventilation rate)

Calculation Sequence:

1. Conversion of the given transfer functions into single series x_j, y_j, and z_j. This calculation is a polynomial division*, i.e.,

$$x_o z^o + x_1 z^{-1} + x_2 z^{-2} + x_3 z^{-3} + \ldots$$

$$= \frac{a_o z^o + a_1 z^{-1} + a_2 z^{-2} + \ldots}{1 + b_1 z^{-1} + b_2 z^{-2} + b_3 z^{-3} + \ldots}$$

where

x_o, x_1, x_2 ... = single series response factor set

a_o, a_1, a_2 ... and

b_1, b_2, b_3 ... = coefficient of the given numerator and denominator series respectively

For example, using given notation in this section for the outside wall, the x's, a's and b's are

$x_o = sCW_o$	$a_o = CW_o$	$b_o = 1.0$
$x_1 = sCW_1$	$a_1 = CW_1$	$b_1 = DW_1$
$x_2 = sCW_2$	$a_2 = CW_2$	$b_2 = DW_2$
.	.	$b_3 = DW_3$
.	.	.
.	.	.

---

* The rules of polynomial division can be obtained from any standard textbooks on numerical analysis.

where the letter "s" in front of CW_j denotes coefficients of the single series.

2. Calculation of the single series of Room Air Response Factors, sRMRT. The factors in this series are given by

$$
\begin{aligned}
sRMRT_j = {} & AF[sBF_j + sCF_j] \\
& + AC[sDC_j + sCC_j] \\
& + AP[sBP_j + sCP_j] \\
& + AW[sCW_j] \\
& + AD[sCD_j] \\
& + AFN[sCFN_j] \\
& + AG[UG_j]^{*} \\
& + 1.08[CFM_j]^{*}
\end{aligned}
$$

where $j > 10$ calculate the ratio R_j

$$R_j = \frac{sRMRT_{j+1}}{sRMRT_j}$$

and when $\left| R_j - R_{j+1} \right| \leq 0.001$ terminate $sRMRT_j$ calculations.

3. Calculation of RMRT

The calculation of RMRT as a ratio of two series consists of three steps:

(a) Calculation of denominator, D(z),

$D(z) = 1.0 - Rz^{-1}$

where R is the last value of the ratio calculated in the $sRMRT_j$ calculations.

---

* Note that $UG_{j=1} = UG$, $CFM_{j=1} = CFM$, $UG_{j>1} = 0.0$ and $CFM_{j>1} = 0.0$.

(b) Calculation of numerator, N(z),

$$N(z) = sRMRT_o z^o + (sRMRT_1 - (R)sRMRT_o)\ z^{-1}$$
$$+ (sRMRT_2 - (R)sRMRT_1)\ z^{-2}$$
$$+ (sRMRT_3 - (R)sRMRT_2)\ z^{-3}$$

(c) The RMRT's are then evaluated by equating the following equation to the one in (b) above

$$N(z) = \frac{X_o + X_1\ z^{-1} + X_2\ z^{-2}}{Y_o + Y_1\ z^{-1}}$$

Typical values are shown in Table A-16.

Table A-16

WEIGHTING FACTORS FOR THE DEVIATION OF SPACE TEMPERATURE, RMRT'S*/

	Weighting Factor Symbol	Heavy Structure	Medium Structure	Light Structure
	X_0	-1.85	-1.81	-1.68
	X_1	+1.95	+1.89	+1.73
MX = 2	X_2	-0.10	-0.08	-0.05
	Y_0	1.00	1.00	1.00
MY = 1	Y_1	-0.91	-0.87	-0.82

* The X coefficients given in this Table are for a room with zero heat conductance to surrounding spaces and are normalized to unit floor area. To get the X_j coefficients for a room with a total conductance K between room air and surroundings, ventilation rate V_t and infiltration rate VI_t it is necessary to multiply each X_j value by room floor area and then add $[K + (V_t + VI_t)\ 1.08]\ (1.00 - Y_1)$ to the resulting X_0 value (where V_t and VI_t are in cfm and K is in Btu/hr °F.

Note: That X_0 value changes with the changes of V_t and VI_t values.

HEXT

An Algorithm for Calculating the Rate at Which Sensible Heat is Extracted From the Space

Data:

SCL_t: Sensible cooling load at time t, which is calculated for a constant space design temperature of TM, Btu per hr (Calculated in HCL)

X_j, Y_j: Weighting factors for use with θ_{t-j}, for j = 0, 1, ... , (Calculated in RMRT with typical values shown in Table A-16)

θ_{t-j}: History of hourly space air temperature deviation from the assumed constant value TM, for j = 1, 2 ... , F

C: Average heat extraction rate of the apparatus in a space when the space air temperature is TM, Btu per hr

D: Change in the rate of heat extraction of the apparatus caused by one degree change in space air temperature, Btu per (hr) (F)

HE_{t-j}: History of heat extracted from the space, for j = 1, 2 ... , Btu per hr

INFIL

An Algorithm for Calculating Air Infiltration

It is well recognized that the air infiltration constitutes as much as 30% of home heating load and a significant part of the load of non-pressurized commercial buildings. The air leakage of a building depends upon the tightness of its exterior walls, windows, and doors, the wind characteristics and temperature difference between the inside and outside, and to some extent how the building is operated with respect to the opening and closing of its door.

The rate of air infiltration can be empirically expressed by

$$Q = C*A*\Delta P**N$$

where

- Q: air flow rate
- C: flow coefficient
- A: flow opening area
- N: pressure exponent
- ΔP: pressure difference

Unfortunately it is very difficult to determine accurate values of flow opening area and pressure difference for actual buildings, which consist of complex air leakage passages. A limited amount of data are given in the 1972 ASHRAE Handbook of Fundamentals for equivalent opening area of typical windows, doors and walls. The pressure difference depends upon the wind characteristics around the building and the temperature difference between the inside and the outside of the building.

Compiled in this section is a methodology to approximately calculate the pressure difference between a given space and its adjacent space including the outdoor. The basic mathematical principle involved is to attain a solution to a set of pressure difference equations of the following type:

$$Q_i = \Sigma\, Q_{i,k} = 0$$

$$Q_{i,k} = \Sigma\, A_{i,k} * C_{i,k} * (P_i - P_k) ** N_{i,k}$$

where

Q_i: net air flow out of space i

$Q_{i,k}$: air exchange between space i and space k

$A_{i,k}$: flow opening area between space i and k

$C_{i,k}$: flow coefficient applicable to the air flow between the spaces i and k

$N_{i,k}$: pressure exponent applicable to the flow between the spaces i and k

A special computational routine is required to solve this set of simultaneous, non-linear equations.

As mentioned previously, air leakage through various openings such as doors, windows, window frames, pinholes in the wall and service shafts may be approximated by an equation of the following type:

$$LEAK = 4000 * A * K * (DP) ** N$$

$$= C * (DP) ** N$$

where

LEAK = air leakage in cu. ft per min.

A = opening area, sq. ft

K = flow coefficient, dimensionless

DP = pressure difference across the opening, inches of water

N = pressure exponent, dimensionless

C = equivalent flow coefficient (EFC)

The values of K and N vary depending upon the type of opening. Moreover, the exact value of A is not well known for many types of openings, such as wall pinholes or cracks around the windows. Table A-17 lists the values of Equivalent Flow Coefficient C and the flow exponent N for various types of openings common to many buildings. These values are derived from the air leakage data compiled in Chapter 19 "Infiltration and Natural Ventilation" of the 1972 ASHRAE Handbook of Fundamentals.

Table A-17

	C	N
1. Double-hung wooden windows (locked)*		
non-weatherstripped loose fit	6	0.66
average fit	2	0.66
weatherstripped loose fit	2	0.66
average fit	1	0.66
2. Window frames*		
masonry frame with no caulking	1.2	0.66
masonry frame with caulking	0.2	0.66
wooden frame	1	0.66
3. Swinging doors* 1/2" crack	160	0.5
1/4" crack	80	0.5
1/8" crack	40	0.5
4. Walls** 8" plain brick	1	0.8
8" brick and plaster	0.01	0.8
13" brick	0.8	0.8
13" brick and plaster	0.004	0.7
13" brick, furring, lath and plaster	0.03	0.9
frame wall, lath and plaster	0.01	0.55
24" shingles on 1 x 6 boards on 14" center	9	0.66
16" shingles on 1 x 4 boards on 5" center	5	0.66
24" shingles on shiplap	3.6	0.7
16" shingles on shiplap	1.2	0.66

* Values of C listed for these openings are per ft of linear crack length.

** Values of C listed for the walls are per unit area of the wall surface.

In many instances, detailed information of air leakage characteristics is not available, but it is still possible to make a calculation. For a modern office building of 120 ft x 120 ft plan dimension with the floor height of 12 ft, Tamura[15/] lumped together all the leakage area for a given floor as follows:

Table A-18

outside wall	2.5 sq. ft per story
4 elevator shaft doors	4.5 " " " "
2 stair shaft doors	0.5 " " " "
floor	3.7 " " " "
brench perimeter and interior air duct	7.0 " " " "
return duct	14.0 " " " "
vertical shafts (elevator or stairwell)	1/3 of the cross-sectional area*

The value of C corresponding to these data can be obtained by multiplying them by 2400 which corresponds to K = 0.6.

Data:

V: Wind speed measured at a 40 ft elevation as taken from the weather tape, knots.

DIR: Wind direction measured clockwise from North, degrees (see Figure A-21)

---

* This particular data were derived from a recent and unpublished experiment of the National Bureau of Standards conducted on two high-rise buildings.

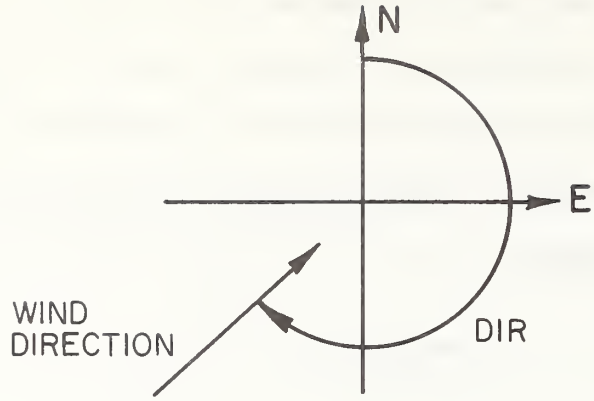


Figure A-21 Definition of Wind Direction Angle

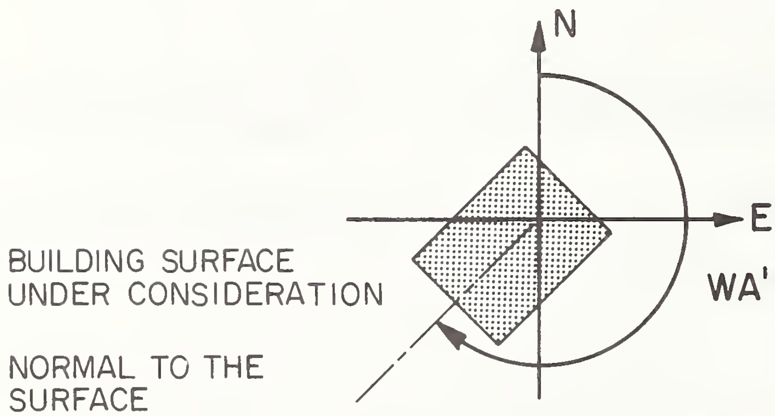


Figure A-22 Definition of the Angle Between North and Normal of the Surface Under Consideration

DB: Outdoor air dry-bulb temperature, F

PB: Barometric pressure, in. Hg.

NF: Number of above-grade floors

HTT: Total height of building (from above-grade), ft.

TZ: Indoor air temperature, F

TS: Elevator and service shaft temperature

WA': Direction angle of the building as defined with respect to North and the normal of the principal surface of the building (see Figure A-22)

HT_k: Height of the floor, ft, for k = 1, 2, 3, ... NF

$CFMSP_k$: Ventilation air supplied to the floor, cu ft per min, for k = 1, 2, 3, ... NF

$CFMEX_k$: Ventilation air exhausted from the floor, cu ft per min, for k = 1, 2, 3, ... NF

Calculation Sequence:

1. V' = 1.153 * V

   TO = 460 + DB

   TI = 460 + TZ

   PO = 0.4910 * PB

   x = DIR - WA'

2. Wind velocity, VH, at height HT on the building, mph

   VH = V' * 0.117 * (1 + 2.81 * Log (0.305 * HT + 4.75))

3. Theoretical wind velocity pressure, PTWV on the building, in. H_2O

   PTWV = 0.000482 * (V ** 2)

4. Wind direction, BWD, relative to building surfaces

BWD = 1 surface on windward side if,

$-45° < x < +45°$

BWD = 2 surface on leeward side if,

$90° < x < 270°$

or, $-90° < x < -270°$

BWD = 3 surface on side if,

$45° < x < 90°$

or, $-45° < x < 90°$

5. Using Table A-19, determine the normal wind velocity pressure correction factor, PTKN.

Table A-19 Values of PTKN

	TB = 1			TB = 2			TB = 3		
NSB	BWD = 1	BWD = 2	BWD = 3	BWD = 1	BWD = 2	BWD = 3	BWD = 1	BWD = 2	BWD = 3
0.5	.1	-.3	-.8	-.5	-.25	-.45	.5	.45	.45
1.0	-.1	-.25	-.5	-.5	-.2	-.3	.45	.3	.3
2.0	.1	-.25	-.4	.0	-.2	-.3	.45	.1	.1
3.0	.1	-.25	-.4	.1	-.2	-.35	.45	.0	.0
5.0	.25	-.35	-.6	.25	-.25	-.45	.5	-.1	-.1
∞	.6	-.35	-.7	.6	-.35	-.7	.6	-.35	-.7

where

TB = 1: Shorter building on windward side

TB = 2: Equals taller building on windward side

TB = 3: Taller building on leeward side

6. Wind velocity pressure correction factor, PTKO, for winds obliquely to the wall surface.

If BWD = 1 (windward side of building)

$$(PTKO)_m = \text{Cos}\ (|\ x\ |)$$

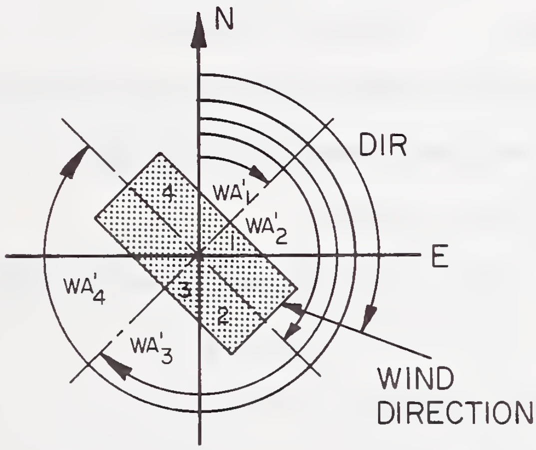
If BWD = 2 (leeward side of building)

$$(PTKO)_l = 1.0$$

If BWD = 3 (side of building)

$$(PTKO)_s = \text{Cos}\ (|\ x\ |)$$

Example:



DIR = 110°

WA'_1 = 45°

WA'_2 = 135°

WA'_3 = 225°

WA'_4 = 315°

Figure A-23 DIR and WA' Angles of Example

Side 1, $DIR\text{-}WA_1' = 110° - 45° = 65°$ (therefore, BWD = 3)

Side 2, $DIR\text{-}WA_2' = 110° - 135° = -25°$ (therefore, BWD = 1)

Side 3, $DIR\text{-}WA_3' = 110° - 225° = 115°$ (therefore, BWD = 2)

Side 4, $DIR\text{-}WA_4' = 110° - 205° = 205°$ (therefore, BWD = 2)

Side 1, $(PTKO)_s = \text{Cos } (+65°)$

Side 2, $(PTKO)_m = \text{Cos } (+25°)$

Side 3, $(PTKO)_1 = 1.0$

Side 4, $(PTKO)_1 = 1.0$

7. Actual wind pressure on the building at height (HT) corresponding to floor (k): $(PAWV)_k$

$$(PAWV)_k = (PTKO)_k * (PTKN)_k * (PTWV),$$

8. Stack effect pressure (PSE) on the outside of the building at building height (HT) and floor (k), in. H_2O

$$(PSE)_k = -0.52 * PO * HT/TO$$

9. Total pressure on the outside of the building (PCO) at floor (k), in. H_2O

$$(PCO)_k = (PAWV)_k + (PSE)_k$$

10. Pressure in the elevator and serve shafts (PSE) at height (HT) corresponding to floor (k), in. H_2O

$$(PSE)_k = -0.52 * PO * HT/TI + (PSE)_1$$

11. Choose appropriate flow coefficients and pressure exponents for air leakage paths of each floor as follows:

Flow coefficients

CWD: Value of C for appropriate window in Table A-17 multiplied by the total crack length of all the windows

CFM: Value of C for appropriate window frame in Table A-17 multiplied by the total crack length of all the window frames

CDR: Value of C for appropriate door in Table A-17 multiplied by the total crack length of all the doors

CWL: Value of C for appropriate walls in Table A-17 multiplied by the total wall area

CCL: Value of A for the ceiling from Table A-18 multiplied by 2400

CFL: Value of A for the floor from Table A-18 multiplied by 2400

CEL: Value of C for elevator doors

CSS: Value of C for the doors to the service shaft

CFS and CES: Value of the cross section of the shaft multiplied by 800

Pressure exponent

NWD: Value of N for the appropriate window in Table A-17

NFM: Value of N for the appropriate window frame in Table A-17

NDR: Value of N for the appropriate door in Table A-17

NWL: Value of N for the appropriate wall in Table A-17

NCL: 0.5

NFL: 0.5

NEL: 0.5

NSS: 0.5

NFS: 0.5

NSE: 0.5

12. Solution of 2 * NF equations

Outdoor air leakage to k-th floor rooms* (see Figure A-23)

Window k leakage

$$LEAKWD_{k,j} = CWD_{k,j} * (PCO_{k,j} - PI_k) ** NWD_{k,j} \quad (1)$$

Window frame leakage

$$LEAKFM_{k,j} = CFM_{k,j} * (PCO_{k,j} - PI_k) ** NFM_{k,j} \quad (2)$$

Door leakage

$$LEAKDR_{k,j} = CDR_{k,j} * (PCO_{k,j} - PI_k) ** NDR_{k,j} \quad (3)$$

Wall leakage

$$LEAKWL_{k,j} = CWL_{k,j} * (PCO_{k,j} - PI_k) ** NWL_{k,j} \quad (4)$$

Ceiling leakage

$$LEAKCL_k = CCL_k * (PI_{k+1} - PI_k) ** NCL_k \quad (5)$$

Floor leakage

$$LEAKFL_k = CFL_k * (PI_{k-1} - PI_k) ** NFL_k \quad (6)$$

---

* In all of above expressions, subscript k refers to the k-th floor and subscript j refers to the j-th side of the building where the convention is j = 1 (south), 2 (west), 3 (north), and 4 (east).

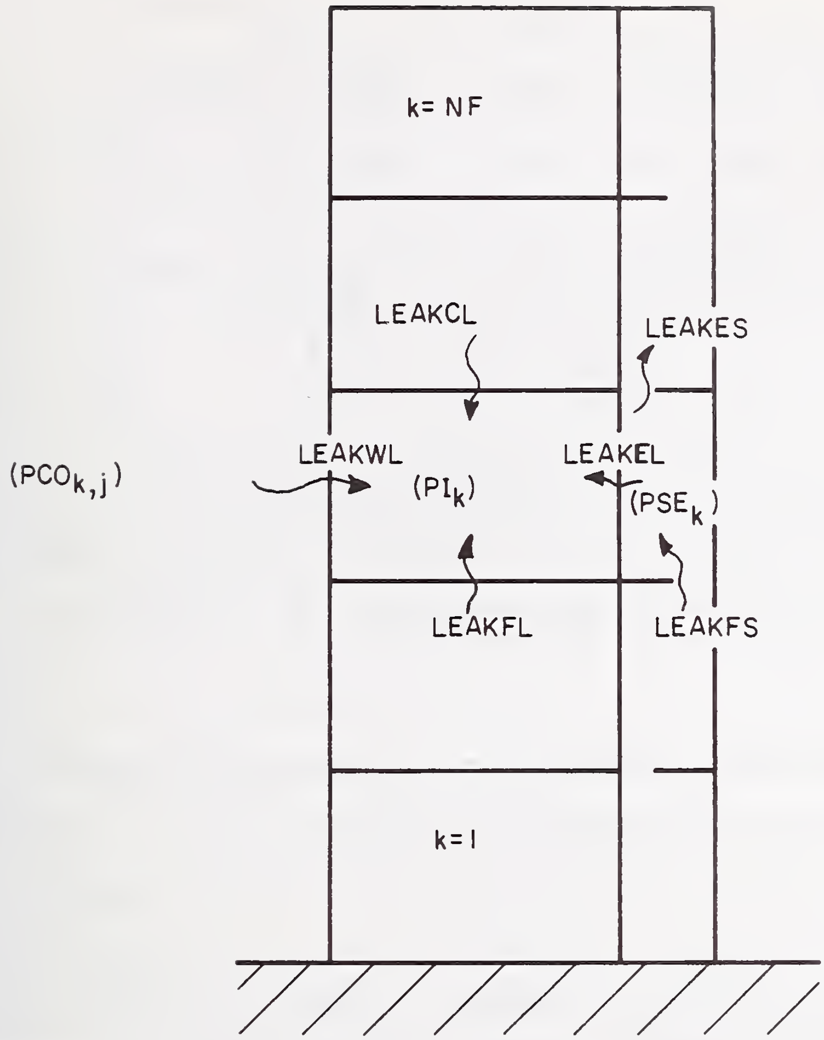


Figure A-23 Air Leakage Pattern of a High-Rise Building

Leakage from the elevator and service shafts*

$$LEAKEL_k = CEL_k * (PSE_k - PI_k) ** NEL_k \tag{7}$$

$$LEAKSS_k = CSS_k * (PSE_k - PI_k) ** NSS_k \tag{8}$$

Air leakage between the floor levels within the shafts*/

$$LEAKFS_k = CFS_k * (PSE_{k-1} - PSE_k) ** NFS_k \tag{9}$$

$$LEAKES_k = CES_k * (PSE_{k-1} - PSE_k) ** NSE_k \tag{10}$$

In the previous equations, unknowns are PI_k for k = 1, 2, 3, ... NF and PSE_k for k-1, 2, 3 ... NF provided that the pressures in all the shafts are assumed equal at a given floor level.

Flow balance equations at the k-th floor (the individual quantities come from equations 1-10 above)

Rooms

$$LEAKWD_{k,j} + LEAKFM_{k,j} + LEAKDR_{k,j} + LEAKWL_{k,j} + LEAKCL_k + LEAKFL_k + LEAKEL_k + LEAKSS_k + CFMSP_k - CFMEX_k = 0$$

---

* In all of above expressions, subscript k refers to the k-th floor and subscript j refers to the j-th side of the building where the convention is j = 1 (south), 2 (west), 3 (north), and 4 (east).

Elevator Shaft or Service Shaft

$$LEAKFS_k + LEAKES_k - LEAKEL_k{}^* + CFMSPS_k - CFMEXS_k = 0$$

where $CFMSPS_k$: ventilation air supplied at the k-th floor in the shaft

$CFMEXS_k$: air exhausted from the shaft at the k-th floor

These 2 * NF sets of flow balance equations must be solved by an appropriate iteration technique to obtain the pressure profiles in the building and in the shafts. Then the calculated pressure values are used to determine the air leakage of the building.

Recently a comprehensive computer program that embodies the basic algorithm described in this section was published by D. M. Sander and G. T. Tamura of the National Research Council of Canada. The details of the program are given in an NRC booklet entitled "A Fortran IV Program to Simulate Air Movement in Multi-Storey Buildings", DBR Computer Program No. 35, (March 1973).

---

* If this equation were for a service shaft, $LEAKEL_k$ would be replaced by $LEAKES_k$.

DST

An Algorithm for Determining the Dates of the Daylight Savings Time

Data:

YR: Year AD

MO: Month of the year

DAY: Day of the month

The main variables calculated in this subroutine are:

DSTX: The day when daylight savings time commences

DSTY: The day when standard time resumes

DST: The daylight savings time indicator

$$\text{DST} = \begin{cases} 0 \text{ during the standard time period} \\ 1 \text{ during the daylight savings time period} \end{cases}$$

Calculation Sequence:

1. If MO is less than 4 or greater than 10, DST = 0.

   If MO is greater than 4 and less than 10, DST = 1.

2. If MO = 4, DAY is less than 25, DST = 0.

   If DAY is greater than 23, call WKDAY subroutine.

   If DAY is Sunday, DSTX = DAY.

   If DAY is less than DSTX, DST = 0, otherwise DST = 1.

3. If MO = 10, DAY is less than 25, DST = 1.

   If DAY is greater than 24, call WKDAY subroutine.

   If DAY is Sunday, DSTY = DAY.

   If DAY is less than DSTY, DST = 1, otherwise DST = 0.

WKDAY

An Algorithm Used to Identify the Day of the Week for Any Given Date of the Year From 1901 to 2000

Data:

YR: Year AD

MO: Month of the year

DAY: Day of the month

The variable calculated in this subroutine is WKDAY, the weekday indicator.

	1	if Sunday
	2	if Monday
	3	if Tuesday
WKDAY =	4	if Wednesday
	5	if Thursday
	6	if Friday
	7	if Saturday

Calculation Sequence:

1. Let FSTDAY(1) = 31, FSTDAY(2) = 59, FSTDAY(3) = 90, FSTDAY(4) = 120

   FSTDAY(5) = 151, FSTDAY(6) = 181, FSTDAY(7) = 212, FSTDAY(8) = 243

   FSTDAY(9) = 273, FSTDAY(10) = 304, FSTDAY(11) = 334, FSTDAY(12 = 365

2. Let N = Integer part of YR/4

   ND = N - 485

   IY = 2, IADD = 2

   If ND = 0, Go to (4)

   If ND is less than 0, ND = -ND and IADD = -2

3. Repeat the following steps for ND times

IY = IY - IADD

If IY is greater than 7, IY = IY - 7

If IY is equal to 0, IY =7

If IY is less than 0, IY = IY + 7

4. Let MD = YR - N * 4

If MD is equal to 0 IWK = IY

If MD is equal to 1 IWK = IY + 2

If MD is equal to 2 IWK = IY + 3

If MD is equal to 3 IWK = IY + 4

If IWK is greater than 7, IWK = IWK - 7

If MO is not equal to 1 go to 5

TDAY = DAY - 1

Go to 7

5. Repeat the following for j = 2 through 12

If MO is equal to j, let TDAY = FSTDAY (j-1) + Day - 1

Otherwise Go to 6

6. If MD is equal to 0 and MO is greater than 2, TDAY = TDAY + 1

7. Let NTX = Integer part of TDAY/7

NDX = TDAY - 7 * NTX + IWK

If NDX is greater than 7, let NDX = NDX - 7

8. Let WKDAY = NDX

9. If this routine is going to be applied for the period outside 1901-2000, the following additional algorithms must be added.

KV = First two digits of YR

KTEST = Last two digits of YR

If MO $\leq$ 2 or KTEST = 0, KV = KV - 1

LTEST = Remainder of KV/4

KV = 4*LV + LTEST

If LTEST = 2, WKDAY = WKDAY + 1

= 1, WKDAY = WKDAY + 2

= 0, WKDAY = WKDAY + 3

Otherwise WKDAY = WKDAY - 3*(LV - 4)

If WKDAY < 0, WKDAY = WKDAY + 7

If WKDAY > 7, WKDAY = WKDAY - 7

An alternate calculation

An alternate calculation sequence for WKDAY has been suggested*

```
***** ALL INTEGER ARITHMETIC *****

1  MDAY=3Ø*(MO-1)+(MO-2)*58/1ØØ-1
   IF(MO.LE.2) MDAY=MDAY+MO

2  NIVC=IYR-(IYR/4ØØ)*4ØØ
   NLYR=NIVC/4
   NCEN=NIVC/1ØØ
   NIC=NIVC-1ØØ*NCEN

3  IY=6-2*NLYR

4  MD=NIVC-NLYR*4
   IF(MD.GE.1) IY=IY+1+MD
   IY=IY-NCEN
   IF(NIC.EQ.Ø.AND.NIVC.GT.Ø) IY=IY+1

5  IDAYR=MDAY+IDA

6  IF(NIC.EQ.Ø.AND.NCEN.GE.1) GO TO 7
   IF(MD.EQ.Ø.AND.MO.GT.2) IDAYR=IDAYR+1

7  JWK=IDAYR+IY
   NDX=JWK-(JWK/7)*7
   IF(NDX.LE.Ø) NDX=NDX+7
```

---

* This was contributed by A. W. Courtney, Scientific Programming, Box 508, Bloomfield Hills, Michigan 48013.

```
8  WKDAY=NDX

NOTE:  IDA FORMERLY CALLED "DAY"
       IYR FORMERLY CALLED "YR"
       IDAYR = NUMBER OF THE DAY OF THE YEAR
       Ø = NUMERICAL ZERO
```

HOLDAY

An Algorithm to Identify the National Holidays of the United States of America

Simple modifications allow the identification of any holidays or any special days in any country as long as the Gregorian Calendar system is employed.

Data:

YR: Year AD

MO: Month

DAY: Day of the month

The primary variable calculated in this subroutine is HOL, the holiday indicator; it is 1 if the date is a holiday and zero if it is a non-holiday.

Calculation Sequence:

HOL = 1

If MO = 1 and DAY = 1
MO = 12, DAY = 31 and WKDAY = 6
MO = 1, DAY = 2 and WKDAY = 2
MO = 2, $22 > DAY \geq 15$ and WKDAY = 2
MO = 5, $DAY \geq 25$ and WKDAY = 2
MO = 7 and DAY = 4
MO = 7, DAY = 3 and WKDAY = 6
MO = 7, DAY = 5 and WKDAY = 2
MO = 9, $7 > DAY$ and WKDAY = 2
MO = 10, $15 > DAY \geq 8$ and WKDAY = 2
MO = 10, $29 > DAY \geq 22$ and WKDAY = 2
MO = 11, $29 > DAY > 21$ and WKDAY = 5
MO = 12, DAY = 24 and WKDAY = 6
MO = 12, DAY = 26 and WKDAY = 2

otherwise HOL = 0

PSY*

Various Algorithms for Approximate Psychrometric Calculations

The following symbols are used throughout the PSY subroutines:

DB:	Dry-bulb temperature, F (determined in CLIMATE)
DP:	Dewpoint temperature, F (determined in CLIMATE)
WB:	Wet-bulb temperature, F (determined in CLIMATE)
t:	Temperature, either DB, WB, or DP, F
PB:	Barometric pressure, in. Hg (determined in CLIMATE)
H:	Enthalpy of moist air, Btu per lb of dry air
HS:	Enthalpy of moist air saturated with water vapor, Btu per lb of dry air
PV:	Partial pressure of water vapor in moist air, in. Hg
PVS:	Partial pressure of water vapor in moisture saturated air, in. Hg
V:	Volume of moist air, cu ft per lb of dry air
W:	Humidity ratio of moist air, lb of water vapor per lb dry air
log(x):	Natural logarithm of x
log10(x):	Common logarithm of x

---

* When the exact Goff-Gratch method is required, algorithms described in Reference 17 should be used. Tables A-19 and A-20 taken from that reference list that the psychrometric properties calculated by the PSY routines and the exact Goff-Gratch method, respectively. From examination of these tables it can be seen that the values calculated by the PSY subroutines are in very good agreement with the values calculated by the exact Goff-Gratch method.

The following algorithms are used for calculating the psychrometric properties of moist air. All of these are not required for load calculations but are presented here in a package and can be applied in a variety of engineering applications.

a. PVS (t)

1. Let

```
A(1) = -7.90298          B(1) = -9.09718
A(2) =  5.02808          B(2) = -3.56654
A(3) = -1.3816 E-7       B(3) =  0.876793
A(4) = 11.344            B(4) =  0.0060273
A(5) =  8.1328 E-3
A(6) = -3.49149
```

2. Let T = (t + 459.688)/1.8
   if T is less than 273.16, go to 3

   Otherwise

```
Let  z = 373.16/T
    P1 = A(1) * (z-1)
    P2 = A(2) * log10 (z)
    P3 = A(3) * (10**(A(4) * (1-1/z))-1)
    P4 = A(5) * (10**(A(6) * (z-1))-1)
```

   Go to 4.

3.

```
Let  z = 273.16/T
    P1 = B(1) * (z-1)
    P2 = B(2) * log10 (z)
    P3 = B(3) * (1-1/z)
    P4 = log10 (B(4)
```

4. PVS = 29.921 * (10**(P1 + P2 + P3 + P4))

b. PV (DB, WB, PB)

1. PVP = PVS (WB)
   WS = 0.622 * PVP/(PB - PVP)
   IF (WB ≤ 32) go to 3
   HL = 1093.049 + 0.441 * DB - WB
   CH = 0.24 + 0.441 * WS
   WH = WS - CH * (DB - WB)/HL

2. PV = PB * WH/(0.622 + WH)

3. PV = PVP - 5.704 * 10^{-4} * PB * (DB - WB)/1.8

c. W (DB, WB, PB)

1. VP = PV (DB, WB, PB)

2. W = 0.622 + VP/(PB - VP)

d. H (DB, WB, PB)

H = 0.24 * DB + (1061 + 0.444 * DB) * W (DB, WB, PB)

e. V (DB, WB, PB)

1. WV = W (DB, WB, PB)

2. V = 0.754 * (DB + 459.7) * (1 + 7000 * WV/4360)/PB

f. H (DB, DP, PB)

1. W = 0.622 * PVS(DP)/(PB-PVS(DP))

2. H = 0.24 * DB + (1061 + 0.444 * DB) * W

g. WB (H, PB)

1. If PB = 29.92 and H > 0

   Let Y = log(H)

   For H < 11.758

$WB = 0.6040 + 3.4841 * Y + 1.3601 * (Y**2) + 0.9731 * (Y**3)$

<u>For $H > 11.758$</u>

$WB = 30.9185 - 39.682 * Y + 20.5841 * (Y**2) - 1.758 * (Y**3)$

If $PB \neq 29.92$, or $H \leq 0$ solve the following equation by iterating WB

$H = 0.24 * WB + (1061 + 0.444 * WB) * W (WB, WB, PB)$

h. <u>DP (PV)</u>

1. Let $Y = Log(PV)$

   If PV is less than 0.18036

   $DP = 71.98 + 24.873 * Y + 0.8927 * (Y**2)$

   Otherwise

   $DP = 79.047 + 20.579 * Y + 1.8893 * (Y**2)$

Attached to this section are the Fortran listings of subroutines developed at the National Bureau of Standards which incorporate the psychrometric algorithms described above.

PVSF(X)	corresponds to PVS (t)
DPF(PV)	corresponds to DP (PV)
WBSF(H,PB)	corresponds to WB (H, PB)

The routine entitled PSY1 generates dewpoint temperature, vapor pressure, humidity ratio, enthalpy, specific volume, and relative humidity when the dry-bulb temperature, wet-bulb temperature and the barometric pressure are provided as input. This subroutine essentially combines all the algorithms described in this section. PSY2 is similar to PSY1 except that the dewpoint temperature is given in lieu of the wet-bulb temperature.

```
      SUBROUTINE PSY1(DB,WB,PB,DP,PV,W,H,V,RH)
C THIS SUBROUTINE CALCULATES VAPOR PRESSURE(PV),HUMIDITY RATIO (W)
C ENTHALPY(H),VOLUME(V),RELATIVE HUMIDITY(RH) AND DDEW-POINT
C TEMPERATURE WHEN THE DRY-BULB TEMPERATURE(DB),WET-BULB TEMPERATUR
C (WB) AND BAROMETRIC PRESSURE(PB) ARE GIVEN
      PVP=PVSF(WB)
      IF(DB-WB)4,4,5
    5 WSTAR=0.622*PVP/(PB-PVP)
      IF(WB-32.)1,1,2
    1 PV=PVP-5.704E-4*PB*(DB-WB)/1.8
      GO TO 3
    4 PV=PVP
      GO TO 3
    2 CDB=(DB-32.)/1.8
      CWB=(WB-32.)/1.8
      HL=597.31+0.4409*CDB-CWB
      CH=0.2402+0.4409*WSTAR
      EX=(WSTAR-CH*(CDB-CWB)/HL)/0.622
      PV=PB*EX/(1.+EX)
    3 W=0.622*PV/(PB-PV)
      V=0.754*(DB+459.7)*(1+7000*W/4360)/PB
      H=0.24*DB+(1061+0.444*DB)*W
      DP=DPF(PV)
      RH=PV/PVSF(DB)
      RETURN
      END
```

```
      SUBROUTINE PSY2(DB,DP,PB,WB,PV,W,H,V,RH)
C THIS SUBROUTINE CALCULATES THE FOLLOWINGS WHEN DRY-BULB TEMPERATURE
C (DB),DEW-POINT TEMPERATURE(DP),AND BAROMETRIC PRESSURE(PB) ARE GIVEN
C WB    WET-BULB TEMPERATURE
C W     HUMIDITY RATIO
C  H    ENTHALPY
C  V    VOLUME
C PV    VAPOR PRESSURE
C RH    RELATIVE HUMIDITY
      PV=PVSF(DP)
      PVS=PVSF(DB)
      RH=PV/PVS
      W=0.622*PV/(PB-PV)
      V=0.754*(DB+459.7)*(1+7000*W/4360)/PB
      H=0.24*DB+(1061+0.444*DB)*W
      WB=WBF(H,PB)
      RETURN
      END
```

```
      FUNCTION WBF(H,PB)
C     THIS PROGRAM APPROXIMATES THE WET-BULB TEMPERATURE WHEN
C     ENTHALPY AND BAROMETRIC PRESSURE ARE GIVEN

      IF(PB.NE.29.92) GO TO 2
      Y=LOG(H)
      IF(H.GT.11.758) GO TO 3
      WBF=0.6041+3.4841*Y+1.3601*Y*Y+0.97307*Y*Y*Y
      GO TO 4
    3 WBF=30.9185-39.68200*Y+20.5841*Y*Y-1.758*Y*Y*Y
      GO TO 4
    2 WB1=150.
      PV1=PVSF(WB1)
      W1=0.622*PV1/(PB-PV1)
      X1=0.24*WB1+(1061+0.444*WB1)*W1
      Y1=H-X1
    9 WB2=WB1-1
      PV2=PVSF(WB2)
      W2=0.622*PV2/(PB-PV2)
      X2=0.24*WB2+(1061+0.444*WB2)*W2
      Y2=H-X2
      IF(Y1*Y2) 6,7,8
    8 WB1=WB2
      Y1=Y2
      GO TO 9
    7 IF(Y1) 10,11,10
   11 WBF=WB1
      GO TO 4
   10 WBF=WB2
      GO TO 4
    6 Z=ABS(Y1/Y2)
      WBF=(WB2*Z+WB1)/(1+Z)
    4 RETURN
      END
```

```
      FUNCTION DPF(PV)
C     THIS SUBROUTINE CALCULATES DEW-POINT TEMPERATURE FOR GIVEN VAPOR PRESSURE
      Y=LOG(PV)
      IF(PV.GT.0.1836) GO TO 1
      DPF=71.98+24.873*Y+0.8927*Y*Y
      GO TO 2
    1 DPF=79.047+30.579*Y+1.8893*Y*Y
    2 RETURN
      END
```

```
      FUNCTION PVSF(X)
      DIMENSION A(6)/-7.90298,5.02808,-1.3816E-7,11.344,8.1328E-3,-3.491
     149/,B(4)/-9.09718,-3.56654,0.876793,0.0060273/,P(4)
      T=(X+459.688)/1.8
      IF(T.LT.273.16) GO TO 3
      Z=373.16/T
      P(1)=A(1)*(Z-1)
      P(2)=A(2)*LOG10(Z)
      Z1=A(4)*(1-1/Z)
      P(3)=A(3)*(10**Z1-1)
      Z1=A(6)*(Z-1)
      P(4)=A(5)*(10**Z1-1)
      GO TO 4
    3 Z=273.16/T
      P(1)=B(1)*(Z-1)
      P(2)=B(2)*LOG10(Z)
      P(3)=B(3)*(1-1/Z)
      P(4)=LOG10(B(4))
    4 SUM=0
      DO 5 I=1,4
    5 SUM=SUM+P(I)
      PVSF=29.921*10**SUM
      RETURN
      END
```

Table A-19

PB = 29.92 in. Hg.

DB	WB	DP	RH (%)	PV	W	H	V
80.0	80.0	80.0	100.0	1.0323	.02223	43.57	14.09
80.0	79.0	78.7	95.7	.9883	.02125	42.50	14.06
80.0	78.0	77.3	91.6	.9453	.02029	41.45	14.04
80.0	77.0	76.0	87.5	.9031	.01936	40.43	14.02
80.0	76.0	74.5	83.5	.8619	.01845	39.43	14.00
80.0	75.0	73.1	79.6	.8215	.01756	38.45	13.98
80.0	74.0	71.6	75.8	.7820	.01669	37.50	13.97
80.0	73.0	70.1	72.0	.7433	.01584	36.57	13.95
80.0	72.0	68.6	68.3	.7054	.01502	35.67	13.93
80.0	71.0	67.0	64.7	.6682	.01421	34.78	13.91
80.0	70.0	65.4	61.2	.6319	.01342	33.92	13.89
80.0	69.0	63.7	57.8	.5963	.01265	33.07	13.88
80.0	68.0	62.0	54.4	.5615	.01190	32.24	13.86
80.0	67.0	60.3	51.1	.5273	.01116	31.44	13.84
80.0	66.0	58.4	47.8	.4939	.01044	30.65	13.83
80.0	65.0	56.5	44.7	.4611	.00974	29.88	13.81
80.0	64.0	54.5	41.6	.4290	.00905	29.12	13.80
80.0	63.0	52.5	38.5	.3976	.00838	28.39	13.78
80.0	62.0	50.3	35.5	.3668	.00772	27.66	13.77
80.0	61.0	48.0	32.6	.3366	.00708	26.96	13.76
80.0	60.0	45.6	29.7	.3070	.00645	26.27	13.74
80.0	59.0	43.0	26.9	.2780	.00583	25.60	13.73
80.0	58.0	40.2	24.2	.2495	.00523	24.94	13.71
80.0	57.0	37.3	21.5	.2216	.00464	24.29	13.70
80.0	56.0	34.0	18.8	.1943	.00407	23.66	13.69
80.0	55.0	30.4	16.2	.1675	.00350	23.04	13.68
80.0	54.0	26.7	13.7	.1412	.00295	22.43	13.67
80.0	53.0	22.4	11.2	.1154	.00241	21.84	13.65
80.0	52.0	17.3	8.7	.0900	.00188	21.26	13.64
80.0	51.0	10.7	6.3	.0652	.00136	20.69	13.63
80.0	50.0	1.6	4.0	.0408	.00085	20.13	13.62
80.0	49.0	-14.6	1.6	.0169	.00035	19.59	13.61

Table A-20

Moist Air Properties Calculated by the
Exact Goff-Gratch Method

PB = 29.92 in. Hg

DB	WB	DP	RH (%)	PV	W	H	S	V
80.0	80.0	80.0	100.0	1.0323	.02233	43.69	.0864	14.09
80.0	79.0	78.7	95.7	.9883	.02135	42.61	.0843	14.07
80.0	78.0	77.3	91.6	.9453	.02039	41.56	.0822	14.05
80.0	77.0	76.0	87.5	.9032	.01945	40.53	.0802	14.03
80.0	76.0	74.6	83.5	.8620	.01854	39.53	.0783	14.01
80.0	75.0	73.1	79.6	.8217	.01764	38.55	.0764	13.99
80.0	74.0	71.7	75.8	.7822	.01677	37.60	.0745	13.97
80.0	73.0	70.2	72.0	.7435	.01592	36.67	.0727	13.95
80.0	72.0	68.6	68.4	.7057	.01509	35.76	.0709	13.93
80.0	71.0	67.1	64.8	.6686	.01428	34.87	.0692	13.91
80.0	70.0	65.5	61.2	.6323	.01349	34.00	.0675	13.90
80.0	69.0	63.8	57.8	.5967	.01271	33.15	.0658	13.88
80.0	68.0	62.1	54.4	.5619	.01196	32.32	.0642	13.86
80.0	67.0	60.3	51.1	.5278	.01122	31.51	.0626	13.85
80.0	66.0	58.5	47.9	.4944	.01050	30.72	.0610	13.83
80.0	65.0	56.6	44.7	.4617	.00979	29.95	.0595	13.81
80.0	64.0	54.6	41.6	.4296	.00910	29.19	.0581	13.80
80.0	63.0	52.5	38.6	.3982	.00843	28.45	.0566	13.78
80.0	62.0	50.4	35.6	.3674	.00777	27.73	.0552	13.77
80.0	61.0	48.1	32.7	.3372	.00712	27.02	.0538	13.76
80.0	60.0	45.6	29.8	.3077	.00649	26.33	.0525	13.74
80.0	59.0	43.1	27.0	.2787	.00587	25.66	.0511	13.73
80.0	58.0	40.3	24.2	.2503	.00527	24.99	.0498	13.72
80.0	57.0	37.3	21.5	.2224	.00468	24.35	.0486	13.70
80.0	56.0	34.0	18.9	.1951	.00410	23.71	.0473	13.69
80.0	55.0	30.5	16.3	.1683	.00353	23.09	.0461	13.68
80.0	54.0	26.8	13.8	.1420	.00293	22.49	.0449	13.67
80.0	53.0	22.6	11.3	.1162	.00244	21.89	.0438	13.65
80.0	52.0	17.5	8.8	.0910	.00191	21.31	.0426	13.64
80.0	51.0	11.0	6.4	.0662	.00138	20.74	.0415	13.63
80.0	50.0	2.0	4.1	.0418	.00087	20.18	.0404	13.62

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8. Appendix B

Weighting Factor Method of Calculating Heating and Cooling Loads and Space Temperature*/

*/ This section was prepared by D. G. Stephenson and G. Mitalas of the National Research Council of Canada for the ASHRAE Task Group on Energy Requirements for Heating and Cooling.

The weighting factor method is based on the assumption that the heat transfer processes occurring in a room can be described by linear equations; and thus that the superposition principle can be used for the calculation of cooling load and space temperature. This means that the relationship between any excitation (e.g., power input to lights) and the corresponding component of the cooling load can be expressed in the form of a characteristic transfer function. Once all the transfer functions have been determined for a room, they can be used to calculate the response to any excitation. The weighting factors are a convenient way of representing these characteristic transfer functions for a room: they relate the Z-transforms of the excitations to the Z-transforms of the corresponding cooling load components.

The Z-transform[1, 2/]

When a continuous signal, $f(t)$, is sampled at regular intervals of Δ, the output of the sampling device is a train of pulses as shown in Figure B1. The Laplace transform of this output signal is

$$f(o) + f(\Delta)e^{-s\Delta} + f(2\Delta)e^{-2s\Delta} + \ldots\ldots \tag{1}$$

If Z is substituted for $e^{s\Delta}$, the transform of the output from the sampler is

$$f(o) + f(\Delta)Z^{-1} + f(2\Delta)Z^{-2} + \ldots\ldots \tag{2}$$

This polynomial in Z^{-1} is the Z-transform of the function $f(t)$. The chief advantage of this type of transform is that it can be obtained just by sampling the function at regular intervals: the successive outputs being the coefficients of successive powers of Z^{-1} in the Z-transform.

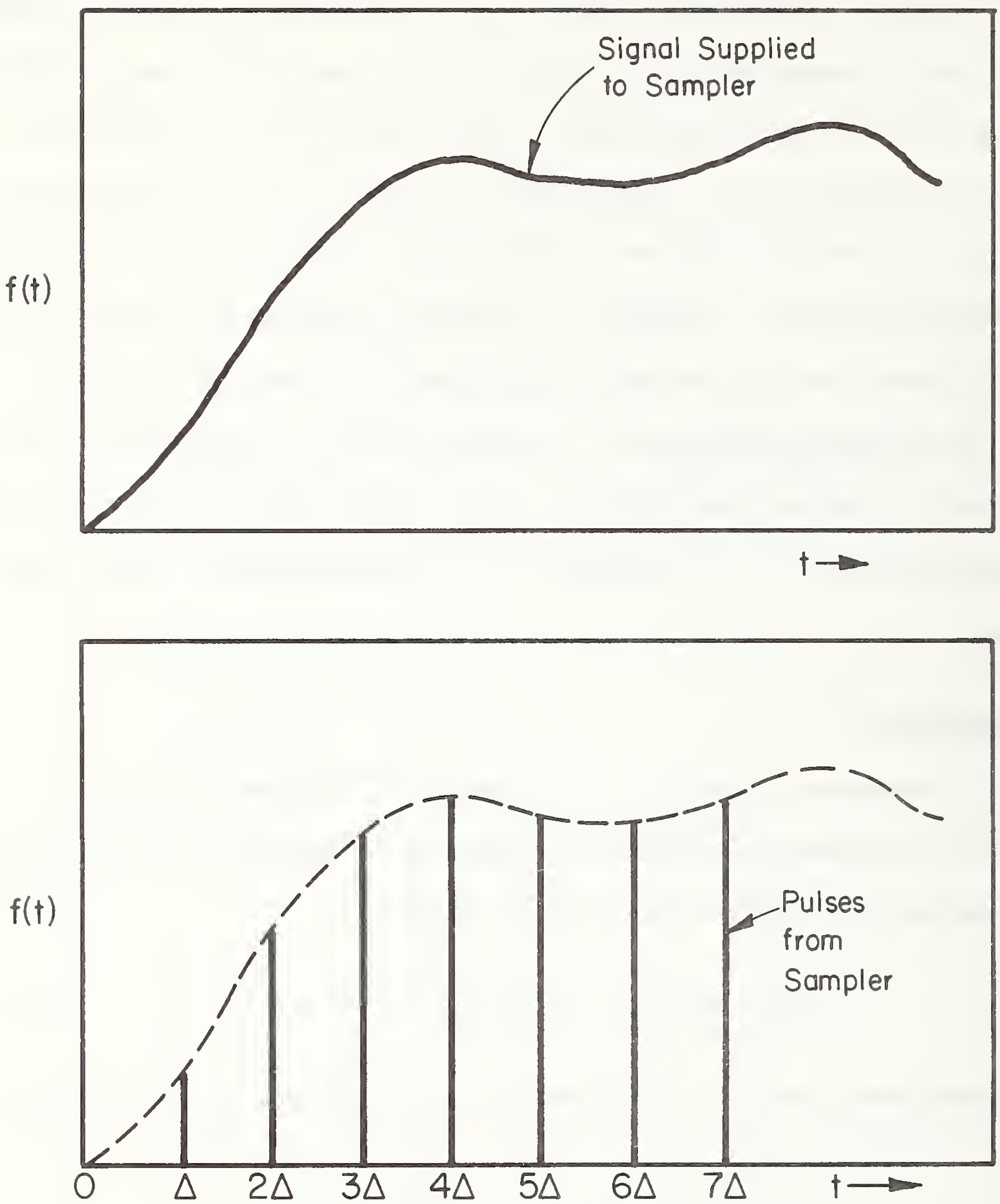

Figure B-1 Pulse Representation of a Continuous Function

If both the input and output of a system are expressed in terms of their Z-transforms, the ratio of the output/input is a Z-transfer function for the system. Assuming that such a transfer function, K(Z), can be found, and that it can be expressed as the ratio of two polynomials in $-Z^{-1}$

$$\text{i.e.,} \qquad K(Z) = \frac{a_0 + a_1 Z^{-1} + a_2 Z^{-2} + \ldots}{b_0 + b_1 Z^{-1} + b_2 Z^{-2} + \ldots} \tag{3}$$

it follows that O(Z), the Z-transform of the output that results from an input represented by I(Z) is

$$O(Z) = K(Z) \cdot I(Z) \tag{4}$$

Both sides of this equation are polynomials so the coefficients of the various powers of Z^{-1} must be the same on the two sides of the equation. Thus, equating the coefficients of Z^{-n} gives

$$\begin{aligned} O_n \cdot b_o = I_n \cdot a_o + I_{n-1} \cdot a_1 + I_{n-2} \cdot a_2 + \ldots \\ - \{O_{n-1} \cdot b_1 + O_{n-2} \cdot b_2 + \ldots\} \end{aligned} \tag{5}$$

where the subscript n on O and I indicates the value of the function at $t = n\Delta$, i.e., O_n is the coefficient of Z^{-n} in the Z-transform O(Z). This expression relates the output at any time $t = n\Delta$ to the input at that time and the values of the input and output at earlier times. The coefficients a_0, a_1, ... and b_0, b_1 ..., contain all the characteristics of the system.

Cooling Load, Heat Extraction and Room Temperature

Using the Z-transfer functions approach, the cooling load is the output that results from the input, which is the heat gain. The weighting factor sets are the transfer functions relating the cooling loads to heat gains. The procedure for calculating cooling load is, therefore, first to calculate the various components of the heat gain, and then to combine them with the appropriate weighting factor sets to obtain the cooling load. An expression like equation (5) is used to compute each component of the cooling load.

The cooling load of a space depends on both the magnitude and the nature of its excitations (i.e., outside air temperature, direct and diffuse solar radiation, electric energy input to lights, etc.). The resulting cooling load also depends on the location of the element that absorbs the energy of the excitation. For example, the cooling load profile resulting from one unit of solar radiation absorbed by the window glass is quite different from that of one unit of solar radiation absorbed by the floor surface. To shorten the computation of cooling load, the heat gain must be subdivided into a limited number of components. For example, the total heat gain by a space can be represented by the following components:

(1) Heat gain through window. (HEATG and HEATG')

(2) Heat gain through exterior walls and roofs. (HEATX)

(3) Total power input to lights. (HEATIS)

(4) Heat gain through doors, partitions, underground walls and floors, and due to internal heat sources other than lights. (HEATDP)

(5) Sensible heat gain due to infiltration. (HEATVS)

Each of these heat gain components is calculated on the basis of a constant air temperature in the space. The actual air temperature generally deviates from this reference value, and consequently the rate of heat extraction from the space, HE, differs from the cooling load. The calculation of actual room air temperature and heat extraction rate is the final step in the sequence of calculation: in this case, the previously calculated cooling load is the input along with the characteristics of the air conditioning unit; and heat extraction rate and air temperature are the outputs. If this transfer function is expressed in the form

$$\frac{HE - CL}{\delta} = \sum_{o}^{v} x_j \, z^{-j} / 1 + \sum_{1}^{w} y_j \, z^{-j},$$

or

$$HE_n = CL_n + \sum_{o}^{v} x_j * \delta_{n-j} - \sum_{1}^{w} y_j * (HE_{n-j} - CL_{n-j}) \qquad (6)$$

where δ is the deviation of actual air temperature from the reference value used to calculate the heat gains.

The heat extraction rate given by equation (6) must match the rate given by the characteristic of the air conditioning unit. For example, a cooling unit with a simple proportional control system has a characteristic of the form

$$HE_n = C + D * \delta_n \qquad (7)$$

where

C = heat extraction rate of the unit operating in a room at the reference temperature

D = change in the rate of heat extraction caused by one degree rise in room air temperature

Equations (6) and (7) can be combined to give an explicit expression for δ_n

$$\delta_n = \frac{CL_n - C + \sum_{1}^{v} x_j * \delta_{n-j} - \sum_{1}^{w} y_j * (HE_{n-j} - CL_{n-j})}{D - x_o} \qquad (8)$$

and then equation (7) can be used to evaluate HE_n.

Equation (8) can be used to calculate δ_n even if the cooling equipment is off: when the equipment is not operating, C and D are both zero.

Calculation of Room Weighting Factors

The calculation of the room weighting factors is based on the solution of a set of heat balance equations for all the room air[3, 4] (RMTMP). A computer program for evaluating weighting factors has been developed by the National Research Council of Canada[5], based on the procedure given in Reference 4.

Three different groups of room weighting factor sets are computed by this program:

(1) The first group is very large, consisting of a set of factors for each excitation at each surface.

(2) The second group combines all of the sets in group 1 that pertain to diffuse solar radiation into a single set; it combines all of the sets for direct solar radiation incident on the room surfaces other than inside window pane, floor, and furniture into another combined set; and lastly, it combines all the sets that

pertain to excitation by the power supplied to the lights into a single set.

(3) The third group of factors carry the consolidation of the various sets of the limit: there is just one set of factors for each component of heat gain.

It is not intended that the first group should be used directly for room cooling or heating load calculations, as the second group give essentially the same results with considerably less computation[6/]. The further simplication provided by the use of the third group require that the following assumptions be made:

(1) That the heat gain through room envelope components can be calculated with sufficient accuracy using combined inside surface heat transfer coefficient and that the room weighting factors are the same for heat gain through window, opaque outside wall, corridor wall and a roof.

(2) That the fraction of the solar radiation absorbed by the window glass and shade, and transmitted directly into the room as well as the portions absorbed by various room surfaces and furniture are constant during the day.

It is probable that the first assumption will not introduce significant errors; however, the second assumption is questionable. At this time, research information is lacking to establish the possible magnitude of the error introduced by this assumption.

