NASA CONTRACTOR REPORT

NASA CR-2590 PART II

NASA CR-2590
PART II

NECAP - NASA'S ENERGY-COST ANALYSIS PROGRAM

Part II - Engineering Manual

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16. Abstract

The NASA's Energy-Cost Analysis Program (NECAP) is an extremely powerful and sophisticated computerized system to determine and minimize building energy consumption.

The program complies with ASHRAE's "Procedures for Determining Heating and Cooling Loads for Computerized Energy Calculations" manual. It calculates the thermodynamic heat gains and losses of a structure, taking accound of the building's thermal storage and hourly weather data. It uses new weighting factors for building lights, and environmental equipment schedules. Infiltration is allowed to vary in accordance to wind velocity. Internal temperature are allowed to vary when equipment capacity is scheduled or does not meet loads. Standard walls and schedules can be used to simplify program input. System simulation models systems now in general use.

Users of NECAP can obtain data for selection of the most economical system, system size, fuels, window area, thermal barries, etc., during the design phase. After installation, users can optimize operating schedules, most economical temperature settings for components, and other valuable data.

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IN ORDER TO MINIMIZE THE AMBIGUITIES INVOLVED IN MATHEMATICAL OPERATIONS, THE FOLLOWING FORTRAN OPERATIONAL SYMBOLS ARE USED PARTIALLY IN THE MAIN BODY OF THIS TEXT.

/	:	Division
*	:	Multiplication
**	:	Exponentiation

SECTION 1
INTRODUCTION

NECAP is a sophisticated building design and energy analysis tool which has embodied within it all of the latest ASHRAE state-of-the-art techniques for performing thermal load calculation and energy useage predictions. NECAP is actually a set of six (6) individual computer programs whose descriptions are given briefly below:

1. RESPONSE FACTOR PROGRAM

   For wall or roof structures different from the typical ones built into NECAP, the Response Factor Program, using a layer-by-layer description of the surface, will calculate and output the set of response factors required to perform transient heat transfer analysis.

2. DATA VERIFICATION PROGRAM

   The Data Verification Program interrogates the building description input data to check for proper order, range and format of the card input data.

3. THERMAL LOAD ANALYSIS PROGRAM

   Performs hourly transient heat transfer calculations for each building space utilizing actual hourly recorded weather, geometry and construction of the building, scheduled internal loads and astronomy of the sun.

4. VARIABLE TEMPERATURE PROGRAM

   Corrects the thermal loads calculated above to account for temperature swings occurring within each space due to thermostat action, equipment capacity and equipment scheduling.

5. SYSTEM AND EQUIPMENT SIMULATION PROGRAM

   For a specified type of distribution system allocation and type of energy conversion equipment, the Simulation Program determines the total load on each distribution system, transfers it to the energy conversion equipment, and based upon part load efficiencies determines the building's monthly demand and consumption of all forms of fuels and energy.

6. OWNING AND OPERATING COST PROGRAM

   For the expected life of the building, the Owning and Operating Cost Program calculates the expected annual expenditure to own and operate the building utility systems.

Each building design and analysis problem might not require use of all of the 6 programs enumerated above. To illustrate the suggested sequential use, refer to Figure 1.1.

The remaining sections of this manual deal with each segment of NECAP and sets forth the algorithms that were programmed into each subroutine.

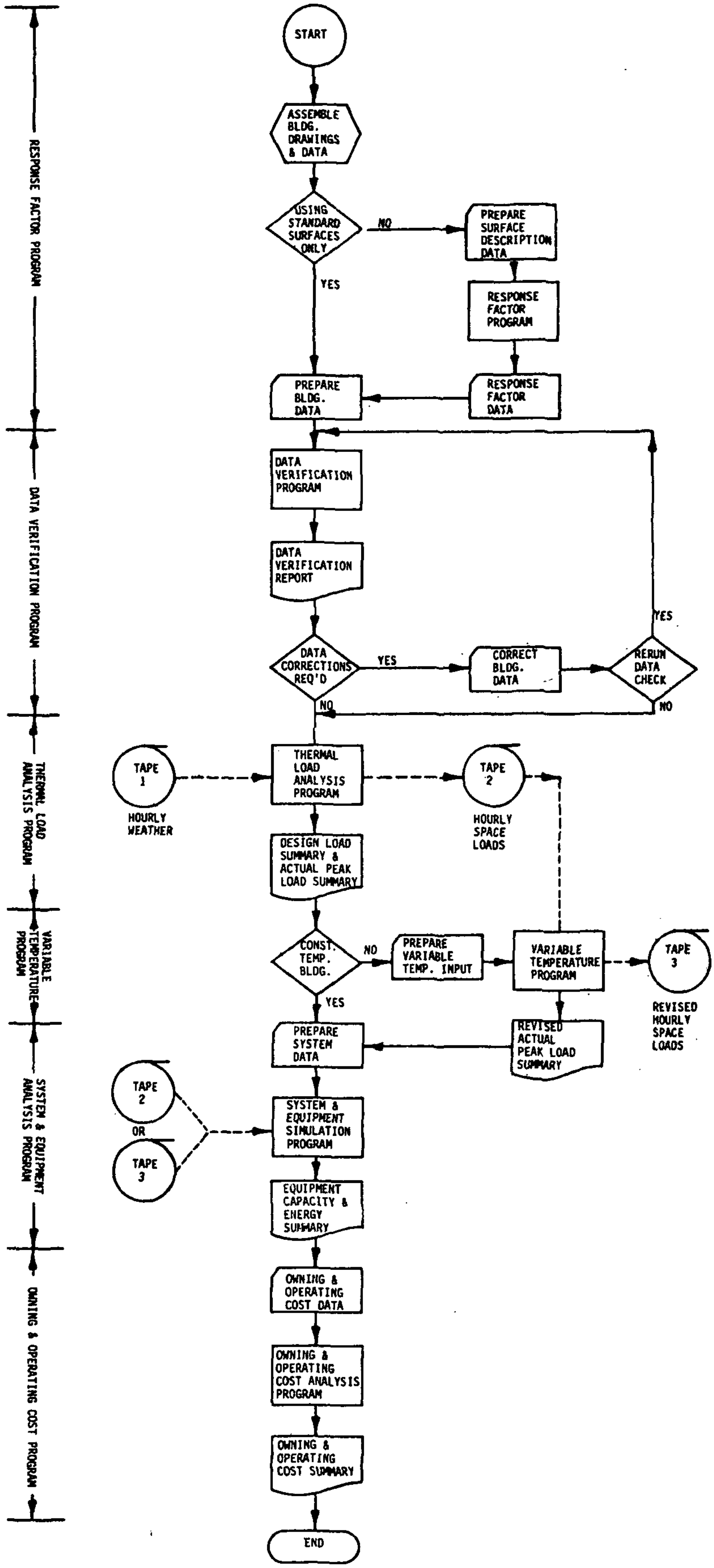


Figure 1.1 NECAP FLOWCHART

SECTION 2
RESPONSE FACTOR PROGRAM

2.1 OBJECTIVE AND DESCRIPTION

The Response Factor Program generates the set of heat transfer factors called response factors required to accurately determine the transient flow of heat into, through and out of building exterior walls and roofs as they react to temperature differences across them. These response factors are a function of the type of materials used and their order of placement and therfore require that the following be known for each layer:

1. XL, thickness, ft.
2. XK, thermal conductivity, BTU per (hr.)(ft.)(°F)
3. D, density, lb. per cu. ft.
4. SH, specific heat, BTU per (lb.) (°F)
5. RES, Resistivity, (hr.)(sq.ft.)(°F) per BTU.

Using this data, the Response Factor Program calculates the set of response factors peculiar to the wall or roof construction in question and then outputs this data onto punched computer cards for direct insertion into the Thermal Load Analysis Program input data deck. The Response Factor Program need not be used if all wall and roof types desired are among the standard walls and roofs built into the Thermal Load Analysis Program and available for use simply by the calling out of an input code. A flow chart explaining the use of the Response Factor Program is given in Figure 2.1.

2.2 ALGORITHMS OF SUBROUTINES

RESFAC
and
DER, FALSE, MATRIX, SLOPE, ZERO

The calculation of the response factors involve a matrix-type solution of the Laplace transform of the heat conduction equation and inversion integral using the residue theorem, detail of which can be found in:

1. "Conduction of Heat in Solids", by H. S. Carslaw and J. C. Jaeger, Second Edition, p. 326.

2. "FORTRAN IV Program to Calculate Heat Flux Response Factors for a Multi-layer Slap", by G. P. Mitalas and J. G. Arseneault, NRC, June 1967.

3. "Thermal Response Factors for Multi-layer Structures of Various Heat Conduction Systems", by T. Kusuda, ASHRAE, January, 1969.

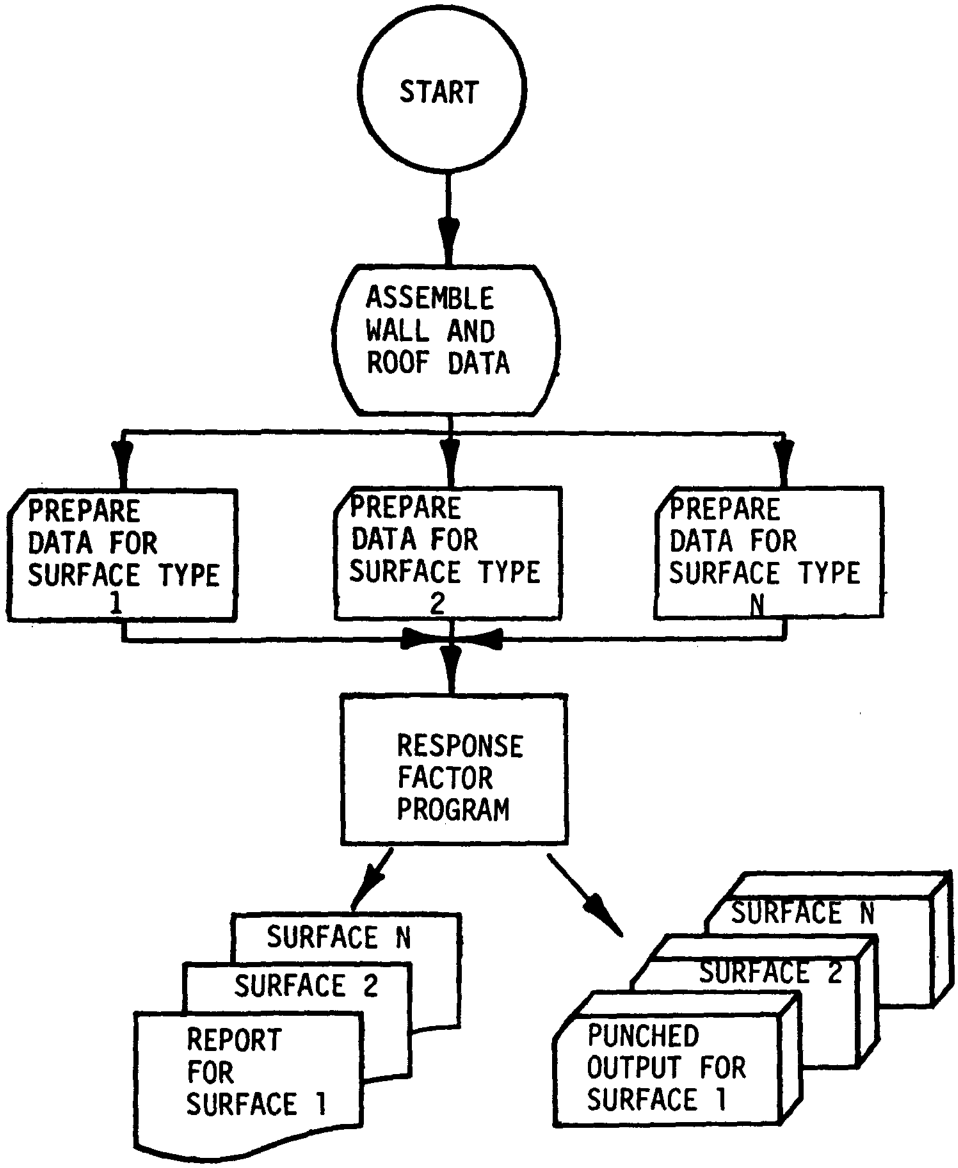


Figure 2.1 RESPONSE FACTOR PROGRAM FLOWCHART

INPUT

NOC : Number of surfaces to be analyzed

NOL : Number of layers to be considered for the analysis of the particular wall or roof

XK_i : Thermal conductivity of each layer, Btu/hr-ft-°F
If the layer was no thermal mass, $XK_i = 0$
where i = 1, 2, . . ., NOL

D_i : Density of each layer, lb/cu ft
If the layer has no thermal mass, $D_i = 0$
where i = 1, 2, . . ., NOL

SH_i : Specific heat of each layer, Btu/lb-°F
If the layer has no thermal mass, $SH_i = 0$
where i = 1, 2, . . ., NOL

XL_i : Thickness of each layer, ft
If the layer has no thermal mass, $XL_i = 0$
where i = 1, 2, . . ., NOL

RES_i : Thermal resistance of the layer which has no thermal mass, hr-sq ft-°F/Btu
If the layer has thermal mass, $RES_i = 0$
where i = 1, 2, . . ., NOL

DT : Time increment for the response factors calculation (set to 1 in program), hr.

The sequence of inputting the values of above properties is important. It must follow the way each layer is laid one after another from the outside or exterior surface to the inside air. It should be noted that when the inside surface heat transfer coefficient FI is constant, it can be included as a single resistance on the inside of the last layer of wall.

OUTPUT

$\left.\begin{array}{l} X_j \\ Y_j \\ Z_j \end{array}\right\}$: Response factors series for j = 1, 2, . . ., M where the value of M, number of the factors in the series. depends upon the type of wall, roof or overhang floor construction

CR : Common ratio between successive terms of each series beyond M calculated by

$$CR = X_{M+1}/X_M = Y_{M+1}/Y_M = Z_{M+1}/Z_M$$

Definitions of X, Y and Z Response Factors

Consider the wall in Figure 2.2 and assume that the heat flow rate into side A is Q_A, and the heat flow rate out of side B is Q_B.

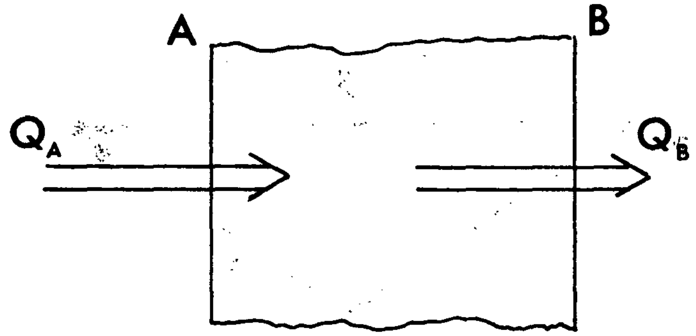


Figure 2.2 A WALL

If a unit pulse of temperature is applied to side A at time zero, the values of Q_A at times 0, 1, 2, . . . are called, respectively, X_0, X_1, X_2, . . . and the values of Q_B at times 0, 1, 2, . . . are called, respectively Y_0, Y_1, Y_2 . . . .

If a unit pulse of temperature is applied to side B at time zero, the values of Q_B at times 0, 1, 2, . . . are called, respectively, Z_0, Z_1, Z_2,. . . and the values of Q_A at times 0, 1, 2, . . . are called, respectively Y_0, Y_1, Y_2, ...

Therefore:

The time series X_0, X_1, X_2, X_3 . . ., or more briefly, X, is the heat flux at A due to a temperature disturbance at A.

The time series Z_0, Z_1, Z_2, Z_3 . . ., or more briefly, Z, is the heat flux at B due to a temperature disturbance at B.

The time series Y_0, Y_1, Y_2, Y_3 . . ., or more briefly, Y, is the heat flux at either side of the wall due to a temperature disturbance at the other side.

These definitions are shown schematically in Figure 2.3

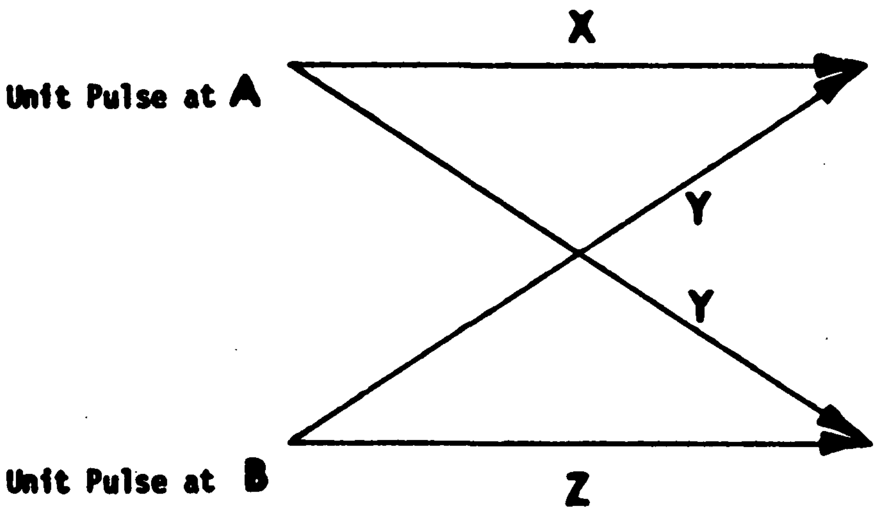


Figure 2.3 MEANING OF X, Y AND Z

SECTION 3
THERMAL LOAD ANALYSIS PROGRAM

3.1 OBJECTIVE AND DESCRIPTION

The Thermal Load Analysis Program, a complex of heat transfer, psychrometric, and geometric subroutines, computes the thermal loads, both heating and cooling, resulting in each building space each hour due to:

1. Transmission gains and losses through walls, roofs, floors and windows.

2. Solar gains through windows.

3. Internal gains from people, lights and building equipment.

4. Infiltration gains and losses due to wind and thermal pressure differences across openings.

5. Ventilation air gains and losses due to fresh air requirements.

Using these capabilities, the Thermal Load Analysis Program can perform two types of analysis:

1. Design load analysis - Utilizing user-defined design weather data, a 24-hour design day analysis is done for each month to determine peak heating and cooling requirements for each space and the entire building.

2. Hourly energy analysis - Utilizing actual hourly weather data, hourly heating and cooling loads for each space are calculated for an entire year of building operation and results stored on magnetic tape for use by other programs.

The input to the Thermal Load Analysis Program reflects building architecture, building construction, building surroundings, local weather, and pertinent astronomy of the sun. The output consists of hourly weather and psychrometric data and hourly sensible loads, latent loads, return air lighting loads, and equipment and lighting power consumption for each building space. All calculations are performed in accordance with algorithms set forth by ASHRAE in their publication entitled "Procedures for Determining Heating and Cooling Loads for Computerized Energy Calculations". Figure 3.1 briefly depicts the overall methodology built into the Thermal Load Analysis Program. Table 3.1 gives a brief description of each subroutine making up the program.