The procedures given in this report to convert room excitation to cooling load and heat extraction are based on the third group of room weighting factors, i.e., RMRG, RMRX, RMRT and RMRTS. In addition, simplified procedures are given for the calculation of the RMRT and RMRTS sets. If the highest possible precision is important, weighting factors in the second group should be used.

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(8) D. G. Stephenson and G. P. Mitalas, "Transient Heat Conduction Through Walls and Roofs, prepared for submission to the International Journal of Heat and Mass Transfer.

(9) T. Kusuda, "Thermal Response Factors for Multi-layer Structures of Various Heat Conduction Systems, presented at ASHRAE Chicago Meeting, 1969.

(10) G. P. Mitalas and J. G. Arseneault, "Fortran IV Program to Calculate Heat Flux Response Factors for Multi-Layer Slabs, DBR Computer Program No. 23, National Research Council of Canada, 1967.

9. Appendix C

NBSLD Data Forms

Introduction

This manual contains the input data forms with instructions for preparing data needed to perform heating and cooling load calculations using NBSLD.

In addition, the manual contains engineering data needed for the computations so that the use of other handbooks or references are generally unnecessary. The required numerical data are to be filled into blank spaces provided on each DATA SHEET and then each sheet can be used directly at a computer terminal or to produce a data card if the program is being run in "batch mode" at a central facility.

General Instruction

Figure C-1 shows the flow diagram or sequence for the data preparation.

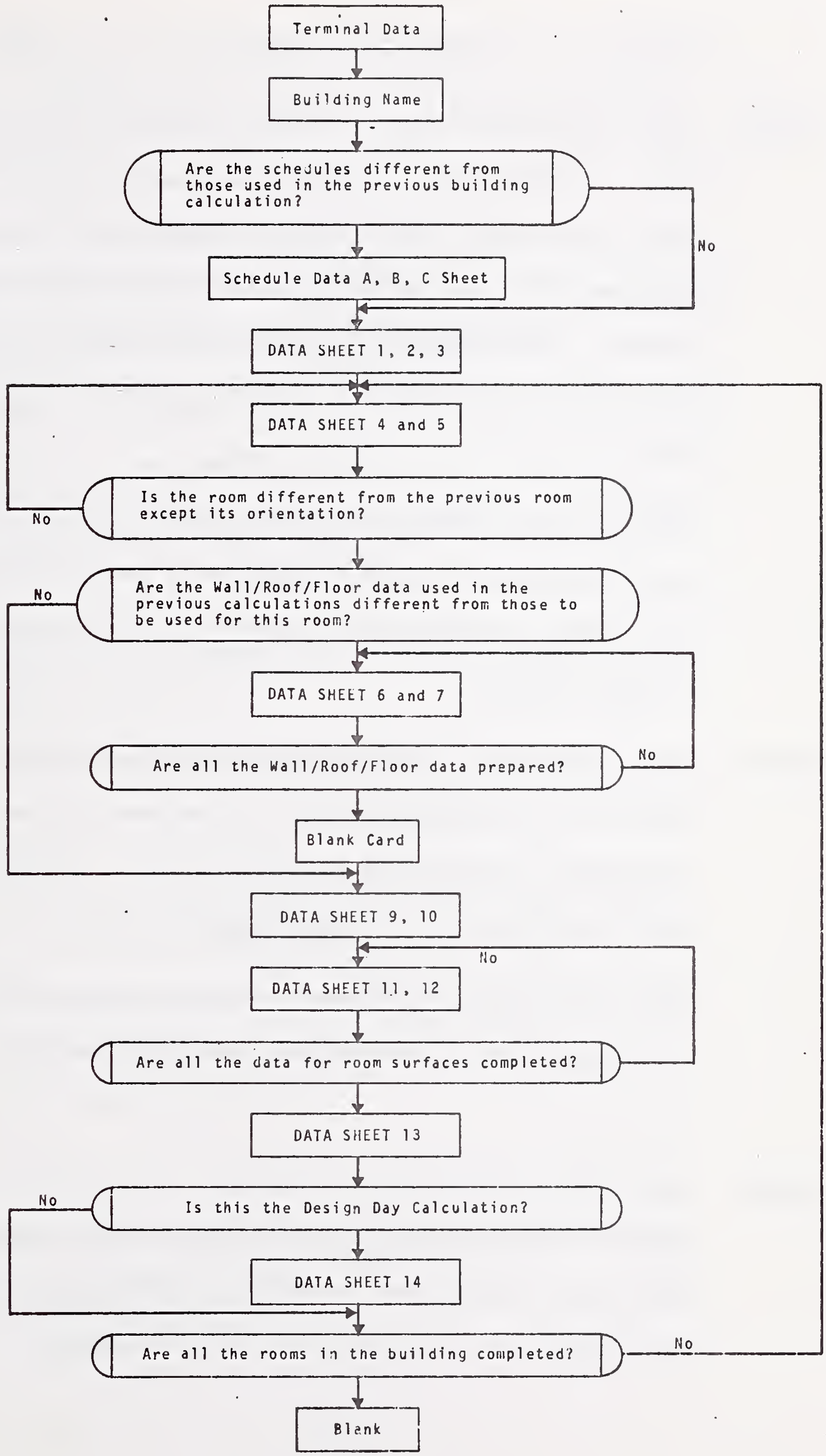
Schedule Profile data sheets A, B, C and D are prepared for a building and are assumed the same for all zones or rooms within the building.

DATA SHEETS 1 through 3 are prepared for each different building, thus need not be repeated for the analysis of rooms within the same building.

DATA SHEETS 6 and 7 usually need to be prepared only for the first room of the building, because other rooms that follow in the same building usually employ the same wall, roof, and floor constructions.

When two rooms have identical shape and construction and differ only in orientation, the second room is considered to be rotated with respect to the first room and requires only DATA SHEETS 4 and 5.

DATA SHEET PREPARATION GUIDE



Operational Data

RUNID: Index for the calculation of Conduction Transfer Functions:

RUNID = 1 if the load calculation being made for this particular run requires the generation of Conduction Transfer Functions for the walls, roof, ceilings and floors in the building. The Conduction Transfer Functions generated during the run will be stored in tape unit 8 for the future rerun.

RUNID = 2 if the Conduction Transfer Functions have already been calculated and stored in tape unit 8 and this particular run does not require the generation of new Conduction Transfer Functions.

RUNTYP: Index for the types of calculations to be performed:

RUNTYP = 1 if the calculation is for the hour by hour determination of heating and cooling load for a specified period by making use of <u>weather data</u> tape (unit 7).

RUNTYP = 2 if the calculation is for the design heating and cooling load. A weather data tape is <u>not</u> required for this run.

ASHRAE: Index for the weighting factor usage:

ASHRAE = 0 if the Weighting Factor Method of the ASHRAE Task Group is replaced by a more exact calculation procedure developed at the National Bureau of Standards.

ASHRAE = 1 if the Weighting Factor Method of the ASHRAE Task Group is used to convert the heat gains and losses to loads.

IDETAL: Index for the output specification:

IDETAL = 0 if output of the run is only the daily maximum and the daily total heating and cooling loads.

IDETAL = 1, output of the run will display input data and details of intermediate results such as Conduction Transfer Functions, Radiation heat exchange factors, solar radiation and solar heat gain.

METHOD: Index for the treatment of room surface radiation heat exchange calculation:

METHOD = 0 if the radiation exchange among the room surfaces are treated individually on room by room basis.

METHOD = 1 if a building zone is treated as a box and all the interior partition walls and floor/ceiling sandwich constructions are treated as a single slab to be distributed uniformly on the floor of the box as an extra layer for that floor.

RFMTAP: Tape drive unit number for the tape to be used by the system simulation program of Ross F. Meriwether. If no tape is needed, RFMTAP = 0.

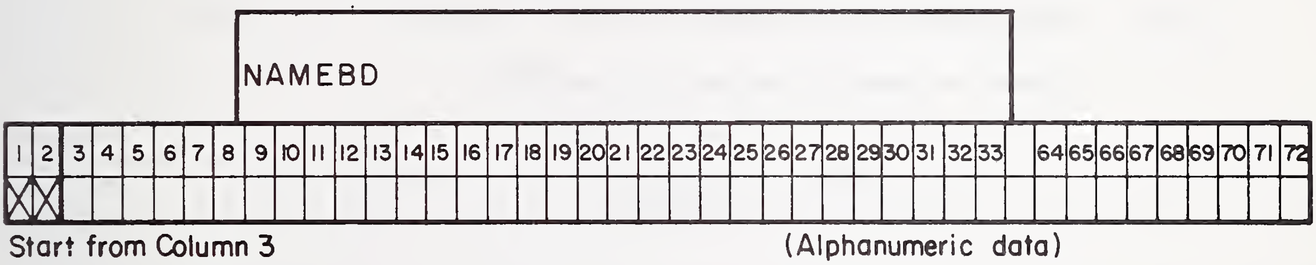
(integer variables)

RUNID	RUNTYP	ASHRAE	IDETAL	METHOD	RFMTAP

Building Name

NAMEBD

Identification of the job, name of the building, address or other pertinent information may be used within the limit of 34 alphabetical/numerical characters.



Schedule Profile-A

QLITX: Normalized* daily schedule (24-hour profile) or power input for lighting during the weekdays.

QEQUX: Normalized* daily schedule (24-hour profile) of power input for electrical appliances and other equipment (other than those involved for heating/cooling equipment) during the weekdays.

QOCUP: Normalized* daily schedule (24-hour profile) of occupancy (number of adults) during the weekdays.

QLITX

QEQUX

* Having a value between 0 and 1.

QOCUP

Schedule Profile-B*

QLITX', QEQUX', QOCUP' are the same as QLITX, QEQUX and QOCUP respectively except that these data are for the weekends.

QLITX'

QEQUX'

QOCUP'

* These data should be all zero for the design day calculation.

Schedule Profile-C*

QLITX", QEQUX", QOCUP" are the same as QLITX, QEQUX, and QOCUP respectively except that these data are for the holidays.

QLITX"

QEQUX"

QOCUP"

* These data should be all zero for the design day calculations.

Schedule Profile-D

Room Temperature and Humidity Schedule

RMDBS: 24 hour profile of room thermostat setting during the occupied cooling day, °F.

RMDBW: 24 hour profile of room thermostat setting during the occupied heating day, °F.

RMDBWO: Constant room thermostat setting during the unoccupied heating day, °F.

RMDBSO: Constant room thermostat setting during the unoccupied cooling day, °F.

RHW: Constant room relative humidity setting during the occupied heating days, %.

RHS: Constant room relative humidity setting during the occupied cooling days, %.

RMDBS

RMDBW

RMDBWO	RMDBSO	RHW	RHS						

Data Sheet 1*

NDAY: Number of days for which the calculations are to be performed.

NSKIP: Number of days to be skipped in case the computation does not start from the first day of the weather tape, which is usually 00 hour, of January 1 if standard NCC 1440 tape is used.

TAPE 2: Tape unit or file number for the output tape, if 0 an output tape or file is not produced. The output tape or file contains the hourly load and weather data needed for the system simulation.

NDAY	NSKIP	TAPE 2							

(integer data)

* For the design calculation or when RUNTYP is 2, all three variables listed here can be input as 0.

Data Sheet 2*

Month: Month for which the calculation is to be done.

Day: Day of the month on which the calculation is to be done.

ELAPS: Number of days elapsed from January 1 to reach the design day. For example, it is 201 for July 21 of a non-leap year.

DBMAX: Maximum outdoor temperature of the design day for cooling (see Table C1 which has been taken from the 1972 ASHRAE Handbook of Fundamentals).

RANGE: Daily range of the outdoor temperature during the design day, °F, (see Table C1).

WBMAX: Summer design wet-bulb temperature, °F, (see Table C1).

DBMWT: Design outdoor air temperature for the heating load calculation, °F, (see Table C1).

TGS: Summer design ground temperature, °F, (see Table C1).

TGW: Winter design ground temperature, °F, (see Table C1).

* If a weather tape is being used and a conventional design calculation is not being done, all variables listed here can be input as 0 except TGS, TGW and UG.

UG: Ground heat transfer coefficient for design heating load calculations based upon Chapter 21, 1972 ASHRAE Handbook of Fundamentals, Btuh*, (use 0.1 if uncertain).

MONTH	DAY	ELAPS	DBMAX	RANGE	WBMAX	DBMWT	TGS	TGW	UG

* Btuh = Btu per (hr) (sq. ft.) (°F).

Data Sheet 3

LONG: Longitude of the building location, degrees.

LAT: Latitude of the building location, degrees (see Table C1).

TZN: Time zone number:

5 Eastern Standard time zone

6 Central Standard time zone

7 Mountain Standard time zone

8 Pacific Standard time zone

ZLF: Room exterior wall perimeter, ft.*.

RHOW: Outdoor air relative humidity for a design heating load calculation, %.

(real variable)

LONG	LAT	TZN	ZLF	RHOW					

* For interior space, use the perimeter bounded by non-air conditioned spaces.

The value of ZL is needed only when ASHRAE = 1. If the value is unknown use ZL = 10. For the case ASHRAE = 0 use ZL = 0.

Data Sheet 4

NAMERM

After this card, the data that follow will refer to this specific room or space in the building.

NAME OF THE ROOM

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
X	X																																								

Start from Column 3

(Alphanumeric data; 34 columns maximum)

Data Sheet 5

IROT: Room rotation index:

= 0: if the room load is to be calculated without reference to any previously described room.

= number of degrees: if this room is to be the same as the previous room except for rotation clockwise a specified number of integer degrees.

ISKIP: Wall/Roof/Floor construction data skip:

= 0: if the room requires a new set of wall/roof/floor construction data.

= 1: if the wall/roof/floor data used by the previous room is reused for this room. If ISKIP = 0, data sheets 6 and 7 should be omitted.

INCLUD: Space load summation index:

= 1: space load not included in the summation.

= 0: space load included in a summation of the space load of the previous room.

(integer variables)

IROT	ISKIP	INCLUD							

Data Sheet 6

Wall/Roof/Floor-A

N: number of layers of composition in a given wall/roof/floor construction.

By referring to the data of Table C3 (taken from the 1972 ASHRAE Handbook of Fundamentals), give the following information for each of the layers starting from the innermost layer to the Nth layer, which is the outermost layer.

L: Thickness of the layer, ft.

K: Thermal conductivity of the layer, Btuh per (hr) (ft) (°F).

P: Density of the layer material, lb per cu. ft.

C: Specific heat of the layer material, Btu per (lb) (°F).

R: Thermal resistance value of the layer in (hr) (sq. ft.) (°F) per Btu.

For the calculation where the ASHRAE weighting factor method is used (ASHRAE = 1), the inner most layer is always the inside surface thermal resistance. If ASHRAE = 0, omit the inside surface thermal resistance. Outside surface thermal resistance is never used in all cases.

The value of R is to be given only when the layer has no apparent thermal mass. If the value of L, K, P, and C are given, R should be zero. If R is given, L, K, P, and C should all be zero, in particular, L should be zero even if it is physically non-zero. For the ground floor, add a finite thickness slab consisting of a 12" thick earth layer.

Note: (1) At least one of the N layers should have non-zero values of L, K, P, and C.

(2) If two or more consecutive layers have no thermal mass, their thermal resistance values should be combined.

(3) If a particular wall is considered to have no appreciable thermal mass, or if it is desired not to consider the thermal mass effect, data for this particular wall should not be included in the data sheets.

IRF*
1

(integer)

N									

(real number)

L	K	P	C	R	
					1st LAYER - innermost
					2nd LAYER
					3rd LAYER
					4th LAYER
					Nth LAYER

* IRF is not the input data in this data sheet. It is the identifier of the particular wall in the sheet.

Data Sheet 7

Wall/Roof/Floor-B

Twenty-four characters are allowed for the brief description of each layer, such as "common brick" or "1/2" plaster board", etc.

The description should identify the corresponding layer given on Data Sheet 6.

The set of wall/roof/floor data and accompanying description will be repeated as many times as there are number of different wall/roof/floor constructions (with an upper limit of 9) pertinent to the room under consideration. Each new set of wall/roof/floor construction will be identified by the IRF number on DATA SHEET 6 (upper right hand corner).

After the last wall/roof/floor has been given, provide a line with 0 or a blank card to indicate that fact.

DESCRIPTION FOR LAYER I THROUGH LAYER N

Blank card if this is the last wall/roof/floor

(Alphanumeric information)

Data Sheet 6

N									

L	K	P	C	R	
					1st LAYER - innermost
					2nd LAYER
					3rd LAYER
					4th LAYER
					Nth LAYER

Data Sheet 7

DESCRIPTION FOR LAYER 1 THROUGH LAYER N

Blank card if this is the last wall/roof/floor

(Alphanumeric information)

Data Sheet 6

N									

L	K	P	C	R	
					1st LAYER - innermost
					2nd LAYER
					3rd LAYER
					4th LAYER
					Nth LAYER

Data Sheet 7

DESCRIPTION FOR LAYER I THROUGH LAYER N

Blank card if this is the last wall/roof/floor

(Alphanumeric information)

Data Sheet 6

N									

L	K	P	C	R	
					1st LAYER - innermost
					2nd LAYER
					3rd LAYER
					4th LAYER
					Nth LAYER

Data Sheet 7

DESCRIPTION FOR LAYER 1 THROUGH LAYER N

Blank card if this is the last wall/roof/floor

(Alphanumeric information)

Data Sheet 6

N									

L	K	P	C	R	
					1st LAYER - innermost
					2nd LAYER
					3rd LAYER
					4th LAYER
					Nth LAYER

Data Sheet 7

DESCRIPTION FOR LAYER I THROUGH LAYER N

Blank card if this is the last wall/roof/floor

(Alphanumeric information)

Data Sheet 6

N									

L	K	P	C	R	
					1st LAYER - innermost
					2nd LAYER
					3rd LAYER
					4th LAYER
					Nth LAYER

Data Sheet 7

DESCRIPTION FOR LAYER I THROUGH LAYER N

Blank card if this is the last wall/roof/floor

(Alphanumeric information)

Data Sheet 6

N									

L	K	P	C	R	
					1st LAYER - innermost
					2nd LAYER
					3rd LAYER
					4th LAYER
					Nth LAYER

Data Sheet 7

DESCRIPTION FOR LAYER 1 THROUGH LAYER N

Blank card if this is the last wall/roof/floor

(Alphanumeric information)

Data Sheet 6

Wall/Roof/Floor-A

N									

L	K	P	C	R	
					1st LAYER - innermost
					2nd LAYER
					3rd LAYER
					4th LAYER
					Nth LAYER

Data Sheet 7

DESCRIPTION FOR LAYER I THROUGH LAYER N

Blank card if this is the last wall/roof/floor

(Alphanumeric information)

Data Sheet 6

IRF*
9

N									

L	K	P	C	R	
					1st LAYER - innermost
					2nd LAYER
					3rd LAYER
					4th LAYER
					Nth LAYER

Data Sheet 7

DESCRIPTION FOR LAYER I THROUGH LAYER N

Blank card if this is the last wall/roof/floor

(Alphanumeric information)

* IRF should not exceed 9 since IRF = 10 is reserved for very lightweight walls, doors and windows in Data Sheet 11.

CFMS: Flow rate of outdoor air introduced for natural cooling purposes, cu. ft. per minute, for the temperature calculation, or the flow rate of outdoor air brought into the room by mechanical means during the occupied period to reduce the cooling load (NVENT = 1). This data should be zero when RUNTYP (page 4c) = 1.

ARCHGS: Infiltration in terms of number of air changes per hour during the summer* months.

ARCHGW: Infiltration in terms of number of air changes per hour during the winter** months.

ARCHGM: Minimum infiltration in terms of air changes per hour when ARCHGS = 0 and ARCHGW = 0.

ZNORM: Number of rooms of the same type being described in the building.

* June through September.

** October through May.

ROOMNO	QLITY	QEQPX	QCU	FLCG	FRAS	TS	CFMS	ARCHGS	ARCHGW
ARCHGM	ZNORM								

Data Sheet 8

ROOMNO: Room identification number.

QLITY: Maximum lighting power input to the room, expressed as watts per sq. ft. of floor area (see Table C4).

QEQPX: Maximum electric power input for the appliances and other equipment in the room exclusive of the heating and air conditioning equipment, expressed as watts per sq. ft. of floor area (see Table C4).

QCU: Maximum number of adult occupants in the room during the day (count a child as 0.5).

FLCG: Fraction of electric power for lighting which can be assumed to go directly to the return air.

FRAS: Fraction of internal heat gains which can be assumed to be absorbed by the room surfaces instantaneously (as a result of radiation).

TS: Supply air temperature to the room from heating/cooling system, °F, for the room temperature calculation, or the upper temperature limit on outdoor air which can be brought in during the occupied period to reduce the cooling load (NVENT = 1) - Data Sheet 16.

Data Sheet 9*

IW: Building weight index:

IW = 1 Heavy structure (approximately 70 lb per sq. ft. of floor use or above).

IW = 2 Medium weight structure (between 30 and 70 lb per sq. ft. of floor area).

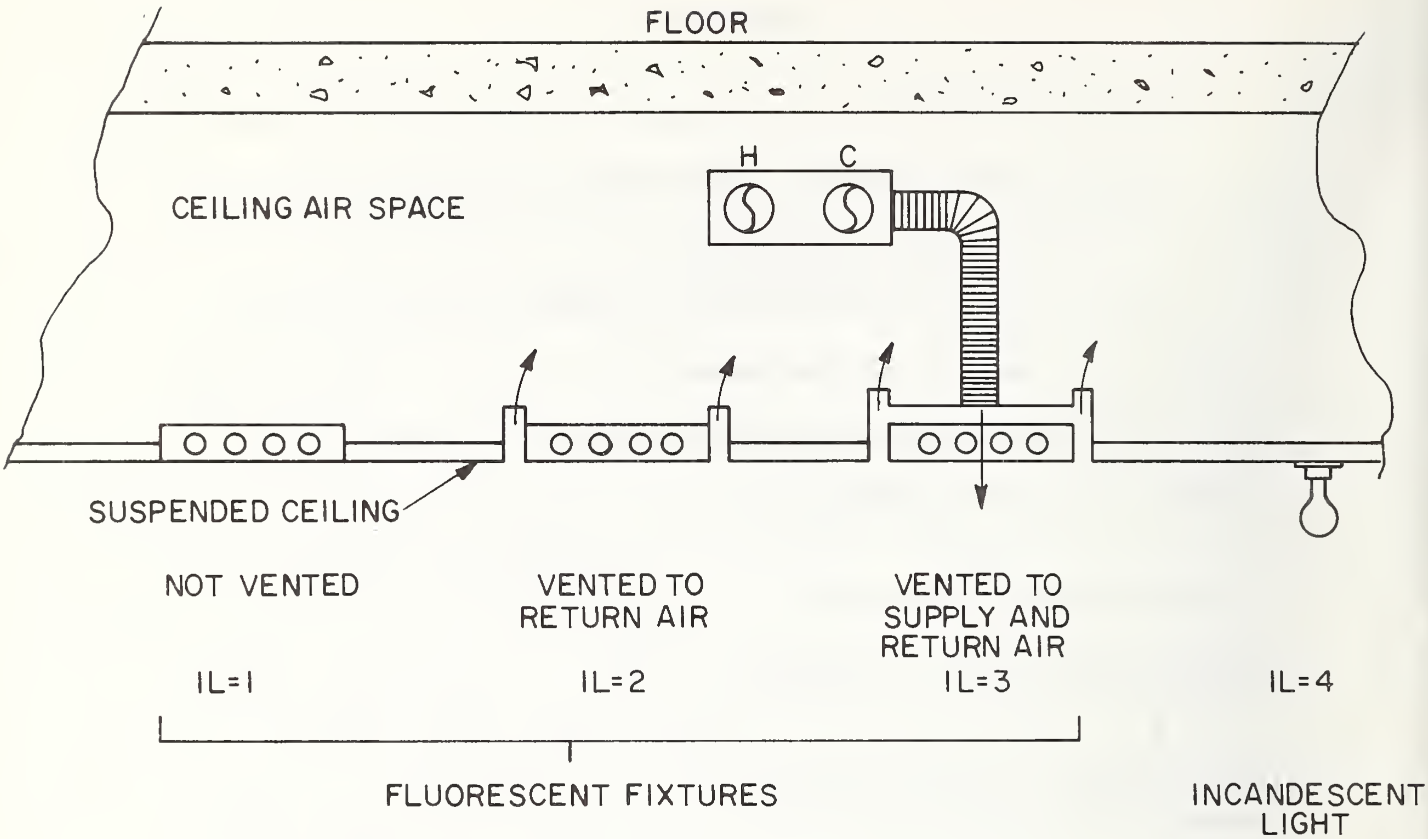
IW = 3 Lightweight structure (below 30 lb per sq. ft. of floor area).

IL: Lighting fixture index.

ISTART: Starting hour of occupancy.

ILEAVE: Ending hour of occupancy.

* This data is used only when ASHRAE = 1.



IW	IL	ISTART	ILEAVE						

Data Sheet 10

Temperature Control Data

TUL: Upper limit of thermostat, above which the room requires cooling, °F.

TLL: Lower limit of thermostat, below which the room requires heating, °F.

QCMAX: Maximum sensible cooling capacity of the room air supply system, Btu per hour (for the design load calculation this data should be zero) ... non-negative value.

QHMAX: Maximum sensible heating capacity of the room air supply system, Btu per hour (for the design load calculation this data should be zero) ... non-negative value.

DBVMAX: Maximum outdoor temperature when the natural cooling by ventilation (economizer cycle) is used.

DBVMIN: Minimum outdoor temperature, below which the economizer cycle is disengaged.

TUL	TLL	QCMAX	QHMAX	DBVMAX	DBVMIN				

Data Sheet 11

Temperature Control Indices, ITHST and ITK

ITHST = 1, ITK = 0: The hourly profile of room temperature, either constant or night setback, is prescribed ... Figure C2.

ITHST = 0, ITK = 1: The room temperature is to be calculated for the room which is neither heated nor cooled ... Figure C3.

ITHST = 1, ITK = 1: The upper and lower limit of the room temperature are given. The room will be heated if the room temperature falls below the lower limit TLL and the room is cooled if the room temperature rises above the upper limit TUL. As long as the room temperature is between these two limits, the room is neither heated nor cooled ... Figure C4.

ITHST = 0, ITK = 0: The same as above except that the maximum capacities of heating and cooling systems are introduced. If the room heating and cooling loads exceed the system heating and cooling capacities respectively, the room temperature drift from the set points TLL and TUL is calculated ... Figure C5.

ITHST	ITK								

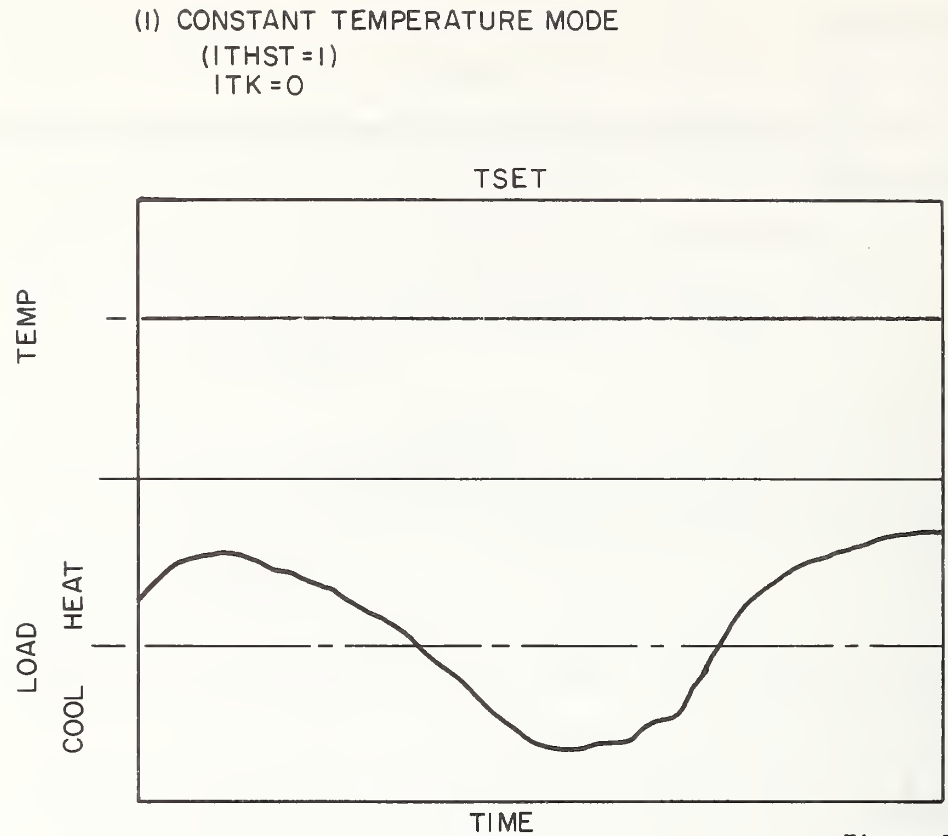


Figure C2

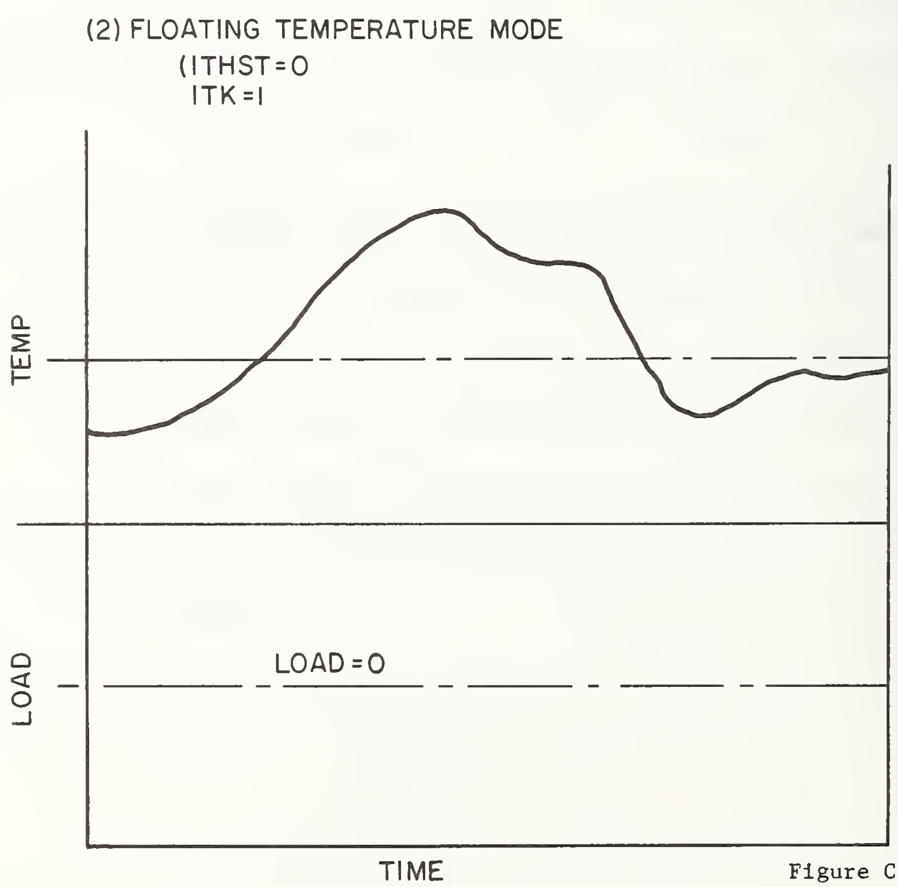
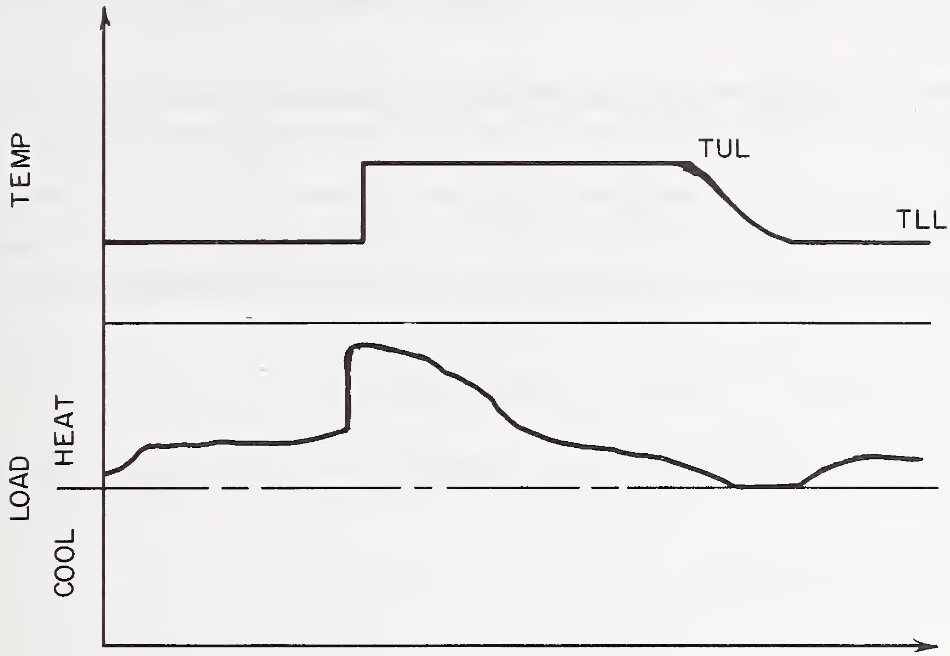


Figure C3

(3) PRESCRIBE TEMPERATURE LIMIT MODE
(ITHST=1)
(ITK=1)



(4) CONTROL SIMULATION MODE
(ITHST=0)
(ITK=0)

Figure C4

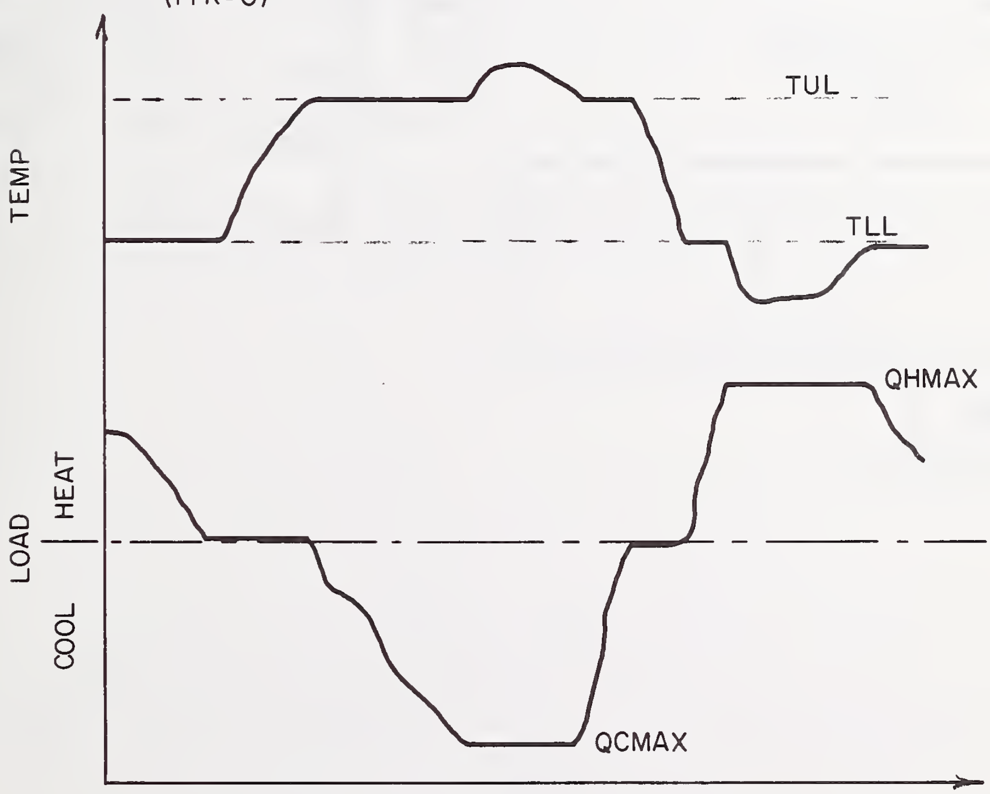


Figure C5

NS: Number of different type heat transfer surfaces in the south wall.

NW: Number of different type heat transfer surfaces in the west wall.

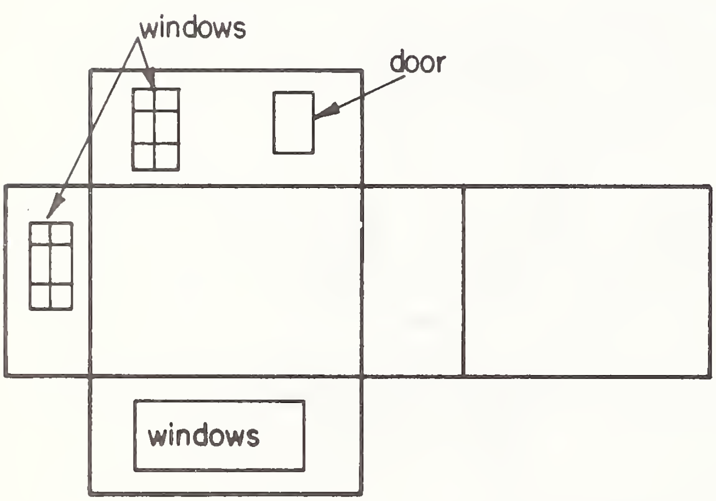
NN: Number of different type heat transfer surfaces in the north wall.

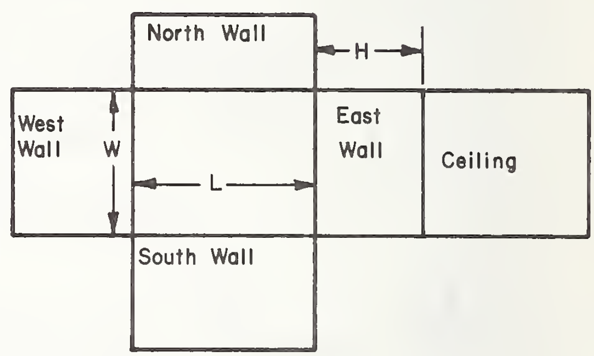
NE: Number of different type heat transfer surfaces in the east wall.

L: Length of the room along the south wall, ft.

W: Width of the room along the west wall, ft.

H: Height of the room ft.





(integers)*

NS	NW	NN	NE						
L	W	H							

(real values)

* NS + NW + NN + NE should not exceed 28.

Data Sheet 13*

ITYPE : Exposure surface type index:

= 1 if roof.

= 2 if exterior wall.

= 3 if window or glass door.

= 4 if door.

= 5 if floor on ground or basement wall.

= 6 if partition walls, party walls, floor/ceiling, furnishings and other internal mass.

= 7 if completely open.

= 8 if the adjacent space is not air conditioned and will be considered as having a temperature the same as the outdoors.

IRF: Roof/wall/floor construction identifier index shown in the upper right corner of the roof/wall/floor data sheet 6. If not applicable (such as the cases for lightweight walls, doors and windows), which are not specified in data sheets 6 and 7. IRF = 10.

A: Area of the surface, sq. ft.

AZW: Surface orientation angle, degrees clockwise from south:

0 for south facing surface, roof/ceiling or floor.

45 for southwest facing surface.

* See note on data sheet 14.

90 for west facing surface.

135 for northwest facing surface.

180 for north facing surface.

-135 for northeast facing surface.

-90 for east facing surface.

U: Overall heat transfer coefficient of a surface (Btuh) for which the data for roof/wall/floor are not provided (IRF = 10). For the surface for which roof/wall/floor data are provided (IRF ≠ 10), U should be zero because it will be computed in the program.

SHADE: Shading coefficient for the ITYPE = 3 surface (window or glass door) (see Table C5 which has been taken from the 1972 ASHRAE Handbook of Fundamentals). For all other types of surfaces, this parameter should be zero.

ABSP: Solar absorption coefficient for the exterior surface (see Table C6 which has been taken from Thermal Radiation Properties Survey, G. G. Gubareff, J. E. Jansen, and R. H. Torborg, Honeywell Research Center, 1960). This value should be zero for the surfaces of ITYPE = 3, 5, 6 and 7, and 8.

SHDW: Shadow parameter = 1 if completely shaded by an adjacent building or an external shading device; = 0 if otherwise.

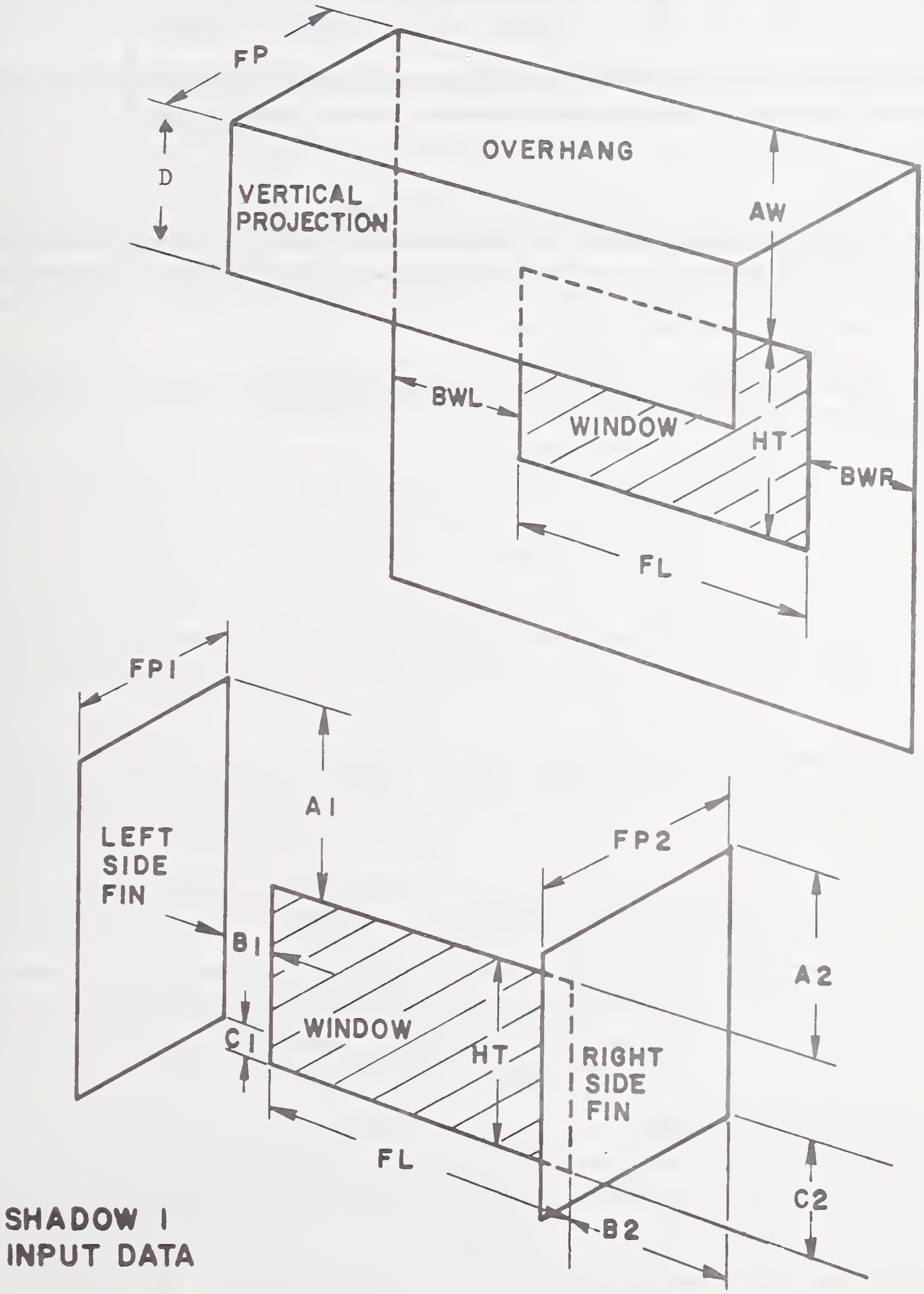
integer		real variable							
ITYPE	IRF	A	AZW	U	SHADE	ABSP	SHD		

Data Sheet 14*

Room Surfaces - B

(Exterior Shading Device Data)

Data are given in ft. and as dictated by the figure below.



FL	HT	FP	AW	BWL	BWR	D			

FP1	A1	B1	C1	FP2	A2	B2	C2		

* The sequence of input should be roof/ceiling, south facing surfaces, west facing surfaces, north facing surfaces, east facing surfaces and floor. While each vertical exposure can accommodate more than one type of surface such as wall, door and window, only one surface should be given for floor and roof/ceiling.

Data Sheets 11 and 12 are to be repeated for each of all the surfaces of the room.

Repetition of Data Sheets 13 and 14

ITYPE	IRF	A	AZW	U	SHADE	ABSP	SHDW		

FL	HT	FP	AW	BWL	BWR	D			

FPI	AI	BI	CI	FP2	A2	B2	C2		

ITYPE	IRF	A	AZW	U	SHADE	ABSP	SHDW		

FL	HT	FP	AW	BWL	BWR	D			

FPI	AI	BI	CI	FP2	A2	B2	C2		

ITYPE	IRF	A	AZW	U	SHADE	ABSP	SHDW		

FL	HT	FP	AW	BWL	BWR	D			

FPI	AI	BI	CI	FP2	A2	B2	C2		

Repetition of Data Sheets 13 and 14

ITYPE	IRF	A	AZW	U	SHADE	ABSP	SHDW		

FL	HT	FP	AW	BWL	BWR	D			

FP1	A1	B1	C1	FP2	A2	B2	C2		

ITYPE	IRF	A	AZW	U	SHADE	ABSP	SHDW		

FL	HT	FP	AW	BWL	BWR	D			

FP1	A1	B1	C1	FP2	A2	B2	C2		

ITYPE	IRF	A	AZW	U	SHADE	ABSP	SHDW		

FL	HT	FP	AW	BWL	BWR	D			

FP1	A1	B1	C1	FP2	A2	B2	C2		

Repetition of Data Sheets 13 and 14

ITYPE	IRF	A	AZW	U	SHADE	ABSP	SHDW		

FL	HT	FP	AW	BWL	BWR	D			

FP1	A1	B1	C1	FP2	A2	B2	C2		

ITYPE	IRF	A	AZW	U	SHADE	ABSP	SHDW		

FL	HT	FP	AW	BWL	BWR	D			

FP1	A1	B1	C1	FP2	A2	B2	C2		

ITYPE	IRF	A	AZW	U	SHADE	ABSP	SHDW		

FL	HT	FP	AW	BWL	BWR	D			

FP1	A1	B1	C1	FP2	A2	B2	C2		

Repetition of Data Sheets 13 and 14

ITYPE	IRF	A	AZW	U	SHADE	ABSP	SHDW		

FL	HT	FP	AW	BWL	BWR	D			

FPI	AI	BI	CI	FP2	A2	B2	C2		

ITYPE	IRF	A	AZW	U	SHADE	ABSP	SHDW		

FL	HT	FP	AW	BWL	BWR	D			

FPI	AI	BI	CI	FP2	A2	B2	C2		

ITYPE	IRF	A	AZW	U	SHADE	ABSP	SHDW		

FL	HT	FP	AW	BWL	BWR	D			

FPI	AI	BI	CI	FP2	A2	B2	C2		

Data Sheet 15*

UENDW: Overall heat transfer coefficient of the end walls (gables) of the attic space, Btuh.

UCELNG: Overall heat transfer coefficient of the ceiling under the attic, Btuh.

AENDW: Area of the attic end walls, sq. ft.

ATCHT: Attic space height, ft.

ARCHGA: Air change per hr. for attic.

AIRNT: Nighttime air change multiplier with respect to ARCHGA.

UENDW	UCELNG	AENDW	ATCHT	ARCHGA	AIRNT				

* This data sheet provides information for the attic space with a flat roof. If gabled roof, it must be treated as an equivalent flat roof.

IEXTED: Exterior shading control index:

IEXTED = 1 if the exterior shading device is controlled to cut down the direct solar heat gain.

IEXTED = 0 if the exterior shading device is not controlled.

IEXMS: The month at which the exterior shading device control starts.

IEXME: The month at which the exterior shading device control ends.

NTVNT: Ventilation air change per hour during the unoccupied period to precool the building. The ventilation system is assumed on only during the cooling season when

a. The room temperature exceeds 75 °F.

b. Outdoor temperature is below 70 °F.

NVENT: Natural ventilation index

NVENT = 1 if outdoor air is brought in during the occupied period to minimize the cooling load.

NVENT = 0 otherwise.

(integer data)

IEXTED	IEXMS	IEXME	NTVNT	NVENT					

Run Sequence

The step by step procedure to perform the heating and cooling load calculation by using NBSLD on the INFONET system is as follows:

1. Complete the data forms described in this manual.
2. Check the data for probable errors.
3. Turn the computer terminal on.
4. Dial the computer center and listen to the high-pitched tone.
5. Place the telephone receiver onto the acoustic coupler of the terminal.
6. Hit the key "T".

   The computer responds with

   "PORT:" Port number

   "CENTER:"

   Type in after "CENTER:" BB

   The computer responds then with

   "LOGON:"

   Type in your identification number after "LOGON:".
7. The computer then returns the carriage of the terminal and types!
8. Every time the computer waits for your command, it responds with ! at the first position of the carriage. Following in the sequence of the commands needed to perform the load calculations.

! EDIT NBSBLI

↑ 1 — Type in the data from your data forms as illustrated in Figure C1.

2

60 — ... all the data are completed.

61

↑ Q — close the data file.

SRU'S: .9 — computer time unit used in the data preparation.

! EQUATE 7 WETDAT — Weather tape file name.

! EQUATE 9 SPACE 1 — Output tape No. 1.

! EQUATE 10 SPACE 2 — Output tape No. 2.

9. Instruction for the terminal data input

Type in the following terminal data:

RUNID, RUNTYP, ASHRAE, IDETAL, METHOD

At this point, the computer starts the load calculation and output such as shown in P103 will be typed out on the terminal.

Weather Tape Handling

The use of Weather Data Tape 1440 provided by the National Climatic Center may be made as follows:

1. Request the tape containing data for specified years from the National Climatic Center

   G. McKay or D. Calloway
   Environmental Data Services
   Asheville, North Carolina 28801
   Telephone: (704) 254-0961

   Remember that beginning January 1, 1965 a new program was initiated for most Weather Bureau Stations reducing the number of hourly observations being recorded from 24 to 8 per day. This format is not compatible with NBSLD as it is presently written since it requires hourly weather data. Note that the tape is 7 channel, 556 BPI density and of even parity.

2. Have the tape mailed to INFONET computing center at the following address:

   Mr. K. Walls
   Center 1
   INFONET Division
   Computer Science Corporation
   650 North Sepulveda Blvd.
   El Segundo, California 90245

3. Ask INFONET to assign a <u>Volume number</u> such as US001.

4. The tape 1440 is then decoded and stored into a weather data file name of which may be obtained by the following INFONET commands:

! DEVICES, QUEUE 0,0,1

! EQUATE 9 WETDAT

! WETHER

VOL, DENS, PARITY, TRACK

VOL: Tape name.

DENS: Tape density in BPI.

PARITY: Date parity, either even or odd.

TRACK: Track number, either 7 or 9.

ISKIP, NDAY, IWRITE ... data

where ISKIP: Number of days to be skipped from the beginning of the tape.

NDAY: Number of days for which the weather data are to be stored in the file.

IWRITE = 1: if the weather data are to be printed out on the terminal as they are processed and stored; otherwise zero.

5. The constants of WETDAT may be checked by a separate routine WETAP by

! EQUATE 9 WETDAT

! WETAP

NDAY, NSKIP

where NDAY: Number of days for which the weather data are to be displayed on the terminal.

NSKIP: Number of days to be skipped from the beginning of the file WETDAT.

When the use is made of WETDAT in any other program, it can be read in the Fortran program as follows:

```
READ(9) DB, DP, WB, WS, PB, TC, NTOC, DAY, IYEAR, MONTH, ICITY
```

where DB, DD, WB, WS, PB, TC, and NTOC are all dimensioned 24 and represent respectively dry-bulb temperature, dewpoint temperature, wet-bulb temperature, wind speed, barometric pressure, total cloud amount, and type of cloud.

Table C1

Design Weather Data

Climatic Conditions for United States and Canada*,[a]

Col. 1 State and Station[b]	Col. 2 Latitude[c] ° ′	Col. 3 Elev,[d] Ft	Winter: Col. 4 Median of Annual Extremes	Col. 4 99%	Col. 4 97½%	Col. 5 Coincident Wind Velocity[e]	Summer: Col. 6 Design Dry-Bulb 1%	Col. 6 2½%	Col. 6 5%	Col. 7 Outdoor Daily Range[f]	Col. 8 Design Wet-Bulb 1%	Col. 8 2½%	Col. 8 5%
ALABAMA													
Alexander City	33 0	660	12	16	20	L	96	94	93	21	79	78	77
Anniston AP	33 4	599	12	17	19	L	96	94	93	21	79	78	77
Auburn	32 4	730	17	21	25	L	98	96	95	21	80	79	78
Birmingham AP	33 3	610	14	19	22	L	97	94	93	21	79	78	77
Decatur	34 4	580	10	15	19	L	97	95	94	22	79	78	77
Dothan AP	31 2	321	19	23	27	L	97	95	94	20	81	80	79
Florence AP	34 5	528	8	13	17	L	97	95	94	22	79	78	77
Gadsden	34 0	570	11	16	20	L	96	94	93	22	78	77	76
Huntsville AP	34 4	619	−6	13	17	L	97	95	94	23	78	77	76
Mobile AP	30 4	211	21	26	29	M	95	93	91	18	80	79	79
Mobile CO	30 4	119	24	28	32	M	96	94	93	16	80	79	79
Montgomery AP	32 2	195	18	22	26	L	98	95	93	21	80	79	78
Selma-Craig AFB	32 2	207	18	23	27	L	98	96	94	21	81	80	79
Talladega	33 3	565	11	15	19	L	97	95	94	21	79	78	77
Tuscaloosa AP	33 1	170r	14	19	23	L	98	96	95	22	81	80	79
ALASKA													
Anchorage AP	61 1	90	−29	−25	−20	VL	73	70	67	15	63	61	59
Barrow	71 2	22	−49	−45	−42	M	58	54	50	12	54	51	48
Fairbanks AP	64 5	436	−59	−53	−50	VL	82	78	75	24	64	63	61
Juneau AP	58 2	17	−11	− 7	− 4	L	75	71	68	15	66	64	62
Kodiak	57 3	21	4	8	12	M	71	66	63	10	62	60	58
Nome AP	64 3	13	−37	−32	−28	L	66	62	59	10	58	56	54
ARIZONA†													
Douglas AP	31 3	4098	13	18	22	VL	100	98	96	31	70	69	68
Flagstaff AP	35 1	6973	−10	0	5	VL	84	82	80	31	61	60	59
Fort Huachuca AP	31 3	4664	18	25	28	VL	95	93	91	27	69	68	67
Kingman AP	35 2	3446	18	25	29	VL	103	100	97	30	70	69	69
Nogales	31 2	3800	15	20	24	VL	100	98	96	31	72	71	70
Phoenix AP	33 3	1117	25	31	34	VL	108	106	104	27	77	76	75
Prescott AP	34 4	5014	7	15	19	VL	96	94	91	30	67	66	65
Tucson AP	33 1	2584	23	29	32	VL	105	102	100	26	74	73	72
Winslow AP	35 0	4880	2	9	13	VL	97	95	92	32	66	65	64
Yuma AP	32 4	199	32	37	40	VL	111	109	107	27	79	78	77
ARKANSAS													
Blytheville AFB	36 0	264	6	12	17	L	98	96	93	21	80	79	78
Camden	33 4	116	13	19	23	L	99	97	96	21	81	80	79
El Dorado AP	33 1	252	13	19	23	L	98	96	95	21	81	80	79
Fayetteville AP	36 0	1253	3	9	13	M	97	95	93	23	77	76	75
Fort Smith AP	35 2	449	9	15	19	M	101	99	96	24	79	78	77
Hot Springs Nat. Pk.	34 3	710	12	18	22	M	99	97	96	22	79	78	77
Jonesboro	35 5	345	8	14	18	M	98	96	95	21	80	79	78
Little Rock AP	34 4	257	13	19	23	M	99	96	94	22	80	79	78
Pine Bluff AP	34 1	204	14	20	24	L	99	96	95	22	81	80	79
Texarkana AP	33 3	361	16	22	26	M	99	97	96	21	80	79	78
CALIFORNIA†													
Bakersfield AP	35 2	495	26	31	33	VL	103	101	99	32	72	71	70
Barstow AP	34 5	2142	18	24	28	VL	104	102	99	37	73	72	71
Blythe AP	33 4	390	26	31	35	VL	111	109	106	28	78	77	76
Burbank AP	34 1	699	30	36	38	VL	97	94	91	25	72	70	69
Chico	39 5	205	23	29	33	VL	102	100	97	36	71	70	69
Concord	38 0	195	27	32	36	VL	96	92	88	32	69	67	66

* Data for U. S. stations extracted from *Evaluated Weather Data for Cooling Equipment Design, Addendum No. 1, Winter and Summer Data,* with the permission of the publisher, Fluor Products Company, Inc., Box 1267, Santa Rosa, California.

[a] Data compiled from official weather stations, where hourly weather observations are made by trained observers, and from other sources. Table 1 prepared by ASHRAE Technical Committee 2.2, Weather Data and Design Conditions. Percentage of *winter* design data show the percent of 3-month period, December through February. Canadian data are based on January only. Percentage of *summer* design data show the percent of 4-month period, June through September. Canadian data are based on July only. Also see References 1 to 7.

[b] When airport temperature observations were used to develop design data, "AP" follows station name, and "AFB" follows Air Force Bases. Data for stations followed by "CO" came from office locations within an urban area and generally reflect an influence of the surrounding area. Stations without designation can be considered semirural and may be directly compared with most airport data.

[c] Latitude is given to the nearest 10 minutes, for use in calculating solar loads. For example, the latitude for Anniston, Alabama is given as 33 4, or 33°40′.

[d] Elevations are ground elevations for each station as of 1964. Temperature readings are generally made at an elevation of 5 ft above ground, except for locations marked r, indicating roof exposure of thermometer.

[e] Coincident wind velocities derived from approximately coldest 600 hours out of 20,000 hours of December through February data per station. Also see References 5 and 6. The four classifications are:

VL = Very Light, 70 percent or more of cold extreme hours ≤7 mph. M = Moderate, 50 to 74 percent cold extreme hours >7 mph.
L = Light, 50 to 69 percent cold extreme hours ≤7 mph. H = High, 75 percent or more cold extreme hours >7 mph, and 50 percent are >12 mph.

[f] The difference between the average maximum and average minimum temperatures during the warmest month.

† More detailed data on Arizona, California, and Nevada may be found in *Recommended Design Temperatures, Northern California,* published by the Golden Gate Chapter; and *Recommended Design Temperatures, Southern California, Arizona, Nevada,* published by the Southern California Chapter.

Climatic Conditions for United States and Canada (Continued)*,[a]

Col. 1 State and Station[b]	Col. 2 Latitude[c] °	′	Col. 3 Elev,[d] Ft	Winter: Col. 4 Median of Annual Extremes	Col. 4 99%	Col. 4 97½%	Col. 5 Coincident Wind Velocity[e]	Summer: Col. 6 Design Dry-Bulb 1%	Col. 6 2½%	Col. 6 5%	Col. 7 Outdoor Daily Range[f]	Col. 8 Design Wet-Bulb 1%	Col. 8 2½%	Col. 8 5%
CALIFORNIA† (continued)														
Covina	34	0	575	32	38	41	VL	100	97	94	31	73	72	71
Crescent City AP	41	5	50	28	33	36	L	72	69	65	18	61	60	59
Downey	34	0	116	30	35	38	VL	93	90	87	22	72	71	70
El Cajon	32	4	525	26	31	34	VL	98	95	92	30	74	73	72
El Centro AP	32	5	−30	26	31	35	VL	111	109	106	34	81	80	79
Escondido	33	0	660	28	33	36	VL	95	92	89	30	73	72	71
Eureka/Arcata AP	41	0	217	27	32	35	L	67	65	63	11	60	59	58
Fairfield-Travis AFB	38	2	72	26	32	34	VL	98	94	90	34	71	69	67
Fresno AP	36	5	326	25	28	31	VL	101	99	97	34	73	72	71
Hamilton AFB	38	0	3	28	33	35	VL	89	85	81	28	71	68	66
Laguna Beach	33	3	35	32	37	39	VL	83	80	77	18	69	68	67
Livermore	37	4	545	23	28	30	VL	99	97	94	24	70	69	68
Lompoc, Vandenburg AFB	34	4	552	32	36	38	VL	82	79	76	20	65	63	61
Long Beach AP	33	5	34	31	36	38	VL	87	84	81	22	72	70	69
Los Angeles AP	34	0	99	36	41	43	VL	86	83	80	15	69	68	67
Los Angeles CO	34	0	312	38	42	44	VL	94	90	87	20	72	70	69
Merced-Castle AFB	37	2	178	24	30	32	VL	102	99	96	36	73	72	70
Modesto	37	4	91	26	32	36	VL	101	98	96	36	72	71	70
Monterey	36	4	38	29	34	37	VL	82	79	76	20	64	63	61
Napa	38	2	16	26	31	34	VL	94	92	89	30	69	68	67
Needles AP	34	5	913	27	33	37	VL	112	110	107	27	76	75	74
Oakland AP	37	4	3	30	35	37	VL	85	81	77	19	65	63	62
Oceanside	33	1	30	33	38	40	VL	84	81	78	13	69	68	67
Ontario	34	0	995	26	32	34	VL	100	97	94	36	72	71	70
Oxnard AFB	34	1	43	32	35	37	VL	84	80	78	19	70	69	67
Palmdale AP	34	4	2517	18	24	27	VL	103	101	98	35	70	68	67
Palm Springs	33	5	411	27	32	36	VL	110	108	105	35	79	78	77
Pasadena	34	1	864	31	36	39	VL	96	93	90	29	72	70	69
Petaluma	38	1	27	24	29	32	VL	94	90	87	31	70	68	67
Pomona CO	34	0	871	26	31	34	VL	99	96	93	36	73	72	71
Redding AP	40	3	495	25	31	35	VL	103	101	98	32	70	69	67
Redlands	34	0	1318	28	34	37	VL	99	96	93	33	72	71	70
Richmond	38	0	55	28	35	38	VL	85	81	77	17	66	64	63
Riverside-March AFB	33	5	1511	26	32	34	VL	99	96	94	37	72	71	69
Sacramento AP	38	3	17	24	30	32	VL	100	97	94	36	72	70	69
Salinas AP	36	4	74	27	32	35	VL	87	85	82	24	67	65	64
San Bernardino, Norton AFB	34	1	1125	26	31	33	VL	101	98	96	38	75	73	71
San Diego AP	32	4	19	38	42	44	VL	86	83	80	12	71	70	68
San Fernando	34	1	977	29	34	37	VL	100	97	94	38	73	72	71
San Francisco AP	37	4	8	32	35	37	L	83	79	75	20	65	63	62
San Francisco CO	37	5	52	38	42	44	VL	80	77	73	14	64	62	61
San Jose AP	37	2	70r	30	34	36	VL	90	88	85	26	69	67	65
San Luis Obispo	35	2	315	30	35	37	VL	89	85	82	26	65	64	63
Santa Ana AP	33	4	115r	28	33	36	VL	92	89	86	28	72	71	70
Santa Barbara CO	34	3	100	30	34	36	VL	87	84	81	24	67	66	65
Santa Cruz	37	0	125	28	32	34	VL	87	84	80	28	66	65	63
Santa Maria AP	34	5	238	28	32	34	VL	85	82	79	23	65	64	63
Santa Monica CO	34	0	57	38	43	45	VL	80	77	74	16	69	68	67
Santa Paula	34	2	263	28	33	36	VL	91	89	86	36	72	71	70
Santa Rosa	38	3	167	24	29	32	VL	95	93	90	34	70	68	67
Stockton AP	37	5	28	25	30	34	VL	101	98	96	37	72	70	69
Ukiah	39	1	620	22	27	30	VL	98	96	93	40	70	69	67
Visalia	36	2	354	26	32	36	VL	102	100	97	38	73	72	70
Yreka	41	4	2625	7	13	17	VL	96	94	91	38	68	66	65
Yuba City	39	1	70	24	30	34	VL	102	100	97	36	71	70	69
COLORADO														
Alamosa AP	37	3	7536	−26	−17	−13	VL	84	82	79	35	62	61	60
Boulder	40	0	5385	− 5	4	8	L	92	90	87	27	64	63	62
Colorado Springs AP	38	5	6173	− 9	− 1	4	L	90	88	86	30	63	62	61
Denver AP	39	5	5283	− 9	− 2	3	L	92	90	89	28	65	64	63
Durango	37	1	6550	−10	0	4	VL	88	86	83	30	64	63	62

Climatic Conditions for United States and Canada (Continued)*[a]

Col. 1 State and Station[b]	Col. 2 Latitude[c] ° ′	Col. 3 Elev,[d] Ft	Winter: Col. 4 Median of Annual Extremes	Winter: Col. 4 99%	Winter: Col. 4 97½%	Winter: Col. 5 Coincident Wind Velocity[e]	Summer: Col. 6 Design Dry-Bulb 1%	Col. 6 2½%	Col. 6 5%	Col. 7 Outdoor Daily Range[f]	Col. 8 Design Wet-Bulb 1%	Col. 8 2½%	Col. 8 5%
COLORADO (continued)													
Fort Collins	40 4	5001	−18	− 9	− 5	L	91	89	86	28	63	62	61
Grand Junction AP	39 1	4849	− 2	8	11	VL	96	94	92	29	64	63	62
Greeley	40 3	4648	−18	− 9	− 5	L	94	92	89	29	65	64	63
La Junta AP	38 0	4188	−14	− 6	− 2	M	97	95	93	31	72	71	69
Leadville	39 2	10177	−18	− 9	− 4	VL	76	73	70	30	56	55	54
Pueblo AP	38 2	4639	−14	− 5	− 1	L	96	94	92	31	68	67	66
Sterling	40 4	3939	−15	− 6	− 2	M	95	93	90	30	67	66	65
Trinidad AP	37 2	5746	− 9	1	5	L	93	91	89	32	66	65	64
CONNECTICUT													
Bridgeport AP	41 1	7	− 1	4	8	M	90	88	85	18	77	76	75
Hartford, Brainard Field	41 5	15	− 4	1	5	M	90	88	85	22	77	76	74
New Haven AP	41 2	6	0	5	9	H	88	86	83	17	77	76	75
New London	41 2	60	0	4	8	H	89	86	83	16	77	75	74
Norwalk	41 1	37	− 5	0	4	M	91	89	86	19	77	76	75
Norwich	41 3	20	− 7	− 2	2	M	88	86	83	18	77	76	75
Waterbury	41 3	605	− 5	0	4	M	90	88	85	21	77	76	75
Windsor Locks, Bradley Field	42 0	169	− 7	− 2	2	M	90	88	85	22	76	75	73
DELAWARE													
Dover AFB	39 0	38	8	13	15	M	93	90	88	18	79	78	77
Wilmington AP	39 4	78	6	12	15	M	93	90	87	20	79	77	76
DISTRICT OF COLUMBIA													
Andrews AFB	38 5	279	9	13	16	M	94	91	88	18	79	77	76
Washington National AP	38 5	14	12	16	19	M	94	92	90	18	78	77	76
FLORIDA													
Belle Glade	26 4	16	31	35	39	M	93	91	90	16	80	79	79
Cape Kennedy AP	28 1	16	33	37	40	L	90	89	88	15	81	80	79
Daytona Beach AP	29 1	31	28	32	36	L	94	92	91	15	81	80	79
Fort Lauderdale	26 0	13	37	41	45	M	91	90	89	15	81	80	79
Fort Myers AP	26 4	13	34	38	42	M	94	92	91	18	80	80	79
Fort Pierce	27 3	10	33	37	41	M	93	91	90	15	81	80	79
Gainesville AP	29 4	155	24	28	32	L	96	94	93	18	80	79	79
Jacksonville AP	30 3	24	26	29	32	L	96	94	92	19	80	79	79
Key West AP	24 3	6	50	55	58	M	90	89	88	9	80	79	79
Lakeland CO	28 0	214	31	35	39	M	95	93	91	17	80	79	78
Miami AP	25 5	7	39	44	47	M	92	90	89	15	80	79	79
Miami Beach CO	25 5	9	40	45	48	M	91	89	88	10	80	79	79
Ocala	29 1	86	25	29	33	L	96	94	93	18	80	79	79
Orlando AP	28 3	106r	29	33	37	L	96	94	93	17	80	79	78
Panama City, Tyndall AFB	30 0	22	28	32	35	M	92	91	90	14	81	80	80
Pensacola CO	30 3	13	25	29	32	M	92	90	89	14	82	81	80
St. Augustine	29 5	15	27	31	35	L	94	92	90	16	81	80	79
St. Petersburg	28 0	35	35	39	42	M	93	91	90	16	81	80	79
Sanford	28 5	14	29	33	37	L	95	93	92	17	80	79	79
Sarasota	27 2	30	31	35	39	M	93	91	90	17	80	80	79
Tallahassee AP	30 2	58	21	25	29	L	96	94	93	19	80	79	79
Tampa AP	28 0	19	32	36	39	M	92	91	90	17	81	80	79
West Palm Beach AP	26 4	15	36	40	44	M	92	91	89	16	81	80	80
GEORGIA													
Albany, Turner AFB	31 3	224	21	26	30	L	98	96	94	20	80	79	78
Americus	32 0	476	18	22	25	L	98	96	93	20	80	79	78
Athens	34 0	700	12	17	21	L	96	94	91	21	78	77	76
Atlanta AP	33 4	1005	14	18	23	H	95	92	90	19	78	77	76
Augusta AP	33 2	143	17	20	23	L	98	95	93	19	80	79	78
Brunswick	31 1	14	24	27	31	L	97	95	92	18	81	80	79
Columbus, Lawson AFB	32 3	242	19	23	26	L	98	96	94	21	80	79	78
Dalton	34 5	720	10	15	19	L	97	95	92	22	78	77	76
Dublin	32 3	215	17	21	25	L	98	96	93	20	80	79	78
Gainesville	34 2	1254	11	16	20	L	94	92	89	21	78	77	76
Griffin	33 1	980	13	17	22	L	95	93	90	21	79	78	77
La Grange	33 0	715	12	16	20	L	96	94	92	21	79	78	77
Macon AP	32 4	356	18	23	27	L	98	96	94	22	80	79	78
Marietta, Dobbins AFB	34 0	1016	12	17	21	L	95	93	91	21	78	77	76

Col. 1 State and Station[b]	Col. 2 Latitude[c] °	′	Col. 3 Elev,[d] Ft	Winter: Col. 4 Median of Annual Extremes	Col. 4 99%	Col. 4 97½%	Col. 5 Coincident Wind Velocity[e]	Summer: Col. 6 Design Dry-Bulb 1%	Col. 6 2½%	Col. 6 5%	Col. 7 Outdoor Daily Range[f]	Col. 8 Design Wet-Bulb 1%	Col. 8 2½%	Col. 8 5%
GEORGIA (continued)														
Moultrie	31	1	340	22	26	30	L	97	95	93	20	80	79	78
Rome AP	34	2	637	11	16	20	L	97	95	93	23	78	77	76
Savannah-Travis AP	32	1	52	21	24	27	L	96	94	92	20	81	80	79
Valdosta-Moody AFB	31	0	239	24	28	31	L	96	94	92	20	80	79	78
Waycross	31	2	140	20	24	28	L	97	95	93	20	80	79	78
HAWAII														
Hilo AP	19	4	31	56	59	61	L	85	83	82	15	74	73	72
Honolulu AP	21	2	7	58	60	62	L	87	85	84	12	75	74	73
Kaneohe	21	2	198	58	60	61	L	85	83	82	12	74	73	73
Wahiawa	21	3	215	57	59	61	L	86	84	83	14	75	74	73
IDAHO														
Boise AP	43	3	2842	0	4	10	L	96	93	91	31	68	66	65
Burley	42	3	4180	−5	4	8	VL	95	93	89	35	68	66	64
Coeur d'Alene AP	47	5	2973	−4	2	7	VL	94	91	88	31	66	65	63
Idaho Falls AP	43	3	4730r	−17	−12	−6	VL	91	88	85	38	65	64	62
Lewiston AP	46	2	1413	1	6	12	VL	98	96	93	32	67	66	65
Moscow	46	4	2660	−11	−3	1	VL	91	89	86	32	64	63	61
Mountain Home AFB	43	0	2992	−3	2	9	L	99	96	93	36	68	66	64
Pocatello AP	43	0	4444	−12	−8	−2	VL	94	91	88	35	65	63	62
Twin Falls AP	42	3	4148	−5	4	8	L	96	94	91	34	66	64	63
ILLINOIS														
Aurora	41	5	744	−13	−7	−3	M	93	91	88	20	78	77	75
Belleville, Scott AFB	38	3	447	0	6	10	M	97	95	92	21	79	78	77
Bloomington	40	3	775	−7	−1	3	M	94	92	89	21	79	78	77
Carbondale	37	5	380	1	7	11	M	98	96	94	21	80	79	78
Champaign/Urbana	40	0	743	−6	0	4	M	96	94	91	21	79	78	77
Chicago, Midway AP	41	5	610	−7	−4	1	M	95	92	89	20	78	76	75
Chicago, O'Hare AP	42	0	658	−9	−4	0	M	93	90	87	20	77	75	74
Chicago, CO	41	5	594	−5	−3	1	M	94	91	88	15	78	76	75
Danville	40	1	558	−6	−1	4	M	96	94	91	21	79	78	76
Decatur	39	5	670	−6	0	4	M	96	93	91	21	79	78	77
Dixon	41	5	696	−13	−7	−3	M	93	91	89	23	78	77	76
Elgin	42	0	820	−14	−8	−4	M	92	90	87	21	78	76	75
Freeport	42	2	780	−16	−10	−6	M	92	90	87	24	78	77	75
Galesburg	41	0	771	−10	−4	0	M	95	92	89	22	79	78	76
Greenville	39	0	563	−3	3	7	M	96	94	92	21	79	78	77
Joliet AP	41	3	588	−11	−5	−1	M	94	92	89	20	78	77	75
Kankakee	41	1	625	−10	−4	1	M	94	92	89	21	78	77	76
La Salle/Peru	41	2	520	−9	−3	1	M	94	93	90	22	78	77	76
Macomb	40	3	702	−5	−3	1	M	95	93	90	22	79	78	77
Moline AP	41	3	582	−12	−7	−3	M	94	91	88	23	79	77	76
Mt. Vernon	38	2	500	0	6	10	M	97	95	92	21	79	78	77
Peoria AP	40	4	652	−8	−2	2	M	94	92	89	22	78	77	76
Quincy AP	40	0	762	−8	−2	2	M	97	95	92	22	80	79	77
Rantoul, Chanute AFB	40	2	740	−7	−1	3	M	94	92	89	21	78	77	76
Rockford	42	1	724	−13	−7	−3	M	92	90	87	24	77	76	75
Springfield AP	39	5	587	−7	−1	4	M	95	92	90	21	79	78	77
Waukegan	42	2	680	−11	−5	−1	M	92	90	87	21	77	76	75
INDIANA														
Anderson	40	0	847	−5	0	5	M	93	91	88	22	78	77	76
Bedford	38	5	670	−3	3	7	M	95	93	90	22	79	78	77
Bloomington	39	1	820	−3	3	7	M	95	92	90	22	79	78	76
Columbus, Bakalar AFB	39	2	661	−3	3	7	M	95	92	90	22	79	78	76
Crawfordsville	40	0	752	−8	−2	2	M	95	93	90	22	79	77	76
Evansville AP	38	0	381	1	6	10	M	96	94	91	22	79	78	77
Fort Wayne AP	41	0	791	−5	0	5	M	93	91	88	24	77	76	75
Goshen AP	41	3	823	−10	−4	0	M	92	90	87	23	77	76	74
Hobart	41	3	600	−10	−4	0	M	93	91	88	21	78	76	75
Huntington	40	4	802	−8	−2	2	M	94	92	89	23	78	76	75
Indianapolis AP	39	4	793	−5	0	4	M	93	91	88	22	78	77	76
Jeffersonville	38	2	455	3	9	13	M	96	94	91	23	79	78	77
Kokomo	40	3	790	−6	0	4	M	94	92	89	22	78	76	75
Lafayette	40	2	600	−7	−1	3	M	94	92	89	22	78	77	76

Climatic Conditions for United States and Canada (Continued)*,a

Col. 1 State and Station[b]	Col. 2 Latitude[c] ° ′	Col. 3 Elev,[d] Ft	Winter: Col. 4 Median of Annual Extremes	Winter: Col. 4 99%	Winter: Col. 4 97½%	Winter: Col. 5 Coincident Wind Velocity[e]	Summer: Col. 6 Design Dry-Bulb 1%	Col. 6 2½%	Col. 6 5%	Summer: Col. 7 Outdoor Daily Range[f]	Summer: Col. 8 Design Wet-Bulb 1%	Col. 8 2½%	Col. 8 5%
INDIANA (continued)													
La Porte	41 3	810	−10	−4	0	M	93	91	88	22	77	76	74
Marion	40 3	791	−8	−2	2	M	93	91	88	23	78	76	75
Muncie	40 1	955	−8	−2	2	M	93	91	88	22	78	77	75
Peru, Bunker Hill AFB	40 4	804	−9	−3	1	M	91	89	86	22	77	76	74
Richmond AP	39 5	1138	−7	−1	3	M	93	91	88	22	78	77	75
Shelbyville	39 3	765	−4	2	6	M	94	92	89	22	78	77	76
South Bend AP	41 4	773	−6	−2	3	M	92	89	87	22	77	76	74
Terre Haute AP	39 3	601	−3	3	7	M	95	93	91	22	79	78	77
Valparaiso	41 2	801	−12	−6	−2	M	92	90	87	22	78	76	75
Vincennes	38 4	420	−1	5	9	M	96	94	91	22	79	78	77
IOWA													
Ames	42 0	1004	−17	−11	−7	M	94	92	89	23	79	78	76
Burlington AP	40 5	694	−10	−4	0	M	95	92	89	22	80	78	77
Cedar Rapids AP	41 5	863	−14	−8	−4	M	92	90	87	23	78	76	75
Clinton	41 5	595	−13	−7	−3	M	92	90	87	23	78	77	76
Council Bluffs	41 2	1210	−14	−7	−3	M	97	94	91	22	79	78	76
Des Moines AP	41 3	948r	−13	−7	−3	M	95	92	89	23	79	77	76
Dubuque	42 2	1065	−17	−11	−7	M	92	90	87	22	78	76	75
Fort Dodge	42 3	1111	−18	−12	−8	M	94	92	89	23	78	77	75
Iowa City	41 4	645	−14	−8	−4	M	94	91	88	22	79	77	76
Keokuk	40 2	526	−9	−3	1	M	95	93	90	22	79	78	77
Marshalltown	42 0	898	−16	−10	−6	M	93	91	88	23	79	77	76
Mason City AP	43 1	1194	−20	−13	−9	M	91	88	85	24	77	75	74
Newton	41 4	946	−15	−9	−5	M	95	93	90	23	79	77	76
Ottumwa AP	41 1	842	−12	−6	−2	M	95	93	90	22	79	78	76
Sioux City AP	42 2	1095	−17	−10	−6	M	96	93	90	24	79	77	76
Waterloo	42 3	868	−18	−12	−8	M	91	89	86	23	78	76	75
KANSAS													
Atchison	39 3	945	−9	−2	2	M	97	95	92	23	79	78	77
Chanute AP	37 4	977	−3	3	7	H	99	97	95	23	79	78	77
Dodge City AP	37 5	2594	−5	3	7	M	99	97	95	25	74	73	72
El Dorado	37 5	1282	−3	4	8	H	101	99	96	24	78	77	76
Emporia	38 2	1209	−4	3	7	H	99	97	94	25	78	77	76
Garden City AP	38 0	2882	−10	−1	3	M	100	98	96	28	74	73	72
Goodland AP	39 2	3645	−10	−2	4	M	99	96	93	31	71	70	69
Great Bend	38 2	1940	−5	2	6	M	101	99	96	28	77	76	75
Hutchinson AP	38 0	1524	−5	2	6	H	101	99	96	28	77	76	75
Liberal	37 0	2838	−4	4	8	M	102	100	99	28	74	73	71
Manhattan, Fort Riley	39 0	1076	−7	−1	4	H	101	98	95	24	79	78	77
Parsons	37 2	908	−2	5	9	H	99	97	94	23	79	78	77
Russell AP	38 5	1864	−7	0	4	M	102	100	97	29	78	76	75
Salina	38 5	1271	−4	3	7	H	101	99	96	26	78	76	75
Topeka AP	39 0	877	−4	3	6	M	99	96	94	24	79	78	77
Wichita AP	37 4	1321	−1	5	9	H	102	99	96	23	77	76	75
KENTUCKY													
Ashland	38 3	551	1	6	10	L	94	92	89	22	77	76	75
Bowling Green AP	37 0	535	1	7	11	L	97	95	93	21	79	78	77
Corbin AP	37 0	1175	0	5	9	L	93	91	89	23	79	77	76
Covington AP	39 0	869	−3	3	8	L	93	90	88	22	77	76	75
Hopkinsville, Campbell AFB	36 4	540	4	10	14	L	97	95	92	21	79	78	77
Lexington AP	38 0	979	0	6	10	M	94	92	90	22	78	77	76
Louisville AP	38 1	474	1	8	12	L	96	93	91	23	79	78	77
Madisonville	37 2	439	1	7	11	L	96	94	92	22	79	78	77
Owensboro	37 5	420	0	6	10	L	96	94	92	23	79	78	77
Paducah AP	37 0	398	4	10	14	L	97	95	94	20	80	79	78
LOUISIANA													
Alexandria AP	31 2	92	20	25	29	L	97	95	94	20	80	80	79
Baton Rouge AP	30 3	64	22	25	30	L	96	94	92	19	81	80	79
Bogalusa	30 5	103	20	24	28	L	96	94	93	19	80	79	78
Houma	29 3	13	25	29	33	L	94	92	91	15	81	80	79
Lafayette AP	30 1	38	23	28	32	L	95	93	92	18	81	81	80
Lake Charles AP	30 1	14	25	29	33	M	95	93	91	17	80	79	79
Minden	32 4	250	17	22	26	L	98	96	95	20	81	80	79

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LOUISIANA (continued)														
Monroe AP	32	3	78	18	23	27	L	98	96	95	20	81	81	80
Natchitoches	31	5	120	17	22	26	L	99	97	96	20	81	80	79
New Orleans AP	30	0	3	29	32	35	M	93	91	90	16	81	80	79
Shreveport AP	32	3	252	18	22	26	M	99	96	94	20	81	80	79
MAINE														
Augusta AP	44	2	350	−13	−7	−3	M	88	86	83	22	74	73	71
Bangor, Dow AFB	44	5	162	−14	−8	−4	M	88	85	81	22	75	73	71
Caribou AP	46	5	624	−24	−18	−14	L	85	81	78	21	72	70	68
Lewiston	44	0	182	−14	−8	−4	M	88	86	83	22	74	73	71
Millinocket AP	45	4	405	−22	−16	−12	L	87	85	82	22	74	72	70
Portland AP	43	4	61	−14	−5	0	L	88	85	81	22	75	73	71
Waterville	44	3	89	−15	−9	−5	M	88	86	82	22	74	73	71
MARYLAND														
Baltimore AP	39	1	146	8	12	15	M	94	91	89	21	79	78	77
Baltimore CO	39	2	14	12	16	20	M	94	92	89	17	79	78	77
Cumberland	39	4	945	0	5	9	L	94	92	89	22	76	75	74
Frederick AP	39	2	294	2	7	11	M	94	92	89	22	78	77	76
Hagerstown	39	4	660	1	6	10	L	94	92	89	22	77	76	75
Salisbury	38	2	52	10	14	18	M	92	90	87	18	79	78	77
MASSACHUSETTS														
Boston AP	42	2	15	−1	6	10	H	91	88	85	16	76	74	73
Clinton	42	2	398	−8	−2	2	M	87	85	82	17	75	74	72
Fall River	41	4	190	−1	5	9	H	88	86	83	18	75	74	73
Framingham	42	2	170	−7	−1	3	M	91	89	86	17	76	74	73
Gloucester	42	3	10	−4	2	6	H	86	84	81	15	74	73	72
Greenfield	42	3	205	−12	−6	−2	M	89	87	84	23	75	74	73
Lawrence	42	4	57	−9	−3	1	M	90	88	85	22	76	74	72
Lowell	42	3	90	−7	−1	3	M	91	89	86	21	76	74	72
New Bedford	41	4	70	3	9	13	H	86	84	81	19	75	73	72
Pittsfield AP	42	3	1170	−11	−5	−1	M	86	84	81	23	74	72	71
Springfield, Westover AFB	42	1	247	−8	−3	2	M	91	88	85	19	76	74	73
Taunton	41	5	20	−9	−4	0	H	88	86	83	18	76	75	74
Worcester AP	42	2	986	−8	−3	1	M	89	87	84	18	75	73	71
MICHIGAN														
Adrian	41	5	754	−6	0	4	M	93	91	88	23	76	75	74
Alpena AP	45	0	689	−11	−5	−1	M	87	85	82	27	74	73	71
Battle Creek AP	42	2	939	−6	1	5	M	92	89	86	23	76	74	73
Benton Harbor AP	42	1	649	−7	−1	3	M	90	88	85	20	76	74	73
Detroit Met. CAP	42	2	633	0	4	8	M	92	88	85	20	76	75	74
Escanaba	45	4	594	−13	−7	−3	M	82	80	77	17	73	71	69
Flint AP	43	0	766	−7	−1	3	M	89	87	84	25	76	75	74
Grand Rapids AP	42	5	681	−3	2	6	M	91	89	86	24	76	74	73
Holland	42	5	612	−4	2	6	M	90	88	85	22	76	74	73
Jackson AP	42	2	1003	−6	0	4	M	92	89	86	23	76	75	74
Kalamazoo	42	1	930	−5	1	5	M	92	89	86	23	76	75	74
Lansing AP	42	5	852	−4	2	6	M	89	87	84	24	76	75	73
Marquette CO	46	3	677	−14	−8	−4	L	88	86	83	18	73	71	69
Mt. Pleasant	43	4	796	−9	−3	1	M	89	87	84	24	75	74	73
Muskegon AP	43	1	627	−2	4	8	M	87	85	82	21	75	74	73
Pontiac	42	4	974	−6	0	4	M	90	88	85	21	76	75	73
Port Huron	43	0	586	−6	−1	3	M	90	88	85	21	76	74	73
Saginaw AP	43	3	662	−7	−1	3	M	88	86	83	23	76	75	73
Sault Ste. Marie AP	46	3	721	−18	−12	−8	L	83	81	78	23	73	71	69
Traverse City AP	44	4	618	−6	0	4	M	89	86	83	22	75	73	72
Ypsilanti	42	1	777	−3	−1	5	M	92	89	86	22	76	74	73
MINNESOTA														
Albert Lea	43	4	1235	−20	−14	−10	M	91	89	86	24	77	76	74
Alexandria AP	45	5	1421	−26	−19	−15	L	90	88	85	24	76	74	72
Bemidji AP	47	3	1392	−38	−32	−28	L	87	84	81	24	73	72	71
Brainerd	46	2	1214	−31	−24	−20	L	88	85	82	24	74	73	72
Duluth AP	46	5	1426	−25	−19	−15	M	85	82	79	22	73	71	69
Faribault	44	2	1190	−23	−16	−12	L	90	88	85	24	77	75	74
Fergus Falls	46	1	1210	−28	−21	−17	L	92	89	86	24	75	74	72
International Falls AP	48	3	1179	−35	−29	−24	L	86	82	79	26	72	69	68

Col. 1 State and Station[b]	Col. 2 Latitude[c] °	′	Col. 3 Elev,[d] Ft	Winter: Col. 4 Median of Annual Extremes	99%	97½%	Col. 5 Coincident Wind Velocity[e]	Summer: Col. 6 Design Dry-Bulb 1%	2½%	5%	Col. 7 Outdoor Daily Range[f]	Col. 8 Design Wet-Bulb 1%	2½%	5%
MINNESOTA (continued)														
Mankato	44	1	785	−23	−16	−12	L	91	89	86	24	77	75	74
Minneapolis/St. Paul AP	44	5	822	−19	−14	−10	L	92	89	86	22	77	75	74
Rochester AP	44	0	1297	−23	−17	−13	M	90	88	85	24	77	75	74
St. Cloud AP	45	4	1034	−26	−20	−16	L	90	88	85	24	77	75	73
Virginia	47	3	1435	−32	−25	−21	L	86	83	80	23	73	71	69
Willmar	45	1	1133	−25	−18	−14	L	91	88	85	24	77	75	73
Winona	44	1	652	−19	−12	− 8	M	91	89	86	24	77	76	74
MISSISSIPPI														
Biloxi, Keesler AFB	30	2	25	26	30	32	M	93	92	90	16	82	81	80
Clarksdale	34	1	178	14	20	24	L	98	96	95	21	81	80	79
Columbus AFB	33	4	224	13	18	22	L	97	95	93	22	79	79	78
Greenville AFB	33	3	139	16	21	24	L	98	96	94	21	81	80	79
Greenwood	33	3	128	14	19	23	L	98	96	94	21	81	80	79
Hattiesburg	31	2	200	18	22	26	L	97	95	94	21	80	79	78
Jackson AP	32	2	330	17	21	24	L	98	96	94	21	79	78	78
Laurel	31	4	264	18	22	26	L	97	95	94	21	80	79	78
McComb AP	31	2	458	18	22	26	L	96	94	93	18	80	79	79
Meridian AP	32	2	294	15	20	24	L	97	95	94	22	80	79	78
Natchez	31	4	168	18	22	26	L	96	94	93	21	80	80	79
Tupelo	34	2	289	13	18	22	L	98	96	95	22	80	79	78
Vicksburg CO	32	2	234	18	23	26	L	97	95	94	21	80	80	79
MISSOURI														
Cape Girardeau	37	1	330	2	8	12	M	98	96	94	21	80	79	78
Columbia AP	39	0	778	− 4	2	6	M	97	95	92	22	79	78	77
Farmington AP	37	5	928	− 2	4	8	M	97	95	93	22	79	78	77
Hannibal	39	4	489	− 7	− 1	4	M	96	94	91	22	79	78	77
Jefferson City	38	4	640	− 4	2	6	M	97	95	93	23	79	78	77
Joplin AP	37	1	982	1	7	11	M	97	95	93	24	79	78	77
Kansas City AP	39	1	742	− 2	4	8	M	100	97	94	20	79	77	76
Kirksville AP	40	1	966	−13	− 7	− 3	M	96	94	91	24	79	78	77
Mexico	39	1	775	− 7	− 1	3	M	96	94	91	22	79	78	77
Moberly	39	3	850	− 8	− 2	2	M	96	94	91	23	79	78	77
Poplar Bluff	36	5	322	3	9	13	M	98	96	94	22	80	79	78
Rolla	38	0	1202	− 3	3	7	M	97	95	93	22	79	78	77
St. Joseph AP	39	5	809	− 8	− 1	3	M	97	95	92	23	79	78	77
St. Louis AP	38	5	535	− 2	4	8	M	98	95	92	21	79	78	77
St. Louis CO	38	4	465	1	7	11	M	96	94	92	18	79	78	77
Sedalia, Whiteman AFB	38	4	838	− 2	4	9	M	97	94	92	22	79	77	76
Sikeston	36	5	318	4	10	14	L	98	96	94	21	80	79	78
Springfield AP	37	1	1265	0	5	10	M	97	94	91	23	78	77	76
MONTANA														
Billings AP	45	5	3567	−19	−10	− 6	L	94	91	88	31	68	66	65
Bozeman	45	5	4856	−25	−15	−11	L	88	85	82	32	61	60	59
Butte AP	46	0	5526r	−34	−24	−16	VL	86	83	80	35	60	59	57
Cut Bank AP	48	4	3838r	−32	−23	−17	L	89	86	82	35	65	63	61
Glasgow AP	48	1	2277	−33	−25	−20	L	96	93	89	29	69	67	65
Glendive	47	1	2076	−28	−20	−16	L	96	93	90	29	71	69	68
Great Falls AP	47	3	3664r	−29	−20	−16	L	91	88	85	28	64	63	61
Havre	48	3	2488	−32	−22	−15	M	91	87	84	33	66	64	63
Helena AP	46	4	3893	−27	−17	−13	L	90	87	84	32	65	63	61
Kalispell AP	48	2	2965	−17	− 7	− 3	VL	88	84	81	34	65	63	62
Lewiston AP	47	0	4132	−27	−18	−14	L	89	86	83	30	65	63	62
Livingston AP	45	4	4653	−26	−17	−13	L	91	88	85	32	63	62	61
Miles City AP	46	3	2629	−27	−19	−15	L	97	94	91	30	71	69	68
Missoula AP	46	5	3200	−16	− 7	− 3	VL	92	89	86	36	65	63	61
NEBRASKA														
Beatrice	40	2	1235	−10	− 3	1	M	99	97	94	24	78	77	76
Chadron AP	42	5	3300	−21	−13	− 9	M	97	95	92	30	72	70	69
Columbus	41	3	1442	−14	− 7	− 3	M	98	96	93	25	78	76	75
Fremont	41	3	1203	−14	− 7	− 3	M	99	97	94	22	78	77	76
Grand Island AP	41	0	1841	−14	− 6	− 2	M	98	95	92	28	76	75	74
Hastings	40	4	1932	−11	− 3	1	M	98	96	94	27	77	75	74
Kearney	40	4	2146	−14	− 6	− 2	M	97	95	92	28	76	75	74
Lincoln CO	40	5	1150	−10	− 4	0	M	100	96	93	24	78	77	76

Col. 1 State and Station[b]	Col. 2 Latitude[c] °	Col. 2 Latitude[c] ′	Col. 3 Elev,[d] Ft	Winter Col. 4 Median of Annual Extremes	Winter Col. 4 99%	Winter Col. 4 97½%	Winter Col. 5 Coincident Wind Velocity[e]	Summer Col. 6 Design Dry-Bulb 1%	Summer Col. 6 Design Dry-Bulb 2½%	Summer Col. 6 Design Dry-Bulb 5%	Summer Col. 7 Outdoor Daily Range[f]	Summer Col. 8 Design Wet-Bulb 1%	Summer Col. 8 Design Wet-Bulb 2½%	Summer Col. 8 Design Wet-Bulb 5%
NEBRASKA (*continued*)														
McCook	40	1	2565	−12	−4	0	M	99	97	94	28	74	72	71
Norfolk	42	0	1532	−18	−11	−7	M	97	95	92	30	78	76	75
North Platte AP	41	1	2779	−13	−6	−2	M	97	94	90	28	74	73	72
Omaha AP	41	2	978	−12	−5	−1	M	97	94	91	22	79	78	76
Scottsbluff AP	41	5	3950	−16	−8	−4	M	96	94	91	31	70	69	67
Sidney AP	41	1	4292	−15	−7	−2	M	95	92	89	31	70	69	67
NEVADA†														
Carson City	39	1	4675	−4	3	7	VL	93	91	88	42	62	61	60
Elko AP	40	5	5075	−21	−13	−7	VL	94	92	90	42	64	62	61
Ely AP	39	1	6257	−15	−6	−2	VL	90	88	86	39	60	59	58
Las Vegas AP	36	1	2162	18	23	26	VL	108	106	104	30	72	71	70
Lovelock AP	40	0	3900	0	7	11	VL	98	96	93	42	65	64	62
Reno AP	39	3	4404	−2	2	7	VL	95	92	90	45	64	62	61
Reno CO	39	3	4490	8	12	17	VL	94	92	89	45	64	62	61
Tonopah AP	38	0	5426	2	9	13	VL	95	92	90	40	64	63	62
Winnemucca AP	40	5	4299	−8	1	5	VL	97	95	93	42	64	62	61
NEW HAMPSHIRE														
Berlin	44	3	1110	−25	−19	−15	L	87	85	82	22	73	71	70
Claremont	43	2	420	−19	−13	−9	L	89	87	84	24	74	73	72
Concord AP	43	1	339	−17	−11	−7	M	91	88	85	26	75	73	72
Keene	43	0	490	−17	−12	−8	M	90	88	85	24	75	73	72
Laconia	43	3	505	−22	−16	−12	M	89	87	84	25	74	73	72
Manchester, Grenier AFB	43	0	253	−11	−5	1	M	92	89	86	24	76	74	73
Portsmouth, Pease AFB	43	1	127	−8	−2	3	M	88	86	83	22	75	73	72
NEW JERSEY														
Atlantic City CO	39	3	11	10	14	18	H	91	88	85	18	78	77	76
Long Branch	40	2	20	4	9	13	H	93	91	88	18	77	76	75
Newark AP	40	4	11	6	11	15	M	94	91	88	20	77	76	75
New Brunswick	40	3	86	3	8	12	M	91	89	86	19	77	76	75
Paterson	40	5	100	3	8	12	M	93	91	88	21	77	76	75
Phillipsburg	40	4	180	1	6	10	L	93	91	88	21	77	76	75
Trenton CO	40	1	144	7	12	16	M	92	90	87	19	78	77	76
Vineland	39	3	95	7	12	16	M	93	90	87	19	78	77	76
NEW MEXICO														
Alamagordo, Holloman AFB	32	5	4070	12	18	22	L	100	98	96	30	70	69	68
Albuquerque AP	35	0	5310	6	14	17	L	96	94	92	27	66	65	64
Artesia	32	5	3375	9	16	19	L	101	99	97	30	71	70	69
Carlsbad AP	32	2	3234	11	17	21	L	101	99	97	28	72	71	70
Clovis AP	34	3	4279	2	14	17	L	99	97	95	28	70	69	68
Farmington AP	36	5	5495	−3	6	9	VL	95	93	91	30	66	65	64
Gallup	35	3	6465	−13	−5	−1	VL	92	90	87	32	64	63	62
Grants	35	1	6520	−15	−7	−3	VL	91	89	86	32	64	63	62
Hobbs AP	32	4	3664	9	15	19	L	101	99	96	29	72	71	70
Las Cruces	32	2	3900	13	19	23	L	102	100	97	30	70	69	68
Los Alamos	35	5	7410	−4	5	9	L	88	86	83	32	64	63	62
Raton AP	36	5	6379	−11	−2	2	L	92	90	88	34	66	65	64
Roswell, Walker AFB	33	2	3643	5	16	19	L	101	99	97	33	71	70	69
Santa Fe CO	35	4	7045	−2	7	11	L	90	88	85	28	65	63	62
Silver City AP	32	4	5373	8	14	18	VL	95	93	91	30	68	67	66
Socorro AP	34	0	4617	6	13	17	L	99	97	94	30	67	66	65
Tucumcari AP	35	1	4053	1	9	13	L	99	97	95	28	71	70	69
NEW YORK														
Albany AP	42	5	277	−14	−5	0	L	91	88	85	23	76	74	73
Albany CO	42	5	19	−5	1	5	L	91	89	86	20	76	74	73
Auburn	43	0	715	−10	−2	2	M	89	87	84	22	75	73	72
Batavia	43	0	900	−7	−1	3	M	89	87	84	22	75	74	72
Binghamton CO	42	1	858	−8	−2	2	L	91	89	86	20	74	72	71
Buffalo AP	43	0	705r	−3	3	6	M	88	86	83	21	75	73	72
Cortland	42	4	1129	−11	−5	−1	L	90	88	85	23	75	73	72
Dunkirk	42	3	590	−2	4	8	M	88	86	83	18	75	74	72
Elmira AP	42	1	860	−5	1	5	L	92	90	87	24	75	73	72
Geneva	42	5	590	−8	−2	2	M	91	89	86	22	75	73	72
Glens Falls	43	2	321	−17	−11	−7	L	88	86	83	23	74	72	71
Gloversville	43	1	770	−12	−6	−2	L	89	87	84	23	75	73	71
Hornell	42	2	1325	−15	−9	−5	L	87	85	82	24	74	72	71

Climatic Conditions for United States and Canada (Continued)*,[a]

Col. 1 State and Station[b]	Col. 2 Latitude[c] °	′	Col. 3 Elev,[d] Ft	Winter: Col. 4 Median of Annual Extremes	Col. 4 99%	Col. 4 97½%	Col. 5 Coincident Wind Velocity[e]	Summer: Col. 6 Design Dry-Bulb 1%	Col. 6 2½%	Col. 6 5%	Col. 7 Outdoor Daily Range[f]	Col. 8 Design Wet-Bulb 1%	Col. 8 2½%	Col. 8 5%
NEW YORK (continued)														
Ithaca	42	3	950	−10	−4	0	L	91	88	85	24	75	73	72
Jamestown	42	1	1390	−5	1	5	M	88	86	83	20	75	73	72
Kingston	42	0	279	−8	−2	2	L	92	90	87	22	76	74	73
Lockport	43	1	520	−4	2	6	M	87	85	82	21	75	74	72
Massena AP	45	0	202r	−22	−16	−12	M	86	84	81	20	75	74	72
Newburgh-Stewart AFB	41	3	460	−4	2	6	M	92	89	86	21	78	76	74
NYC-Central Park	40	5	132	6	11	15	H	94	91	88	17	77	76	75
NYC-Kennedy AP	40	4	16	12	17	21	H	91	87	84	16	77	76	75
NYC-LaGuardia AP	40	5	19	7	12	16	H	93	90	87	16	77	76	75
Niagara Falls AP	43	1	596	−2	4	7	M	88	86	83	20	75	74	73
Olean	42	1	1420	−13	−8	−3	L	87	85	82	23	74	72	71
Oneonta	42	3	1150	−13	−7	−3	L	89	87	84	24	74	72	71
Oswego CO	43	3	300	−4	2	6	M	86	84	81	20	75	74	72
Plattsburg AFB	44	4	165	−16	−10	−6	L	86	84	81	22	74	73	71
Poughkeepsie	41	4	103	−6	−1	3	L	93	90	87	21	77	75	74
Rochester AP	43	1	543	−5	2	5	M	91	88	85	22	75	74	72
Rome-Griffiss AFB	43	1	515	−13	−7	−3	L	90	87	84	22	76	74	73
Schenectady	42	5	217	−11	−5	−1	L	90	88	85	22	75	73	72
Suffolk County AFB	40	5	57	4	9	13	H	87	84	81	16	76	75	74
Syracuse AP	43	1	424	−10	−2	2	M	90	87	85	20	76	74	73
Utica	43	1	714	−12	−6	−2	L	89	87	84	22	75	73	72
Watertown	44	0	497	−20	−14	−10	M	86	84	81	20	75	74	72
NORTH CAROLINA														
Asheville AP	35	3	2170r	8	13	17	L	91	88	86	21	75	74	73
Charlotte AP	35	1	735	13	18	22	L	96	94	92	20	78	77	76
Durham	36	0	406	11	15	19	L	94	92	89	20	78	77	76
Elizabeth City AP	36	2	10	14	18	22	M	93	91	89	18	80	79	78
Fayetteville, Pope AFB	35	1	95	13	17	20	L	97	94	92	20	80	79	78
Goldsboro, Seymour-Johnson AFB	35	2	88	14	18	21	M	95	92	90	18	80	79	78
Greensboro AP	36	1	897	9	14	17	L	94	91	89	21	77	76	75
Greenville	35	4	25	14	18	22	M	95	93	90	19	81	80	79
Henderson	36	2	510	8	12	16	L	94	92	89	20	79	78	77
Hickory	35	4	1165	9	14	18	L	93	91	88	21	77	76	75
Jacksonville	34	5	24	17	21	25	M	94	92	89	18	81	80	79
Lumberton	34	4	132	14	18	22	L	95	93	90	20	81	80	79
New Bern AP	35	1	17	14	18	22	L	94	92	89	18	81	80	79
Raleigh/Durham AP	35	5	433	13	16	20	L	95	92	90	20	79	78	77
Rocky Mount	36	0	81	12	16	20	L	95	93	90	19	80	79	78
Wilmington AP	34	2	30	19	23	27	L	93	91	89	18	82	81	80
Winston-Salem AP	36	1	967	9	14	17	L	94	91	89	20	77	76	75
NORTH DAKOTA														
Bismarck AP	46	5	1647	−31	−24	−19	VL	95	91	88	27	74	72	70
Devil's Lake	48	1	1471	−30	−23	−19	M	93	89	86	25	73	71	69
Dickinson AP	46	5	2595	−31	−23	−19	L	96	93	90	25	72	70	68
Fargo AP	46	5	900	−28	−22	−17	L	92	88	85	25	76	74	72
Grand Forks AP	48	0	832	−30	−26	−23	L	91	87	84	25	74	72	70
Jamestown AP	47	0	1492	−29	−22	−18	L	95	91	88	26	75	73	71
Minot AP	48	2	1713	−31	−24	−20	M	91	88	84	25	72	70	68
Williston	48	1	1877	−28	−21	−17	M	94	90	87	25	71	69	67
OHIO														
Akron/Canton AP	41	0	1210	−5	1	6	M	89	87	84	21	75	73	72
Ashtabula	42	0	690	−3	3	7	M	89	87	84	18	76	75	74
Athens	39	2	700	−3	3	7	M	93	91	88	22	77	76	75
Bowling Green	41	3	675	−7	−1	3	M	93	91	88	23	77	75	74
Cambridge	40	0	800	−6	0	4	M	91	89	86	23	77	76	75
Chillicothe	39	2	638	−1	5	9	M	93	91	88	22	77	76	75
Cincinnati CO	39	1	761	2	8	12	L	94	92	90	21	78	77	76
Cleveland AP	41	2	777r	−2	2	7	M	91	89	86	22	76	75	74
Columbus AP	40	0	812	−1	2	7	M	92	88	86	24	77	76	75
Dayton AP	39	5	997	−2	0	6	M	92	90	87	20	77	75	74
Defiance	41	2	700	−7	−1	1	M	93	91	88	24	77	76	74
Findlay AP	41	0	797	−6	0	4	M	92	90	88	24	77	76	75

Col. 1 State and Station[b]	Col. 2 Latitude[c] °	′	Col. 3 Elev,[d] Ft	Winter Col. 4 Median of Annual Extremes	99%	97½%	Col. 5 Coincident Wind Velocity[e]	Summer Col. 6 Design Dry-Bulb 1%	2½%	5%	Col. 7 Outdoor Daily Range[f]	Col. 8 Design Wet-Bulb 1%	2½%	5%
OHIO (continued)														
Fremont	41	2	600	−7	−1	3	M	92	90	87	24	76	75	74
Hamilton	39	2	650	−2	4	8	M	94	92	90	22	78	77	76
Lancaster	39	4	920	−5	1	5	M	93	91	88	23	77	76	75
Lima	40	4	860	−6	0	4	M	93	91	88	24	77	76	75
Mansfield AP	40	5	1297	−7	1	3	M	91	89	86	22	76	75	74
Marion	40	4	920	−5	1	6	M	93	91	88	23	77	76	75
Middletown	39	3	635	−3	3	7	M	93	91	88	22	77	76	75
Newark	40	1	825	−7	−1	3	M	92	90	87	23	77	76	75
Norwalk	41	1	720	−7	−1	3	M	92	90	87	22	76	75	74
Portsmouth	38	5	530	0	5	9	L	94	92	89	22	77	76	75
Sandusky CO	41	3	606	−2	4	8	M	92	90	87	21	76	75	74
Springfield	40	0	1020	−3	3	7	M	93	90	88	21	77	76	75
Steubenville	40	2	992	−2	4	9	M	91	89	86	22	76	75	74
Toledo AP	41	4	676r	−5	1	5	M	92	90	87	25	77	75	74
Warren	41	2	900	−6	0	4	M	90	88	85	23	75	74	73
Wooster	40	5	1030	−7	−1	3	M	90	88	85	22	76	75	74
Youngstown AP	41	2	1178	−5	1	6	M	89	86	84	23	75	74	73
Zanesville AP	40	0	881	−7	−1	3	M	92	89	87	23	77	76	75
OKLAHOMA														
Ada	34	5	1015	6	12	16	H	102	100	98	23	79	78	77
Altus AFB	34	4	1390	7	14	18	H	103	101	99	25	77	76	75
Ardmore	34	2	880	9	15	19	H	103	101	99	23	79	78	77
Bartlesville	36	5	715	−1	5	9	H	101	99	97	23	79	78	77
Chickasha	35	0	1085	5	12	16	H	103	101	99	24	77	76	75
Enid-Vance AFB	36	2	1287	3	10	14	H	103	100	98	24	78	77	76
Lawton AP	34	3	1108	6	13	16	H	103	101	98	24	78	77	76
McAlester	34	5	760	7	13	17	H	102	100	98	23	79	78	77
Muskogee AP	35	4	610	6	12	16	M	102	99	96	23	79	78	77
Norman	35	1	1109	5	11	15	H	101	99	97	24	78	77	76
Oklahoma City AP	35	2	1280	4	11	15	H	100	97	95	23	78	77	76
Ponca City	36	4	996	1	8	12	H	102	100	97	24	78	77	76
Seminole	35	2	865	6	12	16	H	102	100	98	23	78	77	76
Stillwater	36	1	884	2	9	13	H	101	99	97	24	78	77	76
Tulsa AP	36	1	650	4	12	16	H	102	99	96	22	79	78	77
Woodward	36	3	1900	−3	4	8	H	103	101	98	26	76	74	73
OREGON														
Albany	44	4	224	17	23	27	VL	91	88	84	31	69	67	65
Astoria AP	46	1	8	22	27	30	M	79	76	72	16	61	60	59
Baker AP	44	5	3368	−10	−3	1	VL	94	92	89	30	66	65	63
Bend	44	0	3599	−7	0	4	VL	89	87	84	33	64	62	61
Corvallis	44	3	221	17	23	27	VL	91	88	84	31	69	67	65
Eugene AP	44	1	364	16	22	26	VL	91	88	84	31	69	67	65
Grants Pass	42	3	925	16	22	26	VL	94	92	89	33	68	66	65
Klamath Falls AP	42	1	4091	−5	1	5	VL	89	87	84	36	63	62	61
Medford AP	42	2	1298	15	21	23	VL	98	94	91	35	70	68	66
Pendleton AP	45	4	1492	−2	3	10	VL	97	94	91	29	66	65	63
Portland AP	45	4	21	17	21	24	L	89	85	81	23	69	67	66
Portland CO	45	3	57	21	26	29	L	91	88	84	21	69	68	67
Roseburg AP	43	1	505	19	25	29	VL	93	91	88	30	69	67	65
Salem AP	45	0	195	15	21	25	VL	92	88	84	31	69	67	66
The Dalles	45	4	102	7	13	17	VL	93	91	88	28	70	68	67
PENNSYLVANIA														
Allentown AP	40	4	376	−2	3	5	M	92	90	87	22	77	75	74
Altoona CO	40	2	1468	−4	1	5	L	89	87	84	23	74	73	72
Butler	40	4	1100	−8	−2	2	L	91	89	86	22	75	74	73
Chambersburg	40	0	640	0	5	9	L	94	92	89	23	76	75	74
Erie AP	42	1	732	1	7	11	M	88	85	82	18	76	74	73
Harrisburg AP	40	1	335	4	9	13	L	92	89	86	21	76	75	74
Johnstown	40	2	1214	−4	1	5	L	91	87	85	23	74	73	72
Lancaster	40	1	255	−3	2	6	L	92	90	87	22	77	76	75
Meadville	41	4	1065	−6	0	4	M	88	86	83	21	75	73	72
New Castle	41	0	825	−7	−1	4	M	91	89	86	23	75	74	73

Climatic Conditions for United States and Canada (Continued)*,[a]