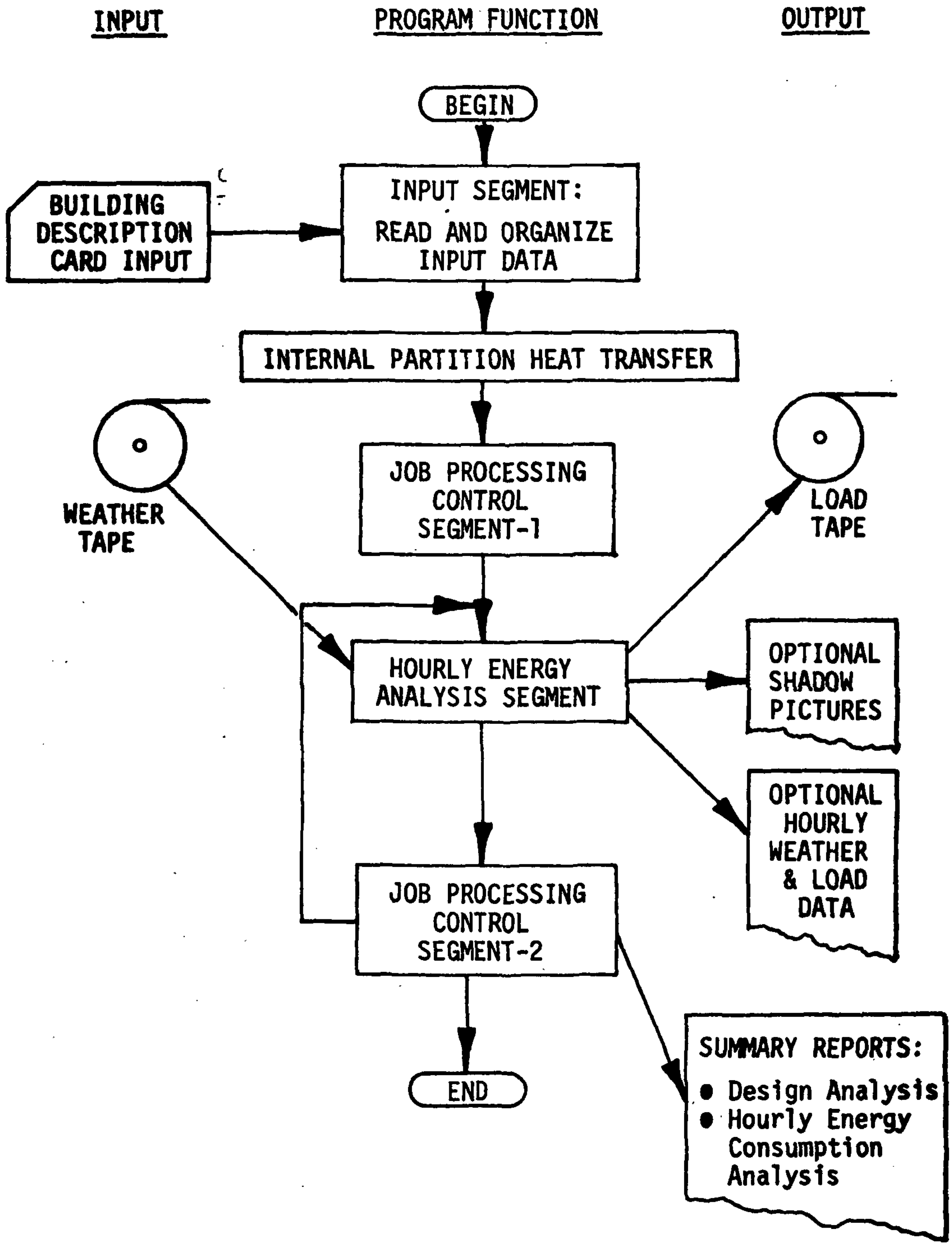


Figure 3.1 THERMAL LOAD ANALYSIS PROGRAM MACRO-FLOW DIAGRAM

TABLE 3.1

THERMAL LOAD ANALYSIS PROGRAM SUBROUTINES

Name of the Subroutine	Function
APOL	Calculates area and orientation of an irregular surface
CCM	Calculates cloud cover modifier
CENTER	Centers the headings of output
DAYMO	Determines the day of month
DESDY	Determines design day temperature correction factors
DST	Determines Daylight Savings Time
FILM	Calculates outside heat transfer film coefficient
HD	Calculates heat gain through slowly responding surfaces (Delayed surfaces)
HL	Calculates sensible and plenum return air heating and cooling load due to a space
HOLDAY	Determines holidays of year
HQ	Calculates heat gain through quickly responding surfaces (Quick surfaces)
INF	Calculates space infiltration air loads
INPUT1	Reads surface geometric data for shading surfaces
INPUT2	Reads surface geometric data for delayed, quick and window surfaces
LEEP	Determines whether the year is a leap-year
MATCON	Converts shadow picture matrix for pictorial display
MONFIN	Determines name of month for printing in reports
NDOW	Determines day of week
PPWVMS	Calculates water vapor pressure of saturated air
PSY	Calculates psychrometric data

TABLE 3.1 (CONT'D)

Name of the Subroutine	Function
QMAX	Keeps track of space peak heating and cooling loads
RECTAN	Calculates vertex coordinates of a rectangular surface
RECAP1	Echos initial portion of input data
RECAP2	Echos surface geometric description data
REPRT1	Prints title page
REPRT2	Prints weather information page
REPRT3	Prints load tape parameter labels
REPRT5	Prints summary of design day weather
REPRT6	Prints summary of design load results
RMRSS	Calculates room hourly weighting factors
SCHDUL	Generates operating schedules for people, lights, and equipment
SCHED	Assigns proper lighting, people, and equipment schedules
SEARCH	Limits shadow pictures to certain times and certain surfaces
SHADOW	Calculates shadow shapes and areas
SHG	Calculates heat gain through windows
STNDRD	Generates response data for standard walls and roofs
SUN1	Calculates daily data on solar radiation
SUN2	Calculates hourly data on solar radiation
SUN3	Calculates solar data which depends on orientation of a surface
TAR	Calculates glass absorption and transmission factors
WBF	Calculates wet-bulb temperature
WEATHER	Decodes weather tape

There is a difference between thermal load calculation procedures for use in the design of the heating and cooling facilities and the procedures for estimates of energy requirements. The load calculation procedure as described in the 1967 ASHRAE Handbook of Fundamentals is for the design calculation. It is valid for simplified design conditions that assume steady-state conditions (such as is largely the case for heating load calculations) or a steady periodic heat flow (as is the case for the cooling load calculation).

The load calculated under these design conditions may be adequate for sizing or selecting heating and cooling equipment and systems, but it is unsatisfactory for predicting the actual hourly thermal loads.

A good load calculation procedure for the determination of energy requirements should be able to predict the performance of the building heating and cooling system when combined with a total system simulation program under actual (randomly fluctuating) climatic and operating conditions.

An important distinction between the design load calculation and energy calculation, therefore, is that the former uses a single value while the latter generates a series of values or time series of thermal loads evaluated at every hour of the year.

Since the load determination of energy requirements involves many more calculations as compared with an ordinary design load determination, the use of a computer is considered mandatory.

The Thermal Load Analysis Program uses a number of subroutines instead of a long continuous algorithm. The rationale behind this arrangement is as follows:

(1) The subroutine algorithms are easier to describe and understand than a long and continuous algorithm of the whole program.

(2) If required, it is easier for the user to alter, delete, or replace portions of his load calculation program.

(3) Many of the subroutine algorithms can be made independently available for many other heat transfer problems such as calculation of refrigeration load, heating and cooling of solid objects, temperature rise of a building wall during fire, propagation of smoke within a building and design of exterior shading devices of buildings.

The basic scheme of the load calculation procedure is first to evaluate the instantaneous heat gains due to solar radiation and heat conduction as accurately as possible. These heat gains are then balanced with those due to infiltration, lighting and other internal sources with a specific consideration that the sum of all of the instantaneous heat gains is not the instantaneous cooling load.

The solar radiation is first absorbed by solid objects in the space and is not manifested as a cooling load until some time later. Exact evaluation of the space cooling load requires solution of a set of the heat balance equations for all the space surfaces, space air and space heat gains.

In order to simplify this calculation procedure, the weighting factor concept is introduced in such a manner that each heat gain contributes to the space cooling load through its own weighting factors.

3.2 THE CONVOLUTION PRINCIPLE

The program takes account of heat storage in the building's structure by a mathematical device called the convolution principle. The example of heat gain through a thick wall will illustrate how the convolution principle works.

The value of heat gain (Q) into the building through a thick wall, for a constant inside air temperature, depends on the present value, and the past history, of the temperature difference (ΔT) between the inside air and the outside surface of the wall. In other words, the graph of the schedule of Q versus time (t) depends on the graph of the schedule of ΔT versus t (see Figure 3.2).

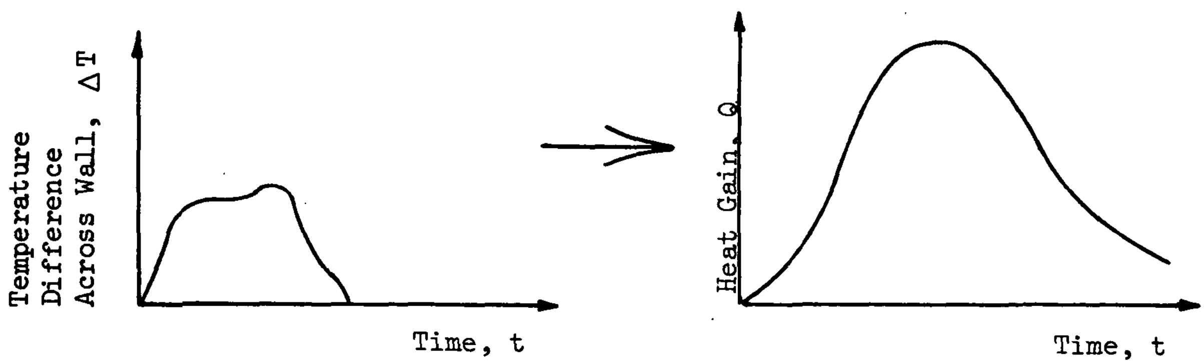


Figure 3.2 DEPENDENCE OF HEAT GAIN SCHEDULE ON TEMPERATURE DIFFERENCE SCHEDULE

Were it necessary to compute Q for each hour, on the basis of the hourly history of ΔT, the differential equation of heat conduction would have to be repeatedly solved by numerical methods, and the computation time would be prohibitive even with a fast computer. Fortunately, the problem can be simplified so that Q need be determined as a function of t for only one temperature difference schedule. The one temperature difference schedule for which the program must compute a heat gain schedule is called the triangular pulse, and the values of Q which the triangular pulse elicits, at successive equal time intervals after the peak of the pulse, are called the response factors (r_0, r_1, r_2, . . .) of the wall (see Figure 3.3).

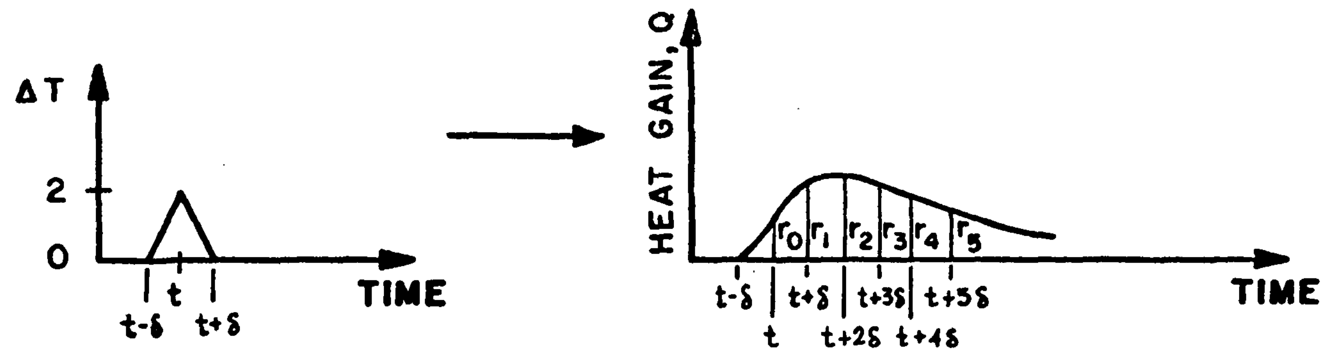
Any arbitrary schedule of ΔT may be squared off to give a schedule of approximate temperature differences, $\Delta T'$, whose values agree with those of ΔT at integral multiples of the time interval, δ. This schedule of approximate temperature differences, $\Delta T'$, may be resolved into a series of triangular pulses (ΔT_1, ΔT_2, ΔT_3, ΔT_4, and ΔT_5) which, when added together, give exactly $\Delta T'$. Each of these component pulses has a base width, or duration, of 2δ, a peak occurring at each integral multiple of δ, and a height equal to the value of $\Delta T'$ at the time of the pulse's peak. Each such pulse alone would elicit its own schedule of heat gains as shown in Figure 3.4. The pulse ΔT_2 would elicit Q_2 and so on. The heat gain schedules elicited by the individual pulses are all the same except for two differences. Their heights are proportional to the heights of the pulses which elicit them, and each is moved to the right, on the time axis, as far as the pulse which produced it.

The values of the individual responses, Q_1 . . . Q_5, may be added at each value of time, to give the curve of sums. A mathematical principle known as the superposition theorem asserts that the curve of sums is exactly the heat gain schedule which would be elicited by the approximate temperature difference schedule, $\Delta T'$. Due to the smoothing effect of the heat transfer process, ΔT and $\Delta T'$ give nearly the heat gain schedule elicited by the original temperature difference schedule, ΔT. This method of resolution and recombination is called the convolution principle.

To the air conditioning engineer, the convolution principle means that the difficult problems of transient heat transfer can be solved, for each simulated hour, by adding and multiplying very few numbers. The convolution principle as applied to heat gain through a thick wall, is expressed mathematically by the equation.

$$Q_j = \sum_{i=0}^{n} r_i \Delta T_{j-i} \qquad \text{(EQ. 1)}$$

where Q_j equals the heat gain at the hour j; ΔT_{j-i} equals the temperature difference i hours previous to hour j; r_i equals the i^{th} response



T = OUTSIDE SURFACE TEMPERATURE

T_o = INSIDE AIR TEMPERATURE

$\Delta T = T - T_o$

Figure 3.3 HEAT GAIN SCHEDULE FOR A TRIANGULAR TEMPERATURE PULSE SHOWING RESPONSE FACTORS

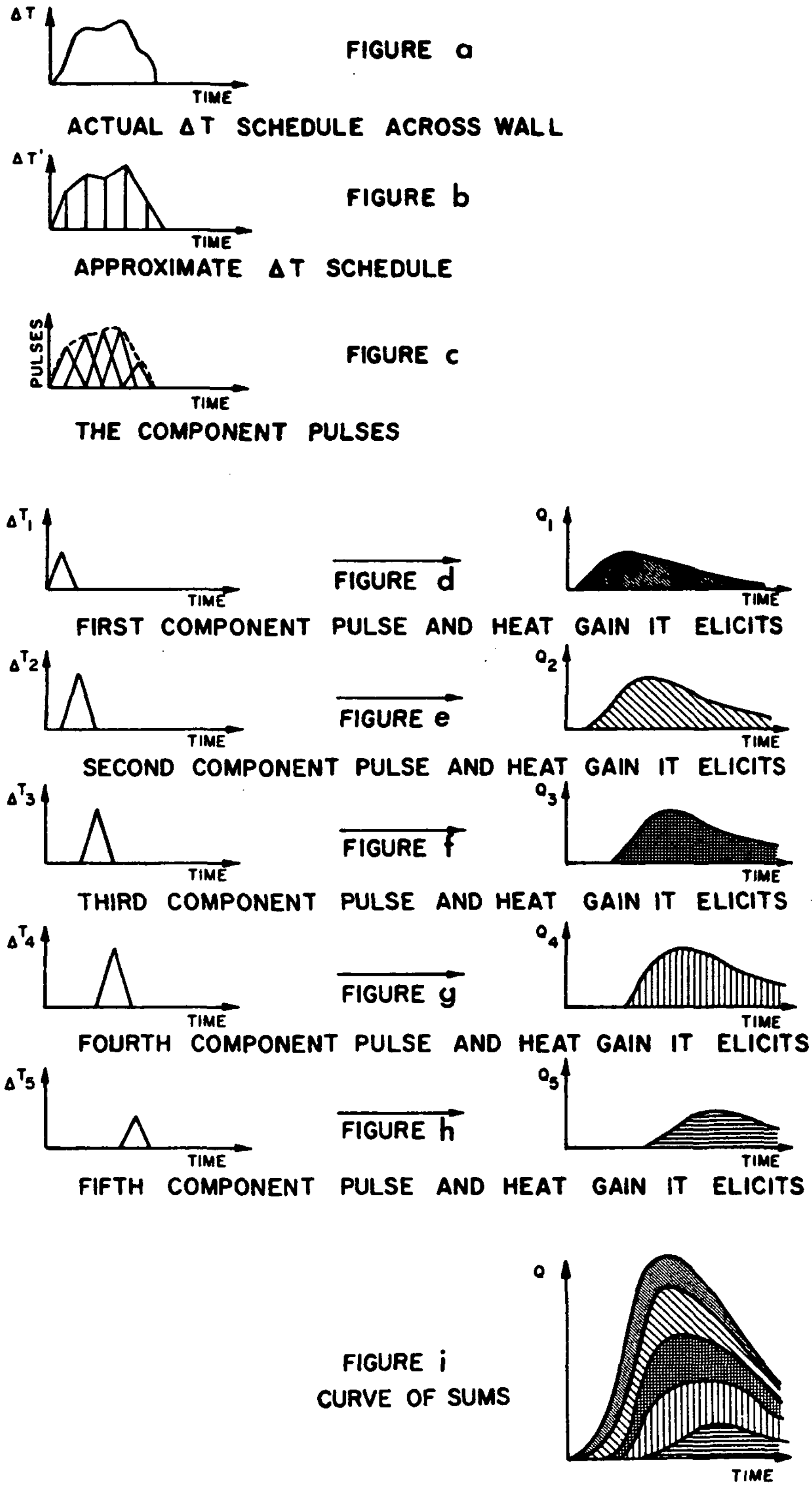


Figure 3.4 THE CONVOLUTION PRINCIPLE

factor for the wall; and n equals the number of hours of the temperature difference history which significantly effect Q_i. Notice that the response factors are the only information about the wall which appears in equation 1. Thus, the response factors characterize completely the thermal properties of the structure of the wall and, alone describe how the structure absorbs and releases heat over a prolonged period of time.

The program allows the user to specify either actual thermal data - that is, layer by layer thicknesses, conductivities, and specific heats - which the program will convert to response factors, or the response factors themselves. Tables of response factors are now available for a variety of structures. Where neither the layer by layer thermal data nor the response factors of a wall or roof are known, a feature is available to generate approximate response factors from these simplified data: U-factor conditions (summer or winter to which the U-factor applies; material of outside layer, and thickness of insulation, if present. The wall and roof construction subroutine works by selecting a wall or roof construction from a stored library of constructions standardized by ASHRAE, to fit the simplified data. The load program uses the response factors of the selected construction.

A cost saving feature of the Load Program is the use of a subtle modification of equation 1 which allows n to equal infinity while saving a good deal of computer time. That is, all previous hours of the temperature difference schedule are taken into account - very inexpensively.

The Load Program uses the convolution principle for the following three purposes.

1. To compute the exterior surface temperature of a thick wall at each simulated hour on the basis of past temperatures and present radiation and convection data.

2. To compute heat gain as already described.

3. To compute the time delay between heat gain to a space and the resulting loads on the air conditioning system. In this last case, the series of numbers which characterizes the structures (room furnishings, floors, partitions) are called room weighting factors, rather than response factors.

To summarize, the convolution principle is used by the thermal load analysis program to simulate, with great accuracy, the transient heat conduction taking place within the structures of the building. Various experiments with the program indicate that the convolution principle, when used in heating and cooling load calculations, gives more realistic values of the maximum loads and more accurate estimates of the times of their occurrence. For example, the program shows that maximum cooling loads occur several hours after the hottest time of the day, at which time some buildings are unoccupied. For practical purposes, this means that the equipment specified with the help of the program will be smaller than equipment specified as a result of hand computation, and that the elusive demand figures for utility services can be determined accurately, allowing a realistic estimation of energy costs.

3.3 MAIN ROUTINE ALGORITHMS

The main routine of the Thermal Load Analysis Program is divided into five segments whose relationship is expressed graphically in Figure 3.1. These segments are as follows:

- Building input
- Internal partition heat transfer
- Job Processing Control-1
- Hourly energy analysis
- Job Processing Control-2

3.3.1 Building Input Segment: Read and Organize Building Description Data

In this segment of the program, building description information is read into the program and organized for processing by segments which follow. A summary of card input data requirements (with card type numbers in parentheses) is given below. Refer to the User's Manual for a complete listing and discussion of card input variables.

READ - identifiers (LC-1,5)

- general program control variables (LC-6,10)

- schedules [people, lighting, and equipment] (LC-11,13)
  - standard (built into program)
  - specific (card input)

READ - common shading polygons (LC-14,16') ++
  - short form
  - long form

READ - delayed surfaces (LC-17,29)
  - response factors
    - standard (built into program)
    - specific (card input)
  - general characteristics
  - geometry ++
    - short form
    - long form
  - deleted common shading surfaces
  - added shading to specific delayed surface ++
    - short form
    - long form

- pictorial output, delayed surface

READ - quick surfaces (LC-30,38)
- general characteristics
- geometry++
  - short form
  - long form
- deleted common shading surfaces
- added shading surfaces to specific quick surface++
  - short form
  - long form
- pictorial output, quick surface

READ - glazed surfaces (LC-39,47)
- general characteristics
- geometry++
  - short form
  - long form
- deleted common shading surfaces
- added shading surfaces to specific glazed surface++
  - short form
  - long form
- pictorial output, glazed surface

READ - internal heat transfer surfaces (LC-48,49)
- area, U-value, adjoining space numbers

READ - underground walls (LC-50,51)
- area, U-value

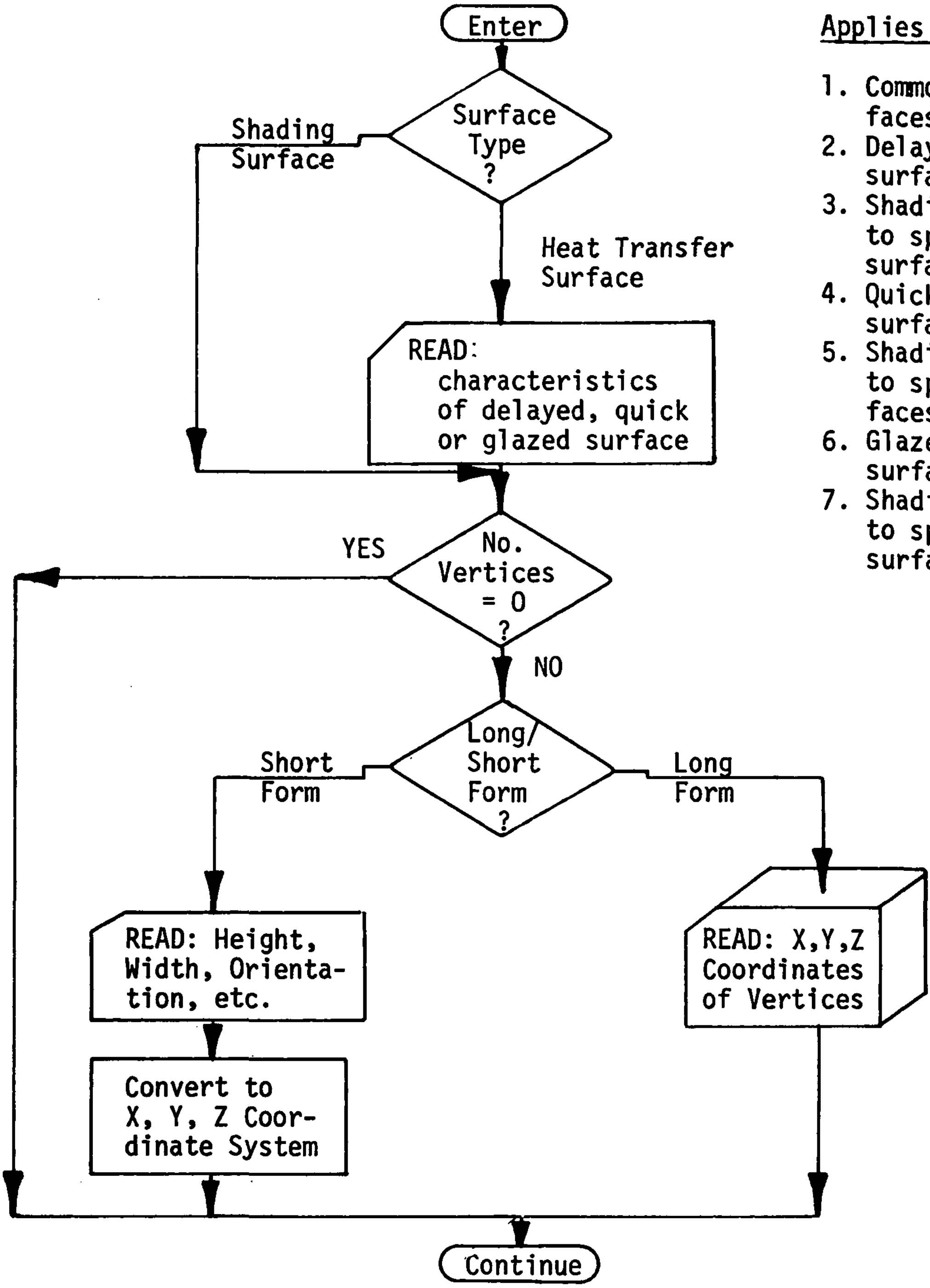
READ - underground floors (LC-52,53)
- area, U-value

READ - ground temperatures for each month (LC-54)

READ - zone description (LC-55,56)
- area of floor, volume, weight of floor
- setpoint temperature
- people, lights, equipment peaks and associated schedules
- infiltration
- indices of previously described heat transfer surfaces
  - delayed
  - quick
  - glazed
  - internal surfaces
  - underground walls
  - underground floors

BEGIN THERMAL ANALYSIS

++ Refer to Figure 3.5 which indicates how polygons are read in and input data organized by the program for later processing.