Col. 1 State and Station[b]	Col. 2 Latitude[c] ° ′	Col. 3 Elev,[d] Ft	Winter: Col. 4 Median of Annual Extremes	Col. 4 99%	Col. 4 97½%	Col. 5 Coincident Wind Velocity[e]	Summer: Col. 6 Design Dry-Bulb 1%	Col. 6 2½%	Col. 6 5%	Col. 7 Outdoor Daily Range[f]	Col. 8 Design Wet-Bulb 1%	Col. 8 2½%	Col. 8 5%
PENNSYLVANIA (continued)													
Philadelphia AP	39 5	7	7	11	15	M	93	90	87	21	78	77	76
Pittsburgh AP	40 3	1137	−1	5	9	M	90	87	85	22	75	74	73
Pittsburgh CO	40 3	749r	1	7	11	M	90	88	85	19	75	74	73
Reading CO	40 2	226	1	6	9	M	92	90	87	19	77	76	75
Scranton/Wilkes-Barre	41 2	940	−3	2	6	L	89	87	84	19	75	74	73
State College	40 5	1175	−3	2	6	L	89	87	84	23	74	73	72
Sunbury	40 5	480	−2	3	7	L	91	89	86	22	76	75	74
Uniontown	39 5	1040	−1	4	8	L	90	88	85	22	75	74	73
Warren	41 5	1280	−8	−3	1	L	89	87	84	24	75	73	72
West Chester	40 0	440	4	9	13	M	92	90	87	20	77	76	75
Williamsport AP	41 1	527	−5	1	5	L	91	89	86	23	76	75	74
York	40 0	390	−1	4	8	L	93	91	88	22	77	76	75
RHODE ISLAND													
Newport	41 3	20	1	5	11	H	86	84	81	16	75	74	73
Providence AP	41 4	55	0	6	10	M	89	86	83	19	76	75	74
SOUTH CAROLINA													
Anderson	34 3	764	13	18	22	L	96	94	91	21	77	76	75
Charleston AFB	32 5	41	19	23	27	L	94	92	90	18	81	80	79
Charleston CO	32 5	9	23	26	30	L	95	93	90	13	81	80	79
Columbia AP	34 0	217	16	20	23	L	98	96	94	22	79	79	78
Florence AP	34 1	146	16	21	25	L	96	94	92	21	80	79	78
Georgetown	33 2	14	19	23	26	L	93	91	88	18	81	80	79
Greenville AP	34 5	957	14	19	23	L	95	93	91	21	77	76	75
Greenwood	34 1	671	15	19	23	L	97	95	92	21	78	77	76
Orangeburg	33 3	244	17	21	25	L	97	95	92	20	80	79	78
Rock Hill	35 0	470	13	17	21	L	97	95	92	20	78	77	76
Spartanburg AP	35 0	816	13	18	22	L	95	93	90	20	77	76	75
Sumter-Shaw AFB	34 0	291	18	23	26	L	96	94	92	21	80	79	78
SOUTH DAKOTA													
Aberdeen AP	45 3	1296	−29	−22	−18	L	95	92	89	27	77	75	74
Brookings	44 2	1642	−26	−19	−15	M	93	90	87	25	77	75	74
Huron AP	44 3	1282	−24	−16	−12	L	97	93	90	28	77	75	74
Mitchell	43 5	1346	−22	−15	−11	M	96	94	91	28	77	76	74
Pierre AP	44 2	1718r	−21	−13	−9	M	98	96	93	29	76	74	73
Rapid City AP	44 0	3165	−17	−9	−6	M	96	94	91	28	72	71	69
Sioux Falls AP	43 4	1420	−21	−14	−10	M	95	92	89	24	77	75	74
Watertown AP	45 0	1746	−27	−20	−16	L	93	90	87	26	76	74	73
Yankton	43 0	1280	−18	−11	−7	M	96	94	91	25	78	76	75
TENNESSEE													
Athens	33 3	940	10	14	18	L	96	94	91	22	77	76	75
Bristol-Tri City AP	36 3	1519	−1	11	16	L	92	90	88	22	76	75	74
Chattanooga AP	35 0	670	11	15	19	L	97	94	92	22	78	78	77
Clarksville	36 4	470	6	12	16	L	98	96	94	21	79	78	77
Columbia	35 4	690	8	13	17	L	97	95	93	21	79	78	77
Dyersburg	36 0	334	7	13	17	L	98	96	94	21	80	79	78
Greenville	35 5	1320	5	10	14	L	93	91	88	22	76	75	74
Jackson AP	35 4	413	8	14	17	L	97	95	94	21	80	79	78
Knoxville AP	35 5	980	9	13	17	L	95	92	90	21	77	76	75
Memphis AP	35 0	263	11	17	21	L	98	96	94	21	80	79	78
Murfreesboro	35 5	608	7	13	17	L	97	94	92	22	79	78	77
Nashville AP	36 1	577	6	12	16	L	97	95	92	21	79	78	77
Tullahoma	35 2	1075	7	13	17	L	96	94	92	22	79	78	77
TEXAS													
Abilene AP	32 3	1759	12	17	21	M	101	99	97	22	76	75	74
Alice AP	27 4	180	26	30	34	M	101	99	97	20	81	80	79
Amarillo AP	35 1	3607	2	8	12	M	98	96	93	26	72	71	70
Austin AP	30 2	597	19	25	29	M	101	98	96	22	79	78	77
Bay City	29 0	52	25	29	33	M	95	93	91	16	81	80	79
Beaumont	30 0	18	25	29	33	M	96	94	93	19	81	80	79
Beeville	28 2	225	24	28	32	M	99	97	96	18	81	80	79
Big Spring AP	32 2	2537	12	18	22	M	100	98	96	26	75	73	72
Brownsville AP	25 5	16	32	36	40	M	94	92	91	18	80	80	79
Brownwood	31 5	1435	15	20	25	M	102	100	98	22	76	75	74
Bryan AP	30 4	275	22	27	31	M	100	98	96	20	79	78	78

Col. 1 State and Station[b]	Col. 2 Latitude[c] °	′	Col. 3 Elev,[d] Ft	Winter: Col. 4 Median of Annual Extremes	Col. 4 99%	Col. 4 97½%	Col. 5 Coincident Wind Velocity[e]	Summer: Col. 6 Design Dry-Bulb 1%	2½%	5%	Col. 7 Outdoor Daily Range[f]	Col. 8 Design Wet-Bulb 1%	2½%	5%
TEXAS (continued)														
Corpus Christi AP	27	5	43	28	32	36	M	95	93	91	19	81	80	80
Corsicana	32	0	425	16	21	25	M	102	100	98	21	79	78	77
Dallas AP	32	5	481	14	19	24	H	101	99	97	20	79	78	78
Del Rio, Laughlin AFB	29	2	1072	24	28	31	M	101	99	98	24	79	77	76
Denton	33	1	655	12	18	22	H	102	100	98	22	79	78	77
Eagle Pass	28	5	743	23	27	31	L	106	104	102	24	80	79	78
El Paso AP	31	5	3918	16	21	25	L	100	98	96	27	70	69	68
Fort Worth AP	32	5	544r	14	20	24	H	102	100	98	22	79	78	77
Galveston AP	29	2	5	28	32	36	M	91	89	88	10	82	81	81
Greenville	33	0	575	13	19	24	H	101	99	97	21	79	78	78
Harlingen	26	1	37	30	34	38	M	96	95	94	19	80	80	79
Houston AP	29	4	50	23	28	32	M	96	94	92	18	80	80	79
Houston CO	29	5	158r	24	29	33	M	96	94	92	18	80	80	79
Huntsville	30	4	494	22	27	31	M	99	97	96	20	80	79	78
Killeen-Gray AFB	31	0	1021	17	22	26	M	100	99	97	22	78	77	76
Lamesa	32	5	2965	7	14	18	M	100	98	96	26	74	73	72
Laredo AFB	27	3	503	29	32	36	L	103	101	100	23	79	78	78
Longview	32	2	345	16	21	25	M	100	98	96	20	81	80	79
Lubbock AP	33	4	3243	4	11	15	M	99	97	94	26	73	72	71
Lufkin AP	31	1	286	19	24	28	M	98	96	95	20	81	80	79
McAllen	26	1	122	30	34	38	M	102	100	98	21	80	79	78
Midland AP	32	0	2815r	13	19	23	M	100	98	96	26	74	73	72
Mineral Wells AP	32	5	934	12	18	22	H	102	100	98	22	78	77	76
Palestine CO	31	5	580	16	21	25	M	99	97	96	20	80	79	78
Pampa	35	3	3230	0	7	11	M	100	98	95	26	73	72	71
Pecos	31	2	2580	10	15	19	L	102	100	97	27	72	71	70
Plainview	34	1	3400	3	10	14	M	100	98	95	26	73	72	71
Port Arthur AP	30	0	16	25	29	33	M	94	92	91	19	81	80	80
San Angelo, Goodfellow AFB	31	2	1878	15	20	25	M	101	99	97	24	76	75	74
San Antonio AP	29	3	792	22	25	30	L	99	97	96	19	77	77	76
Sherman-Perrin AFB	33	4	763	12	18	23	H	101	99	97	22	79	78	77
Snyder	32	4	2325	9	15	19	M	102	100	97	26	75	74	73
Temple	31	1	675	18	23	27	M	101	99	97	22	79	78	77
Tyler AP	32	2	527	15	20	24	M	99	97	96	21	80	79	78
Vernon	34	1	1225	7	14	18	H	103	101	99	24	77	76	75
Victoria AP	28	5	104	24	28	32	M	98	96	95	18	80	79	79
Waco AP	31	4	500	16	21	26	M	101	99	98	22	79	78	78
Wichita Falls AP	34	0	994	9	15	19	H	103	100	98	24	77	76	75
UTAH														
Cedar City AP	37	4	5613	−10	−1	6	VL	94	91	89	32	65	64	62
Logan	41	4	4775	−7	3	7	VL	93	91	89	33	66	65	63
Moab	38	5	3965	2	12	16	VL	100	98	95	30	66	65	64
Ogden CO	41	1	4400	−3	7	11	VL	94	92	89	33	66	65	64
Price	39	4	5580	−7	3	7	L	93	91	88	33	65	64	63
Provo	40	1	4470	−6	2	6	L	96	93	91	32	67	66	65
Richfield	38	5	5300	−10	−1	3	L	94	92	89	34	66	65	64
St. George CO	37	1	2899	13	22	26	VL	104	102	99	33	71	70	69
Salt Lake City AP	40	5	4220	−2	5	9	L	97	94	92	32	67	66	65
Vernal AP	40	3	5280	−20	−10	−6	VL	90	88	84	32	64	63	62
VERMONT														
Barre	44	1	1120	−23	−17	−13	L	86	84	81	23	73	72	70
Burlington AP	44	3	331	−18	−12	−7	M	88	85	83	23	74	73	71
Rutland	43	3	620	−18	−12	−8	L	87	85	82	23	74	73	71
VIRGINIA														
Charlottsville	38	1	870	7	11	15	L	93	90	88	23	79	77	76
Danville AP	36	3	590	9	13	17	L	95	92	90	21	78	77	76
Fredericksburg	38	2	50	6	10	14	M	94	92	89	21	79	78	76
Harrisonburg	38	3	1340	0	5	9	L	92	90	87	23	78	77	76
Lynchburg AP	37	2	947	10	15	19	L	94	92	89	21	77	76	75
Norfolk AP	36	5	26	18	20	23	M	94	91	89	18	79	78	78
Petersburg	37	1	194	10	15	18	L	96	94	91	20	80	79	78

Climatic Conditions for United States and Canada (Continued)*,a

Col. 1 State and Station[b]	Col. 2 Latitude[c] °	′	Col. 2 Elev.[d] Ft	Winter: Col. 4 Median of Annual Extremes	Col. 4 99%	Col. 4 97½%	Col. 5 Coincident Wind Velocity[e]	Summer: Col. 6 Design Dry-Bulb 1%	2½%	5%	Col. 6 Outdoor Daily Range[f]	Col. 8 Design Wet-Bulb 1%	2½%	5%
VIRGINIA (continued)														
Richmond AP	37	3	162	10	14	18	L	96	93	91	21	79	78	77
Roanoke AP	37	2	1174r	9	15	18	L	94	91	89	23	76	75	74
Staunton	38	2	1480	3	8	12	L	92	90	87	23	78	77	75
Winchester	39	1	750	1	6	10	L	94	92	89	21	78	76	75
WASHINGTON														
Aberdeen	47	0	12	19	24	27	M	83	80	77	16	62	61	60
Bellingham AP	48	5	150	8	14	18	L	76	74	71	19	67	65	63
Bremerton	47	3	162	17	24	29	L	85	81	77	20	68	66	65
Ellensburg AP	47	0	1729	− 5	2	6	VL	91	89	86	34	67	65	63
Everett-Paine AFB	47	5	598	13	19	24	L	82	78	74	20	67	65	63
Kennewick	46	0	392	4	11	15	VL	98	96	93	30	69	68	66
Longview	46	1	12	14	20	24	L	88	86	83	30	68	66	65
Moses Lake, Larson AFB	47	1	1183	−14	− 7	− 1	VL	96	93	90	32	68	66	65
Olympia AP	47	0	190	15	21	25	L	85	83	80	32	67	65	63
Port Angeles	48	1	99	20	26	29	M	75	73	70	18	60	58	57
Seattle-Boeing Fld	47	3	14	17	23	27	L	82	80	77	24	67	65	64
Seattle CO	47	4	14	22	28	32	L	81	79	76	19	67	65	64
Seattle-Tacoma AP	47	3	386	14	20	24	L	85	81	77	22	66	64	63
Spokane AP	47	4	2357	− 5	− 2	4	VL	93	90	87	28	66	64	63
Tacoma-McChord AFB	47	1	350	14	20	24	L	85	81	78	22	68	66	64
Walla Walla AP	46	1	1185	5	12	16	VL	98	96	93	27	69	68	66
Wenatchee	47	2	634	− 2	5	9	VL	95	92	89	32	68	66	64
Yakima AP	46	3	1061	− 1	6	10	VL	94	92	89	36	69	67	65
WEST VIRGINIA														
Beckley	37	5	2330	− 4	0	6	L	91	88	86	22	74	73	72
Bluefield AP	37	2	2850	1	6	10	L	88	86	83	22	74	73	72
Charleston AP	38	2	939	1	9	14	L	92	90	88	20	76	75	74
Clarksburg	39	2	977	− 2	3	7	L	92	90	87	21	76	75	74
Elkins AP	38	5	1970	− 4	1	5	L	87	84	82	22	74	73	72
Huntington CO	38	2	565r	4	10	14	L	95	93	91	22	77	76	75
Martinsburg AP	39	2	537	1	6	10	L	96	94	91	21	78	77	76
Morgantown AP	39	4	1245	− 2	3	7	L	90	88	85	22	76	74	73
Parkersburg CO	39	2	615r	2	8	12	L	93	91	88	21	77	76	75
Wheeling	40	1	659	0	5	9	L	91	89	86	21	76	75	74
WISCONSIN														
Appleton	44	2	742	−16	−10	− 6	M	89	87	84	23	75	74	72
Ashland	46	3	650	−27	−21	−17	L	85	83	80	23	73	71	69
Beloit	42	3	780	−13	− 7	− 3	M	92	90	87	24	77	76	75
Eau Claire AP	44	5	888	−21	−15	−11	L	90	88	85	23	76	74	72
Fond du Lac	43	5	760	−17	−11	− 7	M	89	87	84	23	76	74	73
Green Bay AP	44	3	683	−16	−12	− 7	M	88	85	82	23	75	73	72
La Crosse AP	43	5	652	−18	−12	− 8	M	90	88	85	22	78	76	75
Madison AP	43	1	858	−13	− 9	− 5	M	92	88	85	22	77	75	73
Manitowoc	44	1	660	−11	− 5	− 1	M	88	86	83	21	75	74	72
Marinette	45	0	605	−14	− 8	− 4	M	88	86	83	20	74	72	70
Milwaukee AP	43	0	672	−11	− 6	− 2	M	90	87	84	21	77	75	73
Racine	42	4	640	−10	− 4	0	M	90	88	85	21	77	75	73
Sheboygan	43	4	648	−10	− 4	0	M	89	87	84	20	76	74	72
Stevens Point	44	3	1079	−22	−16	−12	M	89	87	84	23	75	73	71
Waukesha	43	0	860	−12	− 6	− 2	M	91	89	86	22	77	75	74
Wausau AP	44	6	1196	−24	−18	−14	M	89	86	83	23	74	72	70
WYOMING														
Casper AP	42	5	5319	−20	−11	− 5	L	92	90	87	31	63	62	60
Cheyenne AP	41	1	6126	−15	− 6	− 2	M	89	86	83	30	63	62	61
Cody AP	44	3	5090	−23	−13	− 9	L	90	87	84	32	61	60	59
Evanston	41	2	6860	−22	−12	− 8	VL	84	82	79	32	58	57	56
Lander AP	42	5	5563	−26	−16	−12	VL	92	90	87	32	63	62	60
Laramie AP	41	2	7266	−17	− 6	− 2	M	82	80	77	28	61	59	58
Newcastle	43	5	4480	−18	− 9	− 5	M	92	89	86	30	68	67	66
Rawlins	41	5	6736	−24	−15	−11	L	86	84	81	40	62	61	60
Rock Springs AP	41	4	6741	−16	− 6	− 1	VL	86	84	82	32	58	57	56
Sheridan AP	44	5	3942	−21	−12	− 7	L	95	92	89	32	67	65	64
Torrington	42	0	4098	−20	−11	− 7	M	94	92	89	30	68	67	66

CANADA

Col. 1 Province and Station[b]	Col. 2 Latitude[c] ° ′	Col. 3 Elev,[d] Ft	Winter: Col. 4 Average Annual Minimum	Winter: Col. 4 99%	Winter: Col. 4 97½%	Winter: Col. 5 Coincident Wind Velocity[e]	Summer: Col. 6 Design Dry-Bulb 1%	Col. 6 2½%	Col. 6 5%	Col. 7 Outdoor Daily Range[f]	Col. 8 Design Wet-Bulb 1%	Col. 8 2½%	Col. 8 5%
ALBERTA													
Calgary AP	51 1	3540	−30	−29	−25	M	87	85	82	26	66	64	63
Edmonton AP	53 3	2219	−30	−29	−26	VL	86	83	80	23	69	67	65
Grande Prairie AP	55 1	2190	−44	−43	−37	VL	84	81	78	23	66	64	63
Jasper CO	52 5	3480	−38	−32	−28	VL	87	84	81	28	66	64	63
Lethbridge AP	49 4	3018	−31	−31	−24	M	91	88	85	28	68	66	64
McMurray AP	56 4	1216	−44	−42	−39	VL	87	84	81	28	69	67	65
Medicine Hat AP	50 0	2365	−33	−30	−26	M	96	93	90	28	72	69	67
Red Deer AP	52 1	2965	−38	−33	−28	VL	88	86	83	25	67	65	64
BRITISH COLUMBIA													
Dawson Creek	55 5	2200	−47	−40	−35	L	84	81	78	25	66	64	63
Fort Nelson AP	58 5	1230	−43	−44	−41	VL	87	84	81	23	66	64	63
Kamloops CO	50 4	1150	−15	−16	−10	VL	97	94	91	31	71	69	68
Nanaimo CO	49 1	100	16	17	20	VL	81	78	75	20	66	64	62
New Westminster CO	49 1	50	12	15	19	VL	86	84	82	20	68	66	65
Penticton AP	49 3	1121	0	− 1	3	L	94	91	88	31	71	69	68
Prince George AP	53 5	2218	−38	−37	−31	VL	85	82	79	26	68	65	63
Prince Rupert CO	54 2	170	9	11	15	L	73	71	69	13	62	60	59
Trail	49 1	1400	− 3	− 2	3	VL	94	91	88	30	70	68	67
Vancouver AP	49 1	16	13	15	19	L	80	78	76	17	68	66	65
Victoria CO	48 3	228	20	20	23	M	80	76	72	16	64	62	60
MANITOBA													
Brandon CO	49 5	1200	−36	−29	−26	M	90	87	84	26	75	73	71
Churchill AP	58 5	115	−43	−40	−38	H	79	75	72	18	68	66	63
Dauphin AP	51 1	999	−35	−29	−26	M	89	86	83	24	74	72	70
Flin Flon CO	54 5	1098	−38	−40	−36	L	85	81	78	19	71	69	67
Portage la Prairie AP	49 5	867	−28	−25	−22	M	90	87	84	22	75	74	72
The Pas AP	54 0	894	−41	−35	−32	M	85	81	78	20	73	71	69
Winnipeg AP	49 5	786	−31	−28	−25	M	90	87	84	23	75	74	72
NEW BRUNSWICK													
Campbellton CO	48 0	25	−20	−18	−14	L	87	84	81	20	74	71	69
Chatham AP	47 0	112	−17	−15	−10	M	90	87	84	22	74	71	69
Edmundston CO	47 2	500	−29	−20	−16	M	84	81	78	21	75	72	70
Fredericton AP	45 5	74	−19	−16	−10	L	89	86	83	23	73	70	68
Moncton AP	46 1	248	−16	−12	− 7	H	88	85	82	21	74	71	69
Saint John AP	45 2	352	−15	−12	− 7	M	81	79	77	18	71	68	66
NEWFOUNDLAND													
Corner Brook CO	49 0	40	− 9	−10	− 5	H	84	81	79	18	69	68	66
Gander AP	49 0	482	− 5	− 5	− 1	H	85	82	79	20	69	68	66
Goose Bay AP	53 2	144	−28	−27	−25	M	86	81	77	18	69	67	65
St. John's AP	47 4	463	1	2	6	H	79	77	75	17	69	68	66
Stephenville	48 3	44	− 4	− 6	− 1	H	79	76	74	13	69	68	66
NORTHWEST TERRITORIES													
Fort Smith AP	60 0	665	−51	−49	−46	VL	85	83	80	25	67	65	64
Frobisher Bay AP	63 5	68	−45	−45	−42	H	63	59	56	14			
Inuvik	68 2	75	−54	−50	−48	VL	80	77	75	23	63	61	60
Resolute AP	74 4	209	−52	−49	−47	M	54	51	49	10			
Yellowknife AP	62 3	682	−51	−49	−47	VL	78	76	74	17	65	63	62
NOVA SCOTIA													
Amherst	45 5	63	−15	−10	− 5	H	85	82	79	21	72	70	68
Halifax AP	44 4	136	− 4	0	4	H	83	80	77	16	69	68	67
Kentville CO	45 0	50	− 8	− 4	0	M	86	83	80	23	72	70	69
New Glasgow	45 4	317	−16	−10	− 5	H	84	81	79	21	72	70	68
Sydney AP	46 1	197	− 3	0	5	H	84	82	80	20	72	70	68
Truro CO	45 2	77	−17	−12	− 7	M	84	81	79	22	72	70	69
Yarmouth AP	43 5	136	2	5	9	H	76	73	71	15	69	68	67
ONTARIO													
Belleville CO	44 1	250	−15	−11	− 7	M	89	86	84	21	77	75	73
Chatham CO	42 2	600	− 1	3	6	M	92	90	88	20	77	75	74
Cornwall	45 0	210	−22	−14	− 9	M	89	86	84	23	77	75	74
Fort William AP	48 2	644	−31	−27	−23	L	86	83	80	23	72	70	68
Hamilton	43 2	303	− 2	0	3	M	91	88	86	21	77	75	73
Kapuskasing AP	49 3	752	−37	−31	−28	M	87	84	81	23	73	71	69
Kenora AP	49 5	1345	−33	−31	−28	M	86	83	80	20	75	73	71
Kingston CO	44 2	300	−16	−10	− 7	M	85	82	80	20	77	75	73

Col. 1 Province and Station[b]	Col. 2 Latitude[c] ° ′	Col. 3 Elev,[d] Ft	Winter: Col. 4 Average Annual Minimum	Col. 4 99%	Col. 4 97½%	Col. 5 Coincident Wind Velocity[e]	Summer: Col. 6 Design Dry-Bulb 1%	Col. 6 2½%	Col. 6 5%	Col. 7 Outdoor Daily Range[f]	Col. 8 Design Wet-Bulb 1%	Col. 8 2½%	Col. 8 5%
ONTARIO (continued)													
Kitchener	43 3	1125	−11	−3	1	M	88	85	83	24	76	75	74
London AP	43 0	912	−9	−1	3	M	90	88	86	22	76	75	74
North Bay AP	46 2	1210	−27	−21	−17	M	87	84	82	18	71	70	69
Oshawa	43 5	370	−11	−5	−2	M	90	87	85	21	77	75	73
Ottawa AP	45 2	339	−21	−17	−13	M	90	87	84	21	75	74	73
Owen Sound	44 3	597	−9	−5	−1	M	87	84	82	21	74	72	71
Peterborough CO	44 2	648	−20	−13	−9	M	90	87	85	22	76	74	73
St. Catharines CO	43 1	325	1	2	5	M	91	88	86	20	77	75	73
Sarnia	43 0	625	−6	2	6	M	92	90	88	19	76	74	73
Sault Ste. Marie CO	46 3	675	−21	−20	−15	M	88	85	83	22	72	70	68
Sudbury	46 3	850	−25	−20	−15	VL	89	86	84	25	72	70	69
Timmins CO	48 3	1100	−37	−33	−28	M	90	87	84	24	73	71	69
Toronto AP	43 4	578	−10	−3	1	M	90	87	85	22	77	75	73
Windsor AP	42 2	637	−1	4	7	M	92	90	88	20	77	75	74
PRINCE EDWARD ISLAND													
Charlottetown AP	46 2	186	−11	−6	−3	H	84	81	79	16	72	70	68
Summerside AP	46 3	78	−10	−8	−3	H	84	81	79	16	72	70	68
QUEBEC													
Bagotville	48 2	536	−35	−26	−22	VL	88	84	81	20	72	71	69
Chicoutimi CO	48 3	150	−31	−24	−20	VL	87	83	80	20	72	71	69
Drummondville CO	45 5	270	−26	−18	−13	M	88	85	82	22	76	74	72
Granby	45 2	550	−23	−17	−12	L	87	84	82	21	76	74	72
Hull	45 3	200	−21	−17	−13	M	90	87	84	21	75	74	73
Mégantic AP	45 4	1362	−27	−20	−16	M	84	81	78	19	75	73	71
Montréal AP	45 3	98	−20	−16	−10	M	88	86	84	18	76	74	73
Québec AP	46 5	245	−25	−19	−13	M	86	82	79	21	75	73	71
Rimouski	48 3	117	−18	−16	−12	H	78	74	71	18	71	69	68
St. Jean	45 2	129	−21	−15	−10	M	87	85	83	20	76	74	73
St. Jérôme	45 5	310	−30	−18	−13	L	87	84	82	23	76	74	73
Sept Îles AP	50 1	190	−29	−27	−22	L	80	78	75	17	66	64	63
Shawinigan	46 3	306	−27	−20	−15	L	88	85	83	21	76	74	72
Sherbrooke CO	45 2	595	−25	−18	−13	L	87	84	81	20	75	73	71
Thetford Mines	46 0	1020	−25	−19	−14	M	86	83	80	22	75	73	71
Trois Rivières CO	46 2	200	−30	−18	−13	M	88	85	82	23	76	74	72
Val d'Or AP	48 0	1108	−37	−31	−27	L	88	85	82	22	72	71	69
Valleyfield	45 2	150	−20	−14	−9	M	87	85	83	21	76	74	73
SASKATCHEWAN													
Estevan AP	49 0	1884	−32	−30	−25	M	93	89	86	25	75	73	71
Moose Jaw AP	50 2	1857	−33	−32	−27	M	93	89	86	27	73	71	69
North Battleford AP	52 5	1796	−33	−33	−29	L	90	86	83	25	71	69	67
Prince Albert AP	53 1	1414	−45	−41	−35	VL	88	84	81	25	72	70	68
Regina AP	50 3	1884	−38	−34	−29	M	92	88	85	27	73	71	69
Saskatoon AP	52 1	1645	−37	−34	−30	M	90	86	83	25	71	69	67
Swift Current AP	50 2	2677	−31	−29	−25	M	93	89	86	24	72	70	68
Yorkton AP	51 2	1653	−38	−33	−28	M	89	85	82	23	74	72	70
YUKON TERRITORY													
Whitehorse AP	60 4	2289	−45	−45	−42	VL	78	75	72	22	62	60	59

* Data for U. S. stations extracted from *Evaluated Weather Data for Cooling Equipment Design, Addendum No. 1, Winter and Summer Data,* with the permission of the publisher, Fluor Products Company, Inc., Box 1267, Santa Rosa, California.

[a] Data compiled from official weather stations, where hourly weather observations are made by trained observers, and from other sources. Table 1 prepared by ASHRAE Technical Committee 2.2, Weather Data and Design Conditions. Percentage of *winter* design data show the percent of 3-month period, December through February. Canadian data are based on January only. Percentage of *summer* design data show the percent of 4-month period, June through September. Canadian data are based on July only. Also see References 1 to 7.

[b] When airport temperature observations were used to develop design data, "AP" follows station name, and "AFB" follows Air Force Bases. Data for stations followed by "CO" came from office locations within an urban area and generally reflect an influence of the surrounding area. Stations without designation can be considered semirural and may be directly compared with most airport data.

[c] Latitude is given to the nearest 10 minutes, for use in calculating solar loads. For example, the latitude for Anniston, Alabama is given as 33 4, or 33°40′.

[d] Elevations are ground elevations for each station as of 1964. Temperature readings are generally made at an elevation of 5 ft above ground, except for locations marked r, indicating roof exposure of thermometer.

[e] Coincident wind velocities derived from approximately coldest 600 hours out of 20,000 hours of December through February data per station. Also see References 5 and 6. The four classifications are:
VL = Very Light, 70 percent or more of cold extreme hours ≤7 mph. M = Moderate, 50 to 74 percent cold extreme hours >7 mph.
L = Light, 50 to 69 percent cold extreme hours ≤7 mph. H = High, 75 percent or more cold extreme hours >7 mph., and 50 percent are >12 mph.

[f] The difference between the average maximum and average minimum temperatures during the warmest month.

† More detailed data on Arizona, California, and Nevada may be found in *Recommended Design Temperatures, Northern, California,* published by the Golden Gate Chapter; and *Recommended Design Temperatures, Southern California, Arizona, Nevada,* published by the Southern California Chapter.

Col. 1 Country and Station	Col. 2 Latitude and Longitude ° ′	Col. 3 Elevation, Ft	Winter, Col. 4: Mean of Annual Extremes	Winter, Col. 4: 99%	Winter, Col. 4: 97½%	Summer, Col. 5 Design Dry-Bulb: 1%	Summer, Col. 5 Design Dry-Bulb: 2½%	Summer, Col. 5 Design Dry-Bulb: 5%	Summer, Col. 6 Outdoor Daily Range F deg	Summer, Col. 7 Design Wet-Bulb: 1%	Summer, Col. 7 Design Wet-Bulb: 2½%	Summer, Col. 7 Design Wet-Bulb: 5%
ADEN												
Aden	12 50N/45 02E	10	63	68	70	102	100	98	11	83	82	82
AFGHANISTAN												
Kabul	34 35N/69 12E	5955	2	6	9	98	96	93	32	66	65	64
ALGERIA												
Algiers	36 46N/3 03E	194	38	43	45	95	92	89	14	77	76	75
ARGENTINA												
Buenos Aires	34 35S/58 29W	89	27	32	34	91	89	86	22	77	76	75
Córdoba	31 22S/64 15W	1388	21	28	32	100	96	93	27	76	75	74
Tucuman	26 50S/65 10W	1401	24	32	36	102	99	96	23	76	75	74
AUSTRALIA												
Adelaide	34 56S/138 35E	140	36	38	40	98	94	91	25	72	70	68
Alice Springs	23 48S/133 53E	1795	28	34	37	104	102	100	27	75	74	72
Brisbane	27 28S/153 02E	137	39	44	47	91	88	86	18	77	76	75
Darwin	12 28S/130 51E	88	60	64	66	94	93	91	16	82	81	81
Melbourne	37 49S/144 58E	114	31	35	38	95	91	86	21	71	69	68
Perth	31 57S/115 51E	210	38	40	42	100	96	93	22	76	74	73
Sydney	33 52S/151 12E	138	38	40	42	89	84	80	13	74	73	72
AUSTRIA												
Vienna	48 15N/16 22E	644	− 2	6	11	88	86	83	16	71	69	67
AZORES												
Lajes (Terceira)	38 45N/27 05W	170	42	46	49	80	78	77	11	73	72	71
BAHAMAS												
Nassau	25 05N/77 21W	11	55	61	63	90	89	88	13	80	80	79
BELGIUM												
Brussels	50 48N/4 21E	328	13	15	19	83	79	77	19	70	68	67
BERMUDA												
Kindley AFB	33 22N/64 41W	129	47	53	55	87	86	85	12	79	78	78
BOLIVIA												
La Paz	16 30S/68 09W	12001	28	31	33	71	69	68	24	58	57	56
BRAZIL												
Belem	1 27S/48 29W	42	67	70	71	90	89	87	19	80	79	78
Belo Horizonte	19 56S/43 57W	3002	42	47	50	86	84	83	18	76	75	75
Brasilia	15 52S/47 55W	3442	46	49	51	89	88	86	17	76	75	75
Curitiba	25 25S/49 17W	3114	28	34	37	86	84	82	21	75	74	74
Fortaleza	3 46S/38 33W	89	66	69	70	91	90	89	17	79	78	78
Porto Alegre	30 02S/51 13W	33	32	37	40	95	92	89	20	76	76	75
Recife	8 04S/34 53W	97	67	69	70	88	87	86	10	78	77	77
Rio de Janeiro	22 55S/43 12W	201	56	58	60	94	92	90	11	80	79	78
Salvador	13 00S/38 30W	154	65	67	68	88	87	86	12	79	79	78
São Paulo	23 33S/46 38W	2608	36	42	46	86	84	82	18	75	74	74
BRITISH HONDURAS												
Belize	17 31N/88 11W	17	55	60	62	90	90	89	13	82	82	81
BULGARIA												
Sofia	42 42N/23 20E	1805	− 2	3	8	89	86	84	26	71	70	69
BURMA												
Mandalay	21 59N/96 06E	252	50	54	56	104	102	101	30	81	80	80
Rangoon	16 47N/96 09E	18	59	62	63	100	98	95	25	83	82	82
CAMBODIA												
Phnom Penh	11 33N/104 51E	36	62	66	68	98	96	94	19	83	82	82
CEYLON												
Colombo	6 54N/79 52E	24	65	69	70	90	89	88	15	81	80	80
CHILE												
Punta Arenas	53 10S/70 54W	26	22	25	27	68	66	64	14	56	55	54
Santiago	33 27S/70 42W	1706	27	32	35	90	89	88	32	71	70	69
Valparaiso	33 01S/71 38W	135	39	43	46	81	79	77	16	67	66	65
CHINA												
Chungking	29 33N/106 33E	755	34	37	39	99	97	95	18	81	80	79
Shanghai	31 12N/121 26E	23	16	23	26	94	92	90	16	81	81	80
COLOMBIA												
Baranquilla	10 59N/74 48W	44	66	70	72	95	94	93	17	83	82	82
Bogotá	4 36N/74 05W	8406	42	45	46	72	70	69	19	60	59	58
Cali	3 25N/76 30W	3189	53	57	58	84	82	79	15	70	69	68
Medellin	6 13N/75 36W	4650	48	53	55	87	85	84	25	73	72	72
CONGO												
Brazzaville	4 15S/15 15E	1043	54	60	62	93	92	91	21	81	81	80
Kinasha (Leopoldville)	4 20S/15 18E	1066	54	60	62	92	91	90	19	81	80	80
Stanleyville	0 26N/15 14E	1370	65	67	68	92	91	90	19	81	80	80

Col. 1 Country and Station	Col. 2 Latitude and Longitude ° ′	Col. 3 Elevation, Ft	Winter Col. 4 Mean of Annual Extremes	Winter Col. 4 99%	Winter Col. 4 97½%	Summer Col. 5 Design Dry-Bulb 1%	Col. 5 2½%	Col. 5 5%	Col. 6 Outdoor Daily Range F deg	Col. 7 Design Wet-Bulb 1%	Col. 7 2½%	Col. 7 5%
CUBA												
Guantanamo Bay	19 54N/75 09W	21	60	64	66	94	93	92	16	82	81	80
Havana	23 08N/82 21W	80	54	59	62	92	91	89	14	81	81	80
CZECHOSLOVAKIA												
Prague	50 05N/14 25E	662	3	4	9	88	85	83	16	66	65	64
DENMARK												
Copenhagen	55 41N/12 33E	43	11	16	19	79	76	74	17	68	66	64
DOMINICAN REPUBLIC												
Santo Domingo	18 29N/69 54W	57	61	63	65	92	90	88	16	81	80	80
ECUADOR												
Guayaquil	2 10S/79 53W	20	61	64	65	92	91	89	20	80	80	79
Quito	0 13S/78 32W	9446	30	36	39	73	72	71	32	63	62	62
EL SALVADOR												
San Salvador	13 42N/89 13W	2238	51	54	56	98	96	95	32	77	76	75
ETHIOPIA												
Addis Ababa	9 02N/38 45E	7753	35	39	41	84	82	81	28	66	65	64
Asmara	15 17N/38 55E	7628	36	40	42	83	81	80	27	65	64	63
FINLAND												
Helsinki	60 10N/24 57E	30	−11	−7	−1	77	74	72	14	66	65	63
FRANCE												
Lyon	45 42N/4 47E	938	−1	10	14	91	89	86	23	71	70	69
Marseilles	43 18N/5 23E	246	23	25	28	90	87	84	22	72	71	69
Nantes	47 15N/1 34W	121	17	22	26	86	83	80	21	70	69	67
Nice	43 42N/7 16E	39	31	34	37	87	85	83	15	73	72	72
Paris	48 49N/2 29E	164	16	22	25	89	86	83	21	70	68	67
Strasbourg	48 35N/7 46E	465	9	11	16	86	83	80	20	70	69	67
FRENCH GUIANA												
Cayenne	4 56N/52 27W	20	69	71	72	92	91	90	17	83	83	82
GERMANY												
Berlin	52 27N/13 18E	187	6	7	12	84	81	78	19	68	67	66
Hamburg	53 33N/9 58E	66	10	12	16	80	76	73	13	68	66	65
Hannover	52 24N/9 40E	561	7	16	20	82	78	75	17	68	67	65
Mannheim	49 34N/8 28E	359	2	8	11	87	85	82	18	71	69	68
Munich	48 09N/11 34E	1729	−1	5	9	86	83	80	18	68	66	64
GHANA												
Accra	5 33N/0 12W	88	65	68	69	91	90	89	13	80	79	79
GIBRALTAR												
Gibraltar	36 09N/5 22W	11	38	42	45	92	89	86	14	76	75	74
GREECE												
Athens	37 58N/23 43E	351	29	33	36	96	93	91	18	72	71	71
Thessaloniki	40 37N/22 57E	78	23	28	32	95	93	91	20	77	76	75
GREENLAND												
Narssarssuaq	61 11N/45 25W	85	−23	−12	−8	66	63	61	20	56	54	52
GUATEMALA												
Guatemala City	14 37N/90 31W	4855	45	48	51	83	82	81	24	69	68	67
GUYANA												
Georgetown	6 50N/58 12W	6	70	72	73	89	88	87	11	80	79	79
HAITI												
Port au Prince	18 33N/72 20W	121	63	65	67	97	95	93	20	82	81	80
HONDURAS												
Tegucigalpa	14 06N/87 13W	3094	44	47	50	89	87	85	28	73	72	71
HONG KONG												
Hong Kong	22 18N/114 10E	109	43	48	50	92	91	90	10	81	80	80
HUNGARY												
Budapest	47 31N/19 02E	394	8	10	14	90	86	84	21	72	71	70
ICELAND												
Reykjavik	64 08N/21 56E	59	8	14	17	59	58	56	16	54	53	53
INDIA												
Ahmenabad	23 02N/72 35E	163	49	53	56	109	107	105	28	80	79	78
Bangalore	12 57N/77 37E	3021	53	56	58	96	94	93	26	75	74	74
Bombay	18 54N/72 49E	37	62	65	67	96	94	92	13	82	81	81
Calcutta	22 32N/88 20E	21	49	52	54	98	97	96	22	83	82	82
Madras	13 04N/80 15E	51	61	64	66	104	102	101	19	84	83	83
Nagpur	21 09N/79 07E	1017	45	51	54	110	108	107	30	79	79	78
New Delhi	28 35N/77 12E	703	35	39	41	110	107	105	26	83	82	82
INDONESIA												
Djakarta	6 11S/106 50E	26	69	71	72	90	89	88	14	80	79	78
Kupang	10 10S/123 34E	148	63	66	68	94	93	92	20	81	80	80
Makassar	5 08S/119 28E	61	64	66	68	90	89	88	17	80	80	79
Medan	3 35N/98 41E	77	66	69	71	92	91	90	17	81	80	79
Palembang	3 00S/104 46E	20	67	70	71	92	91	90	17	80	79	79
Surabaya	7 13S/112 43E	10	64	66	68	91	90	89	18	80	79	79

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IRAN												
Abadan	30 21N/48 16E	7	32	39	41	116	113	110	32	82	81	81
Meshed	36 17N/59 36E	3104	3	10	14	99	96	93	29	68	67	66
Tehran	35 41N/51 25E	4002	15	20	24	102	100	98	27	75	74	73
IRAQ												
Baghdad	33 20N/44 24E	111	27	32	35	113	111	108	34	73	72	72
Mosul	36 19N/43 09E	730	23	29	32	114	112	110	40	73	72	72
IRELAND												
Dublin	53 22N/6 21W	155	19	24	27	74	72	70	16	65	64	62
Shannon	52 41N/8 55W	8	19	25	28	76	73	71	14	65	64	63
ISRAEL												
Jerusalem	31 47N/35 13E	2485	31	36	38	95	94	92	24	70	69	69
Tel Aviv	32 06N/34 47E	36	33	39	41	96	93	91	16	74	73	72
ITALY												
Milan	45 27N/09 17E	341	12	18	22	89	87	84	20	76	75	74
Naples	40 53N/14 18E	220	28	34	36	91	88	86	19	74	73	72
Rome	41 48N/12 36E	377	25	30	33	94	92	89	24	74	73	72
IVORY COAST												
Abidjan	5 19N/4 01W	65	64	67	69	91	90	88	15	83	82	81
JAPAN												
Fukuoka	33 35N/130 27E	22	26	29	31	92	90	89	20	82	80	79
Sapporo	43 04N/141 21E	56	−7	1	5	86	83	80	20	76	74	72
Tokyo	35 41N/139 46E	19	21	26	28	91	89	87	14	81	80	79
JORDAN												
Amman	31 57N/35 57E	2548	29	33	36	97	94	92	25	70	69	68
KENYA												
Nairobi	1 16S/36 48E	5971	45	48	50	81	80	78	24	66	65	65
KOREA												
Pyongyang	39 02N/125 41E	186	−10	−2	3	89	87	85	21	77	76	76
Seoul	37 34N/126 58E	285	−1	7	9	91	89	87	16	81	79	78
LEBANON												
Beirut	33 54N/35 28E	111	40	42	45	93	91	90	15	78	77	76
LIBERIA												
Monrovia	6 18N/10 48W	75	64	68	69	90	89	88	19	82	82	81
LIBYA												
Bengasi	32 06N/20 04E	82	41	46	48	97	94	91	13	77	76	75
MADAGASCAR												
Tananarive	18 55S/47 33E	4531	39	43	46	86	84	83	23	73	72	71
MALAYSIA												
Kuala Lumpur	3 07N/101 42E	127	67	70	71	94	93	92	20	82	82	81
Penang	5 25N/100 19E	17	69	72	73	93	93	92	18	82	81	80
Singapore	1 18N/103 50E	33	69	71	72	92	91	90	14	82	81	80
MARTINIQUE												
Fort de France	14 37N/61 05W	13	62	64	66	90	89	88	14	81	81	80
MEXICO												
Guadalajara	20 41N/103 20W	5105	35	39	42	93	91	89	29	68	67	66
Mérida	20 58N/89 38W	72	56	59	61	97	95	94	21	80	79	77
Mexico City	19 24N/99 12W	7575	33	37	39	83	81	79	25	61	60	59
Monterrey	25 40N/100 18W	1732	31	38	41	98	95	93	20	79	78	77
Vera Cruz	19 12N/96 08W	184	55	60	62	91	89	88	12	83	83	82
MOROCCO												
Casablanca	33 35N/7 39W	164	36	40	42	94	90	86	50	73	72	70
NEPAL												
Katmandu	27 42N/85 12E	4388	30	33	35	89	87	86	25	78	77	76
NETHERLANDS												
Amsterdam	52 23N/4 55E	5	17	20	23	79	76	73	10	65	64	63
NEW GUINEA												
Manokwari	0 52S/134 05E	62	70	71	72	89	88	87	12	82	81	81
Point Moresby	9 29S/147 09E	126	62	67	69	92	91	90	14	80	80	79
NEW ZEALAND												
Auckland	36 51S/174 46E	140	37	40	42	78	77	76	14	67	66	65
Christ Church	43 32S/172 37E	32	25	28	31	82	79	76	17	68	67	66
Wellington	41 17S/174 46E	394	32	35	37	76	74	72	14	66	65	64
NICARAGUA												
Managua	12 10N/86 15W	135	62	65	67	94	93	92	21	81	80	79
NIGERIA												
Lagos	6 27N/3 24E	10	67	70	71	92	91	90	12	82	82	81
NORWAY												
Bergen	60 24N/5 19E	141	14	17	20	75	74	73	21	67	66	65
Oslo	59 56N/10 44E	308	−2	0	4	79	77	74	17	67	66	64

Col. 1 Country and Station	Col. 2 Latitude and Longitude ° ′	Col. 3 Elevation, Ft	Winter Col. 4 Mean of Annual Extremes	Winter Col. 4 99%	Winter Col. 4 97½%	Summer Col. 5 Design Dry-Bulb 1%	Col. 5 2½%	Col. 5 5%	Col. 6 Outdoor Daily Range F deg	Col. 7 Design Wet-Bulb 1%	Col. 7 2½%	Col. 7 5%
PAKISTAN												
Chittagong	22 21N/91 50E	87	48	52	54	93	91	89	20	82	81	81
Karachi	24 48N/66 59E	13	45	49	51	100	98	95	14	82	82	81
Lahore	31 35N/74 20E	702	32	35	37	109	107	105	27	83	82	81
Peshwar	34 01N/71 35E	1164	31	35	37	109	106	103	29	81	80	79
PANAMA AND CANAL ZONE												
Panama City	8 58N/79 33W	21	69	72	73	93	92	91	18	81	81	80
PARAGUAY												
Asunción	25 17S/57 30W	456	35	43	46	100	98	96	24	81	81	80
PERU												
Lima	12 05S/77 03W	394	51	53	55	86	85	84	17	76	75	74
PHILIPPINES												
Manila	14 35N/120 59E	47	69	73	74	94	92	91	20	82	81	81
POLAND												
Kraków	50 04N/19 57E	723	− 2	2	6	84	81	78	19	68	67	66
Warsaw	52 13N/21 02E	394	− 3	3	8	84	81	78	19	71	70	68
PORTUGAL												
Lisbon	38 43N/9 08W	313	32	37	39	89	86	83	16	69	68	67
PUERTO RICO												
San Juan	18 29N/66 07W	82	65	67	68	89	88	87	11	81	80	79
RUMANIA												
Bucharest	44 25N/26 06E	269	− 2	3	8	93	91	89	26	72	71	70
SAUDI ARABIA												
Dhahran	26 17N/50 09E	80	39	45	48	111	110	108	32	86	85	84
Jedda	21 28N/39 10E	20	52	57	60	106	103	100	22	85	84	83
Riyadh	24 39N/46 42E	1938	29	37	40	110	108	106	32	78	77	76
SENEGAL												
Dakar	14 42N/17 29W	131	58	61	62	95	93	91	13	81	80	80
SOMALIA												
Mogadiscio	2 02N/49 19E	39	67	69	70	91	90	89	12	82	82	81
SOUTH AFRICA												
Capetown	33 56S/18 29E	55	36	40	42	93	90	86	20	72	71	70
Johannesburg	26 11S/78 03E	5463	26	31	34	85	83	81	24	70	69	69
Pretoria	25 45S/28 14E	4491	27	32	35	90	87	85	23	70	69	68
SOVIET UNION												
Alma Ata	43 14N/76 53E	2543	−18	−10	− 6	88	86	83	21	69	68	67
Archangel	64 33N/40 32E	22	−29	−23	−18	75	71	68	13	60	58	57
Kaliningrad	54 43N/20 30E	23	− 3	+ 1	6	83	80	77	17	67	66	65
Krasnoyarsk	56 01N/92 57E	498	−41	−32	−27	84	80	76	12	64	62	60
Kiev	50 27N/30 30E	600	−12	− 5	+ 1	87	84	81	22	69	68	67
Kharkov	50 00N/36 14E	472	−19	−10	− 3	87	84	82	23	69	68	67
Kuibyshev	53 11N/50 06E	190	−23	−19	−13	89	85	81	20	69	67	66
Leningrad	59 56N/30 16E	16	−14	− 9	− 5	78	75	72	15	65	64	63
Minsk	53 54N/27 33E	738	−19	−11	− 4	80	77	74	16	67	66	65
Moscow	55 46N/37 40E	505	−19	−11	− 6	84	81	78	21	69	67	65
Odessa	46 29N/30 44E	214	− 1	4	8	87	84	82	14	70	69	68
Petropavlovsk	52 53N/158 42E	286	− 9	− 3	0	70	68	65	13	58	57	56
Rostov on Don	47 13N/39 43E	159	− 9	− 2	4	90	87	84	20	70	69	68
Sverdlovsk	56 49N/60 38E	894	−34	−25	−20	80	76	72	16	63	62	60
Tashkent	41 20N/69 18E	1569	− 4	3	8	95	93	90	29	71	70	69
Tbilisi	41 43N/44 48E	1325	12	18	22	87	85	83	18	68	67	66
Vladivostok	43 07N/131 55E	94	−15	−10	− 7	80	77	74	11	70	69	68
Volgograd	48 42N/44 31E	136	−21	−13	− 7	93	89	86	19	71	70	69
SPAIN												
Barcelona	41 24N/2 09E	312	31	33	36	88	86	84	13	75	74	73
Madrid	40 25N/3 41W	2188	22	25	28	93	91	89	25	71	69	67
Valencia	39 28N/0 23W	79	31	33	37	92	90	88	14	75	74	73
SUDAN												
Khartoum	15 37N/32 33E	1279	47	53	56	109	107	104	30	77	76	75
SURINAM												
Paramaribo	5 49N/55 09W	12	66	68	70	93	92	90	18	82	82	81
SWEDEN												
Stockholm	59 21N/18 04E	146	3	5	8	78	74	72	15	64	62	60
SWITZERLAND												
Zurich	47 23N/8 33E	1617	4	9	14	84	81	78	21	68	67	66
SYRIA												
Damascus	33 30N/36 20E	2362	25	29	32	102	100	98	35	72	71	70
TAIWAN												
Tainan	22 57N/120 12E	70	40	46	49	92	91	90	14	84	83	82
Taipei	25 02N/121 31E	30	41	44	47	94	92	90	16	83	82	81

Table C2

Earth Temperature Tables

for

Underground Heat Distribution System Design

The following Tables TG-1 through TG-11 were developed by applying monthly average temperatures prepared by the U. S. Weather Bureau for many localities in the United States to a technique described in the 1965 ASHRAE technical paper entitled "Earth Temperature and Thermal Diffusivity at Selected Stations in the United States" by T. Kusuda and P. R. Achenbach. These temperature data are, however, for the undisturbed earth. The earth temperature immediately under the building may be estimated by taking an arithmetic average of the building temperature and the design earth temperature found in the appropriate table. For example, the floor on grade in the Washington, D. C. area may be treated as a slab of 12" thickness with ground temperature of 70.5 °F if the room temperature is 75 °F and the summer design TG is determined from the data of Upper Marlboro, Maryland for ALPHA = 0.025 which is 66 °F.

Table TG-1
DRY SOIL

AVERAGE EARTH TEMPERATURE IN DEG. F. TG

THERMAL DIFFUSIVITY IN FT**2/HR ALPHA= .010

STATION STATES	WINTER	SPRING	SUMMER	FALL	YEAR
AUBURN, ALABAMA	60.	61.	71.	70.	65.
DECATUR, ALABAMA	52.	54.	65.	65.	59.
PALMER AAES, ALASKA	31.	31.	42.	41.	36.
TEMPE, ARIZONA	62.	64.	73.	74.	68.
TUCSON, ARIZONA	68.	69.	77.	79.	73.
BRAWLEY, CALIFORNIA	70.	73.	83.	84.	77.
DAVIS, CALIFORMIA	61.	61.	72.	72.	67.
FT. COLLINS, COLO.	44.	45.	58.	56.	51.
STORRS, CONN.	46.	45.	58.	58.	52.
GAINESVILLE, FLA.	65.	70.	77.	77.	73.
ATHENS, GEORGIA	59.	61.	72.	72.	66.
MOSCOW, IDAHO	43.	42.	52.	52.	47.
LEMONT, ILLINOIS	46.	45.	59.	59.	52.
URBANA, ILLINOIS	46.	47.	61.	60.	53.
WEST LAFAYETTE, IND	47.	47.	62.	61.	54.
AMES, IOWA	44.	45.	62.	60.	52.
BURLINGTON, IOWA	47.	49.	66.	65.	56.
CASTANA, IOWA	42.	42.	61.	59.	51.
COUNCIL BLUFFS, IOWA	47.	47.	62.	62.	55.
SARATOGA, IOWA	41.	40.	59.	57.	49.
SPENCER, IOWA	42.	42.	58.	57.	50.
GARDEN CITY, KANSAS	48.	51.	66.	66.	58.
MANHATTAN, KANSAS	48.	50.	64.	64.	56.
MOUND VALLEY, KANSAS	52.	54.	68.	68.	60.
LEXINGTON, KENTUCKY	51.	52.	65.	64.	58.
UPPER MARLBORO, MD.	48.	49.	63.	63.	56.
EAST LANSING, MICH.	45.	43.	57.	57.	50.
FAIRMONT, MINNESOTA	42.	43.	58.	57.	50.
FARIBAULT, MINNESOTA	40.	40.	55.	53.	47.
ST. PAUL, MINNESOTA	42.	40.	57.	56.	49.
WASECA, MINNESOTA	41.	46.	59.	54.	50.
STATE UNIV., MISS.	60.	62.	73.	73.	67.
FAUCETT, MISSOURI	47.	47.	61.	61.	54.
KANSAS CITY, MO.	48.	49.	62.	61.	55.
SIKESTON, MISSOURI	52.	54.	67.	67.	60.
SPICKARD, MISSOURI	50.	49.	60.	62.	55.
BOZEMAN, MONTANA	39.	37.	50.	48.	43.
HUNTLEY, MONTANA	44.	44.	58.	57.	50.
LINCOLN, NEBRASKA	45.	45.	60.	60.	53.
NEW BRUNSWICK, N.J.	48.	48.	60.	60.	54.
ITHACA, NEW YORK	44.	43.	54.	54.	49.
COLUMBUS, OHIO	47.	47.	59.	60.	53.
COSHOCTON, OHIO	46.	46.	58.	58.	52.
WOOSTER, OHIO	46.	46.	58.	58.	52.
BARNSDALL, OKLAHOMA	56.	57.	69.	69.	63.
LAKE HEFNER, OKLA.	56.	57.	70.	71.	64.
PAWHUSKA, OKLAHOMA	54.	55.	68.	68.	61.
OTTAWA, ONTARIO	42.	39.	54.	52.	47.
CORVALLIS, OREGON	50.	51.	61.	60.	55.
HOOD RIVER, OREGON	46.	48.	57.	57.	52.

AVERAGE EARTH TEMPERATURE IN DEG. F, TG

THERMAL DIFFUSIVITY IN FT**2/HR ALPHA= .010

STATION STATES	WINTER	SPRING	SUMMER	FALL	YEAR
MEDFORD, OREGON	51.	52.	61.	61.	56.
PENDLETON, OREGON	46.	49.	61.	60.	54.
STATE COLLEGE, PA.	46.	45.	59.	58.	52.
KINGSTON, R. I.	45.	43.	55.	56.	50.
CALHOUN, S.CAROLINA	56.	58.	70.	69.	63.
MADISON, S. DAKOTA	40.	40.	54.	54.	47.
JACKSON, TENNESSEE	53.	55.	66.	64.	59.
TEMPLE, TEXAS	64.	65.	77.	77.	71.
SALT LAKE CITY,UTAH	44.	45.	56.	55.	50.
BURLINGTON, VERMONT	42.	40.	54.	53.	48.
PULLMAN, WASHINGTON	43.	46.	55.	52.	50.
SEATTLE, WASHINGTON	48.	50.	56.	56.	53.
AFTON, WYOMING	43.	43.	53.	53.	48.

Table TG-2
AVERAGE SOIL

AVERAGE EARTH TEMPERATURE IN DEG. F, TG

THERMAL DIFFUSIVITY IN FT**2/HR ALPHA= .025

STATION STATES	WINTER	SPRING	SUMMER	FALL	YEAR
AUBURN, ALABAMA	57.	61.	74.	70.	65.
DECATUR, ALABAMA	49.	53.	69.	66.	59.
PALMER AAES, ALASKA	29.	30.	45.	41.	36.
TEMPE, ARIZONA	58.	63.	77.	74.	68.
TUCSON, ARIZONA	65.	69.	80.	80.	73.
BRAWLEY, CALIFORNIA	66.	73.	87.	85.	77.
DAVIS, CALIFORMIA	57.	60.	76.	73.	67.
FT. COLLINS, COLO.	40.	44.	62.	57.	51.
STORRS, CONN.	43.	44.	62.	59.	52.
GAINESVILLE, FLA.	61.	71.	79.	78.	73.
ATHENS, GEORGIA	55.	60.	75.	73.	66.
MOSCOW, IDAHO	40.	42.	55.	53.	47.
LEMONT, ILLINOIS	42.	44.	64.	60.	52.
URBANA, ILLINOIS	42.	47.	65.	61.	53.
WEST LAFAYETTE, IND	43.	47.	66.	62.	54.
AMES, IOWA	39.	44.	67.	61.	52.
BURLINGTON, IOWA	42.	48.	71.	66.	56.
CASTANA, IOWA	36.	41.	66.	61.	51.
COUNCIL BLUFFS, IOWA	42.	47.	67.	63.	55.
SARATOGA, IOWA	37.	39.	64.	58.	49.
SPENCER, IOWA	37.	41.	62.	58.	50.
GARDEN CITY, KANSAS	42.	51.	71.	67.	58.
MANHATTAN, KANSAS	44.	49.	68.	65.	56.
MOUND VALLEY, KANSAS	47.	54.	72.	69.	60.
LEXINGTON, KENTUCKY	47.	51.	69.	65.	58.
UPPER MARLBORO, MD.	44.	49.	66.	64.	56.
EAST LANSING, MICH.	41.	41.	61.	58.	50.
FAIRMONT, MINNESOTA	38.	43.	63.	57.	50.
FARIBAULT, MINNESOTA	36.	38.	59.	54.	47.
ST. PAUL, MINNESOTA	38.	38.	62.	57.	49.
WASECA, MINNESOTA	36.	47.	64.	54.	50.
STATE UNIV., MISS.	56.	62.	76.	74.	67.
FAUCETT, MISSOURI	43.	45.	65.	61.	54.
KANSAS CITY, MO.	44.	48.	65.	62.	55.
SIKESTON, MISSOURI	48.	54.	72.	68.	60.
SPICKARD, MISSOURI	47.	48.	63.	64.	55.
BOZEMAN, MONTANA	36.	36.	53.	49.	43.
HUNTLEY, MONTANA	40.	43.	63.	57.	50.
LINCOLN, NEBRASKA	40.	44.	65.	61.	53.
NEW BRUNSWICK, N.J.	44.	47.	63.	61.	54.
ITHACA, NEW YORK	41.	41.	58.	54.	49.
COLUMBUS, OHIO	43.	46.	63.	61.	53.
COSHOCTON, OHIO	42.	45.	61.	59.	52.
WOOSTER, OHIO	42.	45.	62.	59.	52.
BARNSDALL, OKLAHOMA	53.	56.	73.	70.	63.
LAKE HEFNER, OKLA.	52.	56.	74.	72.	64.
PAWHUSKA, OKLAHOMA	50.	54.	72.	68.	61.
OTTAWA, ONTARIO	39.	37.	58.	52.	47.
CORVALLIS, OREGON	47.	50.	64.	60.	55.
HOOD RIVER, OREGON	43.	48.	59.	57.	52.