Applies to:

1. Common shading surfaces
2. Delayed heat transfer surfaces
3. Shading surfaces added to specific delayed surfaces
4. Quick heat transfer surfaces
5. Shading surfaces added to specific quick surfaces
6. Glazed heat transfer surfaces
7. Shading surfaces added to specific glazed surfaces

Figure 3.5 POLYGON INPUT FLOW DIAGRAM

3.3.2 Calculate Heat Transfer Through Internal Partitions ($QIHTS_i$)

$$QIHTS_i = \Sigma\ [FIHTS_{jj} * (TSPAC_{adj} - TSPAC_i)];jj = 1, NIHTS_i$$

where

i	- is a subscript referring to the space
$FIHTS_{jj}$	- heat transfer factor (Btu/hr-^{o}F-sq ft)
NIHTS	- number of internal partitions, space i
$TSPAC_i$	- setpoint temperature, space i (^{o}F)
$TSPAC_{adj}$	- setpoint temperature of space on other side of partition (^{o}F)

3.3.3 Job Processing Control Segment-1

If design run is to be done, set up summer design day dry and wet-bulb temperature arrays (TDBSUM, TWBSUM) for March by calling subroutine DESDY.

Initialize building and space peak load and peak load thermal characteristics.

$BHMAX = 0$

$BCMAX = 0$

$SSHMAX_i = 0$

$STCMAX_i = 0$

$QCBLDG_{\ell 1} = 0$

$QHBLDG_{\ell 1} = 0$

$QSUM_{\ell 1,\ell 2} = 0$

$QWIN_{\ell 1,\ell 2} = 0$

BEGIN HOURLY CALCULATION

3.3.4 Hourly Energy Analysis Segment

Refer to Figure 3.6 for Hourly Energy Analysis Segment Flow Diagram.

- initialize flags which indicate if heat transfer through a surface has already been calculated for this hour

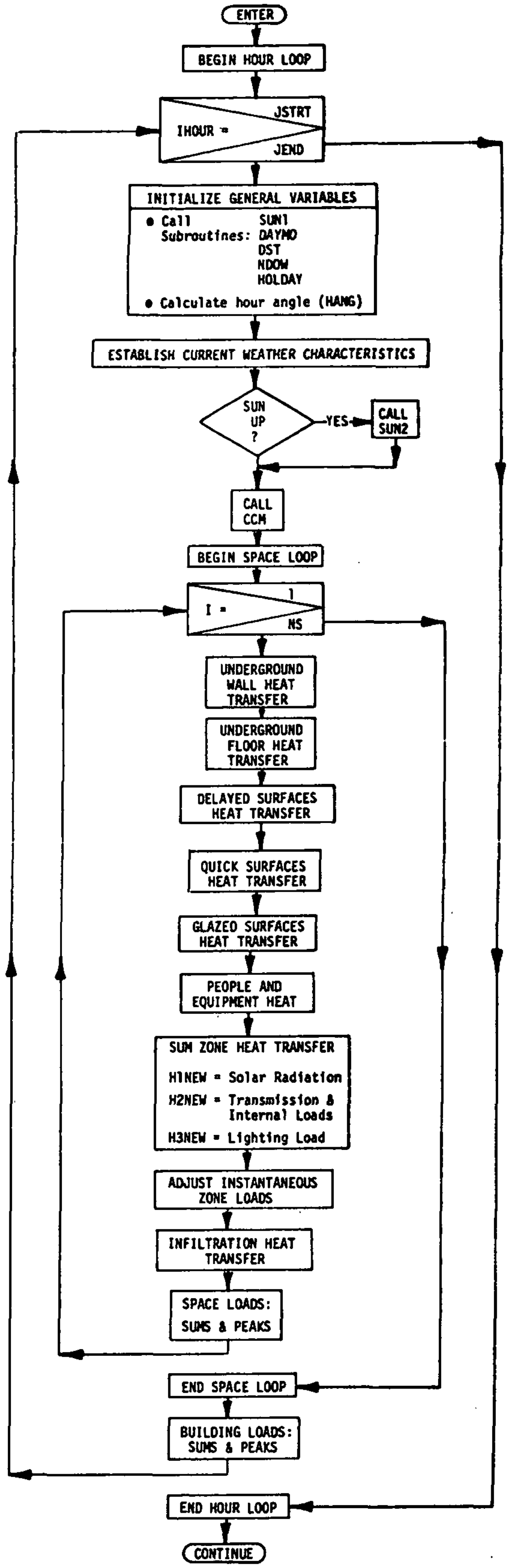


Figure 3.6 THERMAL LOAD ANALYSIS PROGRAM, HOURLY ENERGY ANALYSIS SEGMENT FLOW DIAGRAM

$ICALD_i$ = 0 (delayed surfaces)

$ICALQ_i$ = 0 (quick surfaces)

$ICALW_i$ = 0 (glazed surfaces)

- net hour number

  IHOURP = IHOUR - JSTART + 1

- initialize test case variables for maximum building heating and cooling loads and characteristics

  BHEATT = 0

  BCOOLT = 0

  $QCCOMP_{icc}$ = 0

  $QHCOMP_{icc}$ = 0 (where icc = 1,17)

- establish time references for this hour

  IDOY - day of year

  ITIME - time of day

- if ITIME = 1 (i.e., 1 AM)

  1. Call subroutine SUN1 to calculate:

     SUNRAS - hour angle when solar altitude is zero

     DEABC(1) - tangent of declination angle

     DEABC(2) - equation of time, ET (hours)

     DEABC(3) - apparent solar constant (350-390 Btu/hr-ft^2)

     DEABC(4) - atmospheric extinction coefficient (air mass^{-1})

     DEABC(5) - sky diffuse factor

  2. Call subroutine DAYMO to calculate day of the month and month of the year.

  3. Establish value of CN (Clearness Number) = CNS (summer)
     = CNW (winter)

  4. Call subroutine DST to determine whether or not Daylight Saving Time is in effect.

5. In the first hour of the run, call function NDOW to establish the day of the week (IDAY).

6. Call subroutine HOLDAY to establish if the day is a holiday.

- calculate hour angle for current hour (HANG, radians)

- if Design Load Analysis, by-pass day type flag and weather tape call. Define hourly weather from design load weather tables.

- if Energy Consumption Analysis,

  1) Call subroutine SCHED to determine type of schedules for this day.
  2) Call subroutine WEATHR to read weather data from input tape.

- call subroutine PSY to calculate outside air psychrometric conditions:

  HUMRAT - Humidity Ratio (lbs H_2O/lbm-dry air)

  ENTH - Enthalpy (Btu/lbm-air)

  DENS - Density (lbsm/ft^3)

- if $|\text{HANG}| \leq |\text{SUNRAS}|$, sun above horizon
  J1 = 0
  Call subroutine SUN2 to calculate:

  $\text{RAYCOS}_{X,Y,Z}$ - solar angle direction cosines (X,Y,Z)

  RDN - direct normal radiation (Btu/hr-ft^2)

  BS - sky brightness

  SA - sine of building azimuth (Sin(BAZ))

  CA - cosine of building azimuth (Cos(BAZ))

  If Energy Consumption Analysis, call subroutine CCM to calculate cloud cover modifier (CC) and adjust RDN and BS.

  RDN = RDN * CC

  BS = BS * CC

- if $|\text{HANG}| \geq |\text{SUNRAS}|$, sun below horizon.
  J1 = 1

Call subroutine CCM to calculate cloud cover modifier (CC).

BS = 0

BG = 0

BEGIN SPACE LOAD CALCULATION (repeat for each space)

- calculate ground temperature,

  $TGROND = TGRND_{month} + 460.0$

- underground wall heat transfer

  $QUW_i = \Sigma\ [FUW_{ii} * (TGROND - TSPAC_i)]$ for $ii = 1, NUW_i$

- delayed surface heat transfer (repeat for each delayed surface of zone i)

  If $|\ HANG\ | \leq |\ SUNRAS\ |$, sun above horizon.

  Call subroutine SUN3 to calculate:

GAMMA	-	cosine of surface tilt angle (Cos(WT))
ETA	-	angle of incidence of direct solar ray upon surface
RDIR	-	direct solar radiation incident upon surface
RDIF	-	diffuse solar radiation incident upon surface
RTOT	-	direct + diffuse solar radiation
BG	-	ground brightness (Btu/hr-ft^2)

  Check if picture is to be made of this surface (pictures may be printed on the first day of the month).

  Call subroutine SEARCH to determine if a shadow picture is called.

  Set up deleted common shading polygon array (ILETE) for subroutine SHADOW.

  Set up added shading surface arrays (XA, YA, ZA) for subroutine SHADOW.

  Call subroutine SHADOW to calculate the percent of a surface which is shaded and, if desired, to print a shadow picture of the surface.

- Calculate solar radiation on delayed surface.

  If | HANG | > | SUNRAS |, sun below horizon.

  Solar radiation on surface = 0

  Call subroutine FILM to calculate heat transfer coefficient of the outside air film.

  Call subroutine HD to calculate heat transfer through delayed surfaces.

  Sum heat transfer through delayed surfaces, zone i.

- Quick surface heat transfer (repeat for each quick surface of zone i).

  If | HANG | $\leq$ | SUNRAS |, sun above horizon.

  Call subroutine SUN3 to calculate solar radiation characteristics on quick heat transfer surface.

  Check if picture is to be made of this surface (pictures are done for the first day of the month). Call subroutine SEARCH to determine if a picture is to be made.

  Set up deleted COMMON shading polygon array (ILETE) for subroutine SHADOW.

  Set up added shading surface arrays (XA, YA, ZA) for subroutine SHADOW.

  Call subroutine SHADOW to calculate the percent of a surface which is shaded and, if requested, to print a shadow picture of the surface.

  If | HANG | > | SUNRAS |, sun below horizon.

  Solar radiation on surface = 0

  Call subroutine FILM to calculate heat transfer coefficient of the outside air film.

  Call subroutine HQ to calculate heat transfer through quick surfaces.

  Sum heat transfer through quick surfaces, zone i.

- Glazed surface heat transfer(repeat for each glazed surface of zone i).

  If | HANG | $\leq$ | SUNRAS |, sun above horizon.

  Call subroutine SUN3 to calculate solar radiation characteristics on glazed heat transfer surface.

Check if picture is to be made of this surface. Call subroutine SEARCH to do this.

Set up deleted common shading polygon array (ILETE) for subroutine SHADOW.

Set up added shading surface arrays (XA, YA, ZA) for subroutine SHADOW.

Call subroutine SHADOW to calculate the percent of a surface which is shaded and, if requested, to print a shadow picture of the surface.

Call subroutine TAR to calculate transmission, absorption, and reflection of solar radiation through single and dual glazing.

If | HANG | > | SUNRAS |, sun below horizon.

Solar radiation on surface = 0

Call subroutine FILM to calculate heat transfer coefficient of the outside air film.

Call subroutine SHG to calculate heat transfer through glazed surfaces.

Sum heat transfer through glazed surfaces, zone i.

- Calculate people loads.

  People, sensible

  $$QPS = 28 + Qp(266.4 - 10.25 * Qp) + (T-460.) * (1.2-Qp * (3.07 - 0.128 * Qp)$$

  People, latent

  $$QPL = 206. - Qp(214.9 - 13.8 * Qp) - (T-460.)* (6.7 - Qp * (4.44 - 0.222 * Qp))$$

  where Qp - activity levels of occupants (Btu/hr)

  T - space temperature (^oF)

- Sum thermal loads entering zone at current hour.

  Solar radiation (H1NEW)

  H1NEW = QRAD

  where QRAD - sum of instantaneous solar radiation into zone.

Transmission and internal loads (H2NEW)

$$H2NEW = Q_{eqs} * SCHED_{eq} + Q_{dwall} + Q_{qwall} + Q_{dceil} + Q_{qceil}$$

$$+ Q_{u} + Q_{int} + QPS * SCHED_{peo} * NFOLK + Q_{gc}$$

where Q_{egs} - peak equipment sensible heat (Btu/hr)

$SCHED_{eq}$ - equipment part load operation schedule

Q_{dwall} - sum of delayed wall surface heat transfer (Btu/hr)

Q_{qwall} - sum of quick wall surface heat transfer (Btu/hr)

Q_{dceil} - sum of delayed ceiling surface heat transfer (Btu/hr)

Q_{qceil} - sum of quick ceiling surface heat transfer (Btu/hr)

Q_{u} - sum of quick underground surface heat transfer (Btu/hr)

Q_{int} - Sum of internal partitions heat transfer (Btu/hr)

QPS - Sensible heat given off by one person (Btu/hr)

$SCHED_{peo}$ - Occupancy part load schedule

NFOLK - Maximum number of people in the space

Q_{gc} - Sum of conduction heat transfer through glazed surfaces

Light heat (H3NEW)

$$H3NEW = 3413. * SCHED_{lit} * PLITE$$

where $SCHED_{lit}$ - Internal lighting part load operation schedule

PLITE - Peak lighting power of the space (KW)

- Call subroutine HL to calculate thermal loads to room air and plenum air by adjusting instantaneous loads by the proper weighting factors.

- Call subroutine INF to calculate sensible and latent infiltration thermal loads (QS_{inf}, QL_{inf})

- Sum latent space loads (HLAT)

$$HLAT = QPL * SCHED_{peo} * NFOLK + QL_{eq} * SCHED_{eq} + QL_{inf}$$

- If energy consumption run, write weather and zone data to output tape and line printer (line printer write optional).

- Call subroutine QMAX to sum zone loads and calculate peak loads and thermal characteristics at peak conditions.

END OF SPACE LOAD CALCULATION.

- Calculate building peak loads and associated thermal conditions.

END HOURLY CALCULATION

- Job processing control Segment-2 (see para. 3.3.5)

- Call output report subroutines

- Rewind input and output tapes of energy consumption analysis.

3.3.5 Job Processing Control (JPC) Segment-2

The thermal load analysis program may be operated in three modes as defined by input variable CODE (see input card type LC-7)

1. Design load analysis only.

2. Design load analysis and hourly energy analysis.

3. Hourly energy analysis only.

The above-mentioned types of analysis are accomplished by multiple passes through the hourly analysis segment of the program. The job processing control (JPC) segment governs the mode in which the hourly energy analysis segment is used.

If CODE = 1. (design load analysis only), let: KODE = 1, summer design day analyses for the months of March through November are performed.

KODE = 2, winter design day analysis for the month of December is performed.

If CODE = 2, (design load analysis and hourly energy analysis),
let:
KODE = 1,] as per KODE = 1 above.
KODE = 2,]
KODE = 3, hourly energy consumption analysis for the period specified.

If CODE = 3, (hourly energy analysis only),
KODE = 3, hourly energy consumption analysis for the period specified.

3.4 ALGORITHMS OF SUBROUTINES

APOL

A geometry subroutine which calculates, for a polygon of known vertices, its area, tilt angle (∿ angle from zenith) and azimuth angle of the right-handed normal.

INPUT

n	:	Number of vertices
x_i, y_i, z_i ⋮ x_j, y_j, z_j	:	Coordinates of vertices, ft.

OUTPUT

AREA	:	Area of polygon, ft^2
TILT	:	Tilt angle (∿ angle from zenith), degrees
AZIM	:	Azimuth angle of the right-handed normal, degrees, clockwise from y axis

CALCULATION SEQUENCE

1. $$\text{AREA} = A = |\vec{A}| = \frac{1}{2} \sum_{i=1}^{n} (\vec{V}_i \times \vec{V}_j)$$

where $j = i + 1$ when $i < n$

$j = 1$ when $i = n$

$\vec{V}_i, \vec{V}_j, \ldots$ position vectors of the vertices

2. $$XCOMP = \frac{1}{2} \sum_{i=1}^{n} (y_i z_j - y_j z_i)$$

$$YCOMP = \frac{1}{2} \sum_{i=1}^{n} (z_i x_j - z_j x_i)$$

$$ZCOMP = \frac{1}{2} \sum_{i=1}^{n} (x_i y_j - x_j y_i)$$

3. $TILT = \cos^{-1} (ZCOMP/A)$

4. $PROJ = \sqrt{(XCOMP)^2 + (YCOMP)^2}$

5. If $PROJ << A$ $AZIM = 0.0$

6. If PROJ is appreciable compared to A, use the proper equation given in Table 3.2 for the calculation of AZIM.

TABLE 3.2

EQUATIONS FOR THE CALCULATION OF AZIM

		SIGN OF XCOMP	
		-	0 or +
Sign of YCOMP	-	$\pi + \sin^{-1} (\frac{-XCOMP}{PROJ})$	$\frac{\pi}{2} + \sin^{-1} (\frac{-YCOMP}{PROJ})$
Sign of YCOMP	0 or +	$1.5\pi + \sin^{-1} (\frac{YCOMP}{PROJ})$	$\sin^{-1} (\frac{XCOMP}{PROJ})$

CCM

A subroutine which calculates as a function of solar altitude angle, cloud type and total cloud amount, the coefficients for modifying solar radiation intensity which are calculated for a clear atmosphere.

INPUT

AL : Solar altitude angle, radians

ICLTP : Cloud type index = $\begin{cases} 0 & \text{Cirrus, Cirrostratus} \\ 1 & \text{Stratus} \\ 2 & \text{Other} \end{cases}$

ICLD : Weather Bureau total cloud amount index

OUTPUT

CC : Cloud Cover Modifier

CALCULATION SEQUENCE

The values of CC as a function of AL, ICLTP and ICLD are given in Table 3.3, which is derived from Boeing Company Report, "Summary of Solar Radiation Observation D2-90577-1, December 1964".

TABLE 3.3

CLOUD COVER MODIFIER, CC

ICLTP →	STRATUS		CIRRUS, CIRROSTRATUS	
ICLD ↓	AL ≤ 45°	AL > 45°	AL ≤ 45°	AL > 45°
1	.60	.88	.84	1.
2	.60	.88	.83	1.
3	.58	.88	.83	1.
4	.58	.87	.82	1.
5	.57	.85	.80	.99
6	.53	.83	.77	.98
7	.49	.79	.74	.95
8	.43	.73	.67	.90
9	.35	.61	.60	.84
10	.27	.46	.49	.74

The values in Table 3.3 are curve fitted and the coefficients calculated.

1. SQ = ICLD * ICLD

2a. STRATUS CLOUDS, AL ≤ 45° (0.707=Cos of 45°)

$$CC = 0.598 + 0.00026 * ICLD + 0.00021 * SQ - 0.00035 * ICLD * SQ$$

2b. STRATUS CLOUDS, AL > 45°

$$CC = 0.908 - 0.03214 * ICLD + 0.0102 * SQ - 0.00114 * ICLD * SQ$$

3a. CIRRUS, CIRROSTRATUS CLOUDS, AL $\leq$ 45°

$$CC = 0.849 - 0.01277 * ICLD + 0.00360 * SQ - 0.00059 * ICLD * SQ$$

3b. CIRRUS, CIRROSTRATUS CLOUDS, AL > 45°

$$CC = 1.010 - 0.01394 * ICLD + 0.00553 * SQ - 0.00068 * ICLD * SQ$$

4. Other than Cirrus, Cirrostratus and Stratus clouds, use average value of CC for ICLTP = 0 and 1.

CENTER

A subroutine which centers titles, names, etc. for output pages of reports.

INPUT

IDEN	:	Left-justified title, name, etc.
KODE	:	processing indicator
KAGIT	:	print output device

OUTPUT

IDEN	:	Centered title, name, etc.

CALCULATION SEQUENCE

1. Check IDEN column-by-column to determine number of blanks at righthand.
2. Reallocate IDEN in field with half of blanks of either side.
3. Print IDEN on output device KAGIT.
4. If KODE > 3, write IDEN onto output device 2.

DAYMO

A calendar subroutine which identifies the day of the month and the month of the year.

INPUT

LEAP : Leap year index = $\begin{cases} 0 & \text{Non-leap year} \\ 1 & \text{Leap year} \end{cases}$

IDOY : Day of the year, from start of year

OUTPUT

IDAY : Day of the month

MONTH : Month of the year

CALCULATION SEQUENCE

1. If IDOY < 31, MONTH = 1 and IDAY = IDOY
2. If 31 < IDOY ≤ (59 + LEAP), MONTH = 2, IDAY = IDOY - 31
3. If (59 + LEAP) < IDOY ≤ (90 + LEAP), MONTH = 3,

   IDAY = IDOY - 59 - LEAP
4. If (90 + LEAP) < IDOY ≤ (120 + LEAP), MONTH = 4,

   IDAY = IDOY - 90 - LEAP
5. If (120 + LEAP) < IDOY ≤ (151 + LEAP), MONTH 5,

   IDAY = IDOY - 120 - LEAP
6. If (151 + LEAP) < IDOY ≤ (181 + LEAP), MONTH = 6,

   IDAY = IDOY - 151 - LEAP
7. If (181 + LEAP) < IDOY ≤ (212 + LEAP), MONTH = 7,

   IDAY = IDOY - 181 - LEAP
8. If (212 + LEAP) < IDOY ≤ (243 + LEAP), MONTH = 8,

   IDAY = IDOY - 212 - LEAP
9. If (243 + LEAP) < IDOY ≤ (273 + LEAP), MONTH 9,

   IDAY = IDOY - 243 - LEAP
10. If (273 + LEAP) < IDOY ≤ (304 + LEAP), MONTH 10,

    IDAY = IDOY - 273 - LEAP

11. If (304 + LEAP) < IDOY $\leq$ (334 + LEAP), MONTH = 11,

    IDAY = IDOY - 304 - LEAP

12. IF (334 + LEAP) < IDOY, MONTH = 12 IDAY = IDOY - 334 - LEAP

DST

A subroutine which determines Daylight Saving Time and the date when it commences and when Standard Time resumes.