AVERAGE EARTH TEMPERATURE IN DEG. F, TG

THERMAL DIFFUSIVITY IN FT**2/HR ALPHA= .025

STATION STATES	WINTER	SPRING	SUMMER	FALL	YEAR
MEDFORD, OREGON	48.	52.	64.	61.	56.
PENDLETON, OREGON	41.	49.	65.	61.	54.
STATE COLLEGE, PA.	42.	44.	63.	59.	52.
KINGSTON, R. I.	41.	41.	58.	57.	50.
CALHOUN, S.CAROLINA	52.	57.	73.	70.	63.
MADISON, S. DAKOTA	36.	38.	59.	55.	47.
JACKSON, TENNESSEE	50.	55.	69.	64.	59.
TEMPLE, TEXAS	61.	65.	81.	77.	71.
SALT LAKE CITY,UTAH	40.	45.	60.	56.	50.
BURLINGTON, VERMONT	39.	38.	59.	54.	48.
PULLMAN, WASHINGTON	40.	45.	58.	52.	50.
SEATTLE, WASHINGTON	46.	50.	59.	56.	53.
AFTON, WYOMING	41.	42.	56.	53.	48.

Table TG-3
WET SOIL

AVERAGE EARTH TEMPERATURE IN DEG. F, TG

THERMAL DIFFUSIVITY IN FT**2/HR ALPHA= .050

STATION STATES	WINTER	SPRING	SUMMER	FALL	YEAR
AUBURN, ALABAMA	54.	61.	76.	70.	65.
DECATUR, ALABAMA	46.	53.	71.	65.	59.
PALMER AAES, ALASKA	27.	30.	48.	41.	36.
TEMPE, ARIZONA	56.	64.	79.	74.	68.
TUCSON, ARIZONA	62.	69.	82.	81.	73.
BRAWLEY, CALIFORNIA	63.	73.	90.	84.	77.
DAVIS, CALIFORMIA	55.	60.	78.	73.	67.
FT. COLLINS, COLO.	37.	45.	65.	56.	51.
STORRS, CONN.	40.	44.	65.	59.	52.
GAINESVILLE, FLA.	58.	72.	81.	79.	73.
ATHENS, GEORGIA	52.	61.	78.	73.	66.
MOSCOW, IDAHO	38.	42.	57.	53.	47.
LEMONT, ILLINOIS	39.	44.	67.	60.	52.
URBANA, ILLINOIS	39.	47.	68.	60.	53.
WEST LAFAYETTE, IND	40.	47.	69.	62.	54.
AMES, IOWA	35.	44.	70.	61.	52.
BURLINGTON, IOWA	38.	48.	74.	66.	56.
CASTANA, IOWA	32.	42.	70.	61.	51.
COUNCIL BLUFFS,IOWA	39.	47.	70.	63.	55.
SARATOGA, IOWA	33.	39.	68.	58.	49.
SPENCER, IOWA	33.	42.	66.	58.	50.
GARDEN CITY, KANSAS	38.	52.	74.	67.	58.
MANHATTAN, KANSAS	40.	49.	72.	65.	56.
MOUND VALLEY,KANSAS	44.	55.	75.	69.	60.
LEXINGTON, KENTUCKY	44.	51.	72.	65.	58.
UPPER MARLBORO, MD.	41.	49.	69.	64.	56.
EAST LANSING, MICH.	39.	41.	64.	57.	50.
FAIRMONT, MINNESOTA	35.	43.	67.	57.	50.
FARIBAULT,MINNESOTA	34.	38.	62.	54.	47.
ST. PAUL, MINNESOTA	35.	38.	65.	57.	49.
WASECA, MINNESOTA	31.	49.	67.	53.	50.
STATE UNIV., MISS.	53.	62.	78.	74.	67.
FAUCETT, MISSOURI	41.	45.	68.	61.	54.
KANSAS CITY, MO.	41.	48.	68.	61.	55.
SIKESTON, MISSOURI	45.	54.	75.	68.	60.
SPICKARD, MISSOURI	44.	48.	65.	64.	55.
BOZEMAN, MONTANA	34.	35.	57.	48.	43.
HUNTLEY, MONTANA	37.	43.	66.	57.	50.
LINCOLN, NEBRASKA	36.	44.	68.	62.	53.
NEW BRUNSWICK, N.J.	41.	47.	66.	62.	54.
ITHACA, NEW YORK	39.	41.	61.	54.	49.
COLUMBUS, OHIO	40.	47.	65.	61.	53.
COSHOCTON, OHIO	40.	45.	64.	60.	52.
WOOSTER, OHIO	40.	45.	65.	59.	52.
BARNSDALL, OKLAHOMA	50.	56.	75.	70.	63.
LAKE HEFNER, OKLA.	49.	57.	77.	73.	64.
PAWHUSKA, OKLAHOMA	48.	54.	75.	68.	61.
OTTAWA, ONTARIO	37.	37.	61.	51.	47.
CORVALLIS, OREGON	45.	51.	67.	60.	55.
HOOD RIVER, OREGON	41.	49.	61.	57.	52.

AVERAGE EARTH TEMPERATURE IN DEG. F. TG

THERMAL DIFFUSIVITY IN FT**2/HR ALPHA= .050

STATION STATES	WINTER	SPRING	SUMMER	FALL	YEAR
MEDFORD, OREGON	46.	52.	66.	61.	56.
PENDLETON, OREGON	38.	50.	68.	60.	54.
STATE COLLEGE, PA.	40.	44.	66.	59.	52.
KINGSTON, R. I.	39.	41.	61.	57.	50.
CALHOUN, S.CAROLINA	49.	58.	76.	69.	63.
MADISON, S. DAKOTA	33.	38.	62.	55.	47.
JACKSON, TENNESSEE	48.	55.	72.	64.	59.
TEMPLE, TEXAS	58.	65.	84.	77.	71.
SALT LAKE CITY,UTAH	37.	45.	62.	55.	50.
BURLINGTON, VERMONT	37.	38.	62.	54.	48.
PULLMAN, WASHINGTON	37.	45.	60.	50.	50.
SEATTLE, WASHINGTON	44.	50.	60.	56.	53.
AFTON, WYOMING	39.	42.	59.	53.	48.

Table C3

Thermophysical Properties of Wall/Roof/Floor

Thermal Properties and Code Numbers of Layers Used in Calculations of Coefficients for Wall and Roof Transfer Functions

Description	Code Number	Thickness and Thermal Properties[a]				
		L	*K*	*D*	*SH*	*R*
Outside surface resistance	AO					0.333
1" stucco (asbestos cement or wood siding plaster, etc.)	A1	0.0833	0.4	116	0.20	
4" face brick (dense concrete)	A2	0.333	0.77	125	0.22	
Steel siding (aluminum or other light-weight cladding)	A3	0.005	26.0	480	0.10	
Outside surface resistance, ½" slag, membrane and ⅜" felt	A4	 0.0417 0.0313	 0.83 0.11	 55 70	 0.40 0.40	0.333
Outside surface resistance	A5					0.333
Finish	A6	0.0417	0.24	78	0.26	
Air space resistance	B1					0.91
1" insulation	B2	0.083	0.025	2.0	0.2	
2" insulation	B3	0.167	0.025	2.0	0.2	
3" insulation	B4	0.25	0.025	2.0	0.2	
1" insulation	B5	0.0833	0.025	5.7	0.2	
2" insulation	B6	0.167	0.025	5.7	0.2	
1" wood	B7	0.0833	0.07	37.0	0.6	
2.5" wood	B8	0.2083	0.07	37.0	0.6	
4" wood	B9	0.333	0.07	37.0	0.6	
2" wood	B10	0.167	0.07	37.0	0.6	
3" wood	B11	0.25	0.07	37.0	0.6	
3" insulation	B12	0.25	0.025	5.7	0.2	
4" clay tile	C1	0.333	0.33	70.0	0.2	
4" l.w. concrete block	C2	0.333	0.22	38.0	0.2	
4" h.w. concrete block	C3	0.333	0.47	61.0	0.2	
4" common brick	C4	0.333	0.42	120	0.2	
4" h.w. concrete	C5	0.333	1.0	140	0.2	
8" clay tile	C6	0.667	0.33	70	0.2	
8" l.w. concrete block	C7	0.667	0.33	38.0	0.2	
8" h.w. concrete block	C8	0.667	0.6	61.0	0.2	
8" common brick	C9	0.667	0.42	120	0.2	
8" h.w. concrete	C10	0.667	1.0	140	0.2	
12" h.w. concrete	C11	1.0	1.0	140	0.2	
2" h.w. concrete	C12	0.167	1.0	140	0.2	
6" h.w. concrete	C13	0.5	1.0	140	0.2	
4" l.w. concrete	C14	0.333	0.1	40	0.2	
6" l.w. concrete	C15	0.5	0.1	40	0.2	
8" l.w. concrete	C16	0.667	0.1	40	0.2	
Inside surface resistance	E0					0.685
¾" plaster; ¾" gypsum or other similar finishing layer	E1	0.0625	0.42	100	0.2	
½" slag or stone	E2	0.0417	0.83	55	0.40	
⅜" felt & membrane	E3	0.0313	0.11	70	0.40	
Ceiling air space	E4					1.0
Acoustic Tile	E5	0.0625	0.035	30	0.20	

[a] Units: *L* = feet. *K* = Btu per (hr) (sq ft) (F deg). *D* = lb per cu ft. *SH* = Btu per (lb) (F deg). *R* = (hr) (sq ft) (F deg) per Btu.

Table C4

Typical Watt/ft.^{2} of floor area data

	Lighting	Equipment
Apartment	1.7	1.2
Office	5.0	1.0
Department Stores	4.0	0.0
School	5.0	0.0

Table C5

Shading Coefficients

Reprinted by permission from the 1972 Handbook of Fundamentals (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 345 East 47th Street, New York), pp. 402-408.

Shading Coefficients for Single Glass and Insulating Glass[a]

A. Single Glass

Type of Glass	Nominal Thickness[b]	Solar Trans.[b]	Shading Coefficient	
			$h_0 = 4.0$	$h_0 = 3.0$
Regular Sheet	3/32, 1/8	0.87	1.00	1.00
Regular Plate/Float	1/4	0.80	0.95	0.97
	3/8	0.75	0.91	0.93
	1/2	0.71	0.88	0.91
Grey Sheet	1/8	0.59	0.78	0.80
	3/16	0.74	0.90	0.92
	7/32	0.45	0.66	0.70
	7/32	0.71	0.88	0.90
	1/4	0.67	0.86	0.88
Heat-Absorbing Plate/Float[d]	3/16	0.52	0.72	0.75
	1/4	0.47	0.70	0.74
	3/8	0.33	0.56	0.61
	1/2	0.24	0.50	0.57

B. Insulating Glass[a]

Type of Glass	Nominal Thickness[c]	Solar Trans.[b]		Shading Coefficient	
		Outer Pane	Inner Pane	$h_0 = 4.0$	$h_0 = 3.0$
Regular Sheet Out, Regular Sheet In	3/32, 1/8	0.87	0.87	0.90	0.90
Regular Plate/Float Out, Regular Plate/Float In	1/4	0.80	0.80	0.83	0.83
Heat-Abs Plate/Float Out, Regular Plate/Float In	1/4	0.46	0.80	0.56	0.58

[a] Refers to factory-fabricated units with 3/16, 1/4, or 1/2 in. air space or to prime windows plus storm windows.
[b] Refer to manufacturer's literature for values.
[c] Thickness of each pane of glass, not thickness of assembled unit.
[d] Refers to grey, bronze, and green tinted heat-absorbing plate/float glass.

Shading Coefficients for Single Glass with Indoor Shading by Venetian Blinds and Roller Shades

Type of Glass	Nominal Thickness[a]	Solar Trans.[b]	Type of Shading				
			Venetian Blinds		Roller Shade		
					Opaque		Translucent
			Medium	Light	Dark	White	Light
Regular Sheet Regular Plate/Float Regular Pattern Heat-Absorbing Pattern Grey Sheet	$\frac{3}{32}$ to $\frac{1}{4}$ $\frac{1}{4}$ to $\frac{1}{2}$ $\frac{1}{8}$ to $\frac{9}{32}$ $\frac{1}{8}$ $\frac{3}{16}$, $\frac{7}{32}$	0.87–0.80 0.80–0.71 0.87–0.79 — 0.74, 0.71	0.64	0.55	0.59	0.25	0.39
Heat-Absorbing Plate/Float[d] Heat-Absorbing Pattern Grey Sheet	$\frac{3}{16}$, $\frac{1}{4}$ $\frac{3}{16}$, $\frac{1}{4}$ $\frac{1}{8}$, $\frac{7}{32}$	0.46 — 0.59, 0.45	0.57	0.53	0.45	0.30	0.36
Heat-Absorbing Plate/Float or Pattern Heat-Absorbing Plate/Float[d]	— $\frac{3}{8}$	0.44–0.30 0.34	0.54	0.52	0.40	0.28	0.32
Heat-Absorbing Plate or Pattern	—	0.29–0.15 0.24	0.42	0.40	0.36	0.28	0.31
Reflective Coated Glass							
S.C.[c] = 0.30			0.25	0.23			
0.40			0.33	0.29			
0.50			0.42	0.38			
0.60			0.50	0.44			

[a] Refer to manufacturer's literature for values.
[b] For vertical blinds with opaque white and beige louvers in the tightly closed position, SC is 0.25 and 0.29 when used with glass of 0.71 to 0.80 transmittance.
[c] Shading Coefficient for glass with no shading device.
[d] Refers to grey, bronze, and green tinted heat-absorbing plate/float glass.

Shading Coefficients for Insulating Glass[a] with Indoor Shading by Venetian Blinds and Roller Shades

Type of Glass	Nominal Thickness, each light	Solar Trans.[b]		Type of Shading				
				Venetian Blinds[c]		Roller Shade		
		Outer Pane	Inner Pane			Opaque		Translucent
				Medium	Light	Dark	White	Light
Regular Sheet Out Regular Sheet In Regular Plate/Float Out Regular Plate/Float In	$\frac{3}{32}$, $\frac{1}{8}$ $\frac{1}{4}$	0.87 0.80	0.87 0.80	0.57	0.51	0.60	0.25	0.37
Heat-Absorbing Plate/Float[d] Out Regular Plate/Float In	$\frac{1}{4}$	0.46	0.80	0.39	0.36	0.40	0.22	0.30
Reflective Coated Glass								
SC[e] = 0.20				0.19	0.18			
0.30				0.27	0.26			
0.40				0.34	0.33			

[a] Refers to factory-fabricated units with $\frac{3}{16}$, $\frac{1}{4}$, or $\frac{1}{2}$ in. air space, or to prime windows plus storm windows.
[b] Refer to manufacturer's literature for exact values.
[c] For vertical blinds with opaque white or beige louvers, tightly closed, SC is approximately the same as for opaque white roller shades.
[d] Refers to bronze or green tinted heat-absorbing plate/float glass.
[e] Shading Coefficient for glass with no shading device.

Properties of Representative Indoor Shading

Indoor Shade	Solar Properties (Normal Incidence)		
	Trans.	Reflect.	Absorp.
Venetian Blinds[a] (Ratio of slat width to slat spacing 1.2, slat angle 45 deg)			
Light Colored Slat	0.05	0.55	0.40
Medium Colored Slat	0.05	0.35	0.60
Vertical Blinds			
White Louvers	0.00	0.77	0.23
Roller Shades			
Light Shades (Translucent)	0.25	0.60	0.15
White Shade (Opaque)	0.00	0.80	0.20
Dark Colored Shade (Opaque)	0.00	0.12	0.88

[a] The values shown in this table and preceding tables are based on horizontal Venetian blinds. However, tests show these values may be used for vertical blinds with good accuracy.

Shading Coefficients for Double Glazing with Between-Glass Shading

Type of Glass	Nominal Thickness, each pane	Solar Trans.[a]		Description of Air Space	Type of Shading		
					Venetian Blinds		Louvered Sun Screen
		Outer Pane	Inner Pane		Light	Medium	
Regular Sheet Out / Regular Sheet In	$\frac{3}{32}$, $\frac{1}{8}$	0.87	0.87	Shade in contact with glass or shade separated from glass by air space.	0.33	0.36	0.43
Regular Plate Out / Regular Plate In	$\frac{1}{4}$	0.80	0.80	Shade in contact with glass-voids filled with plastic.	—	—	0.49
Heat-Abs. Plate/Float[b] Out / Regular Plate In	$\frac{1}{4}$	0.46	0.80	Shade in contact with glass or shade separated from glass by air space.	0.28	0.30	0.37
				Shade in contact with glass-voids filled with plastic.	—	—	0.41

[a] Refer to manufacturer's literature for exact values.
[b] Refers to grey, bronze, and green tinted heat-absorbing plate/float glass.

Shading Coefficients for Single and Insulating Glass with Draperies

Glazing	Glass Trans.	Glass SC*	Shading Coefficient For Index Letters in Fig. 10**									
			A	B	C	D	E	F	G	H	I	J
Single Glass												
1/4 in. Regular	0.80	0.95	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80
1/2 in. Regular	0.71	0.88	0.35	0.39	0.43	0.48	0.52	0.56	0.61	0.66	0.70	0.74
1/4 in. Heat Abs.	0.46	0.67	0.33	0.36	0.38	0.41	0.44	0.46	0.49	0.52	0.54	0.57
3/8 in. Heat Abs.	0.34	0.57	0.32	0.34	0.36	0.38	0.41	0.43	0.45	0.47	0.49	0.51
1/2 in. Heat Abs.	0.24	0.50	0.30	0.32	0.33	0.34	0.36	0.38	0.39	0.40	0.42	0.43
Reflective Coated	—	0.60	0.33	0.36	0.38	0.41	0.43	0.46	0.49	0.51	0.54	0.57
(See Manufacturers' literature	—	0.50	0.31	0.33	0.34	0.36	0.38	0.39	0.41	0.42	0.44	0.46
for exact values)	—	0.40	0.26	0.27	0.28	0.29	0.30	0.32	0.33	0.34	0.35	0.36
	—	0.30	0.20	0.21	0.21	0.22	0.23	0.23	0.23	0.24	0.24	0.25
Insulating Glass (1/2 in. Air Space)												
Regular Out and Regular In	0.64	0.83	0:35	0.37	0.42	0.45	0.48	0.52	0.56	0.58	0.62	0.66
Heat Abs. Out and Regular In	0.37	0.56	0.32	0.33	0.35	0.37	0.39	0.41	0.43	0.45	0.47	0.49
Reflective Coated	—	0.40	0.28	0.28	0.29	0.31	0.32	0.34	0.36	0.37	0.37	0.38
(see Manufacturers' literature	—	0.30	0.24	0.24	0.25	0.25	0.26	0.26	0.27	0.27	0.28	0.29
for exact values)	—	0.20	0.15	0.15	0.16	0.16	0.17	0.17	0.18	0.18	0.19	0.19

* For glass alone, with no drapery.
** Shading coefficient values for the SC lines in Fig. 10 for representative glazings. Substitute for the SC index letters in Fig. 10 the values on the line of the glazing selected.

Shading Coefficients for Louvered Sun Screens

Profile Angle, deg	Group 1		Group 2	
	Trans-mittance	SC	Trans-mittance	SC
10	0.23	0.35	0.25	0.33
20	0.06	0.17	0.14	0.23
30	0.04	0.15	0.12	0.21
40 and above	0.04	0.15	0.11	0.20

Profile Angle, deg	Group 3		Group 4	
	Trans-mittance	SC	Trans-mittance	SC
10	0.40	0.51	0.48	0.59
20	0.32	0.42	0.39	0.50
30	0.21	0.31	0.28	0.38
40 and above	0.07	0.18	0.20	0.30

Group 1. Black, width over spacing ratio 1.15/1, 23 louvers per inch.
Group 2. Light color, high reflectance, otherwise same as Group 1.
Group 3. Black or dark color, w/s ratio 0.85/1, 17 louvers per inch.
Group 4. Light color or unpainted aluminum, high reflectance, otherwise same as Group 3.
U-value = 0.85 Btuh/(sq ft)(F deg) for all groups when used with single glazing.

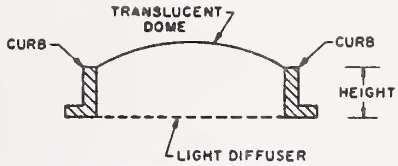
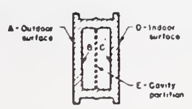


Fig. .... Terminology for Domed Skylights

Table 23 .... Shading Coefficients for Domed Skylights

Dome	Light Diffuser (Translucent)	Curb (See Fig.) Height, in.	Curb Width to Height Ratio	Shading Coefficient	U-Value
Clear $\tau=0.86$	yes $\tau=0.58$	0	∞	0.61	0.46
		9	5	0.58	0.43
		18	2.5	0.50	0.40
Clear $\tau=0.86$	None	0	∞	0.99	0.80
		9	5	0.88	0.75
		18	2.5	0.80	0.70
Translucent $\tau=0.52$	None	0	∞	0.57	0.80
		9	5	0.51	0.75
		18	2.5	0.46	0.70
Translucent $\tau=0.27$	None	0	∞	0.34	0.80
		9	5	0.30	0.75
		18	2.5	0.28	0.70

Shading Coefficients for Hollow Glass Block Wall Panels[a]

Type of Glass Block[b]	Description of Glass Block 	Shading Coefficient[c] Panels[d] in the Sun	Shading Coefficient[c] Panels[e] in the Shade (N, NW, W, SW)
Type I	Glass Colorless or Aqua Smooth Face A, D: Smooth B, C: Smooth or wide ribs, or flutes horizontal or vertical, or shallow configuration. E: None	0.65	0.40
Type IA	Same as Type I except A: Ceramic Enamel on exterior face.	0.27	0.20
Type II	Same as Type I except E: Glass fiber screen.	0.44	0.34
Type III	Glass Colorless or Aqua A, D: Narrow vertical ribs or flutes. B, C: Horizontal light-diffusing prisms, or horizontal light-directing prisms. E: Glass fiber screen.	0.33	0.27
Type IIIA	Same as Type III except E: Glass fiber screen with green ceramic spray coating, or glass fiber screen and gray glass, or glass fiber screen with light-selecting prisms.	0.25	0.18

[a] For glass block used in horizontal skylights see Tables 28 and 29, Chapter 26 of the 1963 ASHRAE GUIDE AND DATA BOOK.

[b] All values are for 7¾ × 7¾ × 3⅞ in. block, set in light-colored mortar. For 11¾ × 11¾ × 3⅞ in. block increase coefficients by 15 percent, and for 5¾ × 5¾ × 3⅞ in. blocks reduce coefficients by 15 percent.

[c] Shading coefficients are to be applied to Heat Gain Factors for one hour earlier than the time for which the load calculation is made to allow for heat storage in the panel.

[d] Shading coefficients are for peak load condition, but provide a close approximation for other conditions. For more precise values for other conditions, see Reference 20.

[e] For NE, E, and SE panels in the shade add 50 percent to the values listed for panels in the shade.

Table C6

Absorptivity of Materials to Solar Radiation

Reprinted by permission from Thermal Radiation Properties Survey (Honeywell Research Center, Minneapolis, Minnesota, 1966), pp. 245-248.

BUILDING MATERIALS, SOLAR ABSORPTIVITY

Material	Solar Absorptivity
BRICKS	
Clay, cream, glazed	0.36
Clay, Fleton, dark portion	0.63
Clay, Felton, light portion	0.40
Lime clay, French	0.46
Gault, cream	0.36
Light buff	0.516
Light buff but darker than above	0.60
Mottled purple	0.77
Red	0.699
Red, common and tiles	0.68
Red, darker, glazed	0.766
Red, wire-cut	0.52
Stafford blue	0.89
Stock, light fawn	0.57
White glazed	0.26
White glazed (2 specimens)	0.25-0.27
TILES	
Clay, purple (dark)	0.82
Clay, dark purple, machine-made	0.81
Red	0.67
Red, hand-made	0.60
Red, light, Dutch	0.43
Red, light, machine- ade	0.66
Red, light, machine-made	0.62
Concrete, uncolored	0.65
Concrete, black	0.91
Concrete, dark	0.91
Concrete, brown	0.85
Concrete, brown, very rough	0.88

(Continued on next page)

Material	Solar Absorptivity
ASPHALT	
New, 3 specimens	0.91
New, 3 specimens	0.91
New, another specimen	0.93
Pavement	0.852
Pavement, free from dust	0.928
Pavement, weathered, 3 specimens	0.82
	0.83
	0.89
ROOFING	
Bituminous felt, aluminized [1]	0.40
Bituminous felt	0.88
Bituminous felt	0.89
Bitumin-covered, brown	0.87
Sheet, green	0.86
Sheet, black matte surface	0.97
Sheet, black matte surface	0.97
ASBESTOS CEMENT	
Aged	0.75
Aged 6 months	0.61
Aged 12 months	0.71
Aged 6 years, very dirty	0.83
Red	0.69
Red	0.74
Washed with soap and water	0.40
White	0.61
White (2 samples)	0.49-0.42
LIMESTONE	
Anston	0.60
Bath	0.53
Clipsham	0.46
Indiana	0.571
Ketton	0.42
Portland	0.36
Steetley	0.33
SAND-LIME	
Light-red	0.55
Red	0.68
White, fine sand	0.41
White, coarse sand	0.50
MARBLE	
White	0.44
Ground, unpolished	0.465
Cleavage	0.592
GRANITE	
Reddish	0.55
FELDSPAR	
$K_2O\ Al_2O_3\ 6SiO_2$	0.606
MORTAR SCREENED	0.73

(Continued on next page)

BUILDING MATERIALS, SOLAR ABSORPTIVITY (Continued)

Material	Solar Absorptivity
SANDSTONE	
Grey, Bristol pennant	0.76
Polmaise, light fawn	0.54
Stancliffe, light grey	0.62
Woolton, red	0.73
WHITEWASH	
On galvanized iron	0.22
On galvanized iron	0.22
On galvanized iron	0.26
On galvanized iron, a very thick layer	0.20
SLATE	
Blue grey	0.87
Blue, grey	0.85
Clay, dark	0.933
Greenish, grey, rough	0.88
Grey, dark	0.90
Grey, dark, fairly rough	0.90
Grey, dark, fairly rough	0.90
Grey, dark, smooth	0.89
Purple	0.86
Silver-grey, Norwegian	0.79

BUILDING MATERIALS, SOLAR ABSORPTIVITY

Building Materials	Solar Absorptivity
Thickly tinned surface	0.05
Wood, smoothly planed	0.78
Basalt	0.72
Red sandstone	0.60
Marble (white)	0.58
Granite	0.45
Dolomite lime	0.41
Clay shale	0.69
Paris plaster	0.78
White plastered wall	0.92
Gravel	0.29
Sand	0.76
Glass	0.93
Sawdust	0.75
Clay	0.39
Red brick wall	0.93

CLOTH, SOLAR REFLECTIVITY

Material	Solar Reflectivity
QM1, cotton sheeting bleached, 4 oz per yd	0.62-0.66
QM2, cotton sateen prepared for dyeing, 9 oz per yd	0.68-0.72
QM4, cotton sateen undyed, 9 oz per yd	0.69-0.72
QM6, cotton sateen, medium gray, 9 oz per yd	0.53
QM7, cotton sateen dark gray, 9 oz per yd	0.24
50 percent wool, 50 percent cotton knit, undyed, 10.5 oz per yd	0.62
Cotton knit, undyed, 3 oz per yd	0.60

PARACHUTE CLOTH, SOLAR ABSORPTIVITY, REFLECTIVITY, AND TRANSMISSIVITY

Material	Absorptivity	Reflectivity	Transmissivity
Dacron, 100 lb	0.05	0.35	0.60
Dacron, 300 lb	0.11	0.54	0.35
Dacron, 600 lb	0.12	0.61	0.27
Dacron, 800 lb	0.19	0.62	0.19
Nylon rip-stop (orange) 1.1 oz per sq yd, MIL-C-7020B Type I	0.13	0.23	0.64
Nylon rip-stop 1.1 oz per sq yd (white) MIL-C-7020	0.08	0.27	0.65
Nylon rip-stop 1.6 oz per sq yd (white) MIL-C-7020B Type III	0.06	0.22	0.72
Nylon cloth 2.25 oz per sq yd, MIL-C-7350B Type I	0.05	0.36	0.59
Nylon cloth 4.30 oz per sq yd, MIL-C-8021 Type I	0.08	0.44	0.48
Nylon cloth 7.0 oz per sq yd, MIL-C-8021 Type II	0.13	0.46	0.41
Nylon cloth 14.0 oz per sq yd, MIL-C-8021 Type III	0.11	0.62	0.27

NBSLD

SAMPLE INPUT/OUTPUT

```
  CEILING TO COND. SPACE-3.16 W-NO SHADE-25( SOLARGRAY
0,0,0,0,0,0,0,1,1,1,1,1,1,1,1,1,1,0,0,0,0,0,0,0
0,0,0,0,0,0,0,1,1,1,1,1,1,1,1,1,1,0,0,0,0,0,0,0
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80,80,80,80,80,80,80,75,75,75,75,75,75,75,75,75,75,80,80,80,80,80,80,80
60,60,60,60,60,60,60,70,70,70,70,70,70,70,70,70,70,60,60,60,60,60,60,60
60,80,20,50
31,0,10
7,21,201,97,20,67,20,60,50,0.1,87,42,6,13.5,60
  ROOM WITH GLASS AREA FACING SOUTH
0,0,0
4
0.167,1.0,140.0,0.2,0.0
0.334,0.025,5.7,0.2,0.0
0.0313,0.11,70.0,0.4,0.0
0.0417,0.83,55.0,0.4,0.0
   2-" HW CONCRETE
   4" INSULATION
   3/8" FELT & MEMBRANE
   1/2" SLAG
4
0.005,26.0,480.0,0.1,0.0
0,0,0,0,.91
0.167,0.0133,2.5,0.38,0.0
0.005,26.0,480.0,0.1,0.0
   STEEL SIDING
   AIR SPACE
   INSULATION MODIFIED
   STEEL SIDING
2
0.5,1.0,140.0,0.2,0.0
0.3637,0.025,5.7,0.2,0.0
   6" CONCRETE
   4.43" INSULATION
3
0.04166,0.42,100.0,0.2,0.0
0,0,0,0,.91
0.04166,0.42,100.0,0.2,0.0
   1/2" GYPSUM BOARD
   AIR SPACE
   1/2" GYPSUM BOARD
2
0.5,1.0,140.0,0.2,0.0
0,0,0,0,1.
   6" CONCRETE
   CEILING AIR SPACE
2
```

```
0,0,0,0,1.
0.5,1.0,140.0,0.2,0.0
   CEILING AIR SPACE
   6" CONCRETE
0
1.0,3.16,1.0,2.0,0.0,0.5,0.0,30.0,0.25,0.25,0.0,1.0
3,1,8,17
75,60,0,0,70,60
1,1
2,1,1,1
13.5,13.5,9.0
6,6,182.25,0,0,0,.85,0
0,0,0,0,0,0,0
0,0,0,0,0,0,0,0
2,2,91.12,0,0,0,.85,0
0,0,0,0,0,0,0
0,0,0,0,0,0,0,0
3,10,30.38,0,1.06,.67,0,0
0,0,0,0,0,0,0
0,0,0,0,0,0,0,0
6,4,121.5,90,0,0,0,0
0,0,0,0,0,0,0
0,0,0,0,0,0,0,0
6,4,121.5,180,0,0,0,0
0,0,0,0,0,0,0
0,0,0,0,0,0,0,0
6,4,121.5,-90,0,0,0,0
0,0,0,0,0,0,0
0,0,0,0,0,0,0,0
6,5,182.25,0,0,0,0,0
0,0,0,0,0,0,0
0,0,0,0,0,0,0,0
0,0,0,0,0,0
0,0,0,6,0
  ROOM WITH GLASS AREA FACING WEST
90,1,1
   ROOM WITH GLASS AREA FACING NORTH
90,1,1
   ROOM WITH GLASS AREA FACING EAST
90,1,1
Q


CONGRATULATIONS!! NOW YOU ARE ON NBSLD

 WE ASSUME YOU HAVE ALREADY PREPARED THE DATA
 ON NBS DATA FORMS..IF YOU HAVE NOT, PLEASE TURN OFF
 THE TERMINAL AND HAVE YOUR DATA READY ON THE DATA FORMS


RUNID,RUNTYP,ASHRAE,IDETAL,METHOD,IRFMTP
RUNID.........IDENTIFICATION OF THE RUN
              1 NEED RESPONSE FACTOR DATA
```

```
               2 SKIP RESPONSE FACTOR DATA
RUNTYP........TYPE OF RUN
               1 ENERGY CALCULATION ..NEEDS WEATHER TAPE
               2 DESIGN LOAD CALCULATION
               3 DESIGN AND ENERGY LOAD CALCULATIONS
ASHRAE........0   USE RMTMP
               1   USE ASHRAE WEIGHTING FACTORS
IDETAL........0   NO DETAILED OUTPUT
               1   DETAILED OUTPUT
METHOD........0   REGULAR TREATMENT FOR THE ROOM
               1   SPECIAL TREATMENT OF THE ROOM
IRFMTP........  OUTPUT TAPE UNIT NO. TO ROSS MERIWETHER
                SYSTEM SIMULATION PROGRAM. IF NO TAPE IS
                DESIRED, IRFMTP=0
  CEILING TO COND. SPACE-3.16 W-NO S
LIGHTING SCHEDULE FOR WEEKDAYS
EQUIPMENT USAGE SCHEDULE FOR WEEKDAYS
OCCUPANCY SCHEDULE FOR WEEKDAYS
LIGHTING SCHEDULE FOR WEEKEND
EQUIPMENT SCHEDULE FOR WEEKENDS
OCCUPANCY SCHEDULE FOR WEEKEND
LIGHTING SCHEDULE FOR THE VACATION PERIOD
EQUIPMENT USAGE SCHEDULE FOR THE VACATION PERIOD
OCCUPANCY SCHEDULE FOR THE VACATION PERIOD
THERMOSTAT SETTING FOR THE COOLING SEASON
THERMOSTAT SETTING FOR THE HEATING SEASON
RMDBWO,RMDBSO,RHW,RHS
DATA SHEET NO 1:NDAY,NSKIP,TAPE2
DATA SHEET NO 2 &3 :MONTH,DAY,ELAPS,DBMAX,RANGE,WBMAX,DBMWT,TGS,TGW,UG,LONG,LAT,TZN,ZLF,RHOW
DATA SHEET NO 4: NAME OF THE ROOM
DATA SHEET NO 5:IROT,ISKIP,INCLUDE
DATA SHEET NO 6 N/L,K,P,C,R
DATA SHEET NO 7: DESCRIPTION OF EACH LAYER

  IRF=         1

  WALL COMPOSITION
```

LAYER NO	L(I)	K(I)	(I)	C(I)	RES(I)	DESCRIPTION OF LAYERS
1	.167	1.000	140.00	.200	0.	2-" HW CONCRETE
2	.334	.025	5.70	.200	0.	4" INSULATION
3	.031	.110	70.00	.400	0.	3/8" FELT & MEMBRANE
4	.042	.830	55.00	.400	0.	1/2" SLAG

```
                 TIME INCREMENT DT= 1.

                THERMAL CONDUCTANCE       UT=   .072
```

RESPONSE FACTORS

J	X	Y	Z
0	4.6018	.0039	1.9307
1	-4.3324	.0375	-1.8332
2	-.1798	.0241	-.0213
3	-.0150	.0055	-.0034
4	-.0020	.0010	-.0006
5	-.0003	.0002	-.0001
6	-.0001	.0000	-.0000
7	-.0000	.0000	-.0000
8	-.0000	.0000	-.0000

COMMON RATIO CR= .17519

DATA SHEET NO 7: DESCRIPTION OF EACH LAYER

IRF= 2

WALL COMPOSITION

LAYER NO	L(I)	K(I)	(I)	C(I)	RES(I)	DESCRIPTION OF LAYERS
1	.005	26.000	480.00	.100	0.	STEEL SIDING
2	0.	0.	0.	0.	.91	AIR SPACE
3	.167	.013	2.50	.380	0.	INSULATION MODIFIED
4	.005	26.000	480.00	.100	0.	STEEL SIDING

TIME INCREMENT DT= 1.

THERMAL CONDUCTANCE UT= .074

RESPONSE FACTORS

J	X	Y	Z
0	.3598	.0467	.3705
1	-.2851	.0271	-.2958
2	-.0004	.0004	-.0004
3	-.0000	.0000	-.0000
4	-.0000	.0000	-.0000

COMMON RATIO CR= .01336

DATA SHEET NO 7: DESCRIPTION OF EACH LAYER

IRF= 3

WALL COMPOSITION

LAYER NO	L(I)	K(I)	(I)	C(I)	RES(I)	DESCRIPTION OF LAYERS
1	.500	1.000	140.00	.200	0.	6" CONCRETE
2	.364	.025	5.70	.200	0.	4.43" INSULATION

TIME INCREMENT DT= 1.

THERMAL CONDUCTANCE UT= .066

RESPONSE FACTORS

J	X	Y	Z
0	5.9702	.0001	.1906
1	-3.5466	.0043	-.1088
2	-.7415	.0129	-.0111
3	-.4844	.0134	-.0025
4	-.3376	.0104	-.0007
5	-.2367	.0075	-.0003
6	-.1661	.0053	-.0002

COMMON RATIO CR= .70105

DATA SHEET NO 7: DESCRIPTION OF EACH LAYER

IRF= 4

WALL COMPOSITION

LAYER NO	L(I)	K(I)	(I)	C(I)	RES(I)	DESCRIPTION OF LAYERS
1	.042	.420	100.00	.200	0.	1/2" GYPSUM BOARD
2	0.	0.	0.	0.	.91	AIR SPACE
3	.042	.420	100.00	.200	0.	1/2" GYPSUM BOARD

TIME INCREMENT DT= 1.

THERMAL CONDUCTANCE UT= .902

RESPONSE FACTORS

J	X	Y	Z
0	1.6653	.8321	1.6653
1	-.7631	.0701	-.7631
2	0.	0.	0.
3	0.	0.	0.
4	0.	0.	0.

COMMON RATIO CR=0.

DATA SHEET NO 7: DESCRIPTION OF EACH LAYER

IRF= 5

WALL COMPOSITION

LAYER NO	L(I)	K(I)	(I)	C(I)	RES(I)	DESCRIPTION OF LAYERS
1	.500	1.000	140.00	.200	0.	6" CONCRETE
2	0.	0.	0.	0.	1.00	CEILING AIR SPACE

TIME INCREMENT DT= 1.

THERMAL CONDUCTANCE UT= .667

RESPONSE FACTORS

J	X	Y	Z
0	5.9702	.0308	.8739
1	-3.5394	.1876	-.0879
2	-.6987	.1689	-.0459
3	-.4083	.1067	-.0281
4	-.2513	.0660	-.0173
5	-.1552	.0408	-.0107
6	-.0959	.0252	-.0066

COMMON RATIO CR= .61750

DATA SHEET NO 7: DESCRIPTION OF EACH LAYER

IRF= 6

WALL COMPOSITION

LAYER NO	L(I)	K(I)	(I)	C(I)	RES(I)	DESCRIPTION OF LAYERS
1	0.	0.	0.	0.	1.00	CEILING AIR SPACE
2	.500	1.000	140.00	.200	0.	6" CONCRETE

TIME INCREMENT DT= 1.

THERMAL CONDUCTANCE UT= .667

RESPONSE FACTORS

J	X	Y	Z
0	.8739	.0308	5.9702
1	-.0879	.1876	-3.5394
2	-.0459	.1689	-.6987
3	-.0281	.1067	-.4083
4	-.0173	.0660	-.2513
5	-.0107	.0408	-.1552

COMMON RATIO CR= .61731

CONDUCTION TRANSFER FUNCTIONS FOR IRF= 1

J	X	Y	Z	CR
1	4.60175	.00387	1.93073	.17519
2	-5.13862	.03679	-2.17146	
3	.57926	.01753	.29987	
4	.01645	.00125	.00035	
5	.00065	.00005	.00000	
6	.00002	.00000	-.00000	

CONDUCTION TRANSFER FUNCTIONS FOR IRF= 2

J	X	Y	Z	CR
1	.35979	.04672	.37049	.01336
2	-.28990	.02647	-.30073	
3	.00338	.00008	.00350	

CONDUCTION TRANSFER FUNCTIONS FOR IRF= 3

J	X	Y	Z	CR
1	5.97021	.00007	.19055	.70105
2	-7.73202	.00429	-.24238	
3	1.74482	.00983	.06516	
4	.03547	.00437	.00527	
5	.00196	.00102	.00102	

CONDUCTION TRANSFER FUNCTIONS FOR IRF= 4

J	X	Y	Z	CR
1	1.66530	0.	1.66530	0.
2	-.76308	0.	-.76308	

CONDUCTION TRANSFER FUNCTIONS FOR IRF= 5

J	X	Y	Z	CR
1	5.97024	.03084	.87386	.61750
2	-7.22605	.16854	-.62750	
3	1.48689	.05307	.00839	
4	.02317	.00242	.00024	
5	.00080	.00010	.00001	

CONDUCTION TRANSFER FUNCTIONS FOR IRF= 6

J	X	Y	Z	CR
1	.87386	.03084	5.97024	.61731
2	-.62732	.16855	-7.22487	
3	.00837	.05311	1.48619	
4	.00023	.00245	.02303	

DATA SHEET NO 8: ROOMNO,QLITY,QEQPY,QCU,FLCG,FRAS,TS,CFMS,ARCHGS,ARCHGW,ARCHGM,ZNORM
DATA SHEET NO.9: IW,IL,ISTART,ILEAVE
DATA SHEET NO 10: TUL,TLL,QCMAX,QHMAX,DBVMAX,DBVMIN
DATA SHEET NO 11: ITHST,ITK
DATA SHEET NO 12: NS,NW,NN,NE,L,W,H
DATA SHEET 13 AND 14: ROOM SURFACE DATA AND EXTERIOR SURFACE SHADOW DATA

ROOMNO	HT	AG	NOFLR	QCU	ARCHGS	ARCHGW
1.0	9.0	182.3	1.0	2.0	.3	.3

LAT	LONG	TZN	ZNORM
42.0	87.0	6.0	1.0

QLITY	QEQPX	CFMV	DBIN	TG	TV	DPIN
3.2	1.0	30.0	70.0	0.	0.	50.0

NEXP	ITK	ITHST
7	1	1

DATA SHEET NO 15: UENDW,UCELNG,AENDW,ATCHT,AIRCHG,AIRNT
DATA SHEET NO 16: IEXTSD,IEXMS,IEXME,NTVNT,NVENT

UENDW	UCELNG	AENDW	ATCHT
0.	0.	0.	0.

SURFACE NO	ITYPE	IHT	IRF	ABSP	U	H	A	WAZ	SHADE	UT	HI
1	6	1	6	0.	.46	0.	182.25	0.	0.	.67	.54
2	2	1	2	.85	.07	6.00	91.12	0.	0.	.07	.54
3	3	-1	10	0.	1.06	6.00	30.38	0.	.67	10.89	.54
4	6	1	4	0.	.56	0.	121.50	90.00	0.	.90	.54
5	6	1	4	0.	.56	0.	121.50	180.00	0.	.90	.54
6	6	1	4	0.	.56	0.	121.50	-90.00	0.	.90	.54
7	6	1	5	0.	.46	0.	182.25	0.	0.	.67	.54

SHADOW CASTING DATA

FL	HT	FP	AW	BWL	BWR	D	FP1	A1	B1	C1	FP2	A2	B2	C2
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

RADIATION INTERCHANGE FACTORS

SURFACE	1	2	3	4	5	6	7	8	9	10
1	0.	.127	.043	.170	.170	.170	.320			
2	.255	0.	0.	.171	.148	.171	.255			
3	.255	0.	0.	.171	.148	.171	.255			
4	.255	.128	.043	0.	.171	.148	.255			
5	.255	.111	.037	.171	0.	.171	.255			
6	.255	.128	.043	.148	.171	0.	.255			

7	.320	.127	.043	.170	.170	.170	0.

HEATING LOAD IN BTU PER HOUR

```
        SENSIBLE LOAD =      3917.
        LATENT   LOAD =       317.
        -------------------------
        TOTAL    LOAD =      4234.
```

SOLAR DATA (QSUN/QGLASS)

	1																						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	2																						
0.	0.	0.	0.	2.	13.	23.	44.	80.	109.	128.	133.	125.	104.	73.	36.	21.	11.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	3																						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	1.	9.	15.	21.	37.	56.	69.	73.	67.	53.	33.	19.	14.	8.	0.	0.	0.	0.	0.	0.
	4																						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	5																						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	6																						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	7																						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

ROOM NAME= ROOM WITH GLASS AREA FACING SOUTH

MONTH	DAY	MHR	QLMAX	CLDAY	HLDAY	DBA
7	21	14	-4483.	-39486.	0.	85.7

***** YEAR = 2000 ***** MONTH = 7 ***** DAY = 21

TIME	DBOUT	WBOUT	DBIN	RHIN	QLS	QLL
1	79.6	60.9	77.6	36.1	0.	0.
2	78.6	60.5	77.4	36.3	0.	0.
3	77.8	60.2	77.3	36.5	0.	0.

4	77.2	60.0	77.1	36.7	0.	0.
5	77.0	60.0	77.0	36.8	-0.	0.
6	77.4	60.1	77.1	36.7	-0.	0.
7	78.4	60.4	77.3	36.5	-0.	0.
8	80.2	61.1	75.0	50.0	-2897.	2.
9	82.8	62.0	75.0	50.0	-3224.	48.
10	85.8	63.0	75.0	50.0	-3611.	48.
11	89.2	64.1	75.0	50.0	-3989.	48.
12	92.4	65.1	75.0	50.0	-4301.	48.
13	94.8	65.9	75.0	50.0	-4483.	48.
14	96.4	66.4	75.0	50.0	-4531.	48.
15	97.0	66.6	75.0	50.0	-4451.	48.
16	96.4	66.4	75.0	50.0	-4294.	48.
17	95.0	65.9	75.0	50.0	-4141.	48.
18	92.8	65.2	79.4	34.1	0.	0.
19	90.2	64.4	79.1	34.4	-0.	0.
20	87.6	63.6	78.8	34.8	-0.	0.
21	85.4	62.8	78.5	35.1	0.	0.
22	83.4	62.2	78.2	35.4	-0.	0.
23	81.8	61.6	78.0	35.7	-0.	0.
24	80.6	61.2	77.8	35.9	-0.	0.

```
DBA = 85.74
QLDSUM =    -39486.


TOTAL COOLING CONSUMPTION PER DAY =    -39486. BTU
TOTAL HEATING CONSUMPTION PER DAY =          0. BTU
TOTAL COOLING CONSUMPTION FOR THE ROOM OVER THE   1 DAY PERIOD =-.39486E+05 BTU
TOTAL HEATING CONSUMPTION FOR THE ROOM OVER THE   1 DAY PERIOD = .42152E-03 BTU
TOTAL COOLING CONSUMPTION FOR  1 ROOMS =-.39486E+05 BTU
TOTAL HEATING CONSUMPTION FOR  1 ROOMS = .42152E-03 BTU
DATA SHEET NO 4: NAME OF THE ROOM
 STOP
L
  CEILING TO COND. SPACE-3.16 W-NO SHADE-25( SOLARGRAY
0,0,0,0,0,0,0,1,1,1,1,1,1,1,1,1,1,0,0,0,0,0,0,0
0,0,0,0,0,0,0,1,1,1,1,1,1,1,1,1,1,0,0,0,0,0,0,0
0,0,0,0,0,0,0,1,1,1,1,1,1,1,1,1,1,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
80,80,80,80,80,80,80,75,75,75,75,75,75,75,75,75,75,80,80,80,80,80,80,80
60,60,60,60,60,60,60,70,70,70,70,70,70,70,70,70,70,60,60,60,60,60,60,60
60,80,20,50
31,0,0
7,21,201,97,20,67,20,60,50,0.1,87,42,6,13.5,60
  ROOM WITH GLASS AREA FACING SOUTH
```

```
   18      0,0,0
   60      1.0,3.16,1.0,2.0,0.0,0.5,0.0,30.0,0.25,0.25,0.0,1.0
   61      3,1,8,17
   62      75,60,0,0,70,60
   63      1,1
   64      2,1,1,1
   65      13.5,13.5,9.0
   66      6,6,182.25,0,0,0,.85,0
   67      0,0,0,0,0,0,0
   68      0,0,0,0,0,0,0,0
   69      2,2,91.12,0,0,0,.85,0
   70      0,0,0,0,0,0,0
   71      0,0,0,0,0,0,0,0
   72      3,10,30.38,0,1.06,.67,0,0
   73      0,0,0,0,0,0,0
   74      0,0,0,0,0,0,0,0
   75      6,4,121.5,90,0,0,0,0
   76      0,0,0,0,0,0,0
   77      0,0,0,0,0,0,0,0
   78      6,4,121.5,180,0,0,0,0
   79      0,0,0,0,0,0,0
   80      0,0,0,0,0,0,0,0
   81      6,4,121.5,-90,0,0,0,0
   82      0,0,0,0,0,0,0
   83      0,0,0,0,0,0,0,0
   84      6,5,182.25,0,0,0,0,0
   85      0,0,0,0,0,0,0
   86      0,0,0,0,0,0,0,0
   87      0,0,0,0,0,0
   88      0,0,0,6,0
Q


CONGRATULATIONS!! NOW YOU ARE ON NBSLD

 WE ASSUME YOU HAVE ALREADY PREPARED THE DATA
 ON NBS DATA FORMS..IF YOU HAVE NOT, PLEASE TURN OFF
 THE TERMINAL AND HAVE YOUR DATA READY ON THE DATA FORMS


RUNID,RUNTYP,ASHRAE,IDETAL,METHOD,IRFMTP
RUNID.........IDENTIFICATION OF THE RUN
              1 NEED RESPONSE FACTOR DATA
              2 SKIP RESPONSE FACTOR DATA
RUNTYP........TYPE OF RUN
              1 ENERGY CALCULATION ..NEEDS WEATHER TAPE
              2 DESIGN LOAD CALCULATION
              3 DESIGN AND ENERGY LOAD CALCULATIONS
ASHRAE........0   USE RMTMP
              1   USE ASHRAE WEIGHTING FACTORS
IDETAL........0   NO DETAILED OUTPUT
              1   DETAILED OUTPUT
METHOD........0   REGULAR TREATMENT FOR THE ROOM
```

```
              1   SPECIAL TREATMENT OF THE ROOM
IRFMTP........  OUTPUT TAPE UNIT NO. TO ROSS MERIWETHER
                SYSTEM SIMULATION PROGRAM. IF NO TAPE IS
                DESIRED, IRFMTP=0
  CEILING TO COND. SPACE-3.16 W-NO S
LIGHTING SCHEDULE FOR WEEKDAYS
EQUIPMENT USAGE SCHEDULE FOR WEEKDAYS
OCCUPANCY SCHEDULE FOR WEEKDAYS
LIGHTING SCHEDULE FOR WEEKEND
EQUIPMENT SCHEDULE FOR WEEKENDS
OCCUPANCY SCHEDULE FOR WEEKEND
LIGHTING SCHEDULE FOR THE VACATION PERIOD
EQUIPMENT USAGE SCHEDULE FOR THE VACATION PERIOD
OCCUPANCY SCHEDULE FOR THE VACATION PERIOD
THERMOSTAT SETTING FOR THE COOLING SEASON
THERMOSTAT SETTING FOR THE HEATING SEASON
RMDBWO,RMDBSO,RHW,RHS
DATA SHEET NO 1:NDAY,NSKIP,TAPE2
DATA SHEET NO 2 &3 :MONTH,DAY,ELAPS,DBMAX,RANGE,WBMAX,DBMWT,TGS,TGW,UG,LONG,LAT,IZN,ZLF,RHOW
DATA SHEET NO 4: NAME OF THE ROOM
DATA SHEET NO 5:IROT,ISKIP,INCLUDE
DATA SHEET NO 8: ROOMNO,QLITY,QEQPY,QCU,FLCG,FRAS,TS,CFMS,ARCHGS,ARCHGW,ARCHGM,ZNORM
DATA SHEET NO.9: IW,IL,ISTART,ILEAVE
DATA SHEET NO 10: TUL,TLL,QCMAX,QHMAX,DBVMAX,DBVMIN
DATA SHEET NO 11: ITHST,ITK
DATA SHEET NO 12: NS,NW,NN,NE,L,W,H
DATA SHEET 13 AND 14: ROOM SURFACE DATA AND EXTERIOR SURFACE SHADOW DATA
DATA SHEET NO 15: UENDW,UCELNG,AENDW,ATCHT,AIRCHG,AIRNI
DATA SHEET NO 16: IEXTSD,IEXMS,IEXME,NTVNT,NVENT
```

ROOM NAME= ROOM WITH GLASS AREA FACING SOUTH

MONTH	DAY	MHR	QLMAX	CLDAY	HLDAY	DBA
1	1	13	0.	-0.	0.	33.4
1	2	8	2558.	-0.	13858.	24.0
1	3	8	2625.	-0.	10834.	28.8
1	4	15	-1074.	-4118.	3971.	41.8
1	5	6	0.	-0.	0.	36.1
1	6	20	0.	-0.	0.	31.3
1	7	8	2023.	-0.	10091.	35.5
1	8	8	1723.	-0.	9349.	35.5
1	9	8	1372.	-0.	4460.	36.7
1	10	12	-256.	-316.	4195.	37.6
1	11	8	2710.	-0.	16146.	28.5
1	12	16	0.	-0.	0.	32.6
1	13	15	0.	-0.	0.	37.5
1	14	8	2667.	-0.	13764.	24.4
1	15	9	3459.	-0.	24939.	17.4

1	16	9	3366.	-0.	16866.	22.8
1	17	10	3425.	-0.	26931.	13.8
1	18	8	2763.	-0.	17555.	18.2
1	19	12	0.	-0.	0.	25.0
1	20	15	0.	-0.	0.	32.5
1	21	8	1784.	-461.	4521.	40.3
1	22	15	-957.	-5860.	625.	48.6
1	23	10	-1143.	-6187.	698.	49.1
1	24	8	2975.	-0.	16799.	25.4
1	25	8	2195.	-0.	12361.	30.0
1	26	12	0.	-0.	0.	38.5
1	27	8	0.	-0.	0.	40.8
1	28	8	1516.	-0.	7301.	37.2
1	29	8	1434.	-0.	5529.	38.5
1	30	8	1682.	-0.	8781.	38.0
1	31	8	1548.	-0.	7599.	35.2

```
TOTAL COOLING CONSUMPTION FOR  1 ROOMS =-.16941E+05 BTU
TOTAL HEATING CONSUMPTION FOR  1 ROOMS = .23717E+06 BTU
DATA SHEET NO 4: NAME OF THE ROOM
 STOP
```

10. Appendix D

Fortran Listing of NBSLD

Although the attached Fortran listing of the NBSLD routine basically embodies the algorithms of Appendix A, some of the subroutines are considerably simplified if compared with the exact adaptation of Appendix A.