INPUT

JAHR	:	Year AD
MONTH	:	Month of the year
IDAY	:	Day of the month

OUTPUT

IDST	:	The Dayling Saving Time indicator = {0 Standard Time period; 1 Daylight Saving Time period}
DSTS	:	The day when Daylight Saving Time commences
DSTF	:	The day when Standard Time resumes

CALCULATION SEQUENCE

1. If MONTH is less than 4 and greater than 10, IDST = 0
2. If MONTH is greater than 4 and less than 10, IDST = 1
3. If MONTH = 4 and IDAY is less than 24, IDST = 0

4a. If MONTH = 4 and IDAY is greater than 23, find JDAY > 23 for which DAY OF THE WEEK = NDOW (JAHR, 4, IDAY) is equal to 1, DSTS = JDAY.

4b. If IDAY is less than DSTS, IDST = 0; otherwise, IDST = 1

5. If MONTH = 10 and IDAY is less than 25, IDST = 1

6a. If MONTH = 10 and IDAY is greater than 24, find JDAY >24 for which DAY OF THE WEEK = NDOW (JAHR, 10, IDAY) is equal to 1, DSTF = JDAY.

6b. If IDAY is less than DSTF, IDST = 1; otherwise, IDST = 0

DESDY

A subroutine for calculating design hourly dry-bulb and wet-bulb temperature for months other than the design summer and winter months using Carrier temperature correction factors.

INPUT

MONTH	:	Month number, 1 to 12
TMAX	:	Maximum dry-bulb temperature for summer design day, ^{o}F
TMIN	:	Minimum dry-bulb temperature for summer design day, ^{o}F
TDEW	:	Average dew point temperature for summer design day, ^{o}F
TWIN	:	Minimum dry-bulb temperature for winter design day, ^{o}F
PATM	:	Atmospheric pressure, inches of mercury

OUTPUT

TDB	:	Hourly dry-bulb temperature for design day, ^{o}F
TWB	:	Hourly wet-bulb temperature for design day, ^{o}F
DEN	:	Density of air at 3 PM hour, lb per cu ft
IER	:	Error indicator: 0 Summer design day calculation successful; 1 Winter design day calculation successful; 2 Correction had to be made to wet-bulb calculation for at least one hour

REFERENCE

"Handbook of Air Conditioning System Design", Carrier Corporation Chapter 2, Design Conditions.

Table 2 - Corrections in Outdoor Design Temperature for Time of Day.

Table 3 - Corrections in Outdoor Design Conditions for Time of Day.

CALCULATION SEQUENCE

1. Let the following define the correction factors as listed in subject reference.

a) IDD1 - DBT correction factors for 1 AM hour

IDD2 - DBT correction factors for 2 AM hour

: : : : : : :

IDD24- DBT correction factors for 12 midnite.

b) IDW1 - WBT correction factors for 1 AM hour

IDW2 - WBT correction factors for 2 AM hour

: : : : : : :

IDW24- WBT correction factors for 12 midnite

c) IMD1 - DBT correction factors for March

IMD2 - " " " " April

3 - " " " " May

4 - " " " " June

5 - " " " " July

6 - " " " " August

7 - " " " " September

8 - " " " " October

9 - " " " " November

d) IMW1 - WBT correction factors for March

IMW2 - " " " " April

3 - " " " " May

4 - " " " " June

5 - " " " " July

6 - " " " " August

7 - " " " " September

8 - " " " " October

9 - " " " " November

2. Initialize correction factors

CORM1 = 0.0 Month correction for DBT

CORM2 = 0.0 Month correction for WBT

CORD1 = 0.0 Day correction for DBT

CORD2 = 0.0 Day correction for WBT

3. Calculate Month index

If March, M = 1

If April, M = 2

If May, M = 3

If June, M = 4

If July, M = 5

If August, M = 6

If September, M = 7

If October, M = 8

If November, M = 9

4. Calculate index corresponding to yearly temperature range

RY = TMAX - TMIN

If $RY \leq 50$, L = 1

$50 < RY \leq 55$, L = 2

$55 < RY \leq 60$, L = 3

$\vdots$

$RY \leq 115$, L = 15

5. Calculate index corresponding to daily temperature range

RD = TMAX - TMIN

If $RD \leq 10$, K = 1

$10 < RD \leq 15$, K = 2

$\vdots$

$RD \leq 45$, K = 8

6. For months March through November:

   a) Set CORM1 = ICORM(L,M,1)

      CORM2 = ICORM(L,M,2)

   b) Call PSY to get W, the humidity ratio, at the dew point temperature.

   c) Calculate enthalpy at 3 PM, using TMAX and W.

      H = 0.24 * TMAX + (1061. + 0.444 * TMAX) * W

   d) Call WBF to get wet-bulb temperature, TWREF, corresponding to enthalpy H.

   e) Calculate DBT and WBT for 3 PM and call PSY to get DEN.

      CORD1 = ICORD(K,15,1)

      CORD2 = ICORD(K,15,2)

      TDNEW = TMAX - CORM1 - CORD1

      TWNEW = TWREF - CORM2 - CORD2

      Call PSY (TDNEW, TWNEW, TDEW, PATM, W, H, DEN)

   f) For hours I = 1 to 24, repeat the following:

      CORD1 = ICORD(K,I,1)

      CORD2 = ICORD(K,I,2)

      TDB(J)= TMAX - CORM1 - CORD1

      H = 0.24 * TDB(I) + (1061. + 0.444 * TDB(J) * W

      TWB(I) = WBF(H,PATM)

      If (TWB(J)+3) ≤ TDB(I), set

         TWB(I) = TDB(I) - 3

7. For months January, February and December, generate 24 hours of design weather using following approximation:

   a) Let PI = 3.14

      ALFA = PI/12.0

BETA = 2.0 * ALFA

GAMA = PI/2.4

TETA = 2.0 * GAMA

A = (TMAX-TMIN) * COS(TETA)

B = 0.5 * (TMAX-TMIN) * COS(GAMA)

C = COS(GAMA)*SIN(TETA)-2.0*COS(TETA)*
SIN(GAMA)

b) For hours I = 1 to 24, repeat following:

TDB(I) = 0.5 * (TMAX + TMIN) - (A * SIN(ALFA *
(I-10)))/L + (B*SIN(BETA*(I-10)))

H = 0.24 * TDB(J)+(1061. + 0.444 *
TDB(I)) * W

TWB(I) = WBF(H,PATM)

If (TWB(I)+3) ≤ TDB(I), set

TWB(I) = TDB(I) - 3

FILM

A subroutine which determines the outside surface heat transfer coefficient as a function of wind velocity and the type of surface constructions.

INPUT

V : Wind velocity, mph

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

OUTPUT

FO : Outside surface heat transfer coefficient, Btu/hr-sq ft-^{o}F

CALCULATION SEQUENCE

$$FO = A * V^2 + B * V + C$$

The values of A, B, and C as a function of type of exterior surface are given in Table 3.4

TABLE 3.4

VALUES OF A, B, AND C FOR CALCULATION OF OUTSIDE HEAT TRANSFER COEFFICIENT

IS	A(IS)	B(IS)	C(IS)
1	0	0.535	2.04
2	0.001329	0.369	2.20
3	0	0.380	1.90
4	-0.002658	0.363	1.45
5	0	0.281	1.80
6	-0.001661	0.302	1.45

HD

A subroutine which computes the heat transferred into a space from an outside opaque thick wall (or roof). This is accomplished using the Y response factors and the history of the wall's outside surface temperature. This history of TO_i includes the present temperature, TO_1, which must be computed using the X response factors.

INPUT

X_i	:	Self response factors, BTU/HR - sq. ft. - °F
Y_i	:	Transfer response factors, BTU/HR - sq. ft. - °F
IR	:	Number of response factor terms
RATOS	:	Common ratio
FO	:	Overall film coefficient for the outside surface of wall (includes convection and long wave radiation), BTU/HR - sq ft - °F
A	:	Cosine of angle between zenith and outward normal of wall.
CC	:	Total cloud amount index (previously called ICLD in subroutine CCM).
TM	:	Constant space temperature, °R
TDB	:	Ambient outside air dry-bulb temperature, °R
TO_i	:	Outside wall surface temperature history, (TO_1 is present outside wall surface temperature), °R.
AB	:	Absorptivity of outside surface of wall to radiation in solar spectrum
SOLI	:	Total solar radiation intensity, BTU/HR - sq.ft.
SUMN	:	For previous hour; Used to accomplish the recursive summation of the response factors and outside surface temperature
SUMR	:	
QN	:	
QR	:	

OUTPUT

Q : Space heat gain (+) or loss (-) per unit area of surface, BTU/HR - Sq. ft.

QR :
QN :
SUMN :
SUMR :

For Present Hour;
Used to accomplish the recursive summation of the response factors and outside surface Temperature.

Heat Balance Equation:

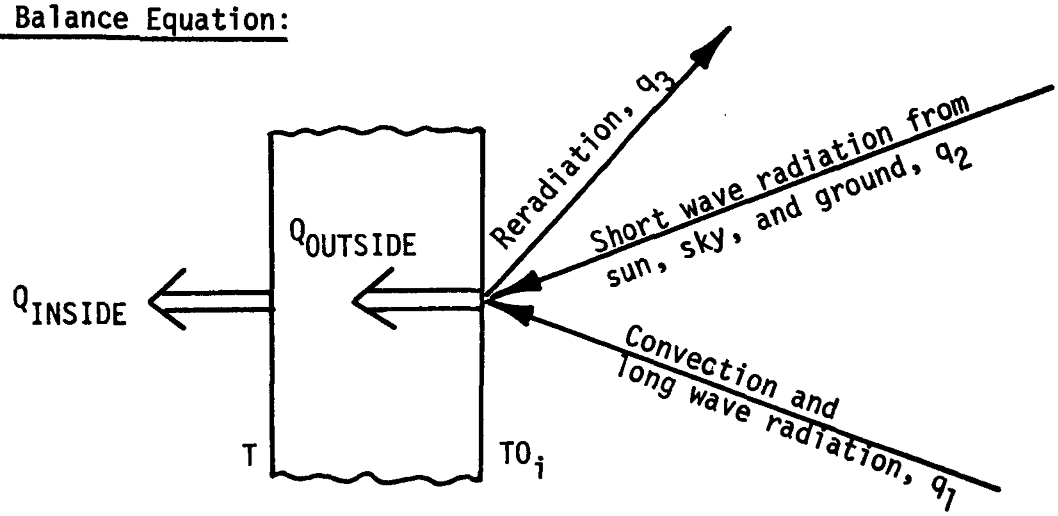


Figure 3.7 CONCEPTS OF HD SUBROUTINE

Using the diagram given in Figure 3.7, the heat balance equation of a wall may be constructed as follows:

By the use of response factors:

$$Q_{OUTSIDE} = \sum_{i=1}^{\infty} (TO_i - TM)X_i \qquad \text{(EQ. 1)}^{\dagger}$$

$$Q_{INSIDE} = \sum_{i=1}^{\infty} (TO_i - TM)Y_i \qquad \text{(EQ. 2)}^{\dagger}$$

† Note that the response factors include the inside convection film coefficient.

Outside Wall Surface Heat Balance:

$$Q_{OUTSIDE} = q_1 + q_2 - q_3 \qquad \text{(EQ. 3)}$$

where

$$q_1 = AB * SØLI \qquad \text{(EQ. 4)}$$

$$q_2 = FØ * (TDB - TO_1) \qquad \text{(EQ. 5)}$$

$$q_3 = 2.0 * A * (10.0 - CC) \qquad \text{(EQ. 6)}$$

Combining equations 1, 3, 4, 5 and 6:

$$\sum_{i=1}^{\infty} (TO_i - TM)X_i = AB * SØLI + FO * (TDB - TO_1) - 2.0 * A * (10.0 - CC) \qquad \text{(EQ. 7)}$$

Equation 7 is the heat balance equation of the outside wall surface at the time in question. Since TO_2, TO_3, etc. are known from past calculations, TO_1 may be solved from this equation.

Rearranging equation 7 as:

$$TO_1 * (X_1 + FO) = X_1 * TM + AB * SOLI + FO * TDB - 2.0 * A * (10.0 - CC) - \sum_{i=2}^{\infty} (TO_i - TM) X_i \qquad \text{(EQ. 8)}$$

and solving equation 8 for TO_1 gives:

$$TO_1 = \frac{X_1*TM+AB*SOLI+FO*TDB-2.0*A*(10.0-CC) - \sum_{i=2}^{\infty} (TO_i - TM)X_1}{X_1 + FO}$$

Now that TO_1 is known, equation 2 may be used to compute Q_{INSIDE} directly.

HL

A subroutine which determines the total space sensible load by combining the different sensible components after being multiplied by their appropriate weighting factors.

INPUT

I	:	Space Number
H1	:	Window solar load from previous hour, BTU/HR
H2	:	Total transmission and internal load from previous hour, BTU/HR
H3	:	Plenum return air load from previous hour, BTU/HR
H1NEW	:	Window solar load for present hour, BTU/HR
H2NEW	:	Total transmission and internal load for present hour, BTU/HR
H3NEW	:	Plenum return air load for present hour, BTU/HR
RMRG1 RMRGC RATRG	: : :	Window solar load weighing factors
RMRX1 RMRXC RATRX	: : :	Space sensible load weighting factors
RMRIS1 RMRISC RATRIS	: : :	Space lighting load weighting factors
RMRPS1 RMRPSC RATRPS	: : :	Return plenum lighting load weighting factors
HRLDS	:	Total space sensible load for present hour, BTU/HR
HRLDL	:	Total plenum sensible load for present hour, BTU/HR

SA : Weighted window solar load for present hour, BTU/HR

SB : Weighted space sensible load for present hour, BTU/HR

SC : Weighted space lighting load for present hour, BTU/HR

H2P : Components of sensible load from previous hour, BTU/HR

H2NEWP : Components of sensible load for present hour, BTU/HR

SBP(I) : Components of weighted sensible load for present hour, BTU/HR, where

I = 1 equipment
2 quick walls
3 delayed walls
4 underground floors
5 underground walls
6 internal walls
7 people
8 window conduction
9 quick ceilings
10 delayed ceilings

OUTPUT

H1 : Window solar load from previous hour, BTU/HR

H2 : Total transmission and internal load from previous hour, BTU/HR

H3 : Plenum return air load from previous hour, BTU/HR

HRLDS : Total space sensible load for present hour, BTU/HR

HRLDL : Total plenum sensible load for present hour, BTU/HR

SA : Weighted window solar load for present hour, BTU/HR

SB : Weighted space sensible load for present hour, BTU/HR

SC : Weighted space lighting load for present hour, BTU/HR

SBP : Components of weighted sensible load for present hour, BTU/HR

H2P : Components of sensible load for previous hour, BTU/HR

CALCULATION SEQUENCE

$$(\text{SPACE SENSIBLE LOAD})_i = \sum_{j=0}^{\infty} \sum_{i=1}^{n} (\text{LOAD})^i_{t-j} * (\text{WEIGHTING FACTOR})^i_{t-j}$$

where i is a superscript which corresponds to the type of loads and n is the number of the type of loads.

HOLDAY

A subroutine which identifies the National holidays of the United States of America.

INPUT

MO : Month of the year

JAY : Day of the month

NDAY : Day of the week (Sunday = 1, etc.)

OUTPUT

JOL : Holiday Indicator $= \begin{cases} 0 & \text{Not holiday} \\ 1 & \text{Holiday} \end{cases}$

CALCULATION SEQUENCE

1. Set JOL equal to 1 for the following situations:

   If MO = 1 and JAY = 1
   MO = 12, JAY, = 31, and NDAY = 6
   MO = 1, JAY = 2, and NDAY = 2
   MO = 2, and JAY = 22
   MO = 2, JAY = 21, and NDAY = 6
   MO = 2, JAY = 23, and NDAY = 2
   MO = 5, and JAY = 30
   MO = 5, JAY = 29, and NDAY = 6
   MO = 5, JAY = 31, and NDAY = 2
   MO = 7, and JAY = 4
   MO = 7, JAY = 3, and NDAY = 6
   MO = 7, JAY = 5, and NDAY = 2
   MO = 12 and JAY = 25
   MO = 12, JAY = 24, and NDAY = 6
   MO = 12, JAY = 26, and NDAY = 2
   MO = 9, JAY is less than 7 and NDAY = 2
   MO = 1, JAY ig greater than 23, and NDAY = 5

2. Otherwise, set JOL equal to 0.

HQ

A subroutine which computes the heat transferred into a space from an outside opaque quickly-responding wall, door, etc. This subroutine is very similar to the HD subroutine except that it requires no use of response factors.

INPUT

FO	:	Overall film coefficient for the outside surface of wall (includes convection and long wave radiation), BTU/HR - sq. ft. - °F
U	:	Overall heat transfer coefficient of wall, BTU/HR - sq. ft. - °F
A	:	Cosine of angle between zenith and outward normal of wall
CC	:	Total cloud amount index (previously called ICLD in subroutine CCM)
TM	:	Constant space temperature, °R
TDB	:	Ambient outside air dry-bulb temperature, °R
AB	:	Absorptivity of outside surface of wall to radiation in solar spectrum
SOLI	:	Total solar radiation intensity, BTU/HR - sq. ft.

OUTPUT

Q	:	Space heat gain (+) or less (-) per unit area of surface, BTU/HR - sq. ft.

CALCULATION SEQUENCE

Using the same terminology of the HD subroutine, we can write:

$$Q_{OUTSIDE} = Q_{INSIDE} = U * (TO_1 - TM) \qquad \text{(EQ. 1)}$$

where U is the overall heat transfer coefficient.

The heat balance equation of the outside wall surface becomes:

$$U * (TO_1 - TM) = AB * SOLI + FO * (TDB - TO_1) - 2.0 * A * (10.0 - CC) \qquad \text{(EQ. 2)}$$

Solving this equation for TO_1 gives:

$$TO_1 = \frac{U * TM + AB * SOLI + FO * TDB - 2.0 * A * (10.0 - CC)}{U + FO} \qquad \text{(EQ. 3)}$$

Now that TO_1 is known, equation 9 may be used to compute Q_{INSIDE} directly.

INPUT1

A subroutine used to read surface geometric data required for common shading surfaces and shading surfaces added to delayed, quick and window surfaces.

INPUT

KARD	:	Logical unit number for card input device
KAGIT	:	Logical unit number for line printer
NV	:	Number of vertices contained in surface

OUTPUT

$$\left.\begin{array}{l} XX \\ YY \\ ZZ \end{array}\right\} \text{coordinates of vertices}$$

CALCULATION SEQUENCE

1. If NV = 1, the short form of description for a rectangular surface is desired, therefore go to calculation 2; if NV $\geq$ 3, go to calculation 3.

2. Short form input for rectangular surface

   a) Read the following card input data:

   $$\left.\begin{array}{l} XCORN \\ YCORN \\ ZCORN \end{array}\right\} \text{coordinates of lower lefthand vertex, ft}$$

HT	-	height, ft
WD	-	width, ft
AZIM	-	azimuth angle, degrees
TILT	-	tilt angle, degrees

   b) Convert azimuth and tilt angles to radians

   AZIM = 0.01745 * AZIM

   TILT = 0.01745 * TILT

c) Call RECTAN which returns XX, YY, ZZ.

d) Call RECAP2 to echo data.

e) Reset NV = 4.

3. Long form input for any surface shape

   a) For each of NV vertices, read XX, YY, and ZZ from card input data.

   b) Call RECAP2 to echo data.

INPUT2

A subroutine used to read input surface data required for delayed and quick surfaces.

INPUT

KARD	:	Logical unit number for card input device
KAGIT	:	Logical unit number for line printer

OUTPUT

NV	:	Number of vertices contained in surface
XX, YY, ZZ		coordinates of vertices
AZIM	:	Surface azimuth angle, degrees
TILT	:	Surface tilt angle, degrees
AREA	:	Surface area, sq ft
NX	:	Number of X-divisions that surface is to be divided into for shadow calculations
NY	:	Number of Y-divisions that surface is to be divided into for shadow calculations
ND	:	Number of common shading surfaces deleted
NA	:	Number of local shading surfaces added

ISR	:	Surface roughness index
IRF	:	Surface construction type index (used only for delayed surfaces)
H	:	Height, ft
W	:	Width, ft

CALCULATION SEQUENCE

1. Read input card identifying the following surface factors:

   FNV, FNX, FNY, FND, FNA, FISR, FIRF.

2. Convert these factors to integer number.

   NV = FNV + 0.1

   NX = FNX + 0.1

   NY = FNY + 0.1

   ND = FND + 0.1

   NA = FNA + 0.1

   ISR = FISR + 0.1

   IRF = FIRF + 0.1

   and echo data.

3. If NV = 1, the short form of geometric description for a rectangular surface is desired, therefore go to calculation 4; if NV $\geq$ 3, go to calculation 5.

4. Short form input for rectangular surface

   a) Read the following card input data:

   $$\left.\begin{array}{l}\text{XCORN}\\ \text{YCORN}\\ \text{ZCORN}\end{array}\right\}\ \text{coordinates of lower lefthand vertex, ft}$$

   HT - height, ft

   WD - width, ft

AZIM - azimuth angle, degrees

TILT - tilt angle, degrees

b) Convert azimuth and tilt angles to radians and calculate surface area.

AZIM = 0.01745 * AZIM

TILT = 0.01745 * TILT

AREA = HT * WD

c) Call RECTAN which returns XX, YY, ZZ.

d) Call RECAP2 to echo data.

e) Reset NV = 4.

5. Long form input for any surface shape

a) For each of NV vertices, read XX, YY, and ZZ from card input data.

b) Call RECAP2 to echo data.

INF

A subroutine which estimates sensible and latent components of the outside air load which infiltrates through openings.

INPUT

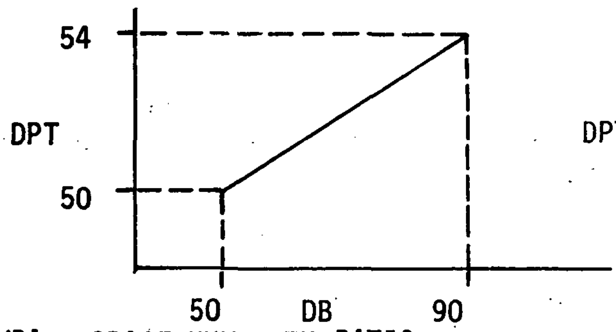
DB	:	Outside air dry-bulb temperature, °F
HUMRA	:	Outside air humidity ratio, lbs water/lb dry air
DEN	:	Outside air density, lbs dry air/cu ft
VO	:	Outside air specific volume, cu ft
TSPA	:	Space temperature, °R
CODE	:	Number of air changes per hour

OUTPUT

QSIN	:	Sensible infiltration load, Btu/hr
QLIN	:	Latent infiltration load, Btu/hr

CALCULATION SEQUENCE

1. If DB is greater than 50°F, cooling coil is probably operating, therefore estimate space humidity ratio as follows



DPT = dew point temperature of air leaving cooling coil

WRA = SPACE HUMIDITY RATIO

$$= \frac{53.2 + 0.245 * (DB - 50.0)}{7000.0}$$

2. If DB is less than 50°F, only heating coil is probably operating, therefore,

   WRA = HUMRA

3. QSIN = 14.4 * DEN * VO * (DB + 460.0 - TSPA)*CODE/60.0

QLIN = 63300.0 * DEN * VO * (HUMRA - WRA) * CODE

LEEP

A subroutine which determines whether a year is a leap year or not.

INPUT

JAHR : Year AD

OUTPUT

LEEP : Leap year index $= \begin{cases} 0 \text{ Not leap year} \\ 1 \text{ Leap year} \end{cases}$

CALCULATION SEQUENCE

If (JAHR - 1900) is evenly divisible by 4, then LEEP = 1,
otherwise LEEP = 0

MATCON

A subroutine which examines the grid elements of a shaded surface and defines an alphameric matrix made up of blank characters for sunlit elements or an asterisk character for shaded or border elements.

INPUT

ISHADE : A two-dimensional matrix representing the grid into which a surface is broken for shadow analysis. Each element of the matrix has a value of either 0, 1, or 2 to indicate respectively:

- sunlit element of surface
- shaded element of surface
- element falling outside surface

See Figure 3.9 for example.

MM : Number of grid elements in the x-axis direction

NN : Number of grid elements in the y-axis direction

OUTPUT

ISHADE : Redefined grid matrix filled with either blank or asterisk characters

CALCULATION SEQUENCE

1. For each element of matrix, i.e., I = 1 to MM and J = 1, NN

   a) If ISHADE (I,J) is greater than 0, go to 2

   b) If ISHADE (I,J) is equal to 0, check to see if element is on border of surface, i.e., I = 1 or MM, J = 1 or NN. If so, set ISHADE (I, J) = 1.

   c) If ISHADE (I,J) is equal to 0, and I $\neq$ 1 or MM or J $\neq$ 1 or NN, check to see if element is on a diagonal border; i.e., element above, below, to right, or to left is equal to 2. If so, set ISHADE (I, J) = 1.

2. For each element of matrix, i.e., I = 1 to MM and J = 1 to NN

   a) If ISHADE (I, J) = 0, set element equal to a blank character

   b) If ISHADE (I,J) is greater than 0, set element equal to an asterick character.

See Figures 3.8 - 3.11 for a visual explanation of the steps performed in making a shadow calculation. Also refer to subroutine SHADOW for further insites into the mechanics of performing such calculations.

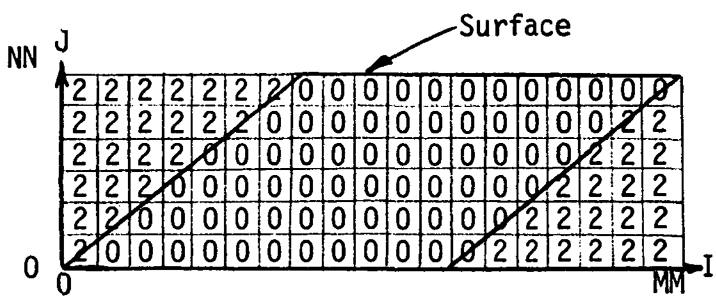


Figure 3.8

Step 1 - Surface broken into grid elements with 0 and 2 indicating if grid midpoint is without or within the surface boundary

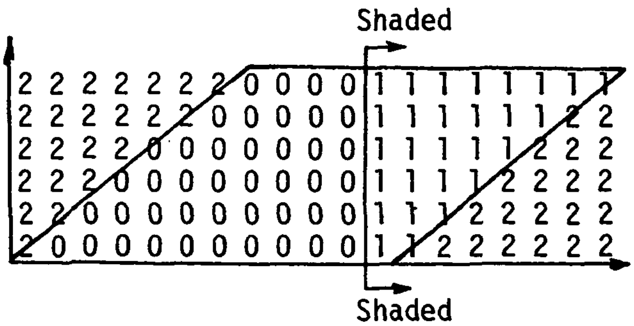


Figure 3.9 .

Step 2 - Surface broken into grid elements with 1 indicating portion that is shaded

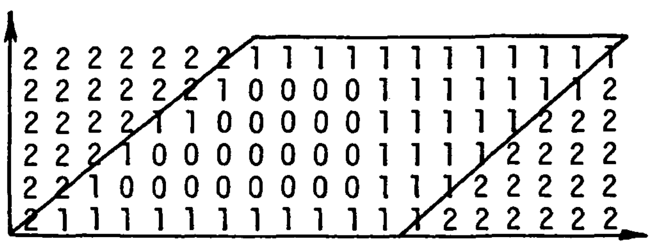


Figure 3.10

Step 3 - Surface broken into grid elements with 1 indicating a shaded element or a boundary element

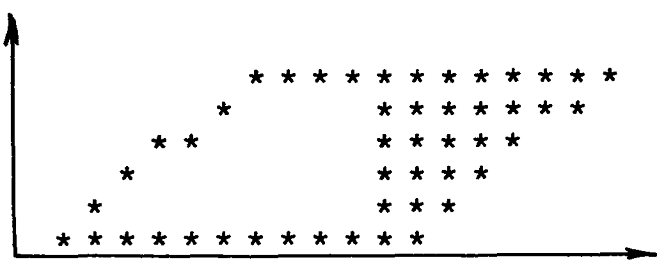


Figure 3.11

Step 4 - Transformed matrix ready for pictorial display

MONFIN

A subroutine to define the alphameric name of a month given the numeric equivalent.

INPUT

MONTH : Month of year, 1 to 12

OUTPUT

MONT : Alphameric name of month corresponding to MONTH.

CALCULATION SEQUENCE

```
If MONTH = 1, MONT = JAN.
         = 2,      = FEB.
         = 3,      = MAR.
         = 4,      = APR.
         = 5,      = MAY
         = 6,      = JUNE
         = 7,      = JULY
         = 8,      = AUG.
         = 9,      = SEP.
         =10       = OCT.
         =11,      = NOV.
         =12,      = DEC.
```

NDOW

A subroutine which determines the day of the week.

INPUT

JR	:	Year AD
MO	:	Month of the year
JAY	:	Day of the month

OUTPUT

NDOW : Week day indicator = $\begin{cases} 1 \text{ if Sunday} \\ 2 \text{ if Monday} \\ 3 \text{ if Tuesday} \\ 4 \text{ if Wednesday} \\ 5 \text{ if Thursday} \\ 6 \text{ if Friday} \\ 7 \text{ if Saturday} \end{cases}$

CALCULATION SEQUENCE

1. Let JST(1) = 31, JST(2) = 59, JST(3) = 90, JST(4) = 120
   JST(5) = 151, JST(6) = 181, JST(7) = 212, JST(8) = 243
   JST(9) = 273, JST(10)= 304, JST(11)= 334, JST(12)= 365

2. Let N = Integer part of JR/4

   ND = N - 485
   IY = 2, IAAD = 2
   If ND = 0, go to (4)
   If ND is less than 0, ND = -ND and IADD = -2.

3. Repeat the following steps ND times

   IY = IY - LADD

   If IY is greater than 7, IY = IY - 7
   If IY is equal to 0, IY = 7
   If IY is less than 0, IY + 7

4. Let MD = JR - N * 4

   If MD is equal to 0, IWK = IY
   1, IWK = IY + 2
   2, IWK = IY + 3
   3, IWK = IY + 4

   If IWK is greater than 7, IWK = IWK - 7

5. Repeat the following for j = 1 through 12.

   If MO is equal to j, let JDAY = JST(j) - 31 + JAY - 1

6. If MD is equal to 0 and MO is greater than 2, JDAY = JDAY + 1

7. NTX = Integer part of JDAY/7
   NDX = JDAY - 7 * NTX + IWK

   If NDX is greater than 7, let NDS = NDX - 7

8. Let NDOW = NDX

PSY AND PPWVMS

A subroutine which calculates humidity ratio, enthalpy and density of outside air.

INPUT

DBT	:	Outside air dry-bulb temperature, ^{o}F
WBT	:	Outside air wet-bulb temperature, ^{o}F
DPT	:	Outside air dew point temperature, ^{o}F
PATM	:	Atmospheric pressure, inches of mercury

OUTPUT

HUMRAT	:	Humidity ratio, lbs water/lb dry air
ENTH	:	Enthalpy, Btu/lb dry air
DENS	:	Density, lbs dry air/cu ft

CALCULATION SEQUENCE

In the calculation of psychrometric properties of moist air, partial pressure of water vapor is needed. This is calculated by the PPWVMS subfunction.

1. If DPT is less than 32, calculate partial pressure of water vapor for DPT.

   PPWV = PPWVMS(DPT)

   Go to step 3.

2. If DPT is greater than 32, calculate partial pressure of water vapor in moisture-saturated air for WBT and obtain partial pressure of water with

$$PPWV = PPWVMS(WBT) - 0.000367 * PATM * (DBT - WBT)/(1.0 + (WBT - 32.0)/1571.0)$$

3. $HUMRAT = 0.622 * PPWV/(PATM - PPWV)$

4. $ENTH = 0.24 * DBT + (1061.0 + 0.444 * DBT) * HUMRAT$

5. $DENS = 1.0/(0.754 * (DBT + 460.0) * (1.0 + 7000.0 * HUMRAT/4360.0)/PATM)$

CALCULATION OF PARTIAL PRESSURE OF WATER IN MOISTURE-SATURATED AIR:

1. Let t be either DBT, WBT or DPT.

2. 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

3. Let T = (t + 459.688)/1.8

   If T is less than 273.16, go to 4.

   Otherwise

   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 5.

4. Let z = 273.16/T
   P1 = B(1) * (x-1)
   P2 = B(2) * Log10 (z)
   P3 = B(3) * (1-1/z)
   P4 = Log 10 (B(4))

5. PVS = 29.921 * 10 ** (P1 + P2 + P3 + P4)

QMAX

A subroutine that sums space loads each hour to get total building load; also keeps track of the peak heating and cooling load for each space.

INPUT

I	:	Space Number
HRLDS	:	Space sensible load for hour, Btu/hr
SSHMAX	:	Maximum space sensible heating load, Btu/hr
TOTAL	:	Space total load for hour, Btu/hr
STCMAX	:	Maximum space total cooling load, Btu/hr
SUMA	:	Space window solar load, Btu/hr
SUMBP(L)	:	Space sensible load components, Btu/hr where:

L = 1	equipment
2	quick walls
3	delayed walls
4	underground floors
5	underground walls
6	internal walls
7	people
8	window conduction
9	quick ceilings
10	delayed ceilings

SUMC	:	Space lighting load, Btu/hr
HLATP	:	Space latent load due to people, Btu/hr
QSINF	:	Space sensible load due to infiltration, Btu/hr
QLINF	:	Space latent load due to infiltration, Btu/hr
HRLDL	:	Space plenum return air load, Btu/hr
QLEQ	:	Space latent load due to equipment, Btu/hr
MONTH	:	Month number
DBT	:	Ambient dry-bulb temperature, °F
WBT	:	Ambient wet-bulb temperature, °F

HUMRAT : Ambient air humidity ratio, lb/lb

DENS : Ambient air density, lb/cu ft

CFMSF : Estimated amount of ventilation air, CFM/sq ft

FLORA : Space floor area, sq ft

TROOM : Space setpoint temperature, °F

MULT : Number of times space is repeated in building

ITIME : Time of day, 1 to 24

IDAY : Day of month

BHEATT : Summation of space heating loads for the hour, Btu/hr

QHCOMP(K) : Components of hourly building heating load, Btu/hr, where K takes on the following definition

K = 1 delayed walls
2 window conduction
3 window solar
4 quick walls
5 internal walls
6 underground walls
7 underground floors
8 people sensible
9 people latent
10 lighting
11 equipment sensible
12 infiltration sensible
13 infiltration latent
14 plenum return air
15 equipment latent
16 quick ceilings
17 delayed ceilings

QCCOMP(K) : Components of hourly buildign cooling load, Btu/hr, where K has same definition as above.

OUTPUT

QHCOMP(K) : Same definition as above

QCCOMP(K) : Same definition as above

QWIN(M,I) : Components of space peak heating load, Btu/hr, where I is the space number and M takes on the following definition

M = 1 delayed walls
2 window conduction
3 window solar
4 quick walls
5 internal walls
6 underground walls
7 underground floors
8 people sensible
9 people latent
10 lighting
11 equipment sensible
12 infiltration sensible
13 infiltration latent
14 plenum return air
15 equipment latent
16 month
17 ambient dry-bulb temperature
18 ambient wet-bulb temperature
19 ambient humidity ratio
20 hour of day
21 quick ceilings
22 delayed ceilings
23 day of month

QSUM(M,I) : Components of space peak cooling load, Btu/hr; M and I have same definition as for QWIN

CALCULATION SEQUENCE

1. If HRLDS is zero or positive go to 3.
   If HRLDS is negative, go to 2.

2. Heating hour

   a) Add space heating load and space ventilation air load into building heating load for the hour

      BHEATT = BHEATT + HRLDS + QOA

      QOA = 14.4*DENS*CFMSF*FLORA(I)*(DBT-TROOM(I))

   b) Add space heating load components into building heating load components

```
QHCOMP(1) = QHCOMP(1) + SUMBP(I,3)*MULT(I)
      (2) =       (2) + SUMBP(I,8)*MULT(I)
      (3) =       (3) + SUMA (I) * MULT(I)
      (4) =       (4) + SUMBP(I,2)*MULT(I)
      (5) =       (5) + SUMBP(I,6)*MULT(I)
      (6) =       (6) + SUMBP(I,5)*MULT(I)
      (7) =       (7) + SUMBP(I,4)*MULT(I)
```

```
(8) =      (8) + SUMBP(I,7)*MULT(I)
(9) =      (9) + HLATP * MULT(I)
(10) =     (10) + SUMC(I) * MULT(I)
(11) =     (11) + SUMBP(I,1)*MULT(I)
(12) =     (12) + QSINF * MULT(I)
(13) =     (13) + QLINF * MULT(I)
(14) =     (14) + HRLDL(I) * MULT(I)
(15) =     (15) + QLEQ * MULT(I)
(16) =     (16) + SUMBP(I) * MULT(I)
(17) =     (17) + SUMBP(I,10) * MULT (I)
```

c) Check for peak load, i.e., if |HRLDS| > |SSHMAX|, and update peak load data as follows:

```
QWIN(1,I) = SUMBP(I,3)
    (2,I) = SUMBP(I,8)
    (3,I) = SUMA (I)
    (4,I) = SUMBP (I,2)
    (5,I) = SUMBP (I,6)
    (6,I) = SUMBP (I,5)
    (7,I) = SUMBP (I,4)
    (8,I) = SUMBP (I,7)
    (9,I) = HLATP
   (10,I) = SUMC(I)
   (11,I) = SUMBP(I,1)
   (12,I) = QSINF
   (13,I) = QLINF
   (14,I) = HRLDL(I)
   (15,I) = QLEQ
   (16,I) = MONTH
   (17,I) = DBT
   (18,I) = WBT
   (19,I) = HUMRAT
   (20,I) = ITIME
   (21,I) = SUMBP(I,9)
   (22,I) = SUMBP(I,10)
   (23,I) = IDAY
```

3. Cooling hour

a) Add space cooling load and space ventilation air load into the building cooling load for the hour.

BCOOLT = BCOOLT + TOTAL + QSOA + QLOA

QSOA = 14.4*DENS*CFMSF*FLORA*(I)*(DBT - TROOM(I))

QLOA = 63000.*DENS*CFMSF*FLORA(I)*(HUMRAT - 0.0093)

(Room humidity condition is assumed to be approximately 75°F and 50% R.H.)

If QLOA < 0.0 set QLOA = 0.0

b) Add space cooling load components into building cooling load components. Follow same procedures as are outlined in 2b above except use QCCOMP instead of QHCOMP.

c) Check for peak load, i.e., if |TOTAL| > |STCMAX|, and update QSUM peak load data using same procedures as are outlined in 2c above.

RECTAN

A subroutine which calculates coordinates of three vertices of a rectangle, two sides of which are horizontal, if tilt angle, azimuth angle and coordinates of one vertex are given.

INPUT

X	:	Coordinates of one vertex, ft
Y	:	
Z	:	
H	:	Height of surface, ft
W	:	Width of surface, ft
A	:	Azimuth angle, degrees
B	:	Tilt angle, degrees

OUTPUT

XV(I)	:	Coordinates of 4 vertices
YV(I)	:	
ZV(I)	:	

CALCULATION SEQUENCE

1. Let CA = COS(A)
   CB = COS(B)
   SA = SIN(A)
   SB = SIN(B)

2. XV(1) = X - H * CB * SA
   YV(1) = Y - H * CB * CA
   ZV(1) - Z + H * SB

```
XV(2) = X
XV(2) = Y
ZV(2) = Z

XV(3) = X - W * CA
YV(3) = Y + W * SA
ZV(3) = Z

XV(4) = X - W * CA - H * CB * SA
YV(4) = Y + W * SA - H * CB * CA
ZV(4) = Z + H * SB
```

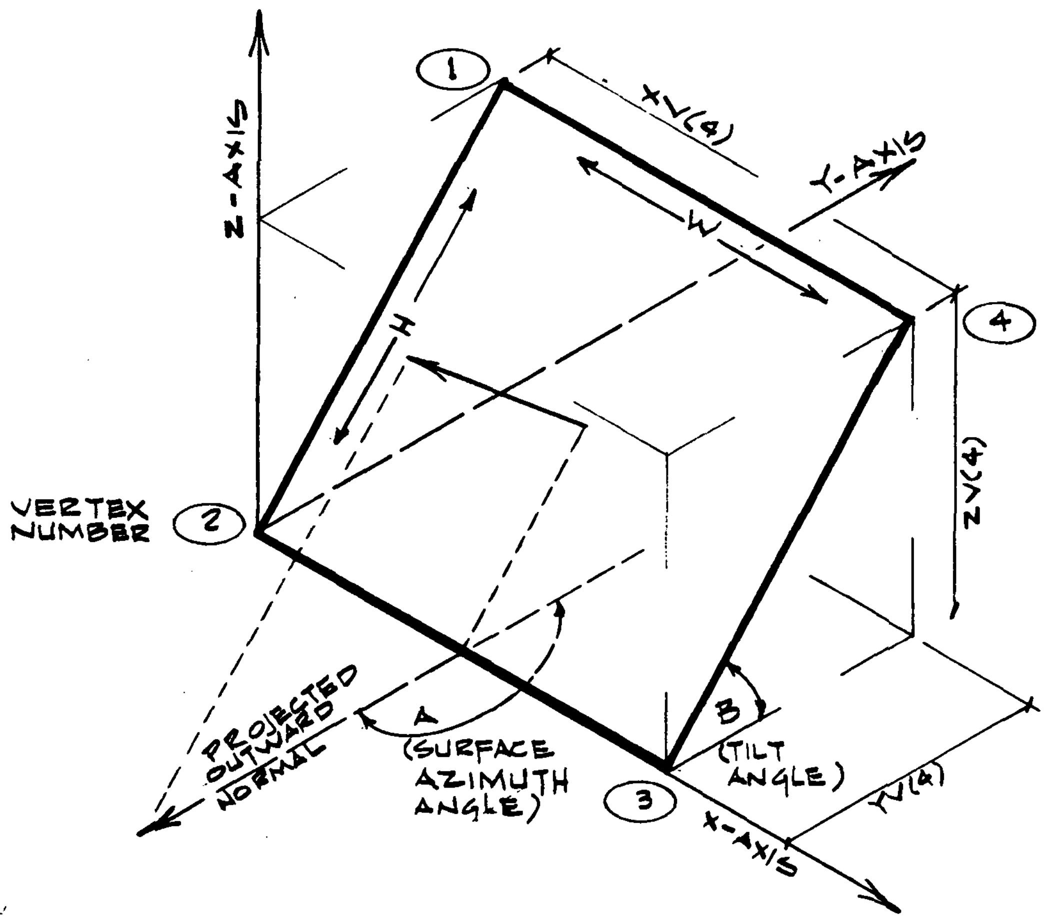


Figure 3.12 DEFINITION OF SURFACE ANGLES AND DIMENSIONS

RECAP1

A subroutine that echos beginning portion of input data, i.e., LC-1 through LC-10.