It is cautioned also that the Fortran used herein is the INFONET version of Fortran V, which is somewhat different from the ANSI standard Fortran.

```
      SUBROUTINE ABCD2 (Z,K,L,G,A,B,C,D,NL)
      DIMENSION AX(10),BX(10),CX(10),DX(10),G(10)
      REAL K(10),L(10)
      PI=4.*ATAN(1.)
      PP=PI*0.5
      DO 50 I=1,NL
      IF (G(I)) 40,40,10
   10 IF (Z) 30,30,20
   20 ZQ=SQRT(Z/G(I))
      ZQL=ZQ*L(I)
      CO=SIN(ZQL)
      C1=COS(ZQL)
      S1=CO/ZQL
      S2=(S1-C1)/ZQL/ZQL
      AX(I)=C1
      BX(I)=L(I)/K(I)*S1
      CX(I)=-ZQL*K(I)/L(I)*CO
      DX(I)=C1
      GO TO 50
   30 AX(I)=1.
      CX(I)=0.
      DX(I)=1.
      BX(I)=L(I)/K(I)
      GO TO 50
   40 AX(I)=1.
      BX(I)=1/K(I)
      CX(I)=0.
      DX(I)=1.
   50 CONTINUE
      A=AX(1)
      B=BX(1)
      C=CX(1)
      D=DX(1)
      IF (NL.LT.2) GO TO 60
      CALL MULT (AX,BX,CX,DX,A,B,C,D,NL)
   60 RETURN
      END
```

ABCD2-PNC PAGE 1

```
      SUBROUTINE ABCDP2 (Z,K,L,G,AP,BP,CP,DP)
      REAL K,L
      PI=4.*ATAN(1.)
      IF (G) 30,30,10
10    PP=PI/4./G
      IF (Z) 40,40,20
20    ZQ=SQRT(Z/G)
      ZQL=ZQ*L
      X=L*L*0.5/G
      RES=L/K
      CO=SIN(ZQL)
      C1=COS(ZQL)
      S1=CO/ZQL
      S2=(S1-C1)/ZQL/ZQL
      AP=X*S1
      BP=X*RES*S2
      CP=X*(S1+C1)/RES
      DP=X*S1
      GO TO 50
30    AP=0.
      BP=0.
      CP=0.
      DP=0.
      GO TO 50
40    CONTINUE
      X=L*L*0.5/G
      AP=X
      BP=X*L/K/3
      CP=K/L*X*2.
      DP=X
      GO TO 50
50    RETURN
      END
```

ABCDP2-PNC PAGE 1

```
      SUBROUTINE ADJUST(QL,QLATNT,MONTH,NK,JJ)
      IF(MONTH.GE.6.AND.MONTH.LE.9) GO TO 1
      IF(QL) 2,2,4
    2 IF(JJ.GT.1) GO TO 5
      IF(NK.LT.8.OR.NK.GT.17) GO TO 5
    4 RETURN
    1 IF(QL) 6,5,5
    6 IF(JJ.GT.1) GO TO 5
      IF(NK.LT.8.OR.NK.GT.17) GO TO 5
      RETURN
    5 QL=0.
      QLATNT=0.
      RETURN
      END
```

ADJUST-PNC PAGE 1

```
      SUBROUTINE ATTIC (X,Y,Z,CR,NR,UX,FO,DB,QSUN,QSKY,TOS,TI,TNEW,TA,TIM,Q%
RFO,QRFI,QO,QI,UENDW,UCELNG,AENDW,AROOF,ATCHT,ATCACG)
%    THIS ROUTINE CALCULATES HEAT INPUT TO THE ROOM BELOW THE
%      ATTIC CEILING. IT ALSO CALCULATES ATTIC TEMPERATURE
%      X,Y,Z  RESPONSE FACTORS FOR ROOF... INSIDE SURFACE THERMAL
%      RESISTANCE IS INCLUDED
%      CR  COMMON RATIO OF THE ROOF RESPONSE FACTORS
% NR   NUMBER OF SIGNIFICANT RESPONSE FACTORS TO BE USED
%      UX  ROOF  OVER ALL HEAT CONDUCTANCE EXCLUDING THE EXTERIOR SURFACE
%      THERMAL RESISTANCE
%      FO  ROOF EXTERIOR SURFACE THERMAL TRANSFER COEFFICIENT
%      DB  OUTDOOR DRY-BULB TEMPERATURE
%      QSUN SOLAR RADIATION OVER THE ROOF
%      QSKY  RADIATION TO THE SKY
%      TOS  ROOF SURACE TEMPERATURE HISTORY
%      TI  ATTIC TEMPERATURE HISTORY
%      TONEW NEW OUTSIDE SURFACE TEMPERATURE
%      TINEW  NEW ATTIC TEMPERATURE
%      QRFO  HEAT CONDUCTED INTO THE ROOF SURFACE
%      QRFI  HEAT CONDUCTED INTO THE ATTIC FROM THE ROOF
%      QO,QI  HEAT CONDUCTED INTO THE ROOM BELOW THE ATTIC
%      UENDW  OVERALL HEAT TRANSFER COEFFICIENT OF THE END WALL
%      UCELNG  OVERALL HEAT TRANSFER COEFFICIENT OF THE CEILING
%      BETWEEN THE ATTIC AIR AND ROOM AIR BELOW
%      AENDW  AREA OF THE ATTIC END WALLS
%      AROOF  TOTAL AREA OF THE CEILING
%      ATCHT  ATTIC HEIGHT
%      ATCACG  ATTIC AIR CHANGE PER HOUR
%   ALL UNITS IN ENGLISH UNIT  ALL LENGTH IN FT
      DIMENSION TOS(1),TI(1),X(1),Y(1),Z(1),TOY(50)
CFM=ATCHT*AROOF*ATCACG/60.
      BB=DB-TIM
      TAM=TA-TIM
      XNUM=QSUN-QSKY+FO*BB
      YNUM=UENDW*BB*AENDW+1.08*CFM*BB+UCELNG*TAM*AROOF
      YDEN=UENDW*AENDW+UCELNG*AROOF+1.08*CFM
      IF(NR.GT.1)GO TO 20
10    TAM=TI(1)
      TONEW=(XNUM+UX*TAM)/(UX+FO)
      QRFO=UX*(TAM-TONEW)
      QRFI=QRFO
      TINEW=(YNUM+UX*AROOF*TONEW)/(YDEN+UX*AROOF)
      TOS(1)=TONEW
      QO=UCELNG*(TAM-TINEW)
      QI=QO
      TI(1)=TINEW
      RETURN
20    DO 30 J=2,NR
30    TOY(J)=TI(J-1)
      DO 40 J=2,NR
```

```
40    TI(J)=TOY(J)
      SUMX=0.
      SUMZ=0.
      SUMY=Y(1)*TI(1)
      SUMXY=0.
      DO 50 J=2,NR
      SUMY=SUMY+Y(J)*TI(J)
      SUMX=SUMX+X(J)*TI(J)
      SUMXY=SUMXY+Y(J)*TOS(J)
50    SUMZ=SUMZ+Z(J)*TOS(J)
      XNUM=XNUM+SUMY-SUMZ+CR*QRFO
      TONEW=XNUM/(Z(1)+FO)
      TOS(1)=TONEW
      SUMZ=SUMZ+Z(1)*TOS(1)
      SUMXY=SUMXY+Y(1)*TOS(1)
      QRFO=SUMY-SUMZ+CR*QRFO
      QRFI=SUMX-SUMXY+CR*QRFI
      SUMX=0.
      SUMY=Y(1)*TOS(1)
      DO 60 J=2,NR
      SUMX=SUMX+X(J)*TI(J)
60    SUMY=SUMY+Y(J)*TOS(J)
      YNUM=YNUM-AROOF*(SUMX-SUMY+CR*QRFI)
      YDEN=AROOF*X(1)+YDEN
      TINEW=YNUM/YDEN
      SUMX=SUMX+TINEW*X(1)
      QRFI=SUMX-SUMY+CR*QRFI
      QO=UCELNG*(TAM-TINEW)
      QI=QO
      TI(1)=TINEW
      RETURN
      END
```

ATTIC-PNC PAGE 2

```
      FUNCTION CCF(IS,CA,TOC,TCA,P,Q,R,CC)
      DIMENSION CA(4,3),TOC(4,3)
      DIMENSION PP(4)/1.06,0.96,0.95,1.14/
      DIMENSION QQ(4)/.012,.033,.030,.003/
      DIMENSION RR(4)/-.0084,-.0106,-.0108,-.0082/
%     IS: SEASON INDEX (1=SPRING, 2=SUMMER, 3=AUTUMN, 4=WINTER)
%     CA(I,J): AMOUNT OF I-TH TYPE CLOUD AT J-TH LAYER
%     TOC(I,J): I-TYPE CLOUD AT J-TH LAYER
%     TCA: TOTAL CLOUD AMOUNT
%     CC: CLOUD COVER
%     CCF: CLOUD COVER FACTOR
%     P,Q,R: TABLE A-6, PAGE 16A, NBSLD REF. MANUAL
      X=0
      DO 1 I=1,4
      DO 1 J=1,3
    1 X=X+CA(I,J)
      CC=TCA-0.5*X
      P=PP(IS)
      Q=QQ(IS)
      R=RR(IS)
      CCF=P+Q*CC+R*CC**2
      RETURN
      END
```

CCF-PNC PAGE 1

```
                  FUNCTION CCM (SALT,NTYPE,TC)
                  REAL CC1(10)/.60,.60,.58,.58,.57,.53,.49,.43,.35,.27/
                  REAL CC2(10)/.88,.88,.88,.87,.85,.83,.79,.73,.61,.46/
                  REAL CC3(10)/.84,.83,.83,.82,.80,.79,.74,.67,.60,.49/
                  REAL CC4(10)/1.,1.,1.,1.,.99,.98,.95,.90,.84,.74/
                  ITC=TC
         IF(ITC.NE.0) GO TO 5
         CCM=1.
         GO TO 50
         5 CONTINUE
                  IF (SALT-45.) 30,30,10
         10       IF (NTYPE.EQ.0) GO TO 20
                  CCM=CC2(ITC)
                  GO TO 50
         20       CCM=CC4(ITC)
                  GO TO 50
         30       IF (NTYPE.EQ.0) GO TO 40
                  CCM=CC1(ITC)
                  GO TO 50
         40       CCM=CC3(ITC)
         50       RETURN
                  END
```

CCM-PNC PAGE 1

```
      SUBROUTINE DBRH(DB,RH,W)
      PVS=PVSF(DB)
      PV=RH*PVS/100.
      W=0.622*PV/(29.92-PV)
      RETURN
      END
```

DBRH-PNC PAGE 1

```
          SUBROUTINE DECODE(WPOSX,WLONGX,NUM,OUTPUT,MM,YR,MO,DAY,LOCAL)
%         THIS SUBROUTINE PRODUCES HOURLY DATA OF  UP TO 10 WEATHER
%         PARAMETERS FOR A GIVEN YEAR,MO AND DATE
%      TAPE POSOTION FOR EACH OF TEN PARAMETERS ARE
%            PARAMETERS             WPOSX       WLONGX
%            WIND SPEED             13          3
%            WIND DIRECTION         11          2
%            DRY-BULB TEMP          16          3
%            WET-BULB TEMP          19          3
%            DEW-POINT TEMP         22          3
%            BAROMETRIC PRESS       34          4
%            TOTAL CLOUD AMOUNT     43          1
%            OPAQUE CLOUD COVER     44          1
%            PRECIPITATION(LIQUID)  68          2
%            PRECIPITATION(FRZ)     70          3
%      TAPE POSITION ON TAPE 280
%            SOLAR DATA             14          4
%            ELEVATION ANGLE        18          2
%             TOTAL CLOUD           42          1
%            1ST LAYER TYPE OF CLOUD 46         1
%            YR          YEAR
%            MO          MONTH
%            DAY         DAY
          INTEGER INPUT(1100),IPS(24),ICHAR(2000),WPOS,WLONG,OUTPUT(24,10)
     ,YR,DAY,WORD,WPOSX(10),WLONGX(10)
          IASS=1000000
          DO 10 I=1,4
     CALL WDNEW(INPUT)
          DO 10 JJ=1,498
          KK=498*(I-1)+JJ
       10 ICHAR(KK)=INPUT(JJ)
          DO 20 I=1,15
          IW=ICHAR(I)
          CALL WDX(IW)
       20 ICHAR(I)=IW
          YR=ICHAR(10)*10+ICHAR(11)+1900
          MO=ICHAR(12)*10+ICHAR(13)
          DAY=ICHAR(14)*10+ICHAR(15)
          LOCAL=ICHAR(9)
          IPWR=1
          DO 18 I=1,4
          IPWR=IPWR*10
       18 LOCAL=LOCAL+ ICHAR(9-I)*IPWR
          DO 402 KU=1,NUM
          WPOS=WPOSX(KU)
          WLONG=WLONGX(KU)
      502 DO 2 I=1,6
          IPS(I)=15+WPOS+80*(I-1)
          DO 2  J=1,3
          II=I+J*6
```

```
    2 IPS(II)=IPS(I)+J*498
      DO 3 I=1,24
      KI=IPS(I)
      KL=KI+WLONG- 1
      DO 401 L2=KI,KL
      IW=ICHAR(L2)
      CALL WDX(IW)
  401 ICHAR(L2)=IW
      LONG=WLONG-1
      IF(ICHAR(KI).EQ.IASS.AND.WLONG.GT.1) LONG=WLONG-2
      WORD=ABS(ICHAR(KL))
      IF(LONG.EQ.0) GO TO 3
      IPWR=1
      DO 5 JK=1,LONG
      IPWR=IPWR*10
    5 WORD=WORD+ICHAR(KL-JK)*IPWR
      IF(ICHAR(KL).LT.0) WORD=-WORD
    3 OUTPUT(I,KU)=WORD
  402 CONTINUE
RETURN
      END
```

DECODE-PNC PAGE 2

```
      SUBROUTINE DERVT (A,B,C,D,AP,BP,CP,DP,APP,BPP,CPP,DPP,N)
      DIMENSION A(N),B(N),C(N),D(N),AP(N),BP(N),CP(N),DP(N),AT(10),BT(10%
     ),CT(10),DT(10),ATT(10),BTT(10),CTT(10),DTT(10)
      DO 30 I=1,N
      DO 20 J=1,N
      IF (I.EQ.J) GO TO 10
      AT(J)=A(J)
      BT(J)=B(J)
      CT(J)=C(J)
      DT(J)=D(J)
      GO TO 20
   10 AT(J)=AP(J)
      BT(J)=BP(J)
      CT(J)=CP(J)
      DT(J)=DP(J)
   20 CONTINUE
   30 CALL MULT (AT,BT,CT,DT,ATT(I),BTT(I),CTT(I),DTT(I),N)
      APP=ATT(1)
      BPP=BTT(1)
      CPP=CTT(1)
      DPP=DTT(1)
      DO 40 I=2,N
      APP=APP+ATT(I)
      BPP=BPP+BTT(I)
      CPP=CPP+CTT(I)
   40 DPP=DPP+DTT(I)
      RETURN
      END
```

DERVT-PNC PAGE 1

```
              FUNCTION DPF (PV)
      %       THIS SUBROUTINE CALCULATES DEW-POINT TEMPERATURE FOR GIVEN VAPOR PRE
              IF(PV) 1,1,2
      1       GO TO 20
      2       CONTINUE
              Y=LOG(PV)
              IF (PV.GT.0.1836) GO TO 10
              DPF=71.98+24.873*Y+0.8927*Y*Y
              GO TO 20
      10      DPF=79.047+30.579*Y+1.8893*Y*Y
      20      RETURN
              END
```

DPF-PNC PAGE 1

```
      SUBROUTINE DST (YR,MO,DAY,DSTX,DSTY)
      INTEGER YR,DAY,DSTX,DSTY
      NDAY=WKDAY(YR,MO,DAY)
      IF (MO.LT.4.OR.MO.GT.10) GO TO 10
      IF (MO.EQ.4.AND.DAY.LT.24) GO TO 10
      IF (NDAY.EQ.1) DSTX=DAY
      IF (MO.EQ.10.AND.DAY.LT.24) GO TO 10
      IF (NDAY.EQ.1) DSTY=DAY
   10 CONTINUE
      RETURN
      END
```

DST-PNC PAGE 1

```
      SUBROUTINE ERROR(IDATA,K)
      DIMENSION MAX(10)/100,100,150,150,150,3500,10,10,99,999/
      DIMENSION MIN(10)/0,0,-40,-40,-40,2000,0,0,0,0/,IDATA(24)
      DO 1  J=1,24
      IZ=IDATA(J)
      IF(IZ.GT.MAX(K)) GO TO 1
      IF(IZ.LT.MIN(K)) GO TO 1
      GO TO 2
    1 CONTINUE
    2 IDATA(1)=IZ
      DO 4  J=2,24
      IZ=IDATA(J)
      IF(IZ.GT.MAX(K)) GO TO 3
      IF(IZ.LT.MIN(K)) GO TO 3
      GO TO 4
    3 IDATA(J)=IDATA(J-1)
    4 CONTINUE
      RETURN
      END
```

ERROR-PNC PAGE 1

```
      FUNCTION F (A,B,C)
%     BC = RECEIVING SURFACE
%     AB = SENDING SURFACE
%     F(A,B,C)= FROM AB TO BC
%     (A*B)*F(A,B,C)=(B*C)*F(C,B,A)
%     F(C,B,A)=F(A,B,C)*A/C
      PI=3.14159
      X=A/B
      Y=C/B
      Z=X*X+Y*Y
      A2=ALOG((1.+X*X)*(1.+Y*Y)/(1.+Z))
      A3=Y*Y*ALOG(Y*Y*(1.+Z)/(1.+Y*Y)/Z)
      A4=X*X*ALOG(X*X*(1.+Z)/(1.+X*X)/Z)
      A5=Y*ATAN(1./Y)
      A6=X*ATAN(1./X)
      A7=SQRT(Z)*ATAN(1./SQRT(Z))
      SUM=(A2+A3+A4)/4.+A5+A6-A7
      F=SUM/PI/Y
      RETURN
      END
```

FARC-PNC PAGE 1

```
      SUBROUTINE FCTR (L,W,H,SF)
      REAL L,SF(6,6)
%     THIS ROUTINE CALCULATES BASIC RADIATION SHAPE FACTORS FOR A ROOM.
%     RADIATION SHAPE FACTOR  F(H,L,W)=(H*L)---*(L*W)
%     TO                           FROM   C        S       W       N      E
%      C      CEILING                     0        FHLW    FHWL    FHLW   FHWL
%      S      SOUTH WALL                FWLH       0       FWHL    RMS    FWHL
%      W      WEST WALL                 FLWH     FLHW       0      FLHW   RMW
%      N      NORTH WALL                FWLH     RMN       FWHL     0     FWHL
%      E      EAST WALL                 FLWH     FLHW      RME     FLHW    0
%      F      FLOOR                      RMF     FHLW      FHWL    FHLW   FHWL
%
%        RM = REMAINDER
      FHLW=F(H,L,W)
      FHWL=F(H,W,L)
      FWLH=F(W,L,H)
      FWHL=F(W,H,L)
      FLWH=F(L,W,H)
      FLHW=F(L,H,W)
      RMC=1.-2.*(FHLW+FHWL)
      RMS=1.-2.*(FWLH+FWHL)
      RMW=1.-2.*(FLWH+FLHW)
      RMN=RMS
      RME=RMW
      RMF=RMC
      SF(1,1)=0.
      SF(1,2)=FHLW
      SF(1,3)=FHWL
      SF(1,4)=FHLW
      SF(1,5)=FHWL
      SF(1,6)=RMC
      SF(2,1)=FWLH
      SF(2,2)=0.
      SF(2,3)=FWHL
      SF(2,4)=RMS
      SF(2,5)=FWHL
      SF(2,6)=FWLH
      SF(3,1)=FLWH
      SF(3,2)=FLHW
      SF(3,3)=0.
      SF(3,4)=FLHW
      SF(3,5)=RMW
      SF(3,6)=FLWH
      SF(4,1)=FWLH
      SF(4,2)=RMN
      SF(4,3)=FWHL
      SF(4,4)=0.
      SF(4,5)=FWHL
      SF(4,6)=FWLH
      SF(5,1)=FLWH
```

FCTR-PNC   PAGE   1

```
      SF(5.2)=FLHW
      SF(5.3)=RME
      SF(5.4)=FLHW
      SF(5.5)=0.
      SF(5.6)=FLWH
      SF(6.1)=RMF
      SF(6.2)=FHLW
      SF(6,3)=FHWL
      SF(6.4)=FHLW
      SF(6,5)=FHWL
      SF(6.6)=0.
      RETURN
      END
```

FCTR-PNC PAGE 2

```
%      THIS SUBROUTINE CALCULATES OUTSIDE SURFACE HEAT TRANSFER
%      COEFFICIENTS,FOT AND FOC
%      FOT.... RADIATION PLUS CONVECTION
%      FOC....CONVECTION
%      V.....WIND VWLOCITY IN KNOTS
       SUBROUTINE FO (V,IS,FOC,FOT,IWD)
       DIMENSION A(6)/0.,0.001,0.,-0.002,0.,-0.00125/,B(6)/.464,0.320,0.3%
30,0.315,0.244,0.262/,C(6)/2.04,2.20,1.90,1.45,1.80,1.45/
       VP=V*1.153
       FOT=A(IS)*VP*VP+B(IS)*VP+C(IS)
%      IWD=1   IF THE SURFACE IS WINDWARD OR PARALLEL TO THE WIND
%      IWD=0  IF THE SURFACE IS LEEWARD
       IF (IWD.EQ.0) GO TO 20
       IF (VP-7.0) 20,20,10
10     FOC=0.23*VP+1.02
       GO TO 30
20     FOC=2.63
30     RETURN
       END
```

FO-PNC PAGE 1

```
      SUBROUTINE GLASS(SHADOW,SHDCF,GLTYP,GLAZE,SHGF)
            DIMENSION TR(9),SH(25)
            REAL LAT,LONG
            COMMON /SOL/ LAT,LONG,TZN,WAZ,WT,CN,DST,LPYR,S(35)
            TR(7)=S(19)
            TR(8)=GLTYP
            TR(9)=GLAZE
            CALL TAR (TR)
            SH(1)=S(24)
            SH(2)=S(22)
            SH(3)=S(23)
            SH(4)=S(19)
            SH(5)=0.5
            SH(6)=0.5
            SH(7)=0.25
            SH(8)=0.
            SH(9)=0.7
      SH(10)=SHADOW
            SH(11)=SHDCF
            SH(12)=TR(1)
            SH(13)=TR(2)
            SH(14)=TR(3)
            SH(15)=TR(5)
            SH(16)=TR(4)
            SH(17)=TR(6)
            CALL SHG (SH)
            SHGF=SH(18)
            RETURN
            END
```

GLASS-PNC PAGE 1

```
            SUBROUTINE GPF (U,ZL,Z)
            DIMENSION Z(1)
            PI=4.*ATAN(1.)
            SQTPI=SQRT(PI)
            PI2=2./PI
            EB=0.001
            DB=0.1
            WRITE (6,30)
            WRITE (6,40)
            Z(1)=2*ZL*SQRT(U)/SQTPI
            ZZ=Z(1)
            Z(2)=Z(1)*(SQRT(2.)-2.)
            DO 10 K=3,50
            ZK=K
10          Z(K)=Z(1)*(SQRT(ZK)-2.*SQRT(ZK-1)+SQRT(ZK-2.))
            DO 20 K=1,50
20          WRITE (6,50) K,Z(K)
            RETURN
%
%
%
30          FORMAT (50H0  RESPONSE FACTORS FOR  SEMI-INFINITE BED
40          FORMAT (50H0         K       Z(K)
50          FORMAT (1I10,3F10.5)
            END
```

GPF-PNC PAGE 1

```
      SUBROUTINE HOLDAY (YR,MO,DAY,NDAY,HOL)
      INTEGER YR,DAY,HOL,WKDAY
      NDAY=WKDAY(YR,MO,DAY)
      HOL=0
      IF (MO.EQ.1.AND.DAY.EQ.1) HOL=1
      IF (MO.EQ.12.AND.DAY.EQ.31.AND.NDAY.EQ.6) HOL=1
      IF (MO.EQ.1.AND.DAY.EQ.2.AND.NDAY.EQ.2) HOL=1
      IF (MO.EQ.2.AND.DAY.EQ.22) HOL=1
      IF (MO.EQ.2.AND.DAY.EQ.21.AND.NDAY.EQ.6) HOL=1
      IF (MO.EQ.2.AND.DAY.EQ.23.AND.NDAY.EQ.2) HOL=1
      IF (MO.EQ.5.AND.DAY.EQ.30) HOL=1
      IF (MO.EQ.5.AND.DAY.EQ.29.AND.NDAY.EQ.6) HOL=1
      IF (MO.EQ.5.AND.DAY.EQ.31.AND.NDAY.EQ.2) HOL=1
      IF (MO.EQ.7.AND.DAY.EQ.4) HOL=1
      IF (MO.EQ.7.AND.DAY.EQ.3.AND.NDAY.EQ.6) HOL=1
      IF (MO.EQ.7.AND.DAY.EQ.5.AND.NDAY.EQ.2) HOL=1
      IF (MO.EQ.12.AND.DAY.EQ.25) HOL=1
      IF (MO.EQ.12.AND.DAY.EQ.24.AND.NDAY.EQ.6) HOL=1
      IF (MO.EQ.12.AND.DAY.EQ.26.AND.NDAY.EQ.2) HOL=1
      IF (MO.EQ.9.AND.DAY.LT.7.AND.NDAY.EQ.2) HOL=1
      IF (MO.EQ.11.AND.DAY.GT.24.AND.NDAY.EQ.5) HOL=1
      RETURN
      END
```

HOLDAY-PNC PAGE 1

```
      SUBROUTINE MULT (A,B,C,D,AT,BT,CT,DT,N)
      DIMENSION A(N),B(N),C(N),D(N)
      ATT=A(1)
      BTT=B(1)
      CTT=C(1)
      DTT=D(1)
      IF (N.LT.2) GO TO 20
      DO 10 J=2,N
      AT=ATT*A(J)+BTT*C(J)
      BT=ATT*B(J)+BTT*D(J)
      CT=CTT*A(J)+DTT*C(J)
      DT=CTT*B(J)+DTT*D(J)
      ATT=AT
      BTT=BT
      CTT=CT
   10 DTT=DT
      GO TO 30
   20 AT=ATT
      BT=BTT
      CT=CTT
      DT=DTT
   30 RETURN
      END
```

MULT-PNC PAGE 1

```
%     .......................NBSLD......................................
%     THIS IS THE ROOM TEMPERATURE CALCULATION ROUTINE
%     OF THE NATIONAL BUREAU OF STANDARDS
%     NBSLD IS A RESEARCH PROGRAM OF NBS FOR THE PURPOSE OF
%     STUDYING HEATING AND COOLING LOAD AND ROOM TEMPERATURE
%     OF BUILDING UNDER ACTUAL WEATHER CONDITION
%     A(I)          AREA OF SURFACE I, FT2
%     ABSP(I)       SOLAR HEAT ABSORPTION COEFFICIENT FOR SURFACE I.
%                   THIS DATA REQUIRED FOR OPAQUE SURFACES ONLY.
%     AENDW         AREA OF THE ATTIC END WALL, FT2
%     AG            GROUND HEAT TRANSFER AREA, FT2  (MAY=0.)
%     AIRCHG        NO. OF ATTIC AIR CHANGES PER HR, DAYTIME
%     AIRNT         ATTIC NIGHT TIME AIR CHANGE MULTIPLIER
%     ARCHGS        NO. OF AIR CHANGES PER HR IN SUMMER
%     ARCHGW        NO. OF AIR CHANGES PER HR IN WINTER
%     ATCACG        NO. OF ATTIC AIR CHANGES PER HR (DAY OR NIGHT)
%     AVEHTG        AVERAGE HOURLY HEAT GAIN ENTIRE BUILDING, BTU/HR
%     AZW(I)        WALL AZIMUTH ANGLE FOR SURFACE I, DEGREES
%                   SOUTH = 0.
%                   WEST = 90.
%                   NORTH = 180.
%                   EAST = -90.
%     BLDMAX        BUILDING MAXIMUM SENSIBLE HEAT GAIN, BTU/HR
%     CFMI          SUMMER INFILTRATION RATE, FT3/MIN.
%     CFMV          VENTILATION RATE, FT3/MIN.
%     CFMWT         WINTER INFILTRATION, FT3/MIN.
%     CLDAY         DAILY TOTAL ENERGY CONSUMPTION FOR A GROUP
%                   (NORM OF THEM) OF ROOMS OF THE SAME CONFIG-
%                   URATION, BTU
%     CLDSUM        RUNNING TOTAL ENERGY CONSUMPTION FOR COOLING OF
%                   ALL THE ROOMS IN A BUILDING OVER A SET TIME
%                   PERIOD, BTU
%     CN            CLEARNESS NUMBER
%     CR(L)         RESPONSE FACTOR COMMON RATIO FOR CONSTRUCTION L
%     DAY           DAY OF YEAR
%     DAYSKP        NO. OF DAYS TO BE SKIPPED FROM THE WEATHER TAPE
%                   (FROM ITS LAST STARTING POSITION)
%     DB(J)         OUTDOOR DRYBULB TEMPERATURE AT HOUR J, F
%     DBA           DAILY AVERAGE OUTSIDE DRYBULB TEMPERATURE, F
%     DBIN          DESIGN INDOOR DRYBULB TEMPERATURE, F
%     DBM           DRYBULB MEAN, F
%     DBMAX         DESIGN OUTDOOR MAXIMUM DRYBULB TEMPERATURE, F
%     DBMWT         DESIGN WINTER OUTDOOR DRYBULB TEMPERATURE, F
%     DBNBS(J)      FRACTION OF RANGE TO USE FOR DESIGN PROFILE
%                   AT HOUR J
%     DP            OUTDOOR DEW POINT, F
%     DPID          INDOOR DEW POINT, F
%     DPIN          DESIGN INDOOR DEW POINT, F
%     DR(L)         RESPONSE FACTOR COMMON RATIO FOR CONSTRUCTION L
%                   (SAME AS CR(L))
```

```
%      DST          DAYLIGHT SAVING TIME INDICATOR
%      ELAPS        DAYS ELAPSED SINCE JANUARY 1
%      G(IV,VI)     RADIATION CONFIGURATION FACTORS FOR
%                   RADIATION FROM SURFACE VI TO SURFACE IV
%      H(I)         EXTERIOR SURFACE HEAT TRANSFER COEFFICIENT
%                   FOR SURFACE I, BTU/HR,FT2,F
%      HI(I)        INTERIOR SURFACE CONVECTION HEAT TRANSFER
%                   COEFFICIENT, BTU/HR,FT2,F
%      HINO         INDOOR ENTHALPY FOR DESIGN CONDITIONS, BTU/LB
%      HLDAY        DAILY TOTAL ENERGY CONSUMPTION FOR HEATING FOR A
%                   GROUP (NORM OF THEM) OF ROOMS OF THE SAME
%                   CONFIGURATION, BTU
%      HLDSUM       RUNNING TOTAL ENERGY CONSUMPTION FOR HEATING OF
%                   ALL THE ROOMS IN A BUILDING, BTU
%      HOUT         OUTDOOR ENTHALPY FOR DESIGN CONDITIONS, BTU/LB
%      HR           INNER SURFACE RADIATIVE HEAT TRANSFER COEFFICIENT
%                   (=4.*(535.**3)*SIGMA)
%      HT           CEILING HEIGHT, FT
%      IHT(I)       HEAT TRANSFER INDEX
%                   =-1 FOR GLASS SURFACE
%                   = 0 OPAQUE
%                   = 1 OTHERWISE
%      IMAX         HOUR OF DAY FOR MAXIMUM COOLING LOAD
%      INCLUD       =0  INCLUDE ROOM IN SUMMARY
%                   =1  OTHERWISE
%      IRF(I)       RESPONSE FACTOR INDEX FOR SURFACE I
%      IROT         DEGREES OF ROTATION
%      ISKIP        = 1 SKIP RESPONSE FACTOR CALCULATION
%                   AND BUILDING DATA INPUT
%                   = 0 OTHERWISE
%      ITK AND ITHST      INDICES FOR ROOM TEMPERATURE COMPUTATION
%      ITK=0, ITHST=1      ROOM TEMP PRESCRIBED, EITHER CONSTANT
%                   OR WITH NIGHT TIME SET-BACK
%      ITK=1, ITHST=0      ROOM TEMP NOT BEING CONTROLLED. NO A/C.
%      ITK=1, ITHST=1      ROOM TEMP FLOAT WITHIN PRESCRIBED UPPER
%                   AND LOWER LIMITS. NO A/C WHEN WITHIN
%                   THE LIMITS.
%      ITK=0, ITHST=0      EQUIPMENT CAPACITY PRESCRIBED. ROOM TEMP
%                   FLOAT WITHIN PRESCRIBED UPPER AND LOWER
%                   LIMITS, AND WHEN EQUIPMENT CAPACITY IS
%                   EXCEEDED.
%      ITYPE(I)     TYPE OF SURFACE I
%                   = 1  ROOF
%                   = 2  EXPOSED WALL
%                   = 3  WINDOW
%                   = 4  DOOR
%                   = 5  GROUND HEAT TRANSFER SURFACE
%                   = 6  INTERNAL MASS, FURNISHINGS, PARTY WALLS,
%                   PARTITION WALLS, AND FLOOR/CEILINGS
%                   = 7  OPEN PASSAGES
```

NBSLD-PNC PAGE 2

```
%                 = 8  EXPOSED FLOOR (EXPOSED UNDERSIDE)
%    LAT          LATITUDE, DEGREES
%    LONG         LONGITUDE, DEGREES
%    LPYR         LEAP YEAR INDICATOR
%    MONTH        MONTH OF YEAR
%    MR(L)        NUMBER OF RESPONSE FACTOR TERMS GENERA-
%                 TED BY RESPTK FOR CONSTRUCTION L
%                 SAME AS NR(L)
%    NAMERD       NAME OF ROOM
%    NE           NUMBER OF SURFACES IN EAST WALL
%    NEXP         TOTAL NUMBER OF SURFACES IN ROOM
%                 = 2+NS+NW+NN+NE
%    NMAX         HR OF THE DAY WHEN QLMAX OCCURS
%    NN           NUMBER OF SURFACES IN NORTH WALL
%    NOFLR        NUMBER OF FLOORS
%    NORM         NO. OF ROOMS HAVING THE SAME"DATA
%    NR(L)        NUMBER OF RESPONSE FACTOR TERMS CALCU-
%                 LATED BY RESPTK FOR CONSTRUCTION L
%    NS           NUMBER OF SURFACES IN SOUTH WALL
%    NW           NUMBER OF SURFACES IN WEST WALL
%    PB           BAROMETRIC PRESSURE
%                 = 29.921 INCHES OF MERCURY
%    PI           = 3.1415...
%    PV           VAPOR PRESSURE, INCHES OF MERCURY
%    OCU          MAXIMUM NUMBER OF OCCUPANTS
%    QDES(I)      HEAT GAIN OF SURFACE I AT HOUR IMAX, BTU/HR
%    QDESIN(I,J)     HEAT GAIN OF SURFACE I AT HOUR J,
%                 BTU/HR
%    QEQPO        EQUIPMENT MAXIMUM HEAT LOAD, BTU/HR
%    QEQPX        MAXIMUM EQUIPMENT LOAD, WATTS/FT2
%    QEQUP(J)     EQUIPMENT LOAD AT HOUR J, BTU/HR
%    QEQUX(J)     EQUIPMENT USE SCHEDULE
%    QGLAS(I,J)     HEAT GAIN OF GLASS FOR I AT HOUR J,
%                   BTU/HR
%    QGX(I)       HEAT TRANSMISSION OF GLASS FOR SURFACE
%                 I AT HOUR IMAX, BTU/HR
%    QI(I)        INSIDE SURFACE HEAT FLUX OF SURFACE I,
%                 BTU/HR,FT2
%    QISAVE(J,I)     INSIDE SURFACE HEAT FLUX OF SURFACE
%                 I AT HOUR J, BTU/HR,FT2
%    QLDS         SUM OF LATENT AND SENSIBLE LOAD AT HOUR
%                 J, BTU/HR
%    QLITE(J)     LIGHT LOAD AT HOUR J, BTU/HR
%    QLITO        MAXIMUM LIGHT LOAD, BTU/HR
%    QLITX(J)     LIGHT USE SCHEDULE
%    QLITY        MAXIMUM LIGHTING LOAD, WATTS/FT2
%    QLMAX        ABSOLUTE VALUE OF THE MAX COOLING (OR
%                 HEATING) LOAD OF THE DAY, BTU/HR
%    QLL(J)       LATENT HEAT LOAD AT HOUR J, BTU/HR
%    QLS(J)       SENSIBLE HEAT LOAD AT HOUR J, BTU/HR
```

```
%    QO(I)      OUTSIDE SURFACE HEAT FLUX OF SURFACE I,
%               BTU/HR, FT2
%    QOCPS(J)   OCCUPANT LOAD AT HOUR J, BTU/HR
%    QOCUP(J)   OCCUPANT SCHEDULE
%    QPEOPL(J)  PEOPLE LATENT LOAD AT HOUR J, BTU/HR
%    QPLX       MAX OCCUPANT LATENT LOAD, BTU/HR,PERSON
%    QPSX       MAX OCCUPANT SENSIBLE LOAD,BTU/HR,PERSON
%    QSAVE(M,J)    HEAT GAINS AND LOADS AT HOUR J, BTU/HR
%               M = 1  TIME, HR
%               M = 2  SENSIBLE HEAT GAIN, BTU/HR
%               M = 3  LATENT HEAT GAIN, BTU/HR
%               M = 4  SENSIBLE LOAD, BTU/HR
%               M = 5  TOTAL LOAD, BTU/HR
%    QSKY(I,J)  HEAT RADIATED TO SKY BY SURFACE I T
%               HOUR J, BTU/HR, FT2
%    QSUMT      SUM OF TOTAL HEAT GAINS FOR 24 HOURS,
%               BTU/HR
%    QSUN(I,J)  INCIDENT SOLAR RADIATION FOR SURFACE I
%               AT HOUR J, BTU/HR,FT2
%    QTL(J)     LATENT HEAT GAIN FROM INFILTRATION AT
%               HOUR J, BTU/HR
%    QWINT      HEAT LOSS IN WINTER, BTU/HR
%    RANGE      DAILY RANGE OF OUTDOOR DRYBULB, F
%    RHIN       DESIGN INDOOR RELATIVE HUMIDITY
%    RHOUT      DESIGN OUTDOOR RELATIVE HUMIDITY
%    ROOMNO     ROOM NUMBER
%    S          INFORMATION ARRAY REQUIRED BY SUBROU-
%               TINE SUN AND GLASS
%    SHADE(I)   SHADING COEFFICIENT FOR SURFACE I
%    SIGMA      = 0.1714E-8
%    SITELD(J)  OVERALL COOLING LOAD AT HOUR J, BTU/HR
%    SITEOL(J)  OVERALL LATENT HEAT GAIN AT HOUR J,
%               BTU/HR
%    SITEOS(J)  OVERALL SENSIBLE HEAT GAIN AT HOUR J,
%               BTU/HR
%    SITETH(J)  OVERALL TOTAL HEAT GAIN AT HOUR J,
%               BTU/HR
%    SITMAX     OVERALL MAXIMUM HEAT GAIN, BTU/HR
%    SOTHTX     OVERALL HEAT GAIN AT HOUR IMAX, BTU/HR
%    SQLLD      TOTAL COOLING LOAD, BTU/HR
%    SQWINT     OVERALL TOTAL HEAT LOSS, BTU/HR
%    TA         ROOM AIR TEMPERATURE, F
%    TASAVE(J)  ROOM AIR TEMPERATURE AT HOUR J, F
%    TCLLD      DAILY RUNNING TOTAL ENERGY CONSUMPTION
%               FOR COOLING FOR A GROUP (NORM OF THEM)
%               OF ROOMS HAVING THE SAME CONFIGURATION,
%               BTU
%    TG         DESIGN SUMMER GROUND TEMPERATURE, F
%    TGW        DESIGN WINTER GROUND TEMPERATURE, F
%    THTLD      DAILY RUNNUNG TOTAL ENERGY CONSUMPTION
```

NBSLD-PNC PAGE 4

```
%                 FOR HEATING FOR A GRUOP (NORM OF THEM)
%                 OF ROOMS HAVING THE SAME CONFIGURATION,
%                 BTU
%    TI(J)        INSIDE SURFACE TEMPERATURE RELATIVE TO
%                 THE REFERENCE TEMPERATURE AT HOUR J
%    TIF(J)       INSIDE SURFACE TEMPERATURE AT HOUR J, F
%    TIFSAV(J,I)    INSIDE SURFACE TEMPERATURE OF SUR-
%                 FACE I AT HOUR J, F
%    TIM          INDOOR DESIGN MEAN (REFERENCE TEMPERA-
%                 TURE), F
%    TIO          INDOOR DESIGN TEMPERATURE, F
%    TIS(I,J)     INSIDE SURFACE TEMPERATURE RELATIVE TO
%                 THE REFERENCE TEMPERATURE OF SURFACE I
%                 AT HOUR J, F
%    TIX(J)       INDOOR DESIGN DRYBULB TEMPERATURE AT
%                 HOUR J, F
%    TNEW(I)      UPDATED OUTSIDE SURFACE TEMPERATURE OF
%                 SURFACE I AT EVERY TIME INCEMENT, F
%    TNUSAV(J,I)    UPDATED OUTSIDE SURFACE TEMPERATRE
%                 OF SURFACE I AT HOUR J, F
%    TOS(I,J)     OUTSIDE SURFACE TEMPERATURE RELATIVE TO
%                 REFERENCE TEMPERATURE OF SURFACE I AT
%                 HOUR J, F
%    TOTHTX       TOTAL COOLING LOAD FOR A ROOM, BTU/HR
%    TOY(J)       ARRAY USED FOR TEMPORARY STORAGE OF
%                 VALUES WHILE ADVANCING TEMPERATURE AS
%                 REQUIRED BY RESPONSE FACTOR METHOD
%    TSAVE        MAXIMUM TOTAL COOLING LOAD, BTU/HR
%    TSITHT       TOTAL OVERALL HEAT GAIN FOR 24 HOURS,
%                 BTU/HR
%    TV           TEMPERATURE OF VENTILATING AIR, F
%    TZN          TIME ZONE NUMBER
%    U(I)         OVERALL HEAT TRANSFER COEFFICIENT FOR
%                 SURFACE I
%    UCELNG       OVERALL HEAT TRANSFER COEFFICIENT OF
%                 THE CEILING BETWEEN THE ATTIC AIR AND
%                 THE ROOM AIR BELOW
%    UENDW        OVERALL HEAT TRANSFER COEFFICIENT OF
%                 THE ATTIC ENDWALL
%    UG           GROUND HEAT TRANSFER COEFFICIENT
%    UGLAS        WINTER GLASS HEAT TRANSFER COEFFICIENT
%    UT(I)        U VALUE WITHOUT SURFACE RESISTANCES
%    VIN          INDOOR AIR SPECIFIC VOLUME, FT3/LB
%    VOUT         OUTDOOR AIR SPECIFIC VOLUME, FT3/LB
%    VT(L)        SAME AS UT(I)
%    WA           OUTDOOR AIR HUMIDITY RATIO, LB OF H2O
%                 VAPOR PER LB OF DRY AIR (= WOUT)
%    WAZ(I)       WALL AZIMUTH ANGLE MEASURED CLOCKWISE
%                 FROM SOUTH, DEGREES
%    WBID         DESIGN INDOOR WETBULB TEMPERATURE, F
```

NBSLD-PNC PAGE 5

```
%      WJMAX       DESIGN OUTDOOR WETBULB TEMPERATURE, F
%      WBSAVE(J)   INDOOR WETBULB TEMPERATURE AT HOUR J, F
%      WID         DESIGN INDOOR HUMIDITY RATIO, LB OF H2O
%                  VAPOR/LB OF DRY AIR
%      WIN         INDOOR HUMIDITY RATIO, LB H2O/LB DRY AIR
%      WOUT        DESIGN OUTDOOR HUMIDITY RATIO, LB H2O
%                  VAPOR/LB DRY AIR
%      WROT        DEGREES OF ROTATION FOR ROOM
%      WT          WALL TILT ANGLE (= 90. DEGREES WHEN
%                  VERTICAL WALL)
%      WV          VENTILATION AIR HUMIDITY RATIO, LB H2O
%                  VAPOR/LB DRY AIR
%      X(L,N)      RESPONSE FACTORS FOR CONSTRUCTION L
%      XX(N,L)     TRANSPOSE OF ARRAY X
%      Y(L,N)      RESPONSE FACTORS FOR CONSTRUCTION L
%      YY(N,L)     TRANSPOSE OF ARRAY Y
%      Z(L,N)      RESPONSE FACTORS FOR CONSTRUCTION L
%      ZBLDG       INPUT ARRAY FOR BUILDING AND EXTERNAL DATA
%      ZPOOM       INPUT ARRAY FOR ROOM DATA
%      ZZ(N,L)     TRANSPOSE OF ARRAY Z
%
%
       COMMON /CC/ X(10,I00),Y(10,100),Z(10,100),ITYPE(30),IHT(30),IRF(30%
       ),ABSP(30),U(30),H(30),HI(30),A(30),UT(30),TOS(30,48),TIS(30,48),G%
       (30,30),TOY(48),DB(24),QLITX(24,3),QEQUX(24,3),QOCUP(24,3),QOCPS(2%
4)     ,QLITE(24),QEQUP(24),QI(30),CR(30),NR(30),QGLAS(30,24),ITHST,UFN%
       DW,AZW(30),SHADE(30),RMDBS(24),RMDBW(24),SHD(30),UCELNG
       DIMENSION XX(100,10),YY(100,10),ZZ(100,10),TNEW(100),TI(48),XDUM(1%
00)    ,YDUM(I00),ZDUM(I00),TDUM(100),QQ(30),TIF(30),QSUN(30,24),QSKY(%
30     ,24),NAMERM(9),NAMEBD(9),VT(10),DR(10),MR(10)
       DIMENSION DPT(24),WBT(24),PBT(24),WST(24),TC(24),NTOC(24)
       DIMENSION SALT(24),IEDAY(12)/15,46,74,105,135,166,196,227,258,288,%
319,   349/
       DIMENSION CALDB(24),CALRH(24),PGLAS(30,24),PSUN(30,24),TATTIC(100)%
       ,QLS(24),QLL(24),ZBLDG(15),ZROOM(12)   ,UW(30)
       DIMENSION HEATG(2),HEATX(2),HEATIS(2),HLCG(2),HLCX(2),HLCIS(2)
       DIMENSION DBPF(24)/.87,.92,.96,.99,1.00,.98,.93,.84,.71,.56,.39 %
       ,.23,.11,.03,0.0,.03,.10,.21,.34,.47,.58,.68,.76,.82/
       COMMON/SHDW/SHAW(30,I5)
       DIMENSION SHDX(20),SHDF(30,24),AIRLK(24),QSOL(24)
       DIMENSION V(15),PLAT(24),AIRLAT(24),RALD(24),BASEL(24)
       INTEGER DSTX,DSTY,RUNID,RUNTYP,ASHRAE
       REAL LAT,LONG,NOFLR
       INTEGER CITY,YEAR,TAPE2
       LOGICAL LL1,LL2
       COMMON /SOL/ LAT,LONG,TZN,WAZ,WT,CN,DSX,LPYR,S(35)
       COMMON NSKP
       PI=3.1415927
       WRITE(6,1051)
       WRITE(6,1052)
```

NBSLD-PNC PAGE 6

```
            WRITE(6,1053)
            WRITE(6,1054)
            WRITE(6,998)
      998   FORMAT(//' RUNID,RUNTYP,ASHRAE,IDETAL,METHOD,NHAY'/%
           ' RUNID.........IDENTIFICATION OF THE RUN '/%
           '               1 NEED RESPONSE FACTOR DATA'/%
           '               2 SKIP RESPONSE FACTOR DATA'/%
           ' RUNTYP........TYPE OF RUN'/%
           '               1 ENERGY CALCULATION ..NEEDS WEATHER TAPE'/%
           '               2 DESIGN LOAD CALCULATION'/%
           '               3 DESIGN AND ENERGY LOAD CALCULATIONS'/%
           ' ASHRAE........0   USE RMTMP'/%
           '               1   USE ASHRAE WEIGHTING FACTORS'/%
           ' IDETAL........0   NO DETAILED OUTPUT'/%
           '               1   DETAILED OUTPUT'/%
           ' METHOD........0   REGULAR TREATMENT FOR THE ROOM'/%
           '               1   SPECIAL TREATMENT OF THE ROOM'/%
           ' NHAY..........0   STANDARD SIMULATION'/%
           '               1   WET ROOF SIMULATION')
            READ(5,*) RUNID,RUNTYP,ASHRAE,IDETAL,METHOD,NHAY
            CALL OBEY('EQUATE 8 RFTR',4)
            IF(RUNID.EQ.1) CALL OBEY('SWITCH IN%:NBSBL1',5)
            IF(RUNID.EQ.2) CALL OBEY('SWITCH IN%:NBSBL2',5)
            CALL OBEY('EQUATE TAPE2 OUTDAT',5)
            READ (5,911) NAMEBD
            WRITE (6,910) NAMEBD
      %     READ 24 HOUR PROFILES FOR LIGHTING,EQUIPMENT AND OCCUPANCY
            J3=3
            DO 10 J=1,J3
            IF(J.EQ.1) WRITE(6,901)
      901   FORMAT(' LIGHTING SCHEDULE FOR WEEKDAYS')
            IF(J.EQ.2) WRITE(6,904)
      904   FORMAT(' LIGHTING SCHEDULE FOR WEEKEND')
            IF(J.EQ.3) WRITE(6,907)
      907   FORMAT(' LIGHTING SCHEDULE FOR THE VACATION PERIOD')
            READ(5,*)(QLITX(I,J),I=1,24)
            IF(J.EQ.1) WRITE(6,902)
      902   FORMAT(' EQUIPMENT USAGE SCHEDULE FOR WEEKDAYS')
            IF(J.EQ.2) WRITE(6,905)
      905   FORMAT(' EQUIPMENT SCHEDULE FOR WEEKENDS')
            IF(J.EQ.3) WRITE(6,908)
      908   FORMAT(' EQUIPMENT USAGE SCHEDULE FOR THE VACATION PERIOD')
            READ(5,*)(QEQUX(I,J),I=1,24)
            IF(J.EQ.1) WRITE(6,903)
      903   FORMAT(' OCCUPANCY SCHEDULE FOR WEEKDAYS')
            IF(J.EQ.2) WRITE(6,906)
      906   FORMAT(' OCCUPANCY SCHEDULE FOR WEEKEND')
            IF(J.EQ.3) WRITE(6,909)
      909   FORMAT(' OCCUPANCY SCHEDULE FOR THE VACATION PERIOD')
            READ(5,*)(QOCUP(I,J),I=1,24)
```

NBSLD-PNC PAGE 7

```
10    CONTINUE
      IF(RUNTYP.GT.2) RUNTYP=2
      WRITE(6,914)
914   FORMAT(' THERMOSTAT SETTING FOR THE COOLING SEASON')
      READ(5,*) RMDBS
      WRITE(6,915)
915   FORMAT(' THERMOSTAT SETTING FOR THE HEATING SEASON')
      READ(5,*) RMDBW
      WRITE(6,916)
916   FORMAT(' RMDBWO,RMDBSO,RHW,RHS')
      READ(5,*) RMDBWO,RMDBSO,RHW,RHS
      SIGMA=0.1714E-8
      HR=4.*0.9*SIGMA*(530.**3)
      WRITE(6,881)
881   FORMAT(' DATA SHEET NO 1:NDAY,NSKIP,TAPE2')
      READ(5,*)NDAY,NSKIP,TAPE2
      WRITE(6,882)
882   FORMAT(' DATA SHEET NO 2 &3 :MONTH,DAY,ELAPS,DBMAX,RANGE,WBMAX,%
DBMWT,TGS,TGW,UG,LONG,LAT,TZN,ZLF,RHOW')
      READ(5,*)ZBLDG
      CLDSUM=0.
      HLDSUM=0.
      DO 750 IJKLMN=1,10
      WRITE(6,883)
883   FORMAT(' DATA SHEET NO 4: NAME OF THE ROOM')
      READ(5,910) NAMERM
%     IF TAPE2 IS NOT BLANK  8 TAPE SHOULD BE ASSIGNED
IF(NAMERM(1).EQ.'    ')STOP
      WRITE(6,884)
884   FORMAT(' DATA SHEET NO 5:IROT,ISKIP,INCLUDE')
      READ(5,*) IROT,ISKIP,INCLUD
%     IF ISKIP .NE. 0, RESPONSE FACTOR CALCULATION IS SKIPPED
%     SO NO WALL DATA IS NEEDED
      IF (ISKIP.NE.0) GO TO 30
      DO 20 I=1,10
      DO 20 J=1,100
      X(I,J)=0.
      Y(I,J)=0.
20    Z(I,J)=0.
      IF(RUNTD.EQ.1) GO TO 21
      READ(8) X,Y,Z,MR,DR,VT
      GO TO 22
%     THIS RESPONSE FACTOR ROUTINE REQUIRES MANY CONSTRUCTION DATA
%     PLEASE REFER TO THE INPUT INSTRUCTIONS
21    CONTINUE
      IF(TDETAL.EQ.0) CALL OBEY('SWITCH OUT$:RESTAR',5)
      CALL RESFX (X,Y,Z,XX,YY,ZZ,MR,DR,VT,10)
      IF(TDETAL.EQ.0) CALL OBEY('SWITCH OUT$:,CLOSE',5)
      WRITE(8) X,Y,Z,MR,DR,VT
      END FILE 8
```

```
22    PB=29.921
30    IF(IROT.NE.0) GO TO 40
      WROT=0.
      WRITE(6,891)
891   FORMAT(' DATA SHEET NO 8: ROOMNO,QLITY,QEQPY,QCU,FLCG,FRAS,TS,CFMS,ARCHGS,ARCHGW,ARCHGM,ZNORM')
      READ(5,*) ZROOM
      WRITE(6,892)
892   FORMAT(' DATA SHEET NO.9: IW,IL,ISTART,ILEAVE')
      READ(5,*) IW,IL,ISTART,ILEAVE
      WRITE(6,893)
893   FORMAT(' DATA SHEET NO 10: TUL,TLL,QCMAX,QHMAX,DBVMAX,DBVMIN')
      READ(5,*) TUL,TLL,QCMAX,QHMAX,DBVMAX,DBVMIN
      WRITE(6,894)
894   FORMAT(' DATA SHEET NO 11: ITHST,ITK')
      READ(5,*) ITHST,ITK
      CALL ROOMX (NEXP,NS,NW,NN,NE,HT)
      ROOMNO=ZROOM(1)
      MONTH=ZBLDG(1)
      AG=A(NEXP)
      NOFIR=1
      QCU=ZROOM(4)
      LAT=ZBLDG(12)
      LONG=ZBLDG(11)
      TZN=ZBLDG(13)
      DAYSKP=NSKIP
      QLITY=ZROOM(2)
      QEQPX=ZROOM(3)
      CFMV=ZROOM(8)
      WBMAX=ZBLDG(6)
      CFMS=CFMV
      FLCG=ZROOM(5)
      TGS=ZBLDG(8)
      TGW=ZBLDG(9)
      LDAY=ZBLDG(2)
      YEAR=2000
      DBWT=ZBLDG(7)
      DBMAX=ZBLDG(4)
      RHOW=ZBLDG(15)
      ZLF=ZBLDG(14)
      DBIN=RMDBW(12)
      RHIN=RHW
      IF(RUNTYP.EQ.2) CALL PSYI(DBMAX,WBMAX,PB,DPMAX,PV,WA,HA,VA,RHO)
      UG=ZBLDG(10)
      TV=ZROOM(7)
      FRAS=ZROOM(6)
      ZNORM=ZROOM(12)
      ARCHGW=ZROOM(10)
      CFMWT=AG*HT*ARCHGW/60.+CFMV
      ARCHGM=ZROOM(11)
      CFMIN=AG*HT*ARCHGM/60.
```

```
          CONST=ARCHGW/0.695
%         THESE AIR CHANGE VALUES ARE FOR THE ATTIC VENTILATION
%         ROOM AIR CHANGE VALUES WILL BE DETERMINED AS A FUNCTION  OF
%         WIND SPEED AND TEMPERATURE DIFFERENTIAL
40        CONTINUE
          IF (IDETAL.EQ.0) GO TO 50
          WRITE(6,874)
          WRITE (6,790)
          WRITE (6,800) ROOMNO,HT,AG,NOFLR,QCU,ZROOM(9),ZROOM(10)
          WRITE (6,1010)
50        CONTINUE
          S(1)=LAT
          S(2)=LONG
          S(3)=TZN
          IF (IDETAL.EQ.0) GO TO 60
          WRITE (6,810)
          WRITE (6,800) LAT,LONG,TZN,ZNORM
          WRITE (6,1010)
          WRITE (6,820)
          RHIN=RHS
          WRITE (6,800) QLITY,QFQPX,CFMV,DHIN,TG,TV,RHIN
          WRITE (6,1010)
          WRITE (6,840) NEXP,ITK,ITHST
          WRITE(6,874)
60        CONTINUE
          IF(IROT.NE.0) GO TO 61
          WRITE(6,841)
841       FORMAT(' DATA SHEET NO 15: UENDW,UCELNG,AENDW,ATCHT,AIRCHG,AIRNT')
          READ(5,*) UENDW,UCELNG,AENDW,ATCHT,AIRCHG,AIRNT
          WRITE(6,842)
842       FORMAT(' DATA SHEET NO 16: IEXTSD,IEXMS,IEXME,NTVNT,NVENT'//)
          READ(5,*) IEXTSD,IEXMS,IEXME,NTVNT,NVENT
          CFMNT=NTVNT*AG*HT/60.
61        CONTINUE
          IF (IDETAL.EQ.0) GO TO 70
          WRITE (6,1010)
          WRITE (6,830)
          WRITE (6,800) UENDW,UCELNG,AENDW,ATCHT
70        CONTINUE
          IF (IROT.NE.0) GO TO 160
          SUM=0.
          DO 151 I=1,NEXP
          K=IRF(I)
          IF (Y(K,1).GT.1.) IRF(I)=10
          NR(I)=MR(K)
IF(IRF(I).EQ.10) NR(I)=1
          UT(I)=VT(K)
          CR(I)=DR(K)
          IF(NR(I).EQ.0) NR(I)=1
          IF (NR(I).GT.48) NR(I)=48
```

```
            IF (ITYPE(I).EQ.3) ABSP(I)=0.
            IF (ITYPE(I).EQ.5) ABSP(I)=0.
            IF(ITYPE(I).GE.6) ABSP(I)=0.
            IHT(I)=1
            IF (ITYPE(I).EQ.3) IHT(I)=-1
             H(I)=6.0
            HI(I)=1.46-HR
            IF (ITYPE(I).GE.5) H(I)=0.
            IF (ITYPE(I).EQ.1) HI(I)=1.630-HR
            IF (ITYPE(I).EQ.5) HI(I)=1.080-HR
            IF (ITYPF(I).EQ.7) U(I)=500.
            IF(ITYPE(I).EQ.8) H(I)=1.46
      IF(IRF(I).NE.10) U(I)=0.
            IF (U(I)) 80,80,90
      80    RU=1./UT(I)+1./(HI(I)+HR)
            IF(ITYPE(I).LT.5.OR.ITYPE(I).EQ.8) RU=RU+1./H(I)
            U(I)=1./RU
      90    CONTINUE
            IF (X(K,2)) 140,100,140
      100   IF (H(I)) 110,120,110
      110   R=1./U(I)-1./H(I)
            GO TO 130
      120   R=1./U(I)
      130   UT(I)=1./(R-1./(HI(I)+HR))
            IF (UT(I).LE.0.) UT(I)=28.0
            IF (ITYPE(I).EQ.7) UT(I)=500.
      140   CONTINUE
            IF(UCELNG)150,150,141
      141 IF(ITYPE(I).NE.1) GO TO 150
      RTA=1./UCFLNG-1./(HI(I)+HR)
            UT(I)=1./RTA
      150   CONTINUE
             UW(I)=U(I)
            IF(ITYPE(I).GT.4) GO TO 151
            SUM=SUM+A(I)*U(I)
      151   CONTINUE
            ZK=SUM/ZLF
            FC=1.-0.02*ZK
      160   IF (IROT.EQ.0) GO TO 180
            WROT=IROT
            DO 170 I=1,NEXP
            AZW(I)=AZW(I)+WROT
            IF (AZW(I).LT.-180.) AZW(I)=AZW(I)+360.
      170   IF (AZW(I).GT.180.) AZW(I)=AZW(I)-360.
            DO 181 I=1,NEXP
             DO 181 J=1,NEXP
      181    G(I,J)=G(I,J)/HR
      180   CONTINUE
            IF (IDETAL.EQ.0) GO TO 220
            WRITE (6,950)
```