INPUT

STALAT	:	Station latitude, degrees
STALON	:	Station longitude, degrees
TZN	:	Time zone number
CNS	:	Summer clearness number
CNW	:	Winter clearness number
BAZ	:	Building azimuth angle, degrees
LCODE	:	Job processing code
CFMSF	:	Ventilation air rate, cfm/sq ft
FPRES	:	Estimated total fan pressure, inches of water
DTC	:	Cold air supply temperature, ^{o}F
DTH	:	Hot air supply temperature, ^{o}F
ALTUD	:	Building altitude, ft.
TDBS	:	Summer maximum DBT, ^{o}F
RANGS	:	Summer daily range of DBT, ^{o}F
TDPS	:	Summer dew point temperature, ^{o}F
WINDS	:	Summer wind speed, mph
TDBW	:	Winter minimum DBT, ^{o}F
RANGW	:	Winter daily range of DBT, ^{o}F
TDPW	:	Winter dew point temperature, ^{o}F
WINDW	:	Winter wind speed, mph
JAHR	:	Weather year
JMONTH	:	Starting month of analysis

LENGTH	:	Length of analysis, days
IXMAS	:	Length of Christmas period, days
TDB	:	Initial temperature of exterior surfaces, ^oF
KPRINT	:	Print code
KAGIT	:	Logical unit number for line printer

OUTPUT

A report similar to that shown in Figure 3.13.

RECAP2

A subroutine that echos surface geometric description input data.

INPUT

NV	:	Number of vertices contained in surface
XCORN	:	Coordinates of lower left-hand vertex, ft.
YCORN	:	
ZCORN	:	
HT	:	Height, ft.
WD	:	Width, ft.
AZIM	:	Azimuth angle, radians
TILT	:	Tilt angle, radians
X	:	Coordinates of all surface vertices, ft.
Y	:	
Z	:	
KAGIT	:	Logical unit number of line printer.

OUTPUT

Several lines of output similar to those indicated in Figure 3.14.

```
************************************
************************************
*****                          *****
*****   ECHO OF INPUT DATA     *****
*****   FOR LOAD PROGRAM       *****
*****                          *****
************************************
************************************


BASIC DATA                 37.00    76.30     5.00     0.98     0.98   325.00

PROCESSING DATA             1.00     0.13     2.00    52.00    55.00   100.00   120.00

DESIGN LOAD DATA
   ALTITUDE                15.00
   SUMMER DAY              91.00    16.00    73.00     8.00
   WINTER DAY              20.00     3.00    17.00    10.00

PRINT CODE                  1.00

NO. OF SCHEDULE TYPES       1.00
```

Figure 3.13 SAMPLE OUTPUT FROM RECAP1

```
DELAYED SURFACE NO. 11
     ABSORBTANCE, REFLECTANCE =                  0.70     0.10
     INDICES =                                   1.00     2.00     2.00     0.0      0.0      2.00     2.00
     X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT =   106.00    46.00     0.0     14.00    12.00     0.0     90.00

DELAYED SURFACE NO. 12
     ABSORBTANCE, REFLECTANCE =                  0.70     0.10
     INDICES =                                   1.00     2.00     2.00     0.0      0.0      2.00     2.00
     X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT =   106.00    46.00    14.00    14.00    12.00     0.0     90.00

DELAYED SURFACE NO. 13
     ABSORBTANCE, REFLECTANCE =                  0.70     0.10
     INDICES =                                   1.00     2.00     2.00     0.0      0.0      2.00     2.00
     X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT =    12.00    46.00     0.0     28.00    12.00     0.0     90.00

DELAYED SURFACE NO. 14
     ABSORBTANCE, REFLECTANCE =                  0.70     0.10
     INDICES =                                   8.00    10.00    10.00     2.00     0.0      2.00     2.00
     VERTEX COORDINATES =                        0.0     46.00     0.0
                                                 0.0     26.00     0.0
                                                 0.0     26.00    12.00
                                                 0.0     20.00    12.00
                                                 0.0     20.00     0.0
                                                 0.0      0.0      0.0
                                                 0.0      0.0     28.00
                                                 0.0     46.00    28.00

DELAYED SURFACE NO. 15
     ABSORBTANCE, REFLECTANCE =                  0.70     0.10
     INDICES =                                   1.00     2.00     2.00     0.0      0.0      2.00     2.00
     X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT =     0.0      0.0      0.0     28.00    12.00   180.00    90.00

DELAYED SURFACE NO. 16
     ABSORBTANCE, REFLECTANCE =                  0.50     0.10
     INDICES =                                   1.00     1.00     1.00     2.00     0.0      1.00     5.00
     X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT =     0.0     46.00    28.00    12.00    46.00   270.00     0.0

DELAYED SURFACE NO. 17
     ABSORBTANCE, REFLECTANCE =                  0.50     0.10
     INDICES =                                   1.00     1.00     1.00     2.00     0.0      1.00     5.00
     X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT =    12.00     0.0     28.00    23.00    94.00   180.00     0.0

DELAYED SURFACE NO. 18
     ABSORBTANCE, REFLECTANCE =                  0.50     0.10
     INDICES =                                   1.00     1.00     1.00     2.00     0.0      1.00     5.00
     X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT =   106.0r    46.00    28.00    23.00    94.00     0.0      0.0

THERE ARE  0 DELAYED SURFACE PICTORAL OUTPUTS DESIRED
```

Figure 3.14 SAMPLE OUTPUT FROM RECAP2

CALCULATION SEQUENCE

1. If NV = 1, go to calculation 2; otherwise go to calculation 3.

2. Echo input data for rectangular surface.

   a) Convert azimuth and tilt angle to degrees.

      AA = AZIM/0.01745

      BB = TILT/0.01745

   b) Print XCORN, YCORN, ZCORN, HT, WD, AA, and BB.

3. Echo input data for surface.

   a) Print column label.

   b) For each of NV surface vertices, print X, Y and Z coordinate.

REPRT1

A subroutine that prints a one-page report summarizing the name of building being studied, its location, name of analyst, project number and date.

INPUT

IDEN1	:	Facility name
IDEN2	:	Facility location
IDEN3	:	Analyst's name
IDEN4	:	Project number
IDEN5	:	Date
KODE	:	Print code indicating if writing on output computer tape is desired
KAGIT	:	Logical unit number for line printer.

OUTPUT

A one-page report similar to that shown in Figures 3.15 and 3.16.

```
*********************************************************************
*                                                                   *
*                                                                   *
*                                                                   *
*                    DESIGN LOAD ANALYSIS FOR                       *
*                                                                   *
*                                                                   *
*                   LRC SYSTEMS ENGINEERING                         *
*                                                                   *
*                                                                   *
*                          BUILDING                                 *
*                                                                   *
*                                                                   *
*                      HAMPTON, VIRGINIA                            *
*                                                                   *
*                                                                   *
*  ENGINEER    - R.JENSEN                                           *
*  PROJECT NO - SZ, 4W, 3IN                                         *
*  DATE        - NOV 26, 1973                                       *
*                                                                   *
*                                                                   *
*********************************************************************
```

Figure 3.15 SAMPLE OUTPUT

```
********************************************************
*                                                      *
*        ANALYSIS OF ENERGY UTILIZATION FOR            *
*                                                      *
*              LRC SYSTEMS ENGINEERING                 *
*                                                      *
*                 HAMPTON, VIRGINIA                    *
*                                                      *
*                                                      *
*   ENGINEER    - R.JENSEN                             *
*   PROJECT NO  - SZ, 4W, 3IN                          *
*   DATE        - NOV 26, 1973                         *
*                                                      *
********************************************************
```

Figure 3.16 SAMPLE OUTPUT

CALCULATION SEQUENCE

1. Print upper part of border.

2. Print first line of report.

   a) If KODE = 1 or 2, print title "Design Load Analysis For".

   b) If KODE > 2, print title "Analysis of Energy Utilization of".

3. Print IDEN1, first calling subroutine CENTER to position title within center of 35 column field.

4. Print IDEN2, again calling subroutine CENTER to position title within center of 35 column field.

5. Print IDEN3, IDEN4 and IDEN5.

6. Print lower part of border.

7. If KODE ≤ 3, write IDEN3, IDEN4 and IDEN5 on output computer tape.

REPRT2

A subroutine that prints a one-page report summarizing calendar data and weather data required for hourly energy analysis run.

INPUT

JSTAT	:	Weather station number
JHOUR	:	Hour of day when analysis is to start
LMONTH	:	Month when analysis is to start
LDAY	:	Day of month when analysis is to start
JAHR	:	Year when analysis is to start
LENGTH	:	Length of analysis in days
ITDB	:	Initial estimate of exterior surface temperature, °F
KAGIT	:	Logical unit number for line printer

OUTPUT

A one-page report similar to that shown in Figure 3.17.

REPRT3

A subroutine that prints a one-page report summarizing data that is printed each hour on load output tape and on line printer, if desired.

INPUT

KAGIT	:	Logical unit number of line printer.

OUTPUT

A one-page report similar to that shown in Figure 3.18.

REPRT5

A subroutine that prints a one-page report summarizing the design weather data generated by subroutine DESDY.

INPUT

TDBS	:	Maximum summer dry-bulb temperature, ^{o}F
RANGS	:	Daily swing of dry-bulb temperature for summer design day, ^{o}F
TDPS	:	Average dew point temperature for summer design day, ^{o}F
WINDS	:	Wind speed for summer design day, mph
TDBW	:	Minimum winter dry-bulb temperature, ^{o}F
RANGW	:	Daily swing of dry-bulb temperature for winter design day, ^{o}F
TDPW	:	Average dew point temperature for winter design day, ^{o}F
WINDW	:	Wind speed for winter design day, mph
PATM	:	Atmospheric pressure, inches of mercury
IPRNT	:	Logical unit number for line printer.

```
*********************************************************************************
*                                                                               *
*                                                                               *
*                               IN THIS RUN                                     *
*                                                                               *
*                                                                               *
* - U. S. WEATHER BUREAU 1440 WEATHER TAPE OF STATION 14819 IS USED.            *
*                                                                               *
*                                                                               *
* - THE FIRST DATA OBTAINED FROM WEATHER TAPE IS FOR 0TH HOUR OF 01/01/1963.    *
*                                                                               *
*                                                                               *
* - THE LENGTH OF THIS STUDY IS 365 DAYS.                                       *
*                                                                               *
*                                                                               *
* - THE INITIAL OUTSIDE SURFACE TEMPERATURE IS 17 DEGREES FAHRENHEIT.           *
*                                                                               *
*                                                                               *
*********************************************************************************
```

Figure 3.17 SAMPLE OUTPUT

```
                     IN THE FOLLOWING PAGES


          THE FIRST LINE OF EACH PRINTED BLOCKS GIVES

TIME              - HOURS, STANDARD TIME FROM FIRST HOUR OF JANUARY
SUN INDEX         - IF EQUAL TO ONE SUN IS DOWN, IF EQUAL TO ZERO SUN IS UP
DRY-BULB TEMP.    - DEGREES FAHRENHEIT
WET-BULB TEMP.    - DEGREES FAHRENHEIT
WIND VELOCITY     - KNOTS
HUMIDITY RATIO    - LBS WATER PER LB DRY-AIR
PRESSURE          - INCHES OF MERCURY
ENTHALPY          - BTU PER LB DRY-AIR
DENSITY           - LBS DRY-AIR PER CUBIC FOOT
CLOUD COVER MODIFIER - FRACTION OF TOTAL SOLAR RADIATION INCIDENT
                       UPON A HORIZONTAL SURFACE

        THE FOLLOWING LINES OF EACH PRINTED BLOCKS GIVES

SPACE NUMBER
NUMBER OF IDENTICAL SPACES IN BUILDING
SPACE SENSIBLE LOAD - BTU PER HOUR
SPACE LATENT LOAD   - BTU PER HOUR
PLENUM RETURN AIR LIGHTING LOAD    - BTU PER HOUR
SPACE LIGHTING AND EQUIPMENT POWER - KILOWATTS

     NOTE - THE LOADS EXCLUDES OUTSIDE VENTILATION AIR LOADS
```

Figure 3.18 SAMPLE OUTPUT

OUTPUT

A one-page report similar to that shown in Figure 3.19.

CALCULATION SEQUENCE

1. Print top part of report summarizing user input data, i.e., TDBS, RANGS, TDPS, WINDS, TDBW, RANGW, TDPW and WINDW.

2. Calculate minimum dry-bulb temperature for summer design day.

   TMIN = TDBS - RANGS

3. For months March through November:

   a) Call subroutine DESDY to calculate the hourly design dry-bulb temperature, TDB, and wet-bulb temperature, TWB for the month.

   b) Print TDB and TWB.

4. Calculate maximum dry-bulb temperature for winter design day.

   TMAX = TDBW + RANGW

5. For month of December:

   a) Call subroutine DESDY to calculate the hourly design dry-bulb temperature, TDB, and wet-bulb temperature, TWB, for month.

   b. Print TDB and TWB.

REPRT6

A subroutine which prints one-page reports for each space and building summarizing peak load data results.

INPUT

IPRNT	:	Logical unit number for line printer
FAC	:	Facility name
CITY	:	Facility location
PROJ	:	Project number
ENGR	:	Engineer name

SUMMARY BY MONTH OF DESIGN DAY WEATHER GENERATED FOR USE IN HEATING AND COOLING CALCULATIONS

SUMMER DAY INPUT PARAMETERS
1. MONTH ASSUMED TO BE JULY OR AUGUST
2. MAXIMUM DRY-BULB TEMPERATURE = 94.
3. DAILY SWING OF DRY-BULB TEMPERATURE = 18.
4. AVERAGE DEW-POINT TEMPERATURE = 72.
5. AVERAGE WIND SPEED = 5.

WINTER DAY INPUT PARAMETERS
1. MONTH ASSUMED TO BE DECEMBER
2. MINIMUM DRY-BULB TEMPERATURE = 20.
3. DAILY SWING OF DRY-BULB TEMPERATURE = 3.
4. AVERAGE DEW-POINT TEMPERATURE = 5.
5. AVERAGE WIND SPEED = 7.

		A.M. 1	2	3	4	5	6	7	8	9	10	11	12	P.M. 1	2	3	4	5	6	7	8	9	10	11	12
MARCH	DBT	62.	61.	60.	60.	60.	62.	64.	66.	68.	70.	72.	75.	77.	79.	80.	79.	78.	77.	75.	73.	71.	69.	66.	64.
	WBT	59.	58.	57.	57.	57.	59.	61.	63.	65.	67.	68.	69.	70.	70.	70.	70.	70.	70.	69.	68.	68.	66.	63.	61.
APRIL	DBT	67.	66.	65.	65.	65.	67.	69.	71.	73.	75.	77.	80.	82.	84.	85.	84.	83.	82.	80.	78.	76.	74.	71.	69.
	WBT	64.	63.	62.	62.	62.	64.	66.	68.	69.	70.	70.	71.	72.	72.	72.	72.	72.	72.	71.	70.	70.	69.	68.	66.
MAY	DBT	72.	71.	70.	70.	70.	72.	74.	76.	78.	80.	82.	85.	87.	89.	90.	89.	88.	87.	85.	83.	81.	79.	76.	74.
	WBT	69.	68.	67.	67.	67.	69.	71.	72.	72.	73.	73.	74.	75.	75.	75.	75.	75.	75.	74.	74.	73.	73.	72.	71.
JUNE	DBT	75.	74.	73.	73.	73.	75.	77.	79.	81.	83.	85.	88.	90.	92.	93.	92.	91.	90.	88.	86.	84.	82.	79.	77.
	WBT	72.	71.	70.	70.	70.	72.	73.	74.	74.	75.	75.	76.	77.	77.	77.	77.	77.	77.	76.	76.	75.	75.	74.	73.
JULY	DBT	76.	75.	74.	74.	74.	76.	78.	80.	82.	84.	86.	89.	91.	93.	94.	93.	92.	91.	89.	87.	85.	83.	80.	78.
	WBT	73.	72.	71.	71.	71.	73.	73.	74.	74.	75.	75.	76.	77.	77.	77.	77.	77.	77.	76.	76.	75.	75.	74.	73.
AUGUST	DBT	76.	75.	74.	74.	74.	76.	78.	80.	82.	84.	86.	89.	91.	93.	94.	93.	92.	91.	89.	87.	85.	83.	80.	78.
	WBT	73.	72.	71.	71.	71.	73.	73.	74.	74.	75.	75.	76.	77.	77.	77.	77.	77.	77.	76.	76.	75.	75.	74.	73.
SEPTEMBER	DBT	73.	72.	71.	71.	71.	73.	75.	77.	79.	81.	83.	86.	88.	90.	91.	90.	89.	88.	86.	84.	82.	80.	77.	75.
	WBT	70.	69.	68.	68.	68.	70.	71.	72.	72.	73.	73.	74.	75.	75.	75.	75.	75.	75.	74.	74.	73.	72.	72.	71.
OCTOBER	DBT	69.	68.	67.	67.	67.	69.	71.	73.	75.	77.	79.	82.	84.	86.	87.	86.	85.	84.	82.	80.	78.	76.	73.	71.
	WBT	66.	65.	64.	64.	64.	66.	68.	70.	70.	71.	71.	72.	73.	73.	73.	73.	73.	73.	72.	72.	71.	70.	70.	68.
NOVEMBER	DBT	61.	60.	59.	59.	59.	61.	63.	65.	67.	69.	71.	74.	76.	78.	79.	78.	77.	76.	74.	72.	70.	68.	65.	63.
	WBT	58.	57.	56.	56.	56.	58.	60.	62.	64.	66.	67.	68.	69.	69.	69.	69.	69.	69.	68.	67.	67.	65.	62.	60.
DECEMBER	DBT	21.	20.	20.	20.	20.	20.	20.	21.	21.	22.	22.	22.	23.	23.	23.	23.	23.	23.	22.	22.	22.	22.	21.	21.
	WBT	17.	17.	17.	16.	16.	16.	17.	17.	17.	17.	18.	18.	18.	18.	19.	18.	18.	18.	18.	18.	18.	17.	17.	17.

NOTE - TEMPERATURE CORRECTION FACTORS BASED ON
CARRIER SYSTEM DESIGN MANUAL PGS. 1-18,19.
WBT IS SET AT LEAST 3 DEG. F BELOW DBT.

Figure 3.19 SAMPLE OUTPUT

DATE	:	Date
NSPAC	:	Number of spaces in building
AREA	:	Space floor areas, sq ft
VOL	:	Space volumes, cu ft
TSPAC	:	Space set point temperature, ^{o}F
DENS	:	Outside air density for summer peak load hour, lbs/cu ft
DENW	:	Outside air density for winter peak load hour, lbs/cu ft
QSUM(I,N)	:	Components of space peak cooling load, Btu/hr, where N is the space number and I takes on the following definition:

I = 1	delayed walls
2	window conduction
3	Window solar
4	quick walls
5	internal walls
6	underground walls
7	underground floors
8	people sensible
9	people latent
10	lighting
11	equipment sensible
12	infiltration sensible
13	infiltration latent
14	plenum return air
15	equipment latent
16	month
17	ambient DBT
18	ambient WBT
19	ambient humidity ratio
20	hour of day
21	quick ceilings
22	delayed ceilings
23	day of month

QWIN(I,N)	:	Components of space peak heating load, Btu/hr; I and N have same definition as for QSUM.
T1(I)	:	Components of building peak cooling load, Btu/hr; I has same definition as for QSUM.
T2(I)	:	Components of building peak heating load, Btu/hr; I has same definition as for QSUM.

CFMSF : Ventilation air rate, cfm/sq ft

FPRES : Estimated total fan pressure, inches of water

MULT : Space repetition factor

OUTPUT

A one-page report for each space similar to that shown in Figure 3.20. Also a one-page report for the building similar to that shown in Figure 3.21. Finally, a one-page report summarizing heating and cooling capacities required for each space (see Figure 3.22).

CALCULATION SEQUENCE

1. For each space, N, print following:

   a) Identification information, i.e., page header, page number, FAC, CITY, space number, MULT, AREA and VOL.

   b) Time and conditions for summer peak load, i.e., dry-bulb temperature, wet-bulb temperature, hour of day, month, and day of month.

   c) Time and conditions for winter peak load, i.e., dry-bulb temperature, wet-bulb temperature, hour of day, month, and day of month.

   d) Components of summer and winter peak load in order indicated in Figure 3.20.

   e) Total summer sensible, summer latent and winter sensible load which are simply the summations of their respective columns.

   f) Total space cooling expressed in Btu/hr, which is simply the summation of the total summer sensible and latent loads.

   g) Total space heating expressed in Btu/hr, the total winter sensible load.

   h) The supply air cfm required to meet the total space sensible cooling load for two values of required zone supply air temperatures:

$$CFM1 = TOT1/(14.4*DENS*(TSPAC(N) - DTC(1))$$

```
DESIGN LOAD CALCULATION RESULTS FOR                                                          PAGE   4
          LRC SYSTEMS ENGINEERING
          HAMPTON, VIRGINIA

          SPACE NO.                                          4

          SPACE REPETITION FACTOR                            1

          AREA (SQ.FT.)                                    500.

          VOLUME (CU.FT.)                                 4700.

          SUMMER COOLING PEAK
               DBT/WBT/HR OF DAY/DATE     98 /  75 / 18 / JULY  1

          WINTER HEATING PEAK
               DBT/WBT/HR OF DAY/DATE    -14 / -14 / 21 / JAN. 23

                                         ***** SUMMER LOAD *****           WINTER
                                          SENSIBLE       LATENT             LOAD
                                           (BTUH)        (BTUH)            (BTUH)
               WALLS                       5800.           0.             -35586.
               CEILINGS                    1709.           0.              -3570.
               WINDOW CONDUCTANCE         20660.           0.             -96917.
               WINDOW SOLAR               20270.           0.                  0.
               QUICK SURFACES                 0.           0.                  0.
               INTERNAL SURFACES              0.           0.                  0.
               UNDERGROUND WALLS              0.           0.                  0.
               UNDERGROUND FLOORS           185.           0.              -1690.
               OCCUPANTS                    111.           0.                 17.
               LIGHT TO SPACE              5529.           0.               1474.
               EQUIPMENT TO SPACE             0.           0.                  0.
               INFILTRATION                   0.           0.                  0.
                                         ---------     ---------          ---------
               TOTAL                      54264.           0.            -136271.

          TOTAL SPACE COOLING          54264. BTUH
          TOTAL SPACE HEATING        -136271. BTUH

          SUPPLY AIR AT  50 F AT DIFFUSER          2223. CFM          4.45 CFM/SQ.FT.
          SUPPLY AIR AT  55 F AT DIFFUSER          2779. CFM          5.56 CFM/SQ.FT.
          SUPPLY AIR AT 120 F AT DIFFUSER          2376. CFM          4.75 CFM/SQ.FT.
          SUPPLY AIR AT 140 F AT DIFFUSER          1645. CFM          3.29 CFM/SQ.FT.
```

Figure 3.20 SAMPLE OUTPUT

```
BUILDING LOAD SUMMARY FOR
        LRC SYSTEMS ENGINEERING
        HAMPTON, VIRGINIA

        SPACE NOS.                                1  THRU   6

        TOTAL FLOOR AREA (SQ.FT.)                      53000.

        TOTAL VOLUME (CU.FT.)                         488800.

        SUMMER COOLING PEAK
             DBT/WBT/HR OF DAY/DATE      93 /  81 / 17 / AUG.  2

        WINTER HEATING PEAK
             DBT/WBT/HR OF DAY/DATE     -15 / -15 /  6 / JAN. 23

                                       ***** SUMMER LOAD *****          WINTER
                                        SENSIBLE       LATENT            LOAD
                                         (BTUH)        (BTUH)           (BTUH)
             WALLS                        4536.            0.         -109526.
             CEILINGS                   108050.            0.         -337488.
             WINDOW CONDUCTANCE          54813.            0.         -344317.
             WINDOW SOLAR                38064.            0.               0.
             QUICK SURFACES                  0.            0.               0.
             INTERNAL SURFACES            7280.            0.            7280.
             UNDERGROUND WALLS               0.            0.               0.
             UNDERGROUND FLOORS          13738.            0.         -178599.
             OCCUPANTS                   85080.        67716.              75.
             LIGHT TO SPACE             579218.            0.           16470.
             EQUIPMENT TO SPACE              0.            0.               0.
             INFILTRATION                    0.            0.               0.
                                       ---------     ---------        ---------
             SUBTOTAL                   890779.        67716.         -946104.
             RETURN AIR                 103640.            0.            2251.
             FAN HEAT                    68029.            0.           68029.
             VENTILATION AIR            111764.       316788.         -729386.
                                       ---------     ---------        ---------
             TOTAL                     1174211.       384504.        -1605210.

        TOTAL BUILDING COOLING       1558714. BTUH         129.9 TONS
        TOTAL BUILDING HEATING      -1605210. BTUH       -1605.2 MBH

                                           ******* VARIABLE VOLUME SYSTEM *******        ******* CONSTANT VOLUME SYSTEM *******
        SUPPLY AIR AT  50 F AT DIFFUSER      36497. CFM    0.69 CFM/SQ.FT. MAX.          42370. CFM    0.80 CFM/SQ.FT. CONST.
        SUPPLY AIR AT  55 F AT DIFFUSER      45621. CFM    0.86 CFM/SQ.FT. MAX.          52962. CFM    1.00 CFM/SQ.FT. CONST.
        SUPPLY AIR AT 120 F AT DIFFUSER      16500. CFM    0.31 CFM/SQ.FT. MAX.          17608. CFM    0.33 CFM/SQ.FT. CONST.
        SUPPLY AIR AT 140 F AT DIFFUSER      11423. CFM    0.22 CFM/SQ.FT. MAX.          12190. CFM    0.23 CFM/SQ.FT. CONST.
```

Figure 3.21 SAMPLE OUTPUT

SUMMARY OF RECOMMENDED HEATING AND COOLING EXTRACTION RATES TO BE USED AS INPUT TO VARIABLE TEMPERATURE PROGRAM

SPACE NO.	HEATING EXTRACTION RATE (BTU/HR)	COOLING EXTRACTION RATE (BTU/HR)
1	-500389.	861499.
2	-143732.	45320.
3	-115744.	35014.
4	-136271.	54264.
5	-113510.	38009.
6	0.	0.

Figure 3.22 SAMPLE OUTPUT

CFM2 = TOT1/(14.4*DENS*(TSPAC(N) - DTC(2))

where TOT1 is total summer sensible load.

i) The supply air cfm required to meet the total space sensible heating load for two values of required zone supply air temperatures:

CFM3 = TOT3/(14.4*DENW*(DTH(1) - TSPAC(N))

CFM4 = TOT3/(14.4*DENW*(DTH(2) - TSPAC(N))

where TOT3 is total winter sensible load.

j) The supply cfm required per square foot of floor area.

SQFT1 = CFM1/AREA(N)

SQFT2 = CFM2/AREA(N)

SQFT3 = CFM3/AREA(N)

SQFT4 = CFM4/AREA(N)

2. Calculate following summations for building.

a) Total floor area

TAREA = Σ(AREA(N)*MULT(N)), for N=1 to NSPAC

b) Total volume

TVOL = Σ(VOL(N)*MULT(N)), for N=1 to NSPAC

c) Total cooling cfm at both temperature conditions

TCFM1 = Σ(CFM1*MULT(N)), for N=1 to NSPAC

TCFM2 = Σ(CFM2*MULT(N)), for N=1 to NSPAC

d) Total heating cfm at both temperature conditions

TCFM3 = Σ(CFM3*MULT(N)), for N=1 to NSPAC

TCFM4 = Σ(CFM4*MULT(N)), for N=1 to NSPAC

3. For the building peak load conditions, print the following:

a) Identification information, i.e., page header, page number, FAC, CITY, number of spaces in building, TAREA and TVOL.

b) Time and conditions for summer peak load, i.e., dry-bulb temperature, wet-bulb temperature, hour of day, month, and day of month.

c) Time and conditions for winter peak load, i.e., dry-bulb temperature, wet-bulb temperature, hour of day, month, and day of month.

d) Components of summer and winter peak load in order indicated in Figure 3.21.

e) Subtotals for summer sensible (SUMT1), summer latent (SUMT3) and winter sensible (SUMT2) loads which are simply the summations of their respective columns.

f) Return air load created by light heat which is picked up by return air as it passes through a ventilated light fixture.

g) Fan heat load

$$QFAN = 0.4014 * TCFM1 * FPRES$$

h) Ventilation air load for summer peak cooling hour

$$QSOAS = 14.4 * DENS * CFMSF * TAREA * (T1(17) - 75.0)$$

$$QLOA = 63000. * DENS * CFMSF * TAREA * (T1(19) - 0.0093)$$

where it is assumed that 75°F and 50% R.H. are the average conditions within the building during the peak cooling hour.

i) Ventilation air load for winter peak heating hour

$$QSOAW = 14.4 * DENW * CFMSF * TAREA * (T2(17) - 75.0)$$

j) Total loads for summer sensible, summer latent and winter sensible loads which are simply the summations of their respective columns.

k) Total building cooling load expressed in Btu/hr and tons, which is the summation of the total summer sensible and latent loads.

l) Total building heating load expressed in Btu/hr and 1000's Btu, the total winter sensible load.

m) The supply air cfm and cfm per square foot required for a variable volume system to meet the building peak sensible heating and cooling loads for two values each of required supply air temperatures.

- Cooling

TCFM5 = SUMT1/(14.4*DENS*(75.0 - DTC(1))

TCFM6 = SUMT1/(14.4*DENS*(75.0 - DTC(2))

TSQFT5 = TCFM5/TAREA

TSQFT6 = TCFM6/TAREA

- Heating

TCFM7 = -SUMT2/(14.4*DENW*(DTH(1) - 75.0))

TCFM8 = -SUMT2/(14.4*DENW*(DTH(2) - 75.0))

TSQFT7 = TCFM7/TAREA

TSQFT8 = TCFM8/TAREA

n) The supply air cfm and cfm per square foot required for a constant volume system to meet the building peak sensible heating and cooling loads for two values each of required supply air temperatures.

- Cooling

TCFM1 = see 2c.

TCFM2 = see 2c.

TSQFT1 = TCFM1/TAREA

TSQFT2 = TCFM2/TAREA

- Heating

TCFM3 = see 2d.

TCFM4 = see 2d.

TSQFT3 = TCFM3/TAREA

TSQFT4 = TCFM4/TAREA

4. Print a table (Figure 3.22) summarizing the maximum heating and cooling capacity required for each space.

RMRSS

A subroutine that sets the weighting factors required to delay the heat transfer between the space and the heating-cooling equipment.

INPUT

IL : Type of lighting fixture (see Figure 3.23)

- = 1 Fluorescent fixture recessed into suspended ceiling, ceiling plenum not vented.
- = 2 Fluorescent fixture recessed into suspended ceiling, return air through ceiling plenum.
- = 3 Fluorescent fixture recessed into suspended ceiling, supply and return through ceiling plenum.
- = 4 Incandescent lights exposed in the room air.

W : Weight of floor, lbs/sq ft

PERCT : Percent of light heat that goes directly into space (obtain from manufacturer's data)

OUTPUT

RMRIS1 :
RMRISC :
RATRIS : Weighting factors for relating light heat entering space to room cooling load.

RMRPS1 :
RMRPSC :
RATRPS : Weighting factors relating heat released into plenum by lights to return air heat pick-up.

RMRX1 :
RMRXC :
RATRX : Weighting factors relating heat gain through walls and roofs to room cooling load.

RMRG1 :
RMRGC :
RATRG : Weighting factors relating solar heat gain through glass to room cooling load.

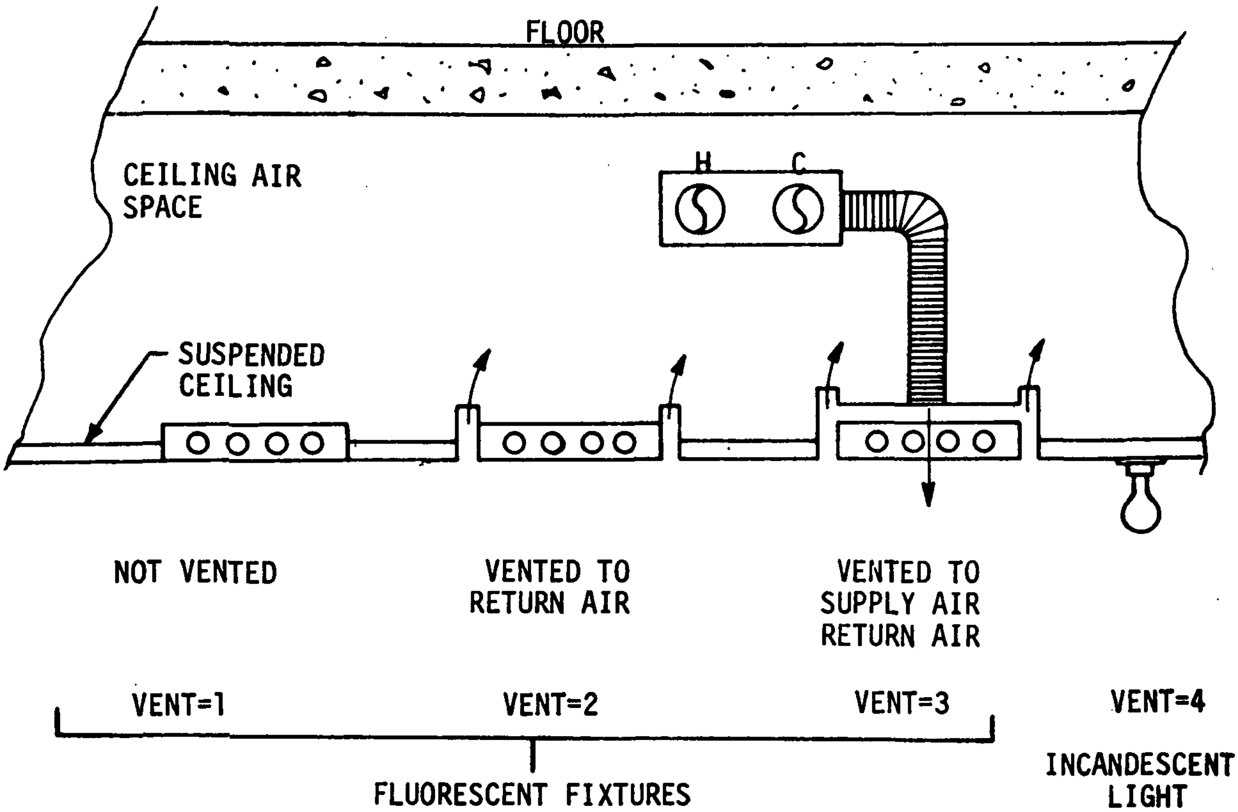


Figure 3.23 TYPES OF LIGHT FIXTURES

CALCULATION SEQUENCE

1. Set of the type of construction on basis of weight of floor.

   If $W \leq 50$, set IW = 1 (Light)

   If $50 < W \leq 100$, set IW = 2 (Medium)

   If $100 < W$, set IW = 3 (Heavy)

2. Set value of weighting factors for handling solar heat gain through glass.

Table 3.5

WEIGHTING FACTOR SYMBOL	TYPE OF CONSTRUCTION		
	LIGHT	MEDIUM	HEAVY
RMRG1	0.224	0.197	0.187
RMRGC	-0.044	-0.067	-0.097
RATRG	0.82	0.87	0.91

Source: "Procedure For Determining Heating and Cooling Loads For Computerized Energy Calculations", ASHRAE, 1971 Revised Edition.

3. Set value of weighting factors for handling wall and surface heat gain.

Table 3.6

WEIGHTING FACTOR SYMBOL	TYPE OF CONSTRUCTION		
	LIGHT	MEDIUM	HEAVY
RMRX1	0.703	0.681	0.676
RMRXC	-0.523	-0.551	-0.586
RATRX	0.82	0.87	0.91

Source: "Procedure of Determining Heating and Cooling Loads For Computerized Energy Calculations", ASHRAE, 1971 Revised Edition.

4. If IL = 1 or 4, set PERCT = 100.0; otherwise leave user defined as is.

5. Set value of weighting factors required for handling space heat gain from lights. Obtain values of RMRIS1, RMRISC and RATRIS from Table 3.7, and then modify the first two for percentage of light heat that goes into space as follows:

   RMRIS1 = RMRIS1 * (PERCT/100.)

   RMRISC = RMRISC * (PERCT/100.)

6. Check for ceiling plenum and set weighting factors accordingly for handling heat added to plenum as a function of lighting load.

   a) If IL = 1 or 4, there is no return plenum, therefore set

      RMRPS1 = 0.0
      RMRPSC = 0.0
      RATRPS = 0.0

   b) If IL = 2 or 3, there is a return plenum, therefore obtain values of RMRIS1, RMRISC and RATRIS from Table 3.7 and then perform following

      RMRPS1 = RMRIS1 * (100. - PERCT)/100.

      RMRPSC = RMRISC * (100. - PERCT)/100.

      RATRPS = RATRIS

Table 3.7

WEIGHTING FACTOR SYMBOL	TYPE OF CONSTRUCTION		
	LIGHT	MEDIUM	HEAVY
Type 1 - Fluorescent fixture recessed into suspended ceiling, ceiling plenum not vented.			
RMRIS1	0.53	0.53	0.53
RMRISC	-0.35	-0.40	-0.44
RATRIS	0.82	0.87	0.91
Type 2 - Florescent fixture recessed into suspended ceiling, return air through ceiling plenum.			
RMRIS1	0.59	0.59	0.59
RMRISC	-0.41	-0.46	-0.50
RATRIS	0.42	0.87	0.91
Type 3 - Fluorescent fixture recessed into suspended ceiling, supply and return air through fixtures.			
RMRIS1	0.87	0.87	0.87
RMRISC	-0.69	-0.74	-0.78
RATRIS	0.82	0.87	0.91
Type 4 - Incandescent lights exposed in the room air			
RMRIS1	0.50	0.50	0.50
RMRISC	-0.32	-0.37	-0.41
RATRIS	0.82	0.87	0.91

Source: "Procedure For Determining Heating and Cooling Loads for Computerized Energy Calculations, ASHRAE, 1971, Revised Edition.

SCHDUL

A subroutine for reading a generating operating schedule to be used for people and lights and equipment.

INPUT

CFKSCH	:	People schedule requirement, no = 0, yes = 1
CLTSCH	:	Lighting schedule requirement, no = 0, yes = 1
FISCH(J,K)	:	Coded schedule number, where J = 1, people schedule 2, light schedule 3, equipment schedule K = 1, Sunday 2, Weekday 3, Saturday 4, Holiday 5, Special period at year end
I	:	Space schedule type number
KARD	:	Logical unit number for card input
KAGIT	:	Logical unit number for line printer
KKMAX	:	Number of types of daily schedules used

OUTPUT

SCHFLK(I,J,K)	:	Hourly people schedule where I = 1 to 3, space schedule type number J = 1 to 9, type of day (Sunday through Saturday, Holiday and Special) K = 1 to 24, Hour of day
SCHLIT(I,J,K)	:	Hourly lighting schedule where I, J and K have same definitions as above.
SCHEQ(I,J,K)	:	Hourly equipment schedule where I, J and K have same definitions as above.

CALCULATION SEQUENCE

1. Fill in matrix for standard non-standard schedules; for each of people, lights and equipment performance following:

   a) For each type of day, if FISCH $\leq$ 10, standard schedule (Figure 3.24) is desired, therefore enter standard 24 hour schedule into appropriate matrix, i.e., SCHFLK, SCHLIT, or SCHEQ.

   b) For each type of day, FISCH > 10, a user defined schedule is desired; therefore, if the non-standard schedule has not been previously defined, read it from card input and enter it into appropriate matrix, i.e., SCHFLK, SCHLIT or SCHEQ.

2. Echo schedules.

SCHED

A subroutine which assigns the proper lighting, people and equipment schedules to spaces and corrects time for Daylight Saving time.

INPUT

IDST : Daylight Saving Time indicator = $\begin{cases} 0 & \text{Standard Time} \\ 1 & \text{Daylight Saving Time} \end{cases}$

ITIME : Hour of day, 1 to 24

IDOW : Day of Week, 1 to 7

IFEAST : Holiday indicator = $\begin{cases} 0 & \text{No Holiday} \\ 1 & \text{Holiday} \end{cases}$

JC : Christmas period indicator = $\begin{cases} 0 & \text{non Christmas period} \\ 1 & \text{Christmas period} \end{cases}$

OUTPUT

J : Type of day, 1 to 9

K : Corrected time, 1 to 24

CALCULATION SEQUENCE

1. a) If JC = 1, J = 9

   b) If JC = 0 and IFEAST = 1, J = 8

   c) If JC = 0 and IFEAST = 0, J = IDOW

2. a) If IDST = 0, K = ITIME

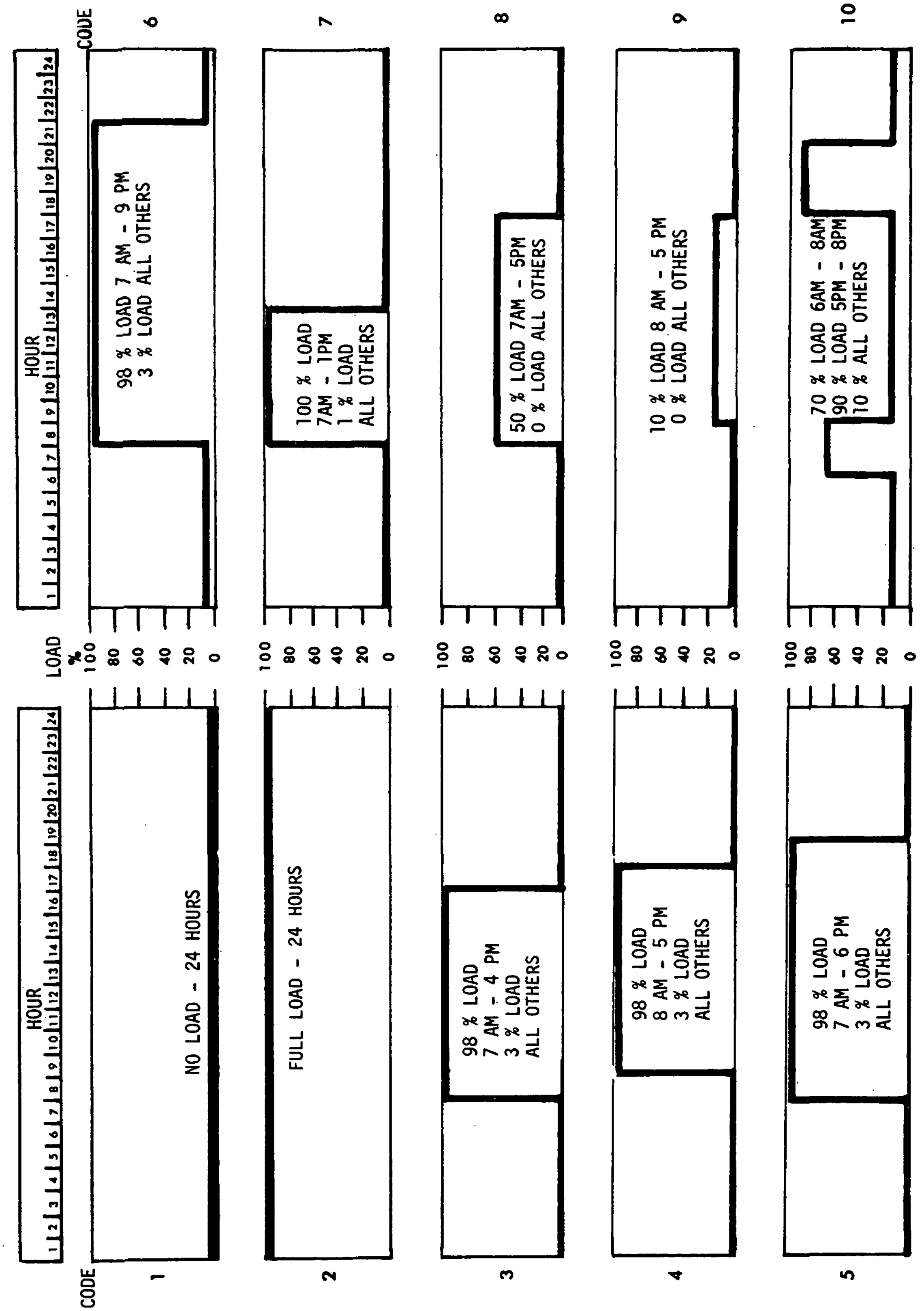


Figure 3.24 STANDARD CODED SCHEDULES

b) If IDST = 1 and ITIME = 1, K = 24

c) If IDST = 1, and ITIME > 1, K = ITIME

SEARCH

A subroutine which indicates a shadow pictorial output is desired for the present hour and surface.