NBSLD-PNC PAGE 11

```
      DO 190 I=1,NEXP
      WRITE (6,920) I,ITYPE(I),IHT(I),IRF(I),ABSP(I),U(I),H(I),A(I),AZW(%
     I),SHADE(I),UT(I),HI(I)
  190 CONTINUE
      WRITE (6,960)
      DO 200 I=1,NEXP
  200 WRITE(6,800) (SHAW(I,J),J=1,15)
      IF(ASHRAE.EQ.1) GO TO 235
      WRITE (6,970)
      WRITE (6,980)
      DO 210 I=1,NEXP
      WRITE (6,990) I,(G(I,J),J=1,NEXP)
  210 CONTINUE
  220 IF(RUNTYP.EQ.2) CALL WINTER(A,UW,ITYPE,NEXP,CFMWT,DBIN,DBWT*
     ,UG,TGW,RHW,RHOW)
      DO 230 I=1,NEXP
      DO 230 J=1,NEXP
  230 G(I,J)=HP*G(I,J)
  235 TIM=TUL
      QLITO=QLITY*AG*3.413*NOFLR
      QEQPO=QEQPX*AG*3.413*NOFLR
      DO 240 I=1,NEXP
      QO(I)=0.
      QI(I)=0.
  240 CONTINUE
      QRFO=0.
      QRFI=0.
    % DBM=TIM= REFERENCE TEMPERATURE
      TA=TIM
      MOT=0
      TCLID=0.
      THTLD=0.
      IF(TJKLMN.GT.1) GO TO 243
      CALL OBEY('SWITCH INB:,CLOSE',5)
  243  CONTINUE
      NEND=DAYSKP+NDAY
      IF(RUNTYP.NE.2) GO TO 241
      NEND=7
      DO 242 J=1,24
      DB(J)=ZBLDG(4)-ZBLDG(5)*DBPF(J)
      DPT(J)=DPMAX
      WST(J)=0.
      PBT(J)=29.921
      TC(J)=0.
      NTOC(J)=0
  242 CONTINUE
  241 DO 740 ND=1,NEND
      NSKP=ND-DAYSKP
      IF(RUNTYP.EQ.2) GO TO 261
      READ(7) DB,DPT,WBT,WST,PBT,TC,NTOC,LDAY,YEAR,MONTH,CITY
```

NBSLD-PNC PAGE 12

```
          N=ND-DAYSKP
          IF (N.LT.1) GO TO 740
          INDAY=DAYSKP+N
          IF (IDETAL.EQ.0) GO TO 250
          WRITE (6,860) N,INDAY,YEAR,MONTH,LDAY
          WRITE (6,850) NAMERM
  250     CONTINUE
          KDAY=WKDAY(YEAR,MONTH,LDAY)
          CALL HOLDAY (YEAR,MONTH,LDAY,KDAY,IHOL)
          CALL DST (YEAR,MONTH,LDAY,DSTX,DSTY)
          IDST=1
          IF (MONTH.LT.4) IDST=0
          IF (MONTH.GT.10) IDST=0
          IF (MONTH.NE.4.OR.MONTH.NE.10) GO TO 260
          IF (MONTH.EQ.4.AND.LDAY.LT.DSTX) IDST=0
          IF (MONTH.EQ.10.AND.LDAY.GT.DSTY) IDST=0
  260     DSX=IDST
          JJ=1
          IF(KDAY.EQ.7.OR.KDAY.EQ.1) JJ=2
          IF (IHOL.EQ.1) JJ=2
  261     IF(RUNTYP.EQ.2) JJ=1
          DO 270 J=1,24
          QLITE(J)=QLITO*QLITX(J,JJ)
          QEQUP(J)=QEQPO*QEQUX(J,JJ)
  270     CONTINUE
          IF (MONTH.EQ.MOT) GO TO 390
          TG=TGW
          IF(MONTH.GT.5.AND.MONTH.LT.10) TG=TGS
          MOT=MONTH
          S(4)=IEDAY(MONTH)
          IF(RUNTYP.EQ.2) S(4)=ZBLOG(3)
          S(6)=IDST
          IF(RUNTYP.EQ.2) S(6)=0.
          S(7)=0.2
          S(8)=1.0
          S(33)=1.
          IF (IDETAL.EQ.0) GO TO 280
          WRITE (6,1000)
  280     CONTINUE
          DO 370 I=1,NEXP
          IF (ITYPE(I).LT.5) GO TO 300
          DO 290 J=1,24
          QSUN(I,J)=0.
          QGLAS(I,J)=0.
  290     QSKY(I,J)=0.
          GO TO 360
  300     WAZ=AZW(I)
          S(9)=WAZ
          S(10)=90.
          IF (ITYPE(I).EQ.1) S(10)=0.
```

```
            IF(ITYPE(I).NE.3) GO TO 301
            SHDX(1)=SHAW(I,1)
            SHDX(2)=SHAW(I,2)
            SHDX(3)=SHAW(I,3)
            SHDX(4)=SHAW(I,4)
            SHDX(5)=SHAW(I,5)
            SHDX(6)=SHAW(I,6)
            SHDX(7)=SHAW(I,7)
            SHDX(8)=SHAW(I,8)
            SHDX(9)=SHAW(I,9)
            SHDX(10)=SHAW(I,10)
            SHDX(11)=SHAW(I,11)
            SHDX(12)=SHAW(I,12)
            SHDX(13)=SHAW(I,13)
            SHDX(14)=SHAW(I,14)
            SHDX(15)=SHAW(I,15)
      301   CONTINUE
            DO 350 J=1,24
            QSKY(I,J)=0.
            TIME=J
            S(5)=TIME
            CALL SUN
            SALT(J)=S(20)
            IF (S(25).GT.0.) GO TO 310
            QSUN(I,J)=0.
            QGLAS(I,J)=0.
            GO TO 350
      310   QSUN(I,J)=S(25)*ABSP(I)
            QGLAS(I,J)=0.
            PHI=S(21)*PI/180.
            XQ=S(20)*PI/180.
            COSZ=SIN(XQ)
            IF(SHD(I))311,311,312
      312   SHDF(I,J)=0.
            GO TO 345
      311   SHDF(I,J)=1.
            IF(SHDX(1)) 345,345,316
      316   SHDX(16)=S(9)*PI/180.
            CALL SHADOW(SHDX,PHI,COSZ,SHDF(I,J))
      345   CONTINUE
            IF(ITYPE(I).NE.3) GO TO 346
            IF(IEXTSD.EQ.0) GO TO 347
            IF(MONTH.GE.IEXMS.AND.MONTH.LE.IEXME) SHDF(I,J)=0.
      347   CONTINUE
            CALL GLASS(SHDF(I,J),SHADE(I),1.,1.,QGLAS(I,J))
      346   CONTINUE
            S34=S(25)-S(26)-S(27)
            QSUN(I,J)=(S34*SHDF(I,J)+S(26)+S(27))*ABSP(I)
      350   CONTINUE
      360   IF (IDETAL.NE.0) WRITE (6,930) I
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NBSLD-PNC PAGE 14

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      IF (IDETAL.NE.0) WRITE (6,940) (QSUN(I,J),J=1,24)
      IF (IDETAL.NE.0) WRITE (6,940) (QGLAS(I,J),J=1,24)
370   CONTINUE
      DO 380 I=1,NEXP
      DO 380 J=1,24
      PGLAS(I,J)=QGLAS(I,J)
380   PSUN(I,J)=QSUN(I,J)
390   CONTINUE
      IF(N.NE.1) GO TO 440
      DO 400 J=1,24
      DO 400 I=1,NEXP
400   TOS(I,J)=DB(24-J+1)-TIM
      DO 410 J=25,48
      DO 410 I=1,NEXP
410   TOS(I,J)=TOS(I,J-24)
      DO 420 I=1,NEXP
      DO 420 J=1,48
420   TIS(I,J)=0.
      TA=TIM
      DO 430 J=1,48
      TNEW(J)=0.
430   TATTIC(J)=0.
      IF(ASHRAE)440,440,441
441   DO 443 I=1,NEXP
      DO 442 J=1,24
442   TIS(I,J)=RMDBS(24-J+1)-TIM
      DO 443 J=25,48
443   TIS(I,J)=TIS(I,J-24)
      DO 444 II=1,2
      HEATG(II)=0.
      HEATX(II)=0.
      HEATIS(II)=0.
      HLCG(II)=0
      HLCX(II)=0.
444   HLCIS(II)=0.
440   CONTINUE
%     END OF INITIALIZATION
%     TIME CALCULATION BEGINS HERE
      DO 670 NK=1,24
      LL1=NK.GE.ISTART.AND.NK.LE.ILEAVE
      LL2=NK.LT.ISTART.OR.NK.GT.ILEAVE
      IF(ITK.NE.0) GO TO 459
      IF(ITHST.NE.1) GO TO 459
      CALL TEMPSH(MONTH,JJ,NK,RMDBS,RMDBW,RMDBWO,RMDBSO,TA)
459   CONTINUE
      IF(RUNTYP.NE.2) GO TO 451
      FOT=4.
      ACHG=ZROOM(9)
      CM=1.
      GO TO 452
```

```
451   WSTX=WST(NK)
      CALL FO (WSTX,3,FOC,FOT,0)
%     AIR CHANGE AS A FUNCTION OF WIND SPEED
%     COBLENZ AND ACHENBACH  1963 ASHRAE TRANSACTION
      ACH=0.15+0.013*WST(NK)+0.005*ABS(DB(NK)-TA)
      ACHG=ACH*CONST
      CM=CCM(SALT(NK),NTOC(NK),TC(NK))
452   CFML=A(1)*ACHG*HT/60.+CFMIN
      CFMLX=CFML
      CFMV=CFMS
      IF(LL1) GO TO 453
      CFMV=0.
      GO TO 454
453   IF(LL.GT.1) CFMV=0.
454   CONTINUE
      DO 470 I=1,NEXP
      NRR=NR(I)
      QSUN(I,NK)=PSUN(I,NK)*CM
      QGLAS(I,NK)=PGLAS(I,NK)*CM
      QSKY(I,NK)=0.
      IF (ITYPE(I).EQ.1) QSKY(I,NK)=2.*(10.-TC(NK))
      IF(NRR.LT.2) GO TO470
      DO 450 NTT=2,NRR
450   TOY(NTT)=TOS(I,NTT-1)
      DO 460 NTT=2,NRR
460   TOS(I,NTT)=TOY(NTT)
470   CONTINUE
      DO 550 I=1,NEXP
      NRR=NR(I)
      IF(ASHRAE.GT.0) TIS(I,1)=TA-TIM
      K=IPF(I)
      DO 480 J=1,NRR
      XDUM(J)=X(K,J)
      YDUM(J)=Y(K,J)
      ZDUM(J)=Z(K,J)
      TDUM(J)=TOS(I,J)
      IF(ITYPE(I).EQ.6.OR.ITYPE(I).EQ.7) TDUM(J)=TIS(I,J)
      IF (ITYPE(I).EQ.5) TDUM(J)=TG-TIM
      TI(J)=TIS(I,J)
480   CONTINUE
      UX=U(I)
      IF (H(I)) 500,500,490
490   H(I)=FOT
      RX=1./UI(I)+1./(HI(I)+HR)
      RXX=RX+1./H(I)
      U(I)=1./RXX
      UX=1./RX
500   CONTINUE
      AUENDW=ABS(UENDW)
      IF (ITYPE(I).EQ.1.AND.AUENDW.GT.1.E-5) GO TO 510
```

NBSLD-PNC PAGE 16

```
          GO TO 530
    510   ATCACG=AIRCHG*AIRNT
          IF(LL1) ATCACG=AIRCHG
          CALL ATTIC (XDUM,YDUM,ZDUM,CR(I),NRR,UX,H(I),DB(NK),QSUN(I,NK),QSKY(I,%
          NK),TDUM,TATTIC,TNEWO,TA,TIM,DRFO,DRF1,QO(I),QI(I),UENDW,UCELNG,AE%
          NDW,A(I),ATCHT,ATCACG)
          DO 520 J=1,NRR
          TNEW(J)=TDUM(J)
    520   TOS(I,J)=TATTIC(J)
          GO TO 550
    530   CONTINUE
          IF(ITYPE(I).EQ.1.AND).AUENDW.GT.1.E-5) TEMAT=TA-QI(I)/UCELNG
   1563   FORMAT('  AT HOUR',I5,'   ATTIC TEMPERATURE = ',F10.3)
          HIBB=H(I)
          IF(NHAY.NE.1) GO TO 9009
          IF(ITYPE(I).NE.1) GO TO 9009
          IF(MONTH.LE.4.OR.MONTH.GE.10) GO TO 9008
          QSKY(I,NK)=QSKY(I,NK)+0.2*(DB(NK)-WBT(NK))*62.4*3.5/12.
          IF(NK.GE.7.AND.NK.LE.20) QSUN(I,NK)=0.
          IF(NK.GE.7.AND.NK.LE.20) QSKY(I,NK)=0.
          IF(NK.GE.7.AND.NK.LE.20) HIBB=(H(I)*0.024)/(0.024+0.5*H(I))
          GO TO 9009
   9008   IF(NK.LE.7.OR.NK.GE.20) QSKY(I,NK)=0.
          IF(NK.LE.7.OR.NK.GE.20) HIBB=(H(I)*0.024)/(0.024+0.5*H(I))
   9009   CONTINUE
      *   IF(PRNTYP.EQ.2.AND.ND.EQ.7) WRITE(6,1560) HIBB,QSKY(I,NK)
    1560  FORMAT(15F8.1)
          CALL OUTSID (XDUM,YDUM,ZDUM,CR(I),JK,HIBB,DB(NK),TIM,QO(I),QI(I),Q%
          SUN(I,NK),QSKY(I,NK),TDUM,TI,TNEWO,TA,ITEMP,NRR)
          DO 540 J=1,NRR
    540   TOS(I,J)=TDUM(J)
    550   CONTINUE
          QOCPS(NK)=QOCUP(NK,JJ)*10.*(100.-TA)*QCU
          QOCPL=10.*(TA-60.)*QOCUP(NK,JJ)*QCU
          IF (TA-100.) 570,560,560
    560   QOCPS(NK)=0.
          QOCPL=400.*QOCUP(NK,JJ)*QCU
          GO TO 590
    570   IF(TA-65.) 580,590,590
    580   QOCPS(NK)=350.*QOCUP(NK,JJ)*QCU
          QOCPL=50.*QOCUP(NK,JJ)*QCU
    590   DO 620 I=1,NEXP
          NRR=NR(I)
          IF(NRR.LT.2) GO TO 620
          DO 600 NTT=2,NRR
    600   TOY(NTT)=TIS(I,NTT-1)
          DO 610 NTT=2,NRR
    610   TIS(I,NTT)=TOY(NTT)
    620   CONTINUE
          IF(ASHRAE) 1621,1621,622
```

NBSLD-PNC PAGE 17

```
      622   QSUMG=0.
            QSUMX=0.
            DO 623 I=1,NEXP
            IF(ITYPE(I).LE.3.OR.ITYPE(I).EQ.8)QSUMX=QSUMX-QI(I)*A(I)
            IF(ITYPE(I).EQ.3) QSUMG=QSUMG+QGLAS(I,NK)*A(I)
      623   CONTINUE
            HEATG(1)=HEATG(2)
            HEATG(2)=QSUMG
            HEATX(1)=HEATX(2)
            HEATX(2)=QSUMX+QOCPS(NK)+QEQUP(NK)
            HEATIS(1)=HEATIS(2)
            NKK=NK-1
            IF(NKK.EQ.0) NKK=24
            HEATIS(2)=QLITE(NKK)
            HLCG(1)=HLCG(2)
            HLCX(1)=HLCX(2)
            HLCIS(1)=HLCIS(2)
            ISC=1
            CALL RMRT(HEATG,HLCG,HEATX,HLCX,HEATIS,HLCIS,IW,IL,FC,ISC)
            QL=HLCG(2)+HLCX(2)+HLCIS(2)+1.08*CFML*(DB(NK)-TA)
            QGAIN=HEATG(2)+HEATX(2)+HEATIS(2)
            QL=-QL
            GO TO 624
     1621   CONTINUE
            DO 1623 I=1,NEXP
            HI(I)=0.542
            HTEST=TIS(I,1)
            IF(I.NE.1) GO TO 1624
            IF(HTEST) 1625,1625,1626
     1625   HI(1)=0.712
            GO TO 1623
     1626   HI(1)=0.162
            GO TO 1623
     1624   IF(I.NE.NEXP) GO TO 1623
            IF(HTEST) 1627,1627,1628
     1627   HI(NEXP)=0.162
            GO TO 1623
     1628   HI(NEXP)=0.712
     1623   CONTINUE
            IF(NTVNT.EQ.0) GO TO 1630
            IF(DB(NK)-DBVMAX) 1632,1630,1630
     1632   IF(TA-DBVMIN) 1630,1630,1631
     1631   IF(JJ.GT.1) GO TO 1633
            IF(IL1) GO TO 1630
     1633   IF(QL+10)1636,1630,1630
     1636   CFML=CFMLX+CFMNT
     1630   CONTINUE
            V(1)=TV
            IF(NVENT.NE.0) V(1)=DB(NK)
            V(2)=CFML
```

NBSLD-PNC PAGE 18

```
      V(3)=0.
      IF(NVENT.NE.0) V(3)=CFMV
      V(4)=FRAS
      V(5)=FLCG
      V(6)=TIM
      V(7)=QCMAX
      V(8)=QHMAX
      IF(LL.GT.1) GO TO 1634
      IF(LL2) GO TO 1634
      V(9)=TUL
      V(10)=TLL
      GO TO 1635
1634  V(9)=RMDBSO
      V(10)=RMDBWO
1635  CONTINUE
      V(11)=TA
      V(12)=FRAS
      V(13)=HR
      V(14)=METHOD
      CALL RMTMK(V,TIF,QL,TA,NEXP,NK,ITK)
624   CALL PSY2(DB(NK),DPT(NK),PBT(NK),WBT(NK),PVO,WA,HA,VA,RHA)
      PLAT(NK)=-QOCPL*ZNORM
      WV=WA
      QOCPL=QOCPL/1060.
      IF(QL) 1645,1645,1646
1645  RHIN=RHS
      GO TO 1647
1646  RHIN=RHW
      IF(TA.GT.RMDBS(12)) GO TO 1640
      IF(TA.LT.RMDBW(12)) GO TO 1640
1647  CONTINUE
      CALL DBRH(TA,RHIN,WIN)
      IF(ABS(QL)-1.) 1640,1640,640
1640  CONTINUE
      WIN=(4.5*CFML*WA+QOCPL)/4.5/CFML
627   PVI=PB*WIN/(0.622+WIN)
      RHIN=100.*PVI/PVSF(TA)
IF(RHIN.GT.100.) RHIN=100.
640   CONTINUE
      CALDB(NK)=TA
      CALRH(NK)=RHIN
      AIRLAT(NK)=4.5*CFML*(WIN-WA)*1060.*ZNORM
      RALD(NK)=QLITE(NK)*FLCG*ZNORM
      BASEL(NK)=(QLITE(NK)+QEQUP(NK))*ZNORM
      AIRLK(NK)=1.08*(CFML+CFMV)*(TA-DB(NK))*ZNORM
      QSOL(NK)=PSUN(1,NK)
      QLATNT=(4.5*CFML*(WIN-WA)+4.5*CFMV*(WIN-WV)-QOCPL)*1060.
      IF(RUNTYP.EQ.2) GO TO 641
      IF(ASHRAE.EQ.0) GO TO 641
      CALL ADJUST(QL,QLATNT,MONTH,NK,JJ)
```

NBSLD-PNC PAGE 19

```
641   CONTINUE
      QL=QL+1.08*CFMV*(TA-DB(NK))
      QLS(NK)=QL*ZNORM
      QLL(NK)=QLATNT*ZNORM
      IF(ABS(QLS(NK))-1.)642,642,643
642   QLL(NK)=0.
643   CONTINUE
      IF(AUENDW.LT.1.E-5) GO TO 1147
650   NRR=NR(1)
      DO 660 J=1,NRR
660   TOS(1,J)=TNEW(J)
 1147 IF(RUNTYP.NE.2.OR.ND.LT.7) GO TO 670
%     WRITE(6,1562)
 1562 FORMAT('  HOUR      TYPE SURFACE CONSTRUCT    ANGLE      FLUX              AREA         LOAD      PER CENT')
      QPTOT=0.
      DO 8910 I=1,NEXP
      QBB=0.
      IF(ITYPE(I).LE.5.OR.ITYPE(I).EQ.8) QBB=Q1(I)*A(I)
      IF(ITYPE(I).EQ.3) QBB=-QGLAS(I,NK)*A(I)+QBB
      QZ=QBB/A(I)
      QPTOT=QPTOT+QBB
%     WRITE(6,1561) NK,ITYPE(I),IRF(I),AZW(I),QZ,A(I),QBB,QSUN(I,NK),QSKY(I,NK),QGLAS(I,NK)
 1561 FORMAT(3I10,7F12.3)
 8910 CONTINUE
      QPTOT=QPTOT-QOCPS(NK)-QEQUP(NK)-QLITE(NK)
      IF(ITYPE(I).EQ.1.AND.AUENDW.GT.1.E-5) WRITE(6,1563) NK,TEMAT
%     WRITE(6,1564) QPTOT
 1564 FORMAT('  QTOT = ',E16.8)
670   CONTINUE
      IF(RUNTYP.EQ.2.AND.NO.LT.7) GO TO 740
      QLMAX=ABS(QLS(1))
      NMAX=1
      TSUM=0.
      QLDSUM=0.
      CLDAY=0.
      HLDAY=0.
      DO 720 NK=1,24
      IF (QLMAX-ABS(QLS(NK))) 680,690,690
680   QLMAX=ABS(QLS(NK))
      NMAX=NK
      GO TO 690
690   CONTINUE
      TSUM=TSUM+DB(NK)
      QLDSUM=QLDSUM+QLS(NK)+QLL(NK)
      QLDS=QLS(NK)+QLL(NK)
      IF (QLDS) 700,700,710
700   CLDAY=CLDAY+QLDS
      GO TO 720
710   HLDAY=HLDAY+QLDS
720   CONTINUE
```

```
            TCLLD=TCLLD+CLDAY
            THTLD=THTLD+HLDAY
            DBA=TSUM/24.
            QLMAX=QLS(NMAX)+QLL(NMAX)
            IF(RUNTYP.EQ.2) N=1
            IF(N.GT.1) GO TO 722
            WRITE(6,760) NAMERM
      722   CONTINUE
            WRITE(6,770) MONTH,LDAY,NMAX,QLMAX,CLDAY,HLDAY,DBA
            IF(ND.EQ.NEND) WRITE(6,874)
            IF(RUNTYP.NE.2) GO TO 721
            IF(ND.NE.NEND) WRITE(6,874)
            WRITE(6,780) YEAR,MONTH,LDAY
            WRITE(6,871)
      871   FORMAT(//'      TIME      DBOUT      WBOUT      DBIN      RHIN      %
      QLS       QLL')
            DO 872 J=1,24
      872   WRITE(6,873) J,DB(J),WBT(J),CALDB(J),CALRH(J),QLS(J),QLL(J)
      873   FORMAT(I10,4F10.1,2F10.0)
            WRITE(6,874)
      874   FORMAT(///)
      721   CONTINUE
            IF (IDETAL.EQ.0) GO TO 730
            WRITE (6,1020) DBA,QLDSUM
            WRITE (6,1030) CLDAY,HLDAY
            WRITE (6,1040) N,TCLLD,N,THTLD
      730   CONTINUE
            IF (TAPE2.EQ.0) GO TO 740
            WRITE (TAPE2) NAMERM,MONTH,LDAY,DB,DPT,WBT,WST,PBT,TC,NTOC,CALDB,C%
            ALRH,QLS,QLL,DBA,CLDAY,HLDAY,TCLLD,THTLD,QLITE,QEQUP,QSOL,QOCPS,AIRLK
            WRITE(10) QLS,PLAT,AIRLAT,DB,DPT,CALDB,RALD,BASEL
      740   CONTINUE
            CLDSUM=CLDSUM+TCLLD
            HLDSUM=HLDSUM+THTLD
            WRITE (6,1050) IJKLMN,CLDSUM,IJKLMN,HLDSUM
            REWIND 7
      750   CONTINUE
            END FILE  TAPE2
            END FILE 10
            STOP
      %
      %
      %
      760   FORMAT(///'   ROOM NAME= '9A4////'      MONTH        DAY        MHR   %
      QLMAX      CLDAY      HLDAY      DBA')
      770   FORMAT (3I10,3F10.0,F10.1)
      780   FORMAT (' ***** YEAR =',I5,' ***** MONTH =',I3,' ***** DAY =',I3/)
      790   FORMAT (8H  ROOMNO,6X'HT',6X'AG',3X'NOFLR',5X'QCU',2X'ARCHGS',2X'A%
      RCHGW')
      800   FORMAT(15F8.1)
```

NBSLD-PNC PAGE 21

```
810    FORMAT (5X'LAT',4X'LONG',5X'TZN',3X'ZNORM')
820    FORMAT (3X'QLITY',3X'QEQPX',4X'CFMV',4X'DBIN',6X'TG',6X'TV',4X'DPI%
N')
830    FORMAT (/'  UENDW  UCFLNG   AENDW   ATCHT')
840    FORMAT (6X,'NEXP',7X,'ITK',5X,'ITHST'/3(8X,I2))
850    FORMAT (1H ,6A6)
860    FORMAT ('  CLIMATIC DATA FOR DAY=',I5/'  DAYS ELAPSED SINCE JAN 1=%
',I5,'  YEAR=',I5,'  MONTH=',I5,'  DAY=',I5)
870    FORMAT (' DB'/2(12F10.2/)' WBT'/2(12F10.2/)' CALDB'/2(12F10.2/)' C%
ALRH'/2(12F10.2/)'  SENSIBLE LOAD'/2(12F10.0/)'  LATENT LOAD'/2(12%
       F10.0/))
880    FORMAT(10I7)
890    FORMAT (10I7)
900    FORMAT (10F7.0)
910    FORMAT (1X,9A4)
911    FORMAT (9A4)
920    FORMAT (I3,3I10,8F10.2)
930    FORMAT (I10,F10.0)
940    FORMAT (24F5.0)
950    FORMAT(' SURFACE NO ITYPE    IHT        IRF        ABSP%
       U          H',9%
       X,'A'9X,'WAZ'5X,'SHADE'8X,'UT'8X,'HI')
960    FORMAT (// '  SHADOW CASTING DATA'/'       FL%
       HT        FP        AW        BWL       BWR        D        FP1%
       A1        B1        C1        FP2       A2         B2       C2')
970    FORMAT (////'    RADIATION INTERCHANGE FACTORS')
980    FORMAT ('  SURFACE             1          2          3          4          %
5         6          7          8          9          10')
990    FORMAT (I10,10F10.3)
1000   FORMAT ('    SOLAR DATA (QSUN/QGLASS)')
1010   FORMAT ('      '/'      ')
1020   FORMAT (' DBA =',F6.2/' QLDSUM =',F10.0//)
1030   FORMAT (' TOTAL COOLING CONSUMPTION PER DAY =',F10.0,' BTU'/' TOTA%
L HEATING CONSUMPTION PER DAY =',F10.0,' BTU')
1040   FORMAT (' TOTAL COOLING CONSUMPTION FOR THE ROOM OVER THE ',I3,' %
DAY PERIOD =',E11.5,' BTU'/' TOTAL HEATING CONSUMPTION FOR THE ROO%
M OVER THE ',I3,' DAY PERIOD =',E11.5,' BTU')
1050   FORMAT (' TOTAL COOLING CONSUMPTION FOR ',I2,' ROOMS =',E11.5,' BT%
U'/' TOTAL HEATING CONSUMPTION FOR ',I2,' ROOMS =',E11.5,' BTU')
1051   FORMAT(///' CONGRATULATIONS!! NOW YOU ARE ON NBSLD')
1052   FORMAT(/'  WE ASSUME YOU HAVE ALREADY PREPARED THE DATA')
1053   FORMAT('  ON NBS DATA FORMS..IF YOU HAVE NOT, PLEASE TURN OFF')
1054   FORMAT('  THE TERMINAL AND HAVE YOUR DATA READY ON THE DATA FORMS')
       END
```

NBSLD-PNC PAGE 22

```
            SUBROUTINE OUTSID (X,Y,Z,CR,UX,FO,DB,TIM,QO,QI,QSUN,QSKY,TO,TI,TON%
            EW,TA,ITEMP,NR)
            DIMENSION TO(1),TI(1),X(1),Y(1),Z(1)
            XNUM=QSUN-QSKY+FO*(DB-TIM)
      IF(NR.NE.1) GO TO 50
   10       IF (FO) 20,20,30
   20       TONEW=TO(1)
            GO TO 40
   30       TAM=TA-TIM
            TONEW=(XNUM+UX*TAM)/(UX+FO)
   40       CONTINUE
            QO=UX*(TAM-TONEW)
            IF (ITEMP.EQ.0) QI=QO
            TO(1)=TONEW
            GO TO 90
   50       SUMZ=0.
            SUMY=Y(1)*TI(1)
            SUMX=X(1)*TI(1)
            SUMXY=0.
            DO 60 J=2,NR
            SUMY=SUMY+Y(J)*TI(J)
            SUMX=SUMX+X(J)*TI(J)
            SUMXY=SUMXY+Y(J)*TO(J)
   60       SUMZ=SUMZ+Z(J)*TO(J)
            XNUM=SUMY-SUMZ+CR*QO+XNUM
            TONEW=XNUM/(Z(1)+FO)
            IF(FO) 70,70,80
   70       TONEW=TO(1)
   80       TO(1)=TONEW
            SUMZ=SUMZ+Z(1)*TO(1)
            SUMXY=SUMXY+Y(1)*TO(1)
            QO=SUMY-SUMZ+CR*QO
            IF (ITEMP.EQ.0) QI=SUMX-SUMXY+CR*QI
   90       CONTINUE
            RETURN
            END
```

OUTSID-PNC PAGE 1

```
      SUBROUTINE PSY1(DB,WB,PB,DP,PV,W,H,V,RH)
      PVP=PVSF(WB)
            IF (DB-WB) 30,30,10
      10    WSTAR=0.622*PVP/(PB-PVP)
            IF (WB-32.) 20,20,40
      20    PV=PVP-5.704E-4*PB*(DB-WB)/1.8
            GO TO 50
      30    PV=PVP
            GO TO 50
      40    CDB=(DB-32.)/1.8
            CWB=(WB-32.)/1.8
            HL=597.31+0.4409*CDB-CWB
            CH=0.2402+0.4409*WSTAR
            EX=(WSTAR-CH*(CDB-CWB)/HL)/0.622
            PV=PB*EX/(1.+EX)
      50    W=0.622*PV/(PB-PV)
            V=0.754*(DB+459.7)*(1+7000*W/4360)/PB
            H=0.24*DB+(1061+0.444*DB)*W
      IF(PV.LE.0) GO TO 60
      IF(DB.NE.WB) GO TO 70
      DP=DB
      RH=1.
      GO TO 60
      70 CONTINUE
            DP=DPF(PV)
            RH=PV/PVSF(DB)
      60 RETURN
            END
```

PSY1-PNC PAGE 1

```
          SUBROUTINE PSY2 (DB,DP,PB,WB,PV,W,H,V,RH)
%    THIS SUBROUTINE CALCULATES THE FOLLOWINGS WHEN DRY-BULB TEMPERATURE
%    (DB),DEW-POINT TEMPERATURE(DP),AND BAROMETRIC PRESSURE(PB) ARE GIVEN
%    WB    WET-BULB TEMPERATURE
%    W     HUMIDITY RATIO
%     H    ENTHALPY
%     V    VOLUME
%    PV    VAPOR PRESSURE
%    RH    RELATIVE HUMIDITY
          IF (DP-DB) 20,10,10
 10       DP=DB
 20       PV=PVSF(DP)
          PV=PVSF(DP)
          PVS=PVSF(DB)
          RH=PV/PVS
          W=0.622*PV/(PB-PV)
          V=0.754*(DB+459.7)*(1+7000*W/4360)/PB
          H=0.24*DB+(1061+0.444*DB)*W
          IF (H) 30,30,40
 30       WB=DP
          RETURN
 40       WB=WBF(H,PB)
          RETURN
          END
```

PSY2-PNC PAGE 1

```
      FUNCTION PVSF (X)
      DIMENSION A(6)/-7.90298,5.02808,-1.3816E-7,11.344,8.1328E-3,-3.491%
49/,B(4)/-9.09718,-3.56654,0.876793,0.0060273/,P(4)
      T=(X+459.688)/1.8
      IF (T.LT.273.16) GO TO 10
      Z=373.16/T
      P(1)=A(1)*(Z-1)
      P(2)=A(2)*LOG10(Z)
      Z1=A(4)*(1-1/Z)
      P(3)=A(3)*(10**Z1-1)
      Z1=A(6)*(Z-1)
      P(4)=A(5)*(10**Z1-1)
      GO TO 20
10    Z=273.16/T
      P(1)=B(1)*(Z-1)
      P(2)=B(2)*LOG10(Z)
      P(3)=B(3)*(1-1/Z)
      P(4)=LOG10(B(4))
20    SUM=0
      DO 30 I=1,4
30    SUM=SUM+P(I)
      PVSF=29.921*10**SUM
      RETURN
      END
```

PVSF-PNC PAGE 1

```
             SUBROUTINE RESF (XX,YY,ZZ,IRUN)
        %    THIS PROGRAM IS DEVELOPED BY T.KUSUDA OF THE NATIONAL BUREAU OF
        %    STANDARDS FOR CALCULTING THE THERMAL RESPONSE FACTORS FOR
        %    COMPOSITE WALLS,FLOORS,ROOFS,BASEMENT WALLS BASEMENT FLOORS
        %    AND INTERNAL FURNISHINGS OF SIMPLE SHAPES
        %    RESPONSE FACTORS ARE USED IN THE FOLLOWING MANNER
        %    X,Y,Z ARE RESPONSE FACTURS
        %   QI=X*TI-Y*TO*GMA   INSIDE WHERE R IS MINIMUM
        %    QO=Y*TI-Z*TO   OUTSIDE WHERE R IS MAXIMUM
        %    TI    INSIDE TEMPERARURE WHERE R IS MINIMUM
        %    TO    OUTSIDE TEMPERATURE WHERE R IS MAXIMUM
        %    K  THERMAL CONDUCTIVITY
        %    G  THERMAL DIFFUSIVITY
        %    L  THICKNESS
        %  IN=0   FINITE THICK WALL
        %  IN=1   SEMI-FINITE WALL
        %  IN=2   SOLID OBJECT
        %  IF RESPONSE FACTORS OF THE SOLID CYLINDER OR SPHERE OF HOMOGENEOUS
        %  PROPETY ARE DESIRED, TREAT THE PROBLEM OF MULTILAYER BUT WITH THE
        %  IDENTICAL PROPERTIES FOR ALL THE LAYERS EXCEPT THE RADIUS
             REAL K(10),G(10),L(10),KG
             DIMENSION X(100),Y(100),Z(100),C(10),D(10),RES(10),RMK(10,6)
             DIMENSION RMKG(6),F(100),XX(100,1),YY(100,1),ZZ(100,1),FF(100,20)
        DELTAT=1.
             IRUN=0
        IN=0
        WRITE(6,241)
        241 FORMAT(' DATA SHEET NO 6 N/L,K,P,C,R')
        20 READ(5,*) NLAYR
             IF (NLAYR.EQ.0) GO TO 200
             IRUN=IRUN+1
             IF (NLAYR.GT.10) GO TO 200
             NNLAYR=NLAYR+1
             IF (NLAYR.EQ.0) GO TO 40
             DO 30 I=1,NLAYR
        30   READ (5,*) L(I),K(I),D(I),C(I),RES(I)
        WRITE(6,242)
        242 FORMAT(' DATA SHEET NO 7: DESCRIPTION OF EACH LAYER')
             IF (IN.EQ.2) GO TO 50
        %  READ K,RHO, AND C OF GROUND IF IN=1
        %   FOLLOWINGS ARE GROUND THERMAL CONDUCTIVITY, DENSITY AND SP.HT IF
        %    IN=2. OTHERWISE THE SAME PROPERTIES OF THE  INTERNAL SLAB
        40   IF (IN.NE.0) READ (5,*) KG,DG,CG
        %   AG  THERMAL DIFFUSIVITY  OF EARTH
             IF (IN.NE.0) AG=KG/CG/DG
             IF (NLAYR.EQ.0) GO TO 100
             IF (IN.EQ.2) READ (5,330) (RMKG(J),J=1,4)
        50   DO 60 I=1,NLAYR
        60   READ (5,330) (RMK(I,J),J=1,4)
             IF (IN.EQ.1) READ (5,330) (RMKG(J),J=1,4)
```

```
      DO 90 I=1,NLAYR
      IF (L(I)) 80,70,80
70    G(I)=0.
      K(I)=1./RES(I)
      GO TO 90
80    G(I)=K(I)/C(I)/D(I)
90    CONTINUE
100   CONTINUE
      CALL RESPTK (K,L,G,AG,KG,X,Y,Z,NLAYR,DELTAT,NRT,CR,UT,IN,F)
      WRITE (6,220) IRUN
      WRITE (6,350)
      WRITE (6,250)
      WRITE (6,260)
      WRITE (6,210)
      IF (NLAYR.EQ.0) GO TO 130
      IF (IN.EQ.2) WRITE (6,360) KG,DG,CG,(RMKG(J),J=1,4)
      DO 120 I=1,NLAYR
      IF (L(I)) 120,110,120
110   K(I)=0.
120   WRITE (6,270) I,L(I),K(I),D(I),C(I),RES(I),(RMK(I,J),J=1,6)
      IF (IN.EQ.1) WRITE (6,360) KG,DG,CG,(RMKG(J),J=1,6)
130   WRITE (6,290) DELTAT
      WRITE (6,280) UT
      WRITE (6,300)
      WRITE (6,210)
      IF (IN.NE.0) GO TO 150
      WRITE (6,310)
      XX(1,IRUN)=FLOAT(NRT)
      YY(1,IRUN)=FLOAT(NRT)
      ZZ(1,IRUN)=FLOAT(NRT)
      XX(2,IRUN)=CR
      YY(2,IRUN)=CR
      ZZ(2,IRUN)=CR
      XX(NRT+3,IRUN)=UT
      DO 140 N=1,NRT
      XX(N+2,IRUN)=X(N)
      YY(N+2,IRUN)=Y(N)
      ZZ(N+2,IRUN)=Z(N)
      JN=N-1
140   WRITE (6,320) JN,X(N),Y(N),Z(N)
      GO TO 190
150   WRITE (6,370)
      IF (IN.EQ.1) GO TO 170
      IF (IN.EQ.2) GO TO 170
      XX(1,IRUN)=FLOAT(NRT)
      XX(2,IRUN)=CR
      XX(NRT+3,IRUN)=UT
      DO 160 N=1,NRT
      JN=N-1
      X(N)=-X(N)
```

RESFNW-PNC PAGE 2

```
              XX(N+2,IRUN)=X(N)
        160   WRITE (6,380) JN,X(N)
              GO TO 190
        170   DO 180 N=1,NRT
              JN=N-1
              FF(N+2,IRUN)=F(N)
        180   WRITE (6,380) JN,F(N)
              FF(1,IRUN)=FLOAT(NRT)
              FF(2,IRUN)=CR
              FF(NRT+3,IRUN)=UT
        190   WRITE (6,210)
              WRITE (6,210)
              WRITE (6,340) CR
              GO TO 20
        200   RETURN
        %
        %
        %
        210   FORMAT (2H0 )
        220   FORMAT ('1  IRF='I10)
        230   FORMAT (10I7)
        240   FORMAT (10F7.0)
        250   FORMAT (77H0  LAYER      L(I)       K(I)        (I)       C(I)     RES(%
        I)   DESCRIPTION       )
        260   FORMAT (77H   NO                                                         %
             OF LAYERS          )
        270   FORMAT (1I6,1F11.3,1F10.3,1F10.2,1F10.3,1F8.2,2X,6A4)
        280   FORMAT (59H0                                      THERMAL CONDUCTANCE      %
         UT=1F7.3)
        290   FORMAT (49H0                                       TIME INCREMENT DT=1F3.0)
        300   FORMAT (50H0                                          RESPONSE FACTORS)
        310   FORMAT (120H0               J                         X               Y %
                       Z                                                      %
        )
        320   FORMAT (1I17,1F23.4,2F15.4)
        330 FORMAT(6A4)
        340   FORMAT (44H0                            COMMON RATIO   CR=1F7.5)
        350   FORMAT (50H0  WALL COMPOSITION                                      )
        360   FORMAT (1F27.3,1F10.2,1F10.3,10X,6A4)
        370   FORMAT (50H0              J                     F                   )
        380   FORMAT (1I24,1F21.5)
              END
```

RESFNW-PNC PAGE 3

```
      SUBROUTINE RESFX (X,Y,Z,XX,YY,ZZ,NR,CR,UT,NEXP)
      DIMENSION XX(100,10),YY(100,10),ZZ(100,10)
      DIMENSION X(10,100),Y(10,100),Z(10,100),NR(10),CR(10),UT(10)
      TEST=1.E-6
      DO 10 K=1,10
      DO 10 J=1,100
      XX(J,K)=0
      YY(J,K)=0
10    ZZ(J,K)=0
      CALL RESF (XX,YY,ZZ,IRUN)
      DO 30 K=1,NEXP
      I=K
IF(YY(5,K)) 101,101,102
101 YY(3,K)=0.
YY(4,K)=0.
YY(5,K)=0.
102 CONTINUE
      IF (K.GT.IRUN) GO TO 30
      X(I,1)=XX(3,K)
      Y(I,1)=YY(3,K)
      Z(I,1)=ZZ(3,K)
      NR(I)=XX(1,K)
      CR(I)=XX(2,K)
      JJJ=NR(I)+3
      UT(I)=XX(JJJ,K)
      NMAX=NR(I)
      WRITE(6,31) K
31    FORMAT(//'     CONDUCTION TRANSFER FUNCTIONS FOR   IRF='I10/*
     '             J           X            Y            Z          CR'/)
      J1=1
      WRITE(6,32) J1,X(I,1),Y(I,1),Z(I,1),CR(I)
      DO 20 J=2,NMAX
      J3=J+2
      J2=J+1
      X(I,J)=XX(J3,K)-XX(J2,K)*CR(I)
      Y(I,J)=YY(J3,K)-YY(J2,K)*CR(I)
      IF(ABS(X(I,J))-TEST) 40,40,41
40    NR(I)=J
      GO TO 30
41    CONTINUE
1     Z(I,J)=ZZ(J3,K)-ZZ(J2,K)*CR(I)
      JK=J
      WRITE(6,32) JK,X(I,J),Y(I,J),Z(I,J)
32    FORMAT(I10,4F10.5)
20    CONTINUE
30    CONTINUE
      RETURN
      END
```

RESFX-PNC PAGE 1

```
      SUBROUTINE RESPTK (K,L,G,AG,KG,X,Y,Z,NL,DT,NR,CR,U,IS,F)
      DIMENSION K(10),L(10),G(10),X(100),Y(100),Z(100),AP(10),BP(10),CP(%
10),DP(10),A(10),B(10),C(10),D(10),ZR1(3),ZR2(3),RB(3),RAP(3),ROOT%
(100),RA(3,100),ZRK(3,100),RX(100),RY(100),AZ(100),F(100)
      REAL K,L,KG
      PI=4.*ATAN(1.)
      M3=3
      IF (IS.NE.1) GO TO 10
      ZL=KG/10.
      UY=100./AG/DT
      CALL GPF (UY,ZL,AZ)
      IF (IS.EQ.1.AND.NL.EQ.0) GO TO 330
10    CALL ABCD2 (0.,K,L,G,AX,BX,CX,DX,NL)
      RB(1)=DX
      RB(2)=1.
      RB(3)=AX
      U=1./BX
      DO 20 I=1,NL
      PX=0
      CALL ABCDP2 (PX,K(I),L(I),G(I),AP(I),BP(I),CP(I),DP(I))
20    CALL ABCD2 (PX,K(I),L(I),G(I),A(I),B(I),C(I),D(I),1)
      IF (NL.LT.2) GO TO 30
      CALL DERVT (A,B,C,D,AP,BP,CP,DP,APP,BPP,CPP,DPP,NL)
      GO TO 40
30    APP=AP(1)
      BPP=BP(1)
      CPP=CP(1)
      DPP=DP(1)
40    RAP(1)=DPP
      RAP(2)=0.
      RAP(3)=APP
      DO 50 I=1,3
      C1=RAP(I)/BX/DT
      C2=RB(I)*BPP/BX/BX/DT
      ZR2(I)=-C1+C2
50    ZR1(I)=-ZR2(I)+RB(I)/BX
%   ROOTS OF B(P)=0.
      NMAX=10
      TESTMX=40.
      PX=0.001
      DPO=0.1/DT
      DLX=0.0001
      N=0
60    DL=DPO
      CALL ABCD2 (PX,K,L,G,AX,BX,CX,DX,NL)
70    PXP=PX+DL
      CALL ABCD2 (PXP,K,L,G,AXP,BXP,CXP,DXP,NL)
      IF (BX*BXP) 90,110,80
80    PX=PXP
      BX=BXP
```

```
      TESTX=PX*DT
      IF (TESTX-TESTMX) 70,170,170
 90   IF (DL-DLX) 140,140,100
 100  DL=DL/2.
      GO TO 70
 110  IF (BX) 130,120,130
 120  RXX=PX
      GO TO 150
 130  RXX=PXP
      GO TO 150
 140  AB=ABS(BX/BXP)
      RXX=(PX+AB*PXP)/(1.+AB)
 150  N=N+1
      ROOT(N)=RXX
      IF (N.GT.1) DPO=ROOT(N)-ROOT(N-1)
      NRT=N
      PX=RXX+DLX
      TESTX=RXX*DT
      IF (TESTX-TESTMX) 160,160,170
 160  IF (N.LT.NMAX) GO TO 60
 170  CONTINUE
      IF (ROOT(NRT)-100.) 190,180,180
 180  NRT=NRT-1
 190  DO 250 JJ=1,NRT
      PX=ROOT(JJ)
      DO 200 J=1,NL
      CALL ABCD2 (PX,K(J),L(J),G(J),A(J),B(J),C(J),D(J),1)
 200  CALL ABCDP2 (PX,K(J),L(J),G(J),AP(J),BP(J),CP(J),DP(J))
      CALL ABCD2 (PX,K,L,G,AX,BX,CX,DX,NL)
      IF (NL.LT.2) GO TO 210
      CALL DERVT (A,B,C,D,AP,BP,CP,DP,APP,BPP,CPP,DPP,NL)
      GO TO 220
 210  APP=AP(1)
      BPP=BP(1)
      CPP=CP(1)
      DPP=DP(1)
 220  PY=BPP*PX*PX*DT
      RA(1,JJ)=DX/PY
      RA(2,JJ)=1./PY
      RA(3,JJ)=AX/PY
      PZ=PX*DT
      IF (PZ-20.) 240,240,230
 230  RX(JJ)=0.
      RY(JJ)=25.E16
      GO TO 250
 240  RX(JJ)=EXP(-PZ)
      RY(JJ)=(1.-EXP(PZ))**2
 250  CONTINUE
      DO 260 JJ=1,NRT
      DO 260 M=1,M3
```

```
              ZR1(M)=RA(M,JJ)*RX(JJ)+ZR1(M)
      260     ZR2(M)=RA(M,JJ)*(RX(JJ)*RX(JJ)-2.*RX(JJ))+ZR2(M)
              II=1
              III=2
              IF (ZR1(2).LT.0) ZR1(2)=0.
              DO 270 M=1,M3
              ZRK(M,1)=ZR1(M)
      270     ZRK(M,2)=ZR2(M)
              NT=100
              DO 300 N=3,NT
              NR=N
              DO 280 M=1,M3
      280     ZRK(M,N)=0.
              DO 290 M=1,M3
              DO 290 JJ=1,NRT
      IF(RX(JJ).GT.1.E-10) GO TO 292
      PZ=0.
      GO TO 290
      292 CONTINUE
              PZ=(RX(JJ))**N
      290     ZRK(M,N)=ZRK(M,N)+PZ*RY(JJ)*RA(M,JJ)
              IF (N.LT.5) GO TO 300
              IF(ZRK(1,N-1)*ZRK(1,N-2))291,310,291
      291     TEST1=ZRK(1,N)/ZRK(1,N-1)
              TEST2=ZRK(1,N-1)/ZRK(1,N-2)
              TEST3=ABS(TEST1-TEST2)
              IF (TEST3-0.001) 310,310,300
      300     CONTINUE
      310     DO 320 N=1,NR
              X(N)=ZRK(1,N)
              Y(N)=ZRK(2,N)
      320     Z(N)=ZRK(3,N)
              CR=TEST2
              IF(X(3))321,322,321
      322     CR=0.
      321     CONTINUE
              IF (IS.EQ.2) GO TO 450
              IF (IS.NE.1) GO TO 470
      330     IF (NL.EQ.0) GO TO 390
              GF=2*KG/SQRT(DT*AG*PI)
              IF (NR.LT.50) GO TO 350
              DO 340 J=50,NR
              ZJ=J
      340     AZ(J)=GF*(SQRT(ZJ)-2.*SQRT(ZJ-1.)+SQRT(ZJ-2.))
              NRR=NR
              GO TO 370
      350     DO 360 J=NR,50
              Z(J+1)=Z(J)*CR
              X(J+1)=X(J)*CR
      360     Y(J+1)=Y(J)*CR
```

```
      NRR=50
370   DO 380 J=1,NRR
380   F(J)=X(J)-Y(J)*Y(J)/(Z(J)+AZ(J))
      NR=NRR
      GO TO 410
390   DO 400 J=1,NR
400   F(J)=AZ(J)
410   CONTINUE
      CR1=1.
      DO 430 J=1,50
      CR=F(J+1)/F(J)
      TESTCR=ABS(CR-CR1)
      IF (TESTCR-0.001) 440,440,420
420   CR1=CR
      JJ=J-1
430   CONTINUE
440   NR=J
      CR=CR1
      GO TO 470
450   CONTINUE
      DO 460 J=1,NR
      F(J)=X(J)+Z(J)-2.*Y(J)
      JJ=J-1
460   CONTINUE
470   RETURN
%
%
      END
```

RESPTK-PNC PAGE 4

```
SUBROUTINE RMRT(HEATG,HLCG,HEATX,HLCX,HEATIS,HLCIS,IW,IL,FC,ISC)
%   FC: CORRECTION FACTORFOR THE HEAT LOST TO THE SURROUNDINGS
%   ISC:SHADING COEFFICIENT INDEX  IF ISC=0 EXTERNAL SHADING
%       OTHERWISE INTERNAL SHADING
DIMENSION HEATG(2),HLCG(2),HEATX(2),HLCX(2),HEATIS(2),HLCIS(2)
DIMENSION AG0(3),AG1(3),AX0(3),AIS1(4,3),AIS2(4,3),B1(3),AX1(3)
DATA AG0/0.187,0.197,0.224/,AG1/-0.097,-0.067,-0.044/
DATA  B1/-0.91,-0.87,-0.82/
DATA AX0/0.676,0.681,0.703/,AX1/-0.586,-0.551,-0.523/
DATA (AIS1(1,J),J=1,3)/0.53,0.53,0.53/
DATA (AIS2(1,J),J=1,3)/-0.44,-0.40,-0.35/
DATA (AIS1(2,J),J=1,3)/0.59,0.59,0.59/
DATA( AIS2(2,J),J=1,3)/-0.50,-0.46,-0.41/
DATA( AIS1(3,J),J=1,3)/0.87,0.87,0.87/
DATA( AIS2(3,J),J=1,3)/-0.78,-0.74,-0.69/
DATA( AIS1(4,J),J=1,3)/0.50,0.50,0.50/
DATA( AIS2(4,J),J=1,3)/-0.41,-0.37,-0.32/
HLCG(2)=FC*(AG0(IW)*HEATG(2)+AG1(IW)*HEATG(1))-B1(IW)*HLCG(1)
HLCX(2)=FC*(AX0(IW)*HEATX(2)+AX1(IW)*HEATX(1))-B1(IW)*HLCX(1)
HLCIS(2)=FC*(AIS1(IL,IW)*HEATIS(2)+AIS2(IL,IW)*HEATIS(1))-B1(IW)*HLCIS(1)
IF(ISC.EQ.0) RETURN
HLCG(2)=FC*(AX0(IW)*HEATG(2)+AX1(IW)*HEATG(1))-B1(IW)*HLCG(1)
RETURN
END
```

RMRT-PNC PAGE 1

```
      SUBROUTINE RMTMK(V,TIF,QL,TA,NEXP,NX,ITK)
      COMMON/CC/ X(10,100),Y(10,100),Z(10,100),ITYPE(30)%
     ,IHT(30),IRF(30),ABSP(30),U(30),H(30),HI(30),A(30)%
     ,UT(30),TOS(30,48),TIS(30,48),G(30,30),TOY(48),DB(24)%
     ,QLITX(24,3),QEQUX(24,3),QOCUP(24,3),QOCPS(24),QLITE(24)%
     ,QEQUP(24),QI(30),CR(30),NR(30),QGLAS(30,24),ITHSI,UENDW%
     ,AZW(30),SHADE(30),RMDBS(24),RMDBW(24),SHD(30),UCELNG
      DIMENSION AA(30,30),BB(30),TT(30),TIF(30),A2(30,30)%
     ,B2(30),B3(30),GSUM(30),V(15)
      TS=V(1)
      CFML=V(2)
      CFMS=V(3)
      RROOM=V(4)
      RCELG=V(5)
      RROOML=V(12)
      TIM=V(6)
      QCMAX=V(7)
      QHMAX=V(8)
      TUL=V(9)
      TLL=V(10)
      TSET=V(11)
      HR=V(13)
      MET=V(14)
      DBNX=DB(NX)-TIM
      TU=TS-TIM
      NEXP2=NEXP+1
      DO 10 I=1,NEXP
      BB(I)=0.
      B2(I)=0.
      DO 10 J=1,NEXP
      A2(I,J)=0.
   10 AA(I,J)=0.
      SHG=0.
      HSUM=0.
      ASUM=0.
      ASUMT=0.
      DO 70 I=1,NEXP
      NRR=NR(I)
      SHG=SHG+QGLAS(I,NX)*A(I)
      ASUMT=ASUMT+A(I)
      GSUM(I)=0.
      DO 20 J=1,NEXP
   20 GSUM(I)=GSUM(I)+G(I,J)
      IF (ITYPE(I).NE.3) ASUM=ASUM+A(I)
      IF(MET.NE.0) GSUM(I)=HR
      HSUM=HSUM+HI(I)*A(I)
      IR=IRF(I)
      CRX=CR(I)
      IF(NRR.GE.2) GO TO 40
      X(IR,1)=UT(I)
```

RMTMK-PNC PAGE 1

```
      Y(IR,1)=UT(I)
      CRX=0.
      Z(IR,1)=UT(I)
40    AA(I,I)=X(IR,1)+HI(I)+GSUM(I)
      DO 50 J=1,NEXP
      IF (I.EQ.J) GO TO 50
      AA(I,J)=-G(I,J)
50    CONTINUE
      AA(I,NEXP2)=-HI(I)
      SUMY=Y(IR,1)*TOS(I,1)
      SUMX=0.
      IF(NRR.LT.2) GO TO 61
      DO 60 J=2,NRR
      SUMY=SUMY+Y(IR,J)*TOS(I,J)
60    SUMX=SUMX+X(IR,J)*TIS(I,J)
61    CONTINUE
      B3(I)=SUMY-CRX*QI(I)-SUMX
70    AA(NEXP2,I)=A(I)*HI(I)
      IF(UENDW.EQ.0) GO TO 80
      RCT=1./UCELNG-1./HI(1)
      UCT=1./RCT
      AA(1,1)=UCT+HI(1)+GSUM(1)
      B3(1)=UCT*TOS(1,1)
80    CONTINUE
      SHX=SHG/ASUM
      QLTEMP=QLITE(NX)*(1-RCELG)*RROOML+(QOCPS(NX)+QEQUP(NX))*RROOM
      QLX=QLTEMP/ASUMT
      DO 90 I=1,NEXP
      SHF=SHX
      QLT=QLX
      IF (ITYPE(I).EQ.3.OR.ITYPE(I).EQ.7) SHF=0.
      IF (ITYPE(I).EQ.7) QLT=0.
90    BB(I)=B3(I)+SHF+QLT
      AA(NEXP2,NEXP2)=-1.08*(CFML+CFMS)-HSUM
      JK=1
      NEXP3=NEXP2+1
      DO 95 I=1,NEXP2
      DO 95 J=1,NEXP2
95    A2(I,J)=AA(I,J)
      SUM1=(QOCPS(NX)+QEQUP(NX))*(1.-RROOM)
      SUM2=QLITE(NX)*(1.-RROOML)*(1.-RCELG)
      SUM3=0.
      SUM=1.08*(CFML*DBNX+CFMS*TU)+SUM1+SUM2
      BB(NEXP2)=-SUM
      IF(ITHST.NE.0.AND.ITK.EQ.0) GO TO 130
102   BB(NEXP2)=-SUM-SUM3
      IF(MET.EQ.0) GO TO 91
      SUM4=0.
      SUM5=0.
      DO 92 I=1,NEXP
```

RMTMK-PNC PAGE 2

```
      SUM4=SUM4+(HI(I)*A(I)*BB(I))/AA(I,I)
      SUM5=SUM5+HI(I)*A(I)*(HI(I)+HR)/AA(I,I)
92    CONTINUE
      TT(NEXP2)=(SUM4-BB(NEXP2))/(-AA(NEXP2,NEXP2)-SUM5)
      GO TO 94
91    CONTINUE
      CALL SOLVP(NEXP2,NEXP3,AA,BB,TT,30)
94    TA=TT(NEXP2)+TIM
      IF(ITHST.EQ.0.AND.ITK.EQ.1) GO TO 133
      IF(JK.EQ.2) GO TO 133
      GO TO 103
130   DO 100 I=1,NEXP2
100   B2(I)=BB(I)-AA(I,NEXP2)*(TA-TIM)
      IF(MET.EQ.0) GO TO 131
      DO 132 I=1,NEXP
      TT(I)=((HI(I)+HR)*(TA-TIM)+BB(I))/AA(I,I)
132   CONTINUE
      GO TO 133
131   CONTINUE
      CALL SOLVP(NEXP,NEXP2,A2,B2,TT,30)
133   CONTINUE
      QL=SUM-1.08*(CFML+CFMS)*(TA-TIM)
      GO TO 140
103   IF(TA-TUL)111,112,112
111   IF(TA-TLL) 114,114,133
112   TA=TUL
      GO TO 130
114   TA=TLL
      GO TO 130
140   SUMQ=0.
      DO 160 I=1,NEXP
      K=IRF(I)
      TIS(I,1)=TT(I)
      TEST=ABS(TT(I))
      IF (TEST.GT.100.) GO TO 170
      IF(ITYPE(I).EQ.10) X(K,1)=UT(I)
      QI(I)=X(K,1)*TT(I)-B3(I)
      IF (ITYPE(I).EQ.7) QI(I)=0.
      IF (UENDW.NE.0..AND.ITYPE(I).EQ.1) QI(I)=UT(I)*(TI(I)-TOS(I,1))
      TIF(I)=TT(I)+TIM
      IF (ITYPE(I).EQ.7) TIF(I)=TA
150   SUMQ=SUMQ+A(I)*HI(I)*(TA-TIF(I))
160   CONTINUE
      QL=-QL+SUMQ
      IF(ITHST.NE.0.OR.ITK.NE.0) GO TO 185
      IF(JK.EQ.2) GO TO 185
      IF(QL) 183,185,184
183   QLTEST=ABS(QL)
      IF(QLTEST-QCMAX) 185,185,182
182   SUM3=-QCMAX
```

RMTMK-PNC PAGE 3

```
          JK=2
          GO TO 102
    184   IF(QL-QHMAX) 185,185,186
    186   SUM3=QHMAX
          JK=2
          GO TO 102
    185   RETURN
    170   CONTINUE
          WRITE (6,190)
          DO 180 I=1,NEXP2
    180   WRITE(6,200) (A2(I,J),J=1,NEXP2),B2(I),TI(I)
          RETURN
    %
    %
    %
    190   FORMAT(' ERROR IN THE TMTMP ROUTINE: MATRIX ELEMENTS ARE LISTED FOR YOUR EXAMINATION%
          IN THE FOLLOWING ORDER : AA(I,J),J=1,NEXP2,B(I),T(I)')
    200   FORMAT(12 F10.3)
          END
```

RMTMK-PNC PAGE 4

```
      SUBROUTINE ROOMX(NEXP,NS,NW,NN,NE,H)
            DIMENSION NNEXP(4)
            COMMON /CC/ X(10,100),Y(10,100),Z(10,100),ITYPE(30),IHT(30),IRF(30%
      ),ABSP(30),U(30),HT(30),HI(30),A(30),V(30),TOS(30,48),TIS(30,48),G%
      (30,30),TOY(48),DB(24),QLITX(24,3),QEQUX(24,3),QOCUP(24,3),QOCPS(2%
      4),QLITF(24),QEQUP(24),QI(30),CR(30),NR(30),NGLAS(30,24),IIHST,UEN%
      DW,AZW(30),SHADE(30),RMDBS(24),RMDBW(24),SHD(30),UCELNG
            REAL L,FS(6,6)
      COMMON/SHOW/SHADW(30,15)
      %
      %                                   ****************
      %                                   * *             *
      %                                   *   *             *
      %                                   *     ****************
      %                                   *     * SOUTH FACING  *
      %                                (W)*     *    WALL       *(H)
      %                                     * *                 *
      %                                       ****************
      %                                             (L)
      %
      %
      %     NS = NUMBER OF HEAT TRANSFER SURFACES IN THE SOUTH WALL
      %     NW = NUMBER OF HEAT TRANSFER SURFACES IN THE WEST  WALL
      %     NN = NUMBER OF HEAT TRANSFER SURFACES IN THE NORTH WALL
      %     NE = NUMBER OF HEAT TRANSFER SURFACES IN THE EAST  WALL
      %     NEXP = TOTAL NUMBER OF HEAT TRANSFER SURFACES = 2+NS+NW+NN+NE
      WRITE(6,101)
      101 FORMAT(' DATA SHEET NO 12: NS,NW,NN,NE,L,W,H')
      READ(5,*)NNEXP
            NS=NNEXP(1)
            NW=NNEXP(2)
            NN=NNEXP(3)
            NE=NNEXP(4)
            NEXP=2+NS+NW+NN+NE
      %     L = ROOM LENGTH ALONG THE SOUTH WALL
      %     W = ROOM WIDTH ALONG THE WEST WALL
      %     H = ROOM CEILING HEIGHT
      READ(5,*)L,W,H
            CALL FCTR (L,W,H,FS)
            NS=NS+1
            NW=NS+NW
            NN=NW+NN
            NE=NE+NN
            AS=L*H
            AW=W*H
            AN=AS
            AE=AW
            AR=L*W
            AF=AR
      WRITE(6,111)
```

```
111 FORMAT(' DATA SHEET 13 AND 14: ROOM SURFACE DATA AND EXTERIOR SURFACE SHADOW DATA')
      DO 10 I=1,NEXP
%     READ FOLLOWING DATA IN THE ORDER OF CEILING, SOUTH WALL, WEST
%     WALL,  NORTH WALL, EAST WALL, FLOOR.
      READ (5,*) ITYPE(I),IRF(I),A(I),AZW(I),U(I),SHADE(I),ABSP(I),SHD(I)
%     READ SHADOW INFORMATION
READ(5,*)(SHADW(I,J),J=1,7)
READ(5,*)(SHADW(I,J),J=8,15)
10    CONTINUE
      DO 20 I=1,NEXP
      IF (I.EQ.1) M=1
      IF (I.GT.1.AND.I.LE.NS) M=2
      IF (I.GT.NS.AND.I.LE.NW) M=3
      IF (I.GT.NW.AND.I.LE.NN) M=4
      IF (I.GT.NN.AND.I.LE.NE) M=5
      IF (I.EQ.NEXP) M=6
      DO 20 J=1,NEXP
      IF (J.EQ.1) G(I,J)=FS(M,1)
      IF (J.GT.1.AND.J.LE.NS) G(I,J)=FS(M,2)*A(J)/AS
      IF (J.GT.NS.AND.J.LE.NW) G(I,J)=FS(M,3)*A(J)/AW
      IF (J.GT.NW.AND.J.LE.NN) G(I,J)=FS(M,4)*A(J)/AN
      IF (J.GT.NN.AND.J.LE.NE) G(I,J)=FS(M,5)*A(J)/AE
      IF (J.EQ.NEXP) G(I,J)=FS(M,6)
20    CONTINUE
      RETURN
      END
```

```
          SUBROUTINE SHADOW(SHDX,PHI,COSZ,SHRAT)
          DIMENSION SHDX(20)
          HT=SHDX(1)
          FL=SHDX(2)
          FP=SHDX(3)
          AW=SHDX(4)
          BWL=SHDX(5)
          BWR=SHDX(6)
          D=SHDX(7)
          FP1=SHDX(8)
          A1=SHDX(9)
          B1=SHDX(10)
          C1=SHDX(11)
          FP2=SHDX(12)
          A2=SHDX(13)
          B2=SHDX(14)
          C2=SHDX(15)
          WAZI=SHDX(16)
%         THIS PROGRAM CALCULATES SHADOW CAST BY OVERHANG AND SIDE FINS
%         THIS PROGRAM HAS BEEN DEVELOPED BY TSENG-YAO SUN
%         PHI....SOLAR AZIMUTH ANGLE
%         COSZ...COSINE OF SOLAR ZENITH ANGLE
%         SHRAT..SHADE RATIO:RATIO OF THE SUNLIT AREA TO THE TOTAL WINDOW AREA
%         HT.....WINDOW HEIGHT
%         FL.....WINDOW WIDTH
%         FP.....DEPTH OF THE OVERHUNG
%         AW.....DISTANCE FROM TOP OF THE WINDOW TO THE OVERHUNG
%         BWL....DISTANCE OF THE OVERHUNG EXTENDED BEYOND THE LEFT EDGE OF THE WINDOOW
%         BWR....DISTANCE OF THE OVERHUNG EXTENDED BEYOND THE RIGHT EDGE OF THE WINDOW
%         D......DEPTH OF VERTICAL PROJECTION AT THE END OF THE OVERHUNG
%         FP1....DEPTH OF THE LEFT FIN
%         A1.....DISTANCE OF THE LEFT FIN EXTENDED ABOVE THE TOP OF THE WINDOW
%         B1.....DISTANCE FROM THE LEFT EDGE OF THE WINDOW TO THE LEFT FIN
%         C1.....DISTANCE OF THE LEFT FIN STOP SHORT ABOVE THE BOTTOM OF THE WINDOW
%         FP2....DEPTH OF THE RIGHT FIN
%         A2.....DISTANCE OF THE RIGHT FIN EXTENDED ABOVE THE TOP OF THE WINDOW
%         B2.....DISTANCE FROM THE RIGHT EDGE OF THE WINDOW TO THE RIGHT FIN
%         C2.....DISTANCE OF THE RIGHT FIN STOP SHORT ABOVE THE BOTTOM OF THE WINDOW
%         WAZI...WINDOW AZIMUTH ANGLE
          SHRAT=1.
1103      A=AW
          H=HT
          GAMMA=PHI-WAZI
          COSG=COS(GAMMA)
          IF(COSG)100,100,104
100       SHRAT=0.
          GO TO 2000
104       CONTINUE
          SBETA=COSZ
          IF(SBETA)100,100,152
```

SHADOW-PNC PAGE 1

```
152     SING=SIN(GAMMA)
        VERT=SBETA/SQRT(1.-SBETA*SBETA)/COSG
        HORIZ=ABS(SING)/COSG
        TCETA=VERT/HORIZ
        IF(GAMMA) 155,154,154
%       -------SUN ON LEFT
154     B=BWL
        GO TO 156
%       -------SUN ON RIGHT
155     B=BWR
156     ARSHF=0.
        AREAV=0.
        ARSIF=0.
        AREAO=0.
        AREA1=0.
        ARSH1=0.
        FL3=0.
        H3=0.
        H1=H
        FL1=FL
        K=1
        L=1
        T1=FP*VERT
        FM1=FP*HORIZ
        IF(FP)37,37,153
153     T=T1
        FM=FM1
        AB=B*TCETA
        UG=(FL+B)*TCETA
        DE=(H+A)/TCETA
%       -------HORIZONTAL OVERHUNG "AREAO"
        IF(T-A)27,27,2
2       IF(AB-A)14,14,3
3       IF(DE-B) 12,12,4
4       IF(FM-B)11,11,5
5       IF(DE-(FL+B))8,8,6
6       IF(FM-(FL+B))9,7,7
%       -------HORIZ 9
7       AREAO=FL*(0.5*(AB+UG)-A)
        GO TO 37
8       IF(T-(H+A))9,10,10
%       -------HORIZ 7
9       AREAO=(T-A)*FL-((FM-B)**2)*TCETA*0.5
        L=2
        GO TO 21
%       -------HORIZ 8
10      AREAO=H*FL-(DE-B)**2*TCETA*0.5
        GO TO 37
%       -------HORIZ 3
11      AREAO=FL*(T-A)
```

```
            L=2
            GO TO 24
      12    IF(T-(H+A)) 11,13,13
      %     -------HORIZ 2
      13    AREAO=H*FL
            GO TO 68
      14    IF(UG-A)27,27,15
      15    IF(DE-(FL+B))18,18,16
      16    IF(FM-(FL+B))20,17,17
      %     -------HORIZ 6
      17    AREAO=(UG-A)**2/TCETA*0.5
            GO TO 37
      18    IF(T-(H+A))20,19,19
      %     -------HORIZ 5
      19    AREAO=H+(FL-(A+0.5*H)/TCETA+B)
            GO TO 37
      %     -------HORIZ 4
      20    AREAO=(T-A)*(FL+B-FM*(1.+A/T)*0.5)
            L=2
      %     -------VERT PROJ "AREAV"
      21    FL3=FL+B-FM
            IF(T+D-(H+A))22,22,23
      %     -------VERT 8
      22    H3=D
            GO TO 3700
      %     -------VERT 9
      23    H3=H+A-T
            GO TO 3700
      24    FL3=FL
            IF(T+D-(H+A))26,26,25
      %     -------VERT 7
      25    H3=H+A-T
            AREAV=H3*FL3
            GO TO 68
      %     -------VERT 6
      26    H3=D
            GO TO 3700
      27    IF(T+D-A)37,37,28
      28    IF(FM-B)34,34,29
      29    IF(FM-(FL+B))31,37,37
      31    FL3=FL+B-FM
            IF(T+D-(H+A))33,33,32
      %     -------VERT 5
      32    H3=H
            GO TO 3700
      %     -------VERT 4
      33    H3=T+D-A
            GO TO 3700
      34    IF(T+D-(H+A))36,35,35
      %     ------VERT 2
```

SHADOW-PNC PAGE 3

```
35     AREAV=H*FL
       GO TO 68
%      VERT 3
36     H3=T+D-A
       FL3=FL
3700   AREAV=FL3*H3
%      -------SIDE FIN AND SHORT SIDE FIN
%      -------SIDE FIN "AREA1" "ARSIF"
37     IF(GAMMA)66,68,74
74     FPF=FP1
       AF=A1
       BF=B1
       CX=C1
       GO TO 84
66     FPF=FP2
       AF=A2
       BF=B2
       CX=C2
84     IF(FPF)68,68,67
67     T=FPF*VERT
       FM=FPF*HORIZ
       AF1=AF
       IF(AREAO)73,73,88
%      -------TEST FOR OVERLAP OF FIN AND OVERHUNG SHADOW
88     AT=A+(BF-B)*TCETA
       IF(AT-AF)711,73,73
%      ------OVERLAP EXISTS..L=2 IF OVERHUNG SHADOW HAS HORIZ EDGE IN WINDOW
711    GO TO(621,712),L
%      ------TEST FOR TYPE OF OVERLAP
712    IF((FM-BF)-(FM1-B))621,622,622
%      ------SET L=1,SHADOW INTERSECT ON INCLINED EDGE OF OVERHUNG SHADOW
%      -------FIN SHADOW IS BELOW INCLINED EDGE OF OVERHUNG SHADOW
621    AF=AT
       L=1
       GO TO 73
%      -------L IS 2, HORIZ EDGE OF OVERHUNG SHADOW-PORTION ABOVE HORIZ EDGE
%      -------NOT IN OVERHUNG SHADOW IS FIN SHADOW
622    AREA1=FL*(T1-A)-AREAO
%      -------RESET TO CALC FIN SHADOW BELOW HORIZ EDGE OF OVHNG SHADOW
       AF=T1-A+AF1
       H=H+AF1-AF
%      ------SHADOW OF FIN (K=1 ON GLASS  K=2 ON VERT PROJ SHADOW)
73     AB=BF*TCETA
       UG=(FL+BF)*TCETA
       DE=(H+AF)/TCETA
       DJ=CX/TCETA
       IF(FM-BF)69,69,38
38     IF(AB-AF)39,50,50
39     IF(UG-AF)48,48,40
40     IF(T-AF)47,47,41
```

```
41     IF(UG-(H+AF))44,44,42
42     IF(T-(H+AF))91,80,80
%      -----FIN 9
80     AREA1=H*((AF+H*0.5)/TCETA-BF)+AREA1
       GO TO 58
44     IF(FM-(FL+BF))91,89,89
%      -------FIN8
89     AREA1=H*FL-(UG-AF)**2/TCETA*0.5+AREA1
       GO TO 58
%      -------FIN 7
91     AREA1=(FM-BF)*H-(T-AF)**2/TCETA*0.5+AREA1
       GO TO 63
48     IF(FM-(FL+BF))47,47,49
%      -------FIN 3
47     AREA1=H*(FM-BF)+AREA1
       GO TO 63
%      -------FIN 2
49     AREA1=H*FL+AREA1
       GO TO 58
50     IF(DE-BF)69,69,51
51     IF(UG-(H+AF))55,55,52
52     IF(T-(H+AF))93,94,94
%      ------FIN 6
94     AREA1=(DE-BF)**2*TCETA*0.5+AREA1
       GO TO 58
%      ------FIN 4
93     AREA1=(FM-BF)*(H+AF-(T+AB)*0.5)+AREA1
       GO TO 63
55     IF(FM-(FL+BF))93,99,99
%      -----FIN 5
99     AREA1=FL*(H-(BF+FL*0.5)*TCETA+AF)+AREA1
%      ------SHORT SIDE FIN "ARSH1","ARSHF"
58     IF(DJ-BF)69,69,59
59     IF(DJ-(FL+BF))61,61,60
%      -------SHORT 3
60     ARSH1=-FL*(CX-(BF+FL/2.)*TCETA)
       GO TO 69
%      -------SHORT 4
61     ARSH1=-(CX-AB)**2/TCETA*0.5
       GO TO 69
63     IF(DJ-BF)69,69,64
64     IF(DJ-FM)61,61,65
%      -------SHORT 2
65     ARSH1=-(FM-BF)*(CX-(T+AB)*0.5)
69     GO TO (77,76),K
76     ARSH1=-ARSH1
       AREA1=-AREA1
77     ARSHF=ARSHF+ARSH1
       ARSIF=ARSIF+AREA1
       GO TO(78,68),K
```

SHADOW-PNC PAGE 5

```
78      IF(AREAV)68,68,72
%       ------RESET PARAMETERS TO DEDUCCT FIN SHADOW OVERLAP ON VERT PROJ SHADOW
72      K=2
        AREA1=0.
        ARSH1=0.
        BBF=BF
        BF=FM1-B+BF
        IF(BF)186,185,185
186     BF=BBF
185     IF(HT+A-T1-D)87,87,188
188     CX=CX-(HT+A-T1-D)
        IF(CX)85,87,87
85      CX=0.
87      AF=T1-A+AF
        H=H3
        FL=FL3
        GO TO 73
%       ------- SHADED AREA "ARSHA"
68      ARSHA=AREAO+AREAV+ARSHF+ARSIF
        SHRAT=(FL1*H1-ARSHA)/(FL1*H1)
        FL=FL1
2000    CONTINUE
        RETURN
        END
```

SHADOW-PNC PAGE 6

```
              SUBROUTINE SHG (SH)
              DIMENSION SH(20)
     %        SH(1)=INTENSITY OF DIRECT NORMAL SOLAR RADIATION
     %        SH(2)=INTENSITY OF DIFFUSE SKY RADIATION
     %        SH(3)=INTENSITY OF GROUND REFLECTED DIFFUSE RADIATION
     %        SH(4)=COSINE OF INCIDENCE OF DIRECT SOLAR RADIATION
     %        SH(5)=FORM FACTOR BETWEEN THE WINDOW AND THE SKY
     %        SH(6)=FORM FACTOR BETWEEN THE WINDOW AND THE GROUND
     %        SH(7)=THERMAL RESISTANCE AT OUTSIDE SURFACE
     %        SH(8)=THERMAL RESISTANCE AT THE AIR SPACE (DOUBLE GLAZING)
     %        SH(9)=THERMAL RESISTANCE AT THE INNER SURFACE
     %        SH(10)=SUNLIT AREA  FACTOR
     %        SH(11)=SHADING  COEFFICIENT ,NON-ZERO VALUE WILL BE GIVEN  ONLY
     %        WHEN THE WINDOW IS SHADED BY DRAPES OR BLINDS OR IF IT HAS
     %        AN INTERPANE SEPARATION OF MORE THAN 1-INCH
     %        SH(12)=TRANSMISSION FACTOR FOR DIRECT RADIATION
     %        SH(13)=TRANSMISSION FACTOR FOR DIFFUSE RADIATION
     %        SH(14)=ABSORPTION FACTOR FOR DIRECT RADIATION (OUTER PANE)
     %        SH(15)=ABSORPTION FACTOR FOR DIRECT RADIATION (INNER PANE)
     %        SH(16)=ABSORPTION FACTOR FOR DIFFUSE RADIATION(OUTER PANE)
     %        SH(17)=ABSORPTION FACTOR FOR DIFFUSE RADIATION(INNER PANE)
     %        SH(18)=SOLAR HEAT GAIN
              COMMON /SOL/ LAT,LONG,TZN,WAZ,WT,CN,DST,LPYR,S(35)
              REAL LAT,LONG,NI,NO
              NI=(SH(7)+SH(8))/(SH(7)+SH(8)+SH(9))
              NO=(SH(7))/(SH(7)+SH(8)+SH(9))
              D=SH(10)*SH(1)*SH(4)*(SH(12)+NO*SH(14)+NI*SH(15))
              DD=(SH(2)*SH(5)+SH(3)*SH(6))*(SH(13)+NO*SH(16)+NI*SH(17))
              IF (SH(11)) 20,10,20
     10       SH(18)=D+DD
              GO TO 30
     20       SH(18)=(D+DD)*SH(11)
     30       RETURN
              END
```

SHG-PNC PAGE 1

```
            SUBROUTINE SOLVP (M,N,C,D,X,I)
      %   THIS IS A ROUTINE FOR SOLVING  SIMULTANEOUS LINEAR  EQUATIONS
      %     THE ROUTINE WAS DEVELOPED BY B.A. PEAVY OF NBS
      %     ROUTINE FAILS WHEN ANY OF THE DIAGONAL ELEMENTS IS ZERO
            DIMENSION A(100,101),C(I,1),D(1),X(1)
            DO 10 IX=1,M
            DO 10 IY=1,M
      10    A(IX,IY)=C(IX,IY)
            DO 20 IZ=1,M
      20    A(IZ,N)=D(IZ)
            L=1
      30    AA=A(L,L)
            DO 40 K=L,N
      40    A(L,K)=A(L,K)/AA
            DO 60 K=1,M
            IF (K.EQ.L) GO TO 60
            AA=-A(K,L)
            DO 50 IA=L,N
      50    A(K,IA)=A(K,IA)+AA*A(L,IA)
      60    CONTINUE
            L=L+1
            IF (L.LE.M) GO TO 30
            DO 70 IP=1,M
      70    X(IP)=A(IP,N)
            RETURN
            END
```

SOLVP-PNC PAGE 1

```
        SUBROUTINE SUN
        DIMENSION A0(5)/.302,-.0002,368.44,.1717,0.0905/,A1(5)/-22.93,.419%
7,      24.52,-.0344,-.0410/,A2(5)/-.229,-3.2265,-1.14,.0032,.0073/,A3(5%
        )/-.243,-.0903,-1.09,.0024,.0015/,B1(5)/3.851,-7.351,.58,-.0043,-.%
0034/  ,B2(5)/.002,-9.3912,-.18,0.,0.0004/,B3(5)/-.055,-.3361,.28,-.%
0008,  -.0006/
        REAL LAT,LATD,LONG,MERID,LOND
        COMMON /SOL/ LAT,LONG,TZN,WAZ,WT,CN,DST,LPYR,S(35)
%       S(1)= LATITUDE,DEGREES(+NORTH,-SOUTH)
%       S(2)= LONGITUDE,DEGREES(+WEST,-EAST)
%       S(3)= TIME ZONE NUMBER
%       STANDARD  TIME        DAYLIGHT  SAVING TIME
%       ATLANTIC       4                      3
%       EASTERN        5                      4
%       CENTRAL        6                      5
%       MOUNTAIN       7                      6
%       PACIFIC        8                      7
%       S(4)= DAYS(FROM START OF YEAR)
%       S(5)= TIME,HOUR AFTER MIDNIGHT)
%       S(6)= DAYLIGHT SAVING TIME INDICATOR
%       S(7)= GROUND REFLECTIVITY
%       S(8)= CLEARNESS NUMBER
%       S(9)= WALL AZIMUTH ANGLE, DEGREES FROM SOUTH
%       S(10)=WALL TILT    ANGLE, DEGREES FROM HORIZON
%       S(11)=SUN RISE TIME  (HOURS AFTER MIDNIGHT)
%       S(12)=SUN SET TIME
%       S(13)=COSZ     DIRECTION COSINES
%       S(14)=COSN     DIRECTION COSINES
%       S(15)=COS(S)   DIRECTION COSINES)
%       S(16)=ALPHA    DIRECTION COSINES NORMAL TO SURFACE
%       S(17)=BETA
%       S(18)=GAMMA
%       S(19)=COS(ETA)COSINE OF INCIDENCE ANGLE
%       S(20)=SOLAR ALTITUDE ANGLE
%       S(21)=SOLAR AZIMUTH  ANGLE
%       S(22)=DIFFUSE SKY RADIATION ON HORIZONTAL SURFACE
%       S(23)=DIFFUSE GROUND REFLECTED RADIATION
%       S(24)=DIRECT NORMAL RADIATION
%       S(25)=TOTAL SOLAR RADIATION INTENSITY
%       S(26)=DIFFUSE SKY RADIATION INTENSITY
%       S(27)=GROUND REFLECTED DIFFUSE RADIATION INTENSITY
%       S(28)=SUN DECLINATION ANGLE,DEGREES
%       S(29)=EQUATION OF TIME ,HOURS
%       S(30)=A     SOLAR FACTOR
%       S(31)=      SOLAR FACTOR
%       S(32)=      SOLAR FACTOR
%       S(33)=      CLOUD COVER  MODIFIER
%       S(34)    INTENSITY OF DIRECT SOLAR RADIATION ON SURFACE
%       S(35)     HOUR ANGLE,DEGREE
        PI=3.1415927
```

SUN-PNC PAGE 1

```
      X=2*PI/366.*S(4)
      C1=COS(X)
      C2=COS(2*X)
      C3=COS(3*X)
      S1=SIN(X)
      S2=SIN(2*X)
      S3=SIN(3*X)
      DO 10 K=1,5
      KS=(K-1)+28
10    S(KS)=A0(K)+A1(K)*C1+A2(K)*C2+A3(K)*C3+B1(K)*S1+B2(K)*S2+B3(K)*S3
      S(29)=S(29)/60.
      LATD=S(1)
      LONG=S(2)
      MERID=15*S(3)
      LOND=LONG-MERID
      Y=S(28)*PI/180.
      YY=LATD*PI/180.
      HP=-TAN(Y)*TAN(YY)
      TR=12/PI*ACOS(HP)
      S(11)=(12-TR)-S(29)+LOND/15.
      S(12)=24.-S(11)
      H=15*(S(5)-12+S(3)+S(29)-S(6))-S(2)
      S(35)=H
      S13=SIN(YY)*SIN(Y)+COS(YY)*COS(Y)*COS(H*PI/180.)
      S(13)=S13
      HP1=180.*ACOS(HP)/PI
      X1=ABS(HP1)
      X2=ABS(H)
      IF (X1-X2) 130,20,20
20    S(14)=COS(Y)*SIN(H*PI/180.)
      S(15)=SQRT(1.-S(13)*S(13)-S(14)*S(14))
      STEST=S(15)
      STEST1=COS(H*PI/180.)-TAN(Y)/TAN(YY)
      IF (STEST1) 40,30,30
30    S(15)=STEST
      GO TO 50
40    S(15)=-STEST
50    S(20)=ASIN(S(13))
      IF (S(15)) 70,60,60
60    S(21)=ASIN(S(14)/COS(S(20)))
      GO TO 80
70    S(21)=PI-ASIN(S(14)/COS(S(20)))
80    S(20)=180.*S(20)/PI
      S(21)=180.*S(21)/PI
      IF(S(21)-180.) 81,81,82
82    S(21)=360.-S(21)
81    CONTINUE
      S(24)=S(30)*S(8)*S(33)*EXP(-S(31)/S(13))
      S(22)=S(32)*S(24)/S(8)/S(8)
      S(23)=S(7)*(S(22)+S(24)*S(13))
```

SUN-PNC PAGE 2

```
      WY=S(10)*PI/180.
      S(16)=COS(WY)
      WA=S(9)*PI/180.
      S(16)=COS(WY)
      S(17)=SIN(WA)*SIN(WY)
      S(18)=COS(WA)*SIN(WY)
      S(19)=S(16)*S(13)+S(17)*S(14)+S(18)*S(15)
      S(34)=S(24)*S(19)
      Y=0.45
      IF (S(19)+0.2) 100,100,90
90    Y=0.55+0.437*S(19)+0.313*S(19)**2
100   IF (S(19)) 110,110,120
110   S(19)=0.
      S(34)=0.
120   CONTINUE
      S(26)=S(22)*Y
      S(27)=S(23)*(1-S(16))/2.
      S(25)=S(34)+S(26)+S(27)
      GO TO 150
130   DO 140 J=14,26
140   S(J)=0.
      S(34)=0
150   RETURN
      END
```

SUN-PNC PAGE 3

```
      SUBROUTINE TAR (TR)
      REAL A1(6)/0.01154,0.77674,-3.94657,8.57881,-8.38135,3.01188/
      REAL A2(6)/0.01636,1.40783,-6.79030,14.37378,-13.83357,4.92439/
      REAL A3(6)/0.01837,1.92497,-8.89134,18.40197,-17.48648,6.17544/
      REAL A4(6)/0.01902,2.35417,-10.4715,21.24322,-19.95978,6.99964/
      REAL A5(6)/0.01712,3.50839,-13.8639,26.34330,-23.84846,8.17372/
      REAL A6(6)/0.01406,4.15958,-15.0628,27.18492,-23.88518,8.03650/
      REAL A7(6)/0.01153,4.55946,-15.4329,26.70568,-22.87993,7.57795/
      REAL A8(6)/0.00962,4.81911,-15.4714,25.86516,-21.69106,7.08714/
      REAL T1(6)/-0.00885,2.71235,-0.62062,-7.07329,9.75995,-3.89922/
      REAL T2(6)/-0.01114,2.39371,0.42978,-8.98262,11.51798,-4.52064/
      REAL T3(6)/-0.01200,2.13036,1.13833,-10.07925,12.44161,-4.83285/
      REAL T4(6)/-0.01218,1.90950,1.61391,-10.64872,12.83698,-4.95199/
      REAL T5(6)/-0.01056,1.29711,2.28615,-10.37132,11.95884,-4.54880/
      REAL T6(6)/-0.00835,0.92766,2.15721,-8.71429,9.87152,-3.73328/
      REAL T7(6)/-0.00646,0.68256,1.82499,-6.95325,7.80647,-2.94454/
      REAL T8(6)/-0.00496,0.51043,1.47607,-5.41985,6.00546,-2.28162/
      REAL A01(6)/0.01407,1.06226,-5.59131,12.15034,-11.78092,4.20070/
      REAL A02(6)/0.01819,1.86277,-9.24831,19.49443,-18.56094,6.53940/
      REAL A03(6)/0.01905,2.47900,-11.7427,24.14037,-22.64299,7.89954/
      REAL A04(6)/0.01862,2.96400,-13.4870,27.13020,-25.11877,8.68895/
      REAL A05(6)/0.01423,4.14384,-16.66709,31.30484,-27.81955,9.36959/
      REAL A06(6)/0.01056,4.71447,-17.33454,30.91781,-26.63898,8.79495/
      REAL A07(6)/0.00819,5.01768,-17.21228,29.46388,-24.76915,8.05040/
      REAL A08(6)/0.00670,5.18781,-16.84820,27.90292,-22.99619,7.38140/
      REAL AI1(6)/0.00228,0.34559,-1.19908,2.22336,-2.05287,0.72376/
      REAL AI2(6)/0.00123,0.29788,-0.92256,1.58171,-1.40040,0.48316/
      REAL AI3(6)/0.00061,0.26017,-0.72713,1.14950,-0.97138,0.32705/
      REAL AI4(6)/0.00035,0.22974,-0.58381,0.84626,-0.67666,0.22102/
      REAL AI5(6)/-0.00009,0.15049,-0.27590,0.25618,-0.12919,0.02859/
      REAL AI6(6)/-0.00016,0.10579,-0.15035,0.06487,0.02759,-0.02317/
      REAL AI7(6)/-0.00015,0.07717,-0.09059,0.00050,0.06711,-0.03394/
      REAL AI8(6)/-0.00012,0.05746,-0.05878,-0.01855,0.06837,-0.03191/
      REAL TD1(6)/-0.00401,0.74050,7.20350,-20.11763,19.68824,-6.74585/
      REAL TD2(6)/-0.00438,0.57818,7.42065,-20.26848,19.79706,-6.79619/
      REAL TD3(6)/-0.00428,0.45797,7.41367,-19.92004,19.40969,-6.66603/
      REAL TD4(6)/-0.00401,0.36698,7.27324,-19.29364,18.75408,-6.43968/
      REAL TD5(6)/-0.00279,0.16468,6.17715,-15.84811,15.28302,-5.23666/
      REAL TD6(6)/-0.00192,0.08180,4.94753,-12.43481,11.92495,-4.07787/
      REAL TD7(6)/-0.00136,0.04419,3.87529,-9.59069,9.16022,-3.12776/
      REAL TD8(6)/-0.00098,0.02576,3.00400,-4.33834,6.98747,-2.38328/
      DIMENSION TR(9),A(8,6),T(8,6),AO(8,6),AI(8,6),TD(8,6)
%     TR(1)= TRANSMISSION FACTOR ,DIRECT
%     TR(2)= TRANSMISSION FACTOR ,DIFFUSE
%     TR(3)= ABSORPTION FACTOR   ,DIRECT, OUTER
%     TR(4)=                     ,DIFFUSE,OUTER
%     TR(5)=                     ,DIRECT ,INNER
%     TR(6)=                     ,DIFFUSE,INNER
%     TR(7)= COSINE OF INCIDENT ANGLE
%      TR(8)=TYPE OF GLASS
```

TAR-PNC PAGE 1

```
%        TR(9)=ID   CODE FOR THE GLAZING
%       ID   =1    SINGLE  GLAZING
%       ID   =2    DOUBLE  GLAZING
        DO 10 J=1,6
        A(1,J)=A1(J)
        A(2,J)=A2(J)
        A(3,J)=A3(J)
        A(4,J)=A4(J)
        A(5,J)=A5(J)
        A(6,J)=A6(J)
        A(7,J)=A7(J)
        A(8,J)=A8(J)
        T(1,J)=T1(J)
        T(2,J)=T2(J)
        T(3,J)=T3(J)
        T(4,J)=T4(J)
        T(5,J)=T5(J)
        T(6,J)=T6(J)
        T(7,J)=T7(J)
        T(8,J)=T8(J)
        AO(1,J)=AO1(J)
        AO(2,J)=AO2(J)
        AO(3,J)=AO3(J)
        AO(4,J)=AO4(J)
        AO(5,J)=AO5(J)
        AO(6,J)=AO6(J)
        AO(7,J)=AO7(J)
        AO(8,J)=AO8(J)
        AI(1,J)=AI1(J)
        AI(2,J)=AI2(J)
        AI(3,J)=AI3(J)
        AI(4,J)=AI4(J)
        AI(5,J)=AI5(J)
        AI(6,J)=AI6(J)
        AI(7,J)=AI7(J)
        AI(8,J)=AI8(J)
        TD(1,J)=TD1(J)
        TD(2,J)=TD2(J)
        TD(3,J)=TD3(J)
        TD(4,J)=TD4(J)
        TD(5,J)=TD5(J)
        TD(6,J)=TD6(J)
        TD(7,J)=TD7(J)
 10     TD(8,J)=TD8(J)
        ETA=TR(7)
        L=TR(8)
        ID=TR(9)
        IF (ID.EQ.2) GO TO 30
        TR(1)=T(L,1)
        TR(2)=T(L,1)/2.
```

```
      TR(3)=A(L,1)
      TR(4)=A(L,1)/2.
      DO 20 J=2,6
      TR(1)=TR(1)+T(L,J)*(ETA**(J-1))
      TR(2)=TR(2)+T(L,J)/(J+1)
      TR(3)=TR(3)+A(L,J)*(ETA**(J-1))
   20 TR(4)=TR(4)+A(L,J)/(J+1)
      TR(5)=0
      TR(6)=0
      GO TO 50
   30 TR(1)=TD(L,1)
      TR(2)=TD(L,1)/2.
      TR(3)=AO(L,1)
      TR(4)=AO(L,1)/2.
      TR(5)=AI(L,1)
      TR(6)=AI(L,1)/2.
      DO 40 J=2,6
      X=ETA**(J-1)
      TR(1)=TR(1)+TD(L,J)*X
      TR(2)=TR(2)+TD(L,J)/(J+1)
      TR(3)=TR(3)+AO(L,J)*X
      TR(4)=TR(4)+AO(L,J)/(J+1)
      TR(5)=TR(5)+AI(L,J)*X
   40 TR(6)=TR(6)+AI(L,J)/(J+1)
   50 TR(2)=2*TR(2)
      TR(4)=2*TR(4)
      TR(6)=2*TR(6)
      RETURN
      END
```

TAR-PNC PAGE 3

```
      SUBROUTINE TEMPSH(MONTH,JJ,NK,RMDBS,RMDBW,RMDBWO,RMDBSO,TA)
      DIMENSION RMDBS(24),RMDBW(24)
      IF(MONTH.GE.6.AND.MONTH.LE.9) GO TO 6
      IF(JJ.GT.1) GO TO 7
      TA=RMDBW(NK)
      GO TO 10
 7    TA=RMDBWO
      GO TO 10
 6    IF(JJ.GT.1) GO TO 5
      TA=RMDBS(NK)
      GO TO 10
 5    TA=RMDBSO
 10   CONTINUE
      RETURN
      END
```

TEMPSH-PNC PAGE 1

```
      FUNCTION WBF (H,PB)
%     THIS PROGRAM APPROXIMATES THE WET-BULB TEMPERATURE WHEN
%     ENTHALPY IS GIVEN
      IF(H) 20,20,5
5     CONTINUE
      Y=LOG(H)
      IF (H.GT.11.758) GO TO 10
      WBF=0.6041+3.4841*Y+1.3601*Y*Y+0.97307*Y*Y*Y
      GO TO 90
10    WBF=30.9185-39.68200*Y+20.5841*Y*Y-1.758*Y*Y*Y
      GO TO 90
20    WB1=150.
      PV1=PVSF(WB1)
      W1=0.622*PV1/(PB-PV1)
      X1=0.24*WB1+(1061+0.444*WB1)*W1
      Y1=H-X1
30    WB2=WB1-1
      PV2=PVSF(WB2)
      W2=0.622*PV2/(PB-PV2)
      X2=0.24*WB2+(1061+0.444*WB2)*W2
      Y2=H-X2
      IF (Y1*Y2) 80,50,40
40    WB1=WB2
      Y1=Y2
      GO TO 30
50    IF (Y1) 70,60,70
60    WBF=WB1
      GO TO 90
70    WBF=WB2
      GO TO 90
80    Z=ABS(Y1/Y2)
      WBF=(WB2*Z+WB1)/(1+Z)
90    RETURN
      END
```

WBS-PNC PAGE 1

```
      SUBROUTINE  WD(INPUT)
      INTEGER INPUT(1100),INCM(83)
      COMMON NRUN,ISKIP,VOL(2),DENS,PARITY,TRACK
      DATA TST/0./
      LEN=83
      IF(NRUN.NE.0) GO TO 42
      IF(DENS.EQ.'    ') GO TO 42
      CALL TPROP(INCM,LEN,STATUS,VOL,DENS,PARITY,TRACK)
      GO TO 41
42    CONTINUE
      IF(DENS.NE.'    ') GO TO 70
      READ(1) INCM
      GO TO 40
70    CONTINUE
      CALL TPRRD(INCM,LEN,STATUS,VOL)
41    IF(STATUS.EQ.TST) GO TO 40
      WRITE(6,50)
50    FORMAT('  TAPE ERROR')
      STOP
40    CONTINUE
      NRUN=NRUN+1
      IF(NRUN.LT.ISKIP) GO TO 42
      DO 30 J=1,LEN
      DO 30 K=1,6
      JJ=(K-1)*6
      JK=(J-1)*6+K
30    INPUT(JK)=FLD(JJ,6,INCM(J))
      RETURN
      END
```

WD-PNC PAGE 1

```
      SUBROUTINE WDX(IW)
      DIMENSION IDATA(10)/012,01,02,03,04,05,06,07,010,011/,JDATA(10)/072%
     ,061,062,063,064,065,066,067,070,071/,KDATA(10)/052,041,042,043,044%
     ,045,046,047,050,051/
      DATA KX/040/
      DO 50 KK=1,10
      IF(IW.EQ.IDATA(KK)) GO TO 60
      IF(IW.EQ.JDATA(KK)) GO TO 60
      IF(IW.EQ.KDATA(KK)) GO TO 61
   50 CONTINUE
      IF(IW.EQ.KX)  GO TO 62
      IW=1000000
      GO TO 40
   60 IW=KK-1
      GO TO 40
   61 IW=-(KK-1)
      GO TO 40
   62 IW=10
   40 RETURN
      END
```

WDX-PNC PAGE 1

```
%      THIS PROGRAM DECODES WEATHER TAPE 144 AND CREATE A BINARY TAPE%
%      ,WHICH IS USEFUL FOR THE LOAD CALCULATIOB PROGRAM NBSLD
       DIMENSION DB(24),DPT(24),WBT(24),WST(24),PBT(24),TC(24),NTOC(24)
       INTEGER WPOS(10)/13,11,16,19,22,34,43,46,68,70/,WLONG(10)/3,2,3,  %
3,     3,4,1,1,2,3/,OUTPUT(24,10),DAY,CITY,YEAR,DAYSKP,INPUT(1100)
       COMMON NRUN,DAYSKP,VOL(2),DENS,PARITY,TRACK
       READ(5,200,PROMPT=' VOL,DENS,PARITY,TRACK:')VOL,DENS,PARITY,TRACK
200    FORMAT(5A4)
       NRUN=0
       WRITE(6,92)
92     FORMAT(' ISKIP  NDAY  IWRITE')
       READ(5,*) ISKIP,NDAY,IWRITE
       DAYSKP=ISKIP*4
       CALL WDNEW(INPUT)
       DO 102 I=1,NDAY
       CALL DECODH(WPOS,WLONG,10,OUTPUT,0,YEAR,MONTH,DAY,CITY)
3      DO 2 K=1,10
2      CALL ERROR(OUTPUT(1,K),K)
       IF(I.GT.1) GO TO 199
       WRITE(6,4)
       WRITE(6,5)
       WRITE(6,6) CITY,YEAR,MONTH,DAY
4      FORMAT(50H0            STARTING DATE ON WEATHER TAPE          )
5      FORMAT(//'       CITY       YEAR      MONTH        DAY')
7      FORMAT(//'         DB          DP          WB          WS          PB      %
       TC       NTOC')
6      FORMAT(5I10)
       IF(IWRITE.NE.0) WRITE(6,7)
199    DO 90 J=1,24
1      IWS=OUTPUT(J,1)
       IDR=OUTPUT(J,2)
       KA=OUTPUT(J,3)
       LA=OUTPUT(J,4)
       IDP=OUTPUT(J,5)
       IATM=OUTPUT(J,6)
       ITCA=OUTPUT(J,7)
       ITOC=2
       ITK=OUTPUT(J,8)
       IF(ITK.EQ.2) ITOC=1
       IF(ITK.EQ.8.OR.ITK.EQ.9) ITOC=0
       IPR=OUTPUT(J,9)
       IPS=OUTPUT(J,10)
       DB(J)=KA
       WBT(J)=LA
       DPT(J)=IDP
       PBT(J)=IATM/100.
       TC(J)=ITCA
       NTOC(J)=ITOC
       WST(J)=IWS
       IF(IWRITE.EQ.0) GO TO 90
```

WETHER-PNC PAGE 1

```
          WRITE(6,91) DB(J),DPT(J),WBT(J),WST(J),PBT(J),TC(J),NTOC(J)
   91     FORMAT(6F10.2,I10)
   90     CONTINUE
  100     WRITE(9) DB,DPT,WBT,WST,PBT,TC,NTOC,DAY,YEAR,MONTH,CITY
          IF(IWRITE.EQ.0) WRITE(6,103) MONTH, DAY
  103     FORMAT(2I10)
  102     CONTINUE
          CALL TPRCL
          END FILE 9
          STOP
          END
```

WETHER-PNC PAGE 2

```
      SUBROUTINE WINTER(A,U,ITYPE,NEXP,CFMWT,DBIN,DBWT,UG,TGW,RHI,RHO)
      DIMENSION A(30),U(30),ITYPE(30)
      CALL DBRH(DBWT,RHO,WO)
      CALL DBRH(DBIN,RHI,WI)
      DT=DBIN-DBWT
      DW=WI-WO
      QWINTS=1.08*CFMWT*DT
      QWINTL=4.5*CFMWT*DW*1060.
      DO 30 I=1,NEXP
      IF(ITYPE(I).EQ.6.OR.ITYPE(I).EQ.7) GO TO 30
      IF(ITYPE(I).NE.5) GO TO 20
      QWINTS=QWINTS+UG*A(I)*(DBIN-TGW)
      GO TO 30
   20 CONTINUE
      QWINTS=QWINTS+U(I)*A(I)*DT
   30 CONTINUE
      TOTAL=QWINTS+QWINTL
      WRITE(6,40) QWINTS,QWINTL,TOTAL
   40 FORMAT(//' HEATING LOAD IN BTU PER HOUR '/%
     '          SENSIBLE LOAD = 'F10.0/%
     '          LATENT   LOAD = 'F10.0/%
     '          -------------------------'/%
     '          TOTAL    LOAD = 'F10.0///)
      RETURN
      END
```

WINTER-PNC PAGE 1

```
      FUNCTION WKDAY (YR,MO,DAY)
%       WKDAY=1 SUNDAY
%       WKDAY=2 MONDAY
%       WKDAY=3 TUESDAY
%       WKDAY=4 WEDNESDAY
%       WKDAY=5 THURSDAY
%       WKDAY=6 FRIDAY
%       WKDAY=7 SATURDAY
      INTEGER YR,DAY,WKDAY,TDAY,FSTDAY
      DIMENSION FSTDAY(12)/31,59,90,120,151,181,212,243,273,304,334,365/
      N=YR/4
      ND=N-485
      IY=2
      IF (ND.EQ.0) GO TO 40
      IF (ND.LT.0) GO TO 10
      IADD=2
      GO TO 20
   10 ND=-ND
      IADD=-2
   20 DO 30 J=1,ND
      IY=IY-IADD
      IF (IY.GT.7) IY=IY-7
      IF (IY.EQ.0) IY=7
      IF (IY.LT.0) IY=IY+7
   30 CONTINUE
   40 MD=YR-N*4
      IF (MD.EQ.0) IWK=1Y
      IF (MD.EQ.1) IWK=IY+2
      IF (MD.EQ.2) IWK=IY+3
      IF (MD.EQ.3) IWK=IY+4
      IF (IWK.GT.7) IWK=IWK-7
      IF (MO.NE.1) GO TO 50
      TDAY=DAY-1
      GO TO 80
   50 DO 60 J=2,12
      IF (MO.NE.J) GO TO 60
      TDAY=FSTDAY(J-1)+DAY-1
      GO TO 70
   60 CONTINUE
   70 IF (MD.EQ.0.AND.MO.GT.2) TDAY=TDAY+1
   80 NTX=TDAY/7
      NDX=TDAY-7*NTX+IWK
      IF (NDX.GT.7) NDX=NDX-7
      WKDAY=NDX
      KV=YR/100
      KTEST=YR-KV*100
      IF (MO.GT.2.OR.KTEST.NE.0) GO TO 90
      KV=KV-1
   90 LV=KV/4
      LTEST=KV-LV*4
```

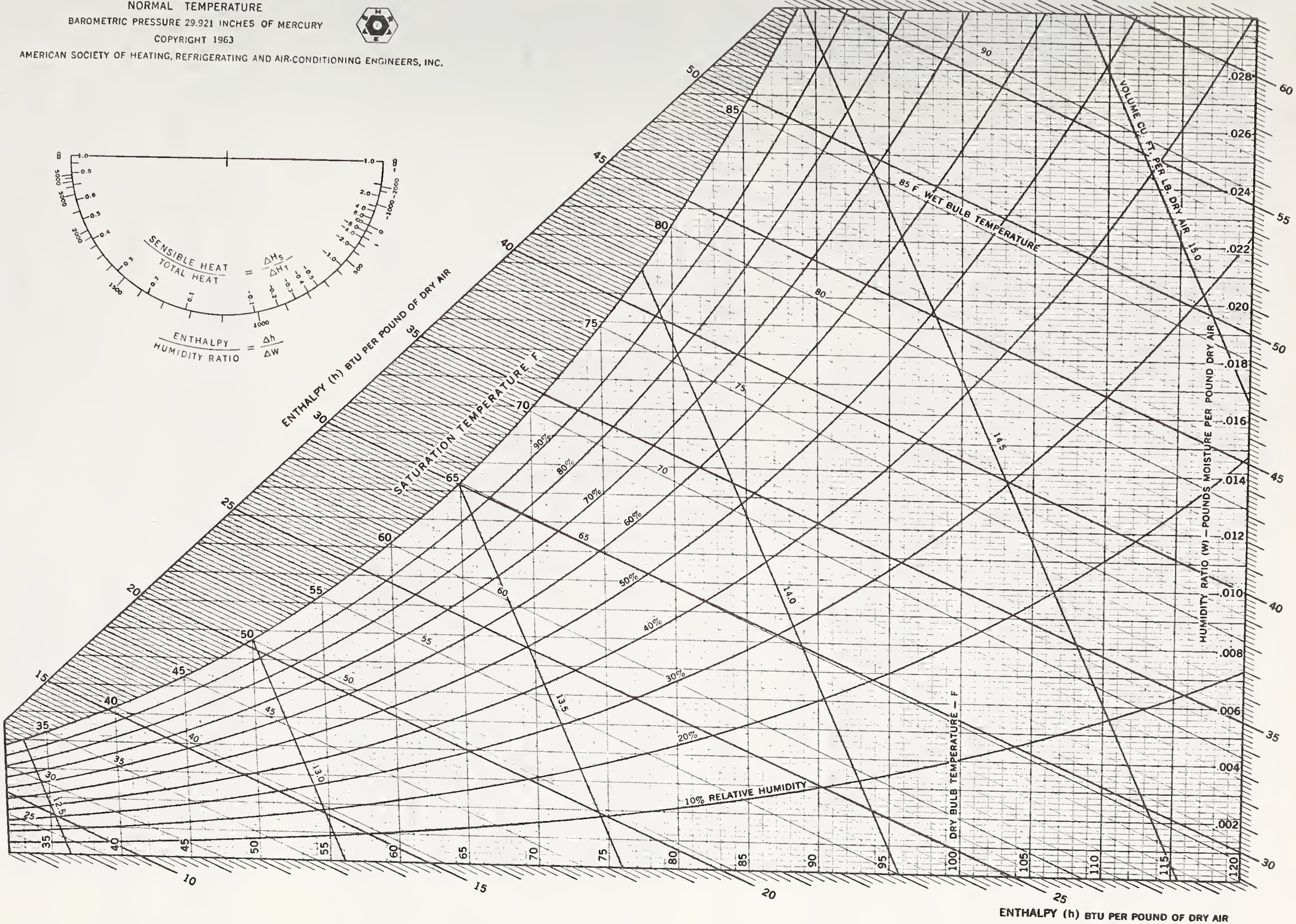
```
      IF (LTEST.EQ.2) WKDAY=WKDAY+1
      IF (LTEST.EQ.1) WKDAY=WKDAY+2
      IF (LTEST.EQ.0) WKDAY=WKDAY+3
      WKDAY=WKDAY-3*(LV-4)
100   IF (WKDAY.LE.0) WKDAY=WKDAY+7
      IF (WKDAY.LE.0) GO TO 100
      IF (WKDAY.GT.7) WKDAY=WKDAY-7
      RETURN
      END
```

WKDAY-PNC PAGE 2

11. ASHRAE PSYCHROMETRIC CHART NO. 1

NORMAL TEMPERATURE

BAROMETRIC PRESSURE 29.921 INCHES OF MERCURY



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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A comprehensive computer program called NBSLD, the National Bureau of Standards Load Determination program, has been developed at NBS to reflect the time change of the many building parameters which are pertinent to accurate estimation of energy usage for heating and cooling. Current status of heating and cooling load techniques is reviewed. Of general interest are unique features of NBSLD which are not available in existing computer programs. A summary of various subroutines of NBSLD is given along with the detailed procedures for them. These subroutines constitute the recommended subroutine algorithms of the ASHRAE Task Group on Energy Requirements. Complete Fortran listing of NBSLD and data preparation forms are given for those who wish to use the program. The NBSLD computation is on the basis of the detailed solution of simultaneous heat balance equations at all the interior surfaces of a room or space. Transient heat conduction through exterior walls in the interior structures is handled by using conduction transfer functions. The use of heat balance equations, although time consuming in calculation, can avoid the vagueness and uncertainties inherent in the more popularly used weighting factor approach. In addition, it is more accurate for a specific building design.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* ASHRAE Task Group on Energy Requirements; conduction transfer functions; heating and cooling load; National Bureau of Standards Heating and Cooling Load Computer Program

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