INPUT

N	:	Number of pictorial outputs desired
NA	:	Month for which pictorial outputs are desired
NB	:	Hour for which pictorial outputs are desired
NC	:	Surface index for which pictorial outputs are desired
IA	:	Present month number
IB	:	Present hour number
IC	:	Present surface index number
J	:	Pictorial output indicator $\left\{\begin{array}{l} 0 = \text{no} \\ 1 = \text{yes} \end{array}\right.$

CALCULATION SEQUENCE

For I = 1 to N

1. If NA(I) = IA and NB(I) = IB and NC(I) = IC, then J = 1.

2. If NA(I) not equal to IA or
   NB(I) not equal to IB or
   NC(I) not equal to IC,
   Then J = 0

SETBAK

A sub-routine which calculates coordinates of vertices for three added shading surfaces. Window must be a rectangle. This routine used only in windows.

INPUT

XX	:	
YY	:	Coordinates of upper left hand
ZZ	:	window vertex
HH	:	Height of window, feet
WW	:	Width of surface, feet
A	:	Azimuth angle of surface, degrees
B	:	Tilt angle, degree
SBK	:	Amount of set back, inches
DB	:	Border, inches

OUTPUT

XV(I,K)	:	
YV(I,K)	:	Coordinates of four vertices of three surfaces
ZV(I,K)	:	

CALCULATION SEQUENCE

1. Let S = SBK/12.0
   D = BD/12
   CA = COS (A)
   CB = COS (B)
   SA = SIN (A)
   SB = SIN (B)
   H = HH+D
   W = WW+D+D

2. VERTEX 1 of the first shading surface

   XV (1,1) = XX+D*CA
   YV (1,1) = YY-D*SA
   ZV (1,1) = ZZ

   VERTEX 2 of the first shading surface

   XV (1,2) = XX+D*CA+S*SA
   YV (1,2) = YY-D*SA+S*CA
   ZV (1,2) = ZZ

   VERTEX 3 of the first shading surface
   (also vertice 2 of the second shading surface)

   XV(1,3) = XX+S*SA-H*CB*SA
   YV(1,3) = YY-D*SA+S*CA-H*CB*CA
   ZV(1,3) = ZZ+H*SB

VERTEX 4 of the first shading surface (also vertice 1 of the second shading surface)

```
XV(1,4)   =   XX+D*CA-H*CB*SA
YV(1,4)   =   YY-H*CB*CA
ZV(1,4)   =   ZZ+H*SB
```

--and so on - -

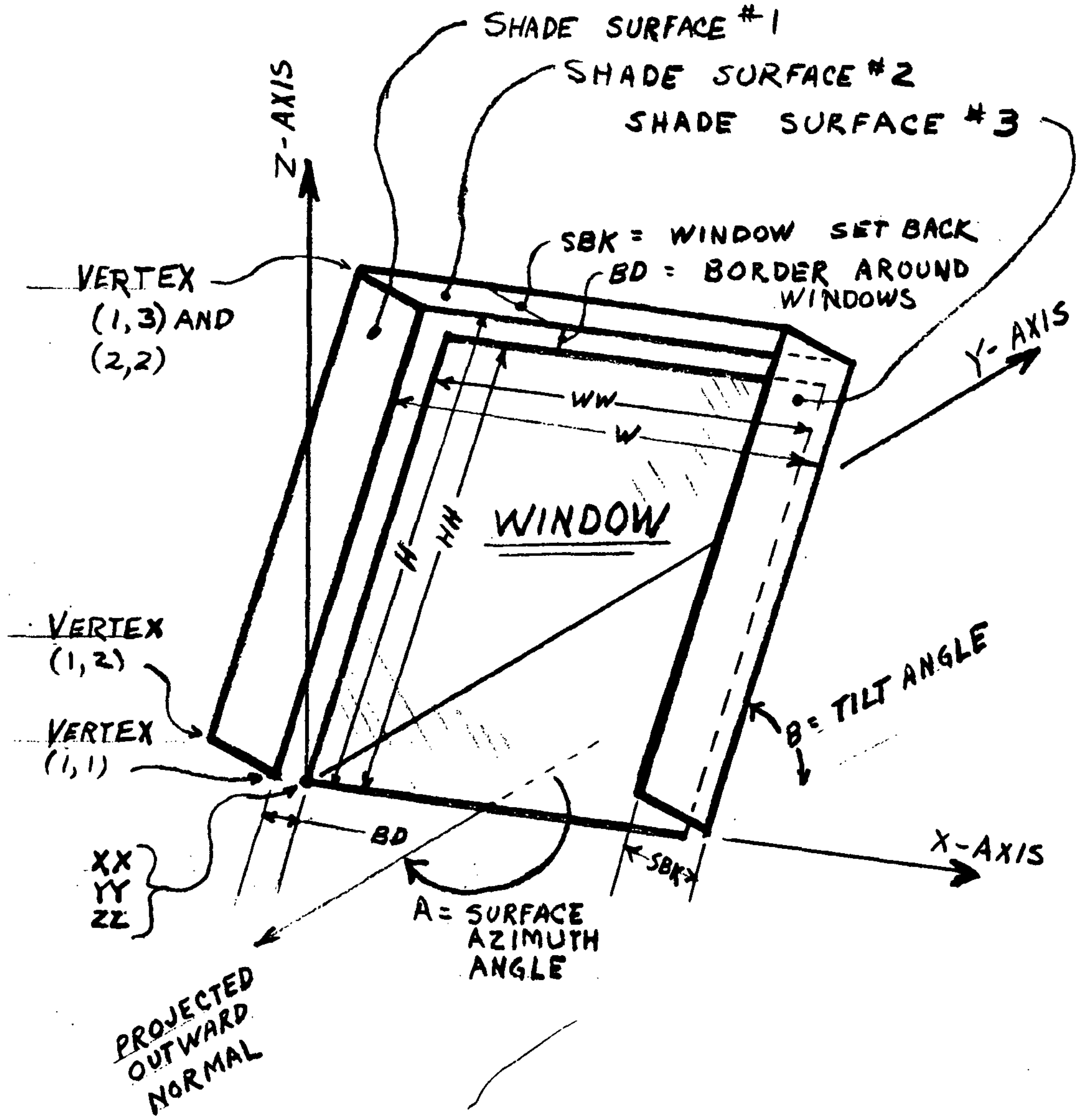


FIGURE 3.24A
DEFINITION OF SURFACE DIMENSIONS

SHADOW

A major portion of the air conditioning load on a building comes from solar radiation. To improve the accuracy of load assessment and thus permit a less conservative, and therefore less expensive, cooling system design, the air conditioning engineer must know how much of a building is shaded and how much lies exposed to the sun's rays.

Development of the digital computer has now made shading amenable to rational solution. In the program, a newly-developed technique is utilized. This technique attacks the general problem and treats complicated shapes with as much ease as it deals with simpler configurations The basis of the technique is the representation of all architectural forms as a series of plane polygons. Even curved surfaces can be so represented with great accuracy. 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 computer program is a pictorial display of the shadows and the surface upon which they are cast. Shadow areas are also printed as floating point numbers. Where shadows are cast by perforated structures, e.g., trees, the pictorial output shows the shadow as a mottled pattern.

INPUT

NVERTF	:	Number of vertices on receiving Polygon (R.P.)
XVERTF	:	x - coordinates of receiving Polygon (R.P.)
YVERTF	:	y - coordinates of receiving Polygon (R.P.)
ZVERTF	:	z - coordinates of receiving Polygon (R.P.)
NUXDIV	:	Number of x - divisions
NUYDIV	:	Number of y - divisions
NPØLY	:	Number of shading Polygons (S.P.)
NVERT	:	Number of vertices of each shading Polygon (S.P.)
PERM	:	Permeability of each shading Polygon (S.P.)
XVERT	:	x - coordinates of shading Polygon vertices (S.P.)
YVERT	:	y - coordinates of shading Polygon vertices (S.P.)
ZVERT	:	z - coordinates of shading Polygon vertices (S.P.)

NPOLYD : Number of shading Polygons deleted

IDLETE : Index number of deleted Polygons

NPOLYA : Number of added Polygons

NVERTA : Number of vertices of added Polygons

PERMA : Permeability of added S.P.'s

XVERTA : x-coordinates of added Polygons

YVERTA : y - coordinates of added Polygons

ZVERTA : z-coordinates of added Polygons

RAYCOS : Direction cosines of solar ray

ARECI : Area of receiving Polygon

LOOK : Picture? $\begin{cases} 0 = \text{No picture} \\ 1 = \text{Picture} \end{cases}$

OUTPUT

ASHADE : Shaded area of receiving Polygon

CALCULATION SEQUENCE

1. Coordinate Transformation

Designate the polygons which cast shadows as shading polygons (S.P.) and those upon which shadows are cast as receiving polygons (R.P.). The vertex coordinates of each R.P., 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 R.P. The first three vertices V_1, V_2, V_3, of the R.P. 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 $$\vec{x}_0 = \vec{x}_2 + \gamma(\vec{x}_3-\vec{x}_2)$$

γ , A Scalar $= (\vec{x}_1-\vec{x}_2) \bullet (\vec{x}_3-\vec{x}_2)/(\vec{x}_3-\vec{x}_2) \bullet (\vec{x}_3-\vec{x}_2)$

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

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

3rd $\vec{row}$ of A = 1st $\vec{row}$ of a $\times$ 2nd $\vec{row}$ of A

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

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

2. Clipping Transformation

Any part of an S.P. whose z' is negative cannot cast a shadow on the R.P. These "submerged" portions of the S.P.'s must be clipped off, prior to projection, lest they project "false" shadows (see Figure 3.25). This is done by finding, through linear interpolation, the points A and B, on the perimeter of the S.P. which pierce the plane of the R.P., 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.

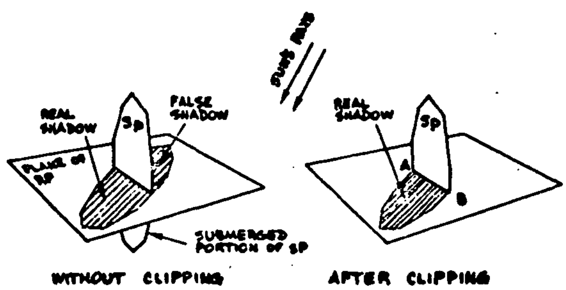


Figure 3.25 CLIPPING

3. 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 R.P.'s

$$X = x' - \frac{x_s'}{z_s'} z'$$

$$Y = y' - \frac{y_s'}{z_s'} z'$$

4. Enclosure Test

The coordinate, clipping and projection transformation have converted all R.P. and S.P.'s in space into two dimensional figures in the

R.P. plane. It remains only to find the points in the R.P. plane which lie inside the R.P. and inside one or more of the S.P. projections, i.e., points of the R.P. which are shaded. At this point, the two-space XY is divided into grid and the center of each element of this grid is tested for enclosure by the R.P. and the S.P. projections. A point, P, whose coordinates are $X_P Y_P$, is inside the 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.

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

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

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

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

5. Display Matrix and Typical Problem

An alphameric matrix is created corresponding to the grid elements in the R.P. plane. A blank component represents a grid element either outside the R.P. or exposed on the sun. An asterisk component represents a shaded grid element or one on the R.P.'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 3.26 shows the solution of a typical problem involving a transmissive structure. Also see Figures 3.8 to 3.11.

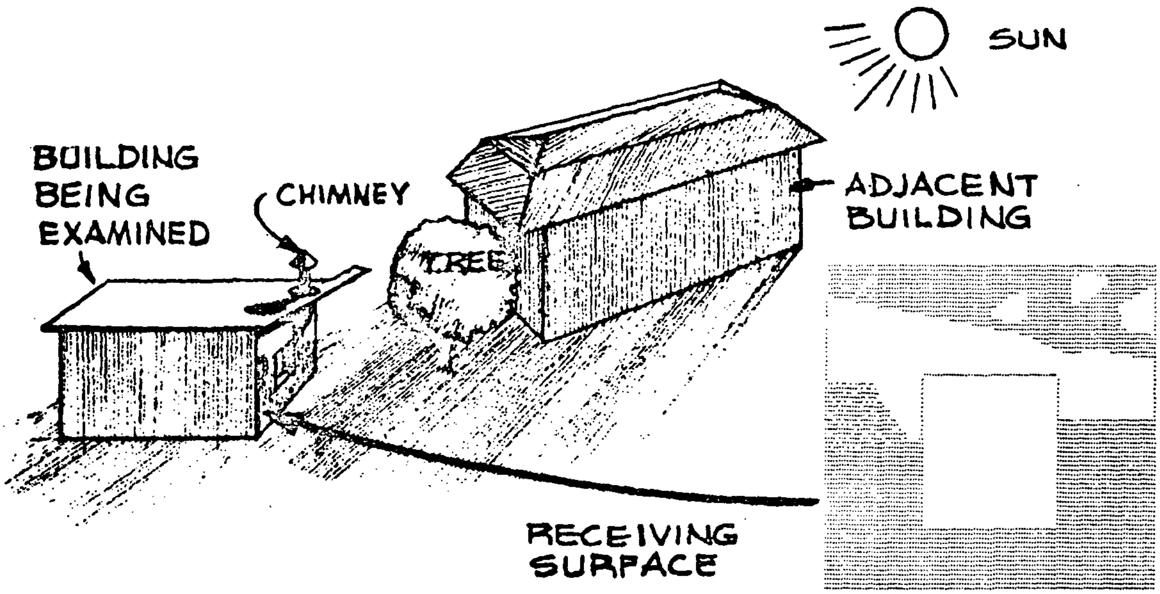


Figure 3.26 THE COMPUTER OUTPUT OF A TYPICAL PROBLEM

SHG

A subroutine which calculates solar heat gain through windows.

INPUT

RDIR	:	Intensity of direct solar radiation normal to window, Btu/hr-sq ft
BS	:	Sky brightness, Btu/hr-sq ft
BG	:	Ground brightness, Btu/hr-sq ft
FWS	:	Form factor between the window and the sky++
FWG	:	Form factor between the window and the ground++
RO	:	Thermal resistance at outside surface, air space, and inside surface, sq ft-hr-°F/Btu
RA	:	
RI	:	

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

SHAW	:	Sunlit area factor
SC	:	Shading coefficient if the window is shaded by drapes or blinds or if it has an interpane separation of more than 1 inch
TDIR TDIF	: :	Transmission factors of direct and diffuse radiation
ADIRO, outer ADIRI, inner	: :	Absorption factors of direct solar radiations through outer and inner window pane
ADIFO, outer ADIFI, inner	: :	Absorption factors of diffuse radiation through outer and inner window pane

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*ℓ = 0.05 of TAR) regardless of the type of glass used.

T	:	Space temperature, °R
TDB	:	Ambient outside air temperature, °R

OUTPUT

QRAY	:	Radiant heat gain through glass, Btu/hr-sq ft
QCON	:	Conductive heat gain through glass, Btu/hr-sq ft

CALCULATION SEQUENCE

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

$$FI = (RO + RA)/(RO + RA + RI)$$

$$FO = RO/(RO + RA + RI)$$

2. Calculate components of solar load

   a) Direct

$$QDIR = SHAW * RDIR$$

b) Diffuse

$$QDIF = BS * FWS + BG * FWG$$

c) Transmitted

$$QTRANS = QDIR * TDIR + QDIF * TDIF$$

d) Absorbed

$$QABS = QDIF * (FO * ADIFO + FI * ADIFI) + QDIR * (FO * ADIRO + FI * ADIRI)$$

3. Calculate solar heat gain through glass

If SC = 0, QRAY = QTRANS + QABS

If SC ≠ 0. QRAY = SC * (QTRANS + QABS)

4. Calculate heat conduction through glass

$$QCON = U * (TDB-T)$$
$$U = 1.0/(RO + RA + RI)$$

STNDRD

A subroutine that generates the response factor data required for standard wall and roof constructions.

INPUT

ISTD : Standard surface number, 1 to 16

OUTPUT

R1 : Common ratio

NRFT : Number of response factor terms

RFX : X-Response factor set, Btu/hr-sq ft-°F

RFY : Y-Response factor set, Btu/hr-sq ft-°F

RFZ : Z-Response factor set, Btu/hr-sq ft-°F

See Figures 3.27 through 3.42 for a description of standard walls and roofs built into the subroutine as well as the accompanying values of R1, NRFT, RFX, RFY, and RFZ.

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	0.0330	0.105	25.0	0.31	0.0	WOOD DROP SIDING
2	0.0650	0.032	18.0	0.45	0.0	SHEATHING(25/32 INSUL. BOARD)
3	0.0	0.0	0.0	0.0	0.97	4 IN. AIR SPACE
4	0.0420	0.093	50.0	0.20	0.0	GYPSUM BOARD (1/2 IN. DRYWALL)
5	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.224 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	0.7229657863	0.0726557570	0.5207289818
1	-0.4760762919	0.1288242763	-0.2719392817
2	-0.0200598977	0.0204772025	-0.0217536458
3	-0.0021301912	0.0022192382	-0.0023144831
4	-0.0002285611	0.0002382457	-0.0002483478
5	-0.0000245306	0.0000255703	-0.0000266542
6	-0.0000026328	0.0000027444	-0.0000028607

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 6
NUMBER OF RESPONSE FACTORS PER SET = 7
COMMON RATIO = 0.1073268628

Figure 3.27 WALL TYPE 1

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	0.0330	0.105	25.0	0.31	0.0	WOOD DROP SIDING
2	0.0650	0.032	18.0	0.45	0.0	SHEATHING(25/32 INSUL. BOARD)
3	0.3330	0.027	0.5	0.16	0.0	4 IN. FIBERGLAS
4	0.0420	0.093	50.0	0.20	0.0	GYPSUM BOARD (1/2 IN. DRYWALL)
5	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.063 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	0.6941580979	0.0113674929	0.4269565407
1	-0.5716134396	0.0367019877	-0.3426492755
2	-0.0500861079	0.0124209695	-0.0194638893
3	-0.0077949790	0.0022810880	-0.0014518610
4	-0.0012205383	0.0003738323	-0.0001518203
5	-0.0001914658	0.0000594358	-0.0000202229
6	-0.0000300521	0.0000093666	-0.0000030035
7	-0.0000047177	0.0000014722	-0.0000004634
8	-0.0000007406	0.0000002312	-0.0000000724
9	-0.0000001163	0.0000000363	-0.0000000113
10	-0.0000000183	0.0000000057	-0.0000000018
11	-0.0000000029	0.0000000009	-0.0000000003

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 11
NUMBER OF RESPONSE FACTORS PER SET = 12
COMMON RATIO = 0.1569960526

Figure 3.28 WALL TYPE 2

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	0.3330	0.770	125.0	0.22	0.0	4 IN. FACE BRICK
2	0.0	0.0	0.0	0.0	0.97	1/2 IN. AIR SPACE
3	0.0650	0.032	18.0	0.45	0.0	SHEATHING(25/32 INSUL. BOARD)
4	0.3330	0.027	0.5	0.16	0.0	4 IN. FIBERGLAS
5	0.0420	0.093	50.0	0.20	0.0	GYPSUM BOARD (1/2 IN. DRYWALL)
6	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.059 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	5.1752936356	0.0001965101	0.4269400411
1	-3.2898511764	0.0064728911	-0.3432131120
2	-0.8104616803	0.0152204263	-0.0207286954
3	-0.4381870018	0.0138525634	-0.0024405844
4	-0.2461277890	0.0094048978	-0.0007116550
5	-0.1404883407	0.0057904012	-0.0003196081
6	-0.0807613436	0.0034352065	-0.0001659625
7	-0.0465702944	0.0020075027	-0.0000914601
8	-0.0268902259	0.0011657843	-0.0000517639
9	-0.0155356625	0.0006751731	-0.0000296466
10	-0.0089778552	0.0003905833	-0.0000170679
11	-0.0051887366	0.0002258387	-0.0000098483
12	-0.0029989589	0.0001305544	-0.0000056881
13	-0.0017333567	0.0000754649	-0.0000032867
14	-0.0010018647	0.0000436196	-0.0000018994
15	-0.0005790709	0.0000252122	-0.0000010978
16	-0.0003346995	0.0000145726	-0.0000006345
17	-0.0001934545	0.0000084229	-0.0000003667

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 17
NUMBER OF RESPONSE FACTORS PER SET = 18
COMMON RATIO = 0.5779947143

Figure 3.29 WALL TYPE 3

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	0.6670	0.387	37.4	0.16	0.0	8 IN. CONCRETE BLOCK
2	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.416 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	1.6954107606	0.0376834476	0.8257356214
1	-0.9976938772	0.1790897307	-0.2620368763
2	-0.1631842836	0.1131325463	-0.0848683679
3	-0.0678252778	0.0492765169	-0.0359238905
4	-0.0289808673	0.0210984541	-0.0153622570
5	-0.0123982925	0.0090269275	-0.0065723528
6	-0.0053043908	0.0038620268	-0.0028118696
7	-0.0022693953	0.0016523042	-0.0012030117

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 7
NUMBER OF RESPONSE FACTORS PER SET = 8
COMMON RATIO = 0.4278334020

Figure 3.30 WALL TYPE 4

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	1.0000	1.040	131.0	0.20	0.0	12 IN. SOLID CONCRETE
2	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.609 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	5.8900960192	0.0001226164	1.2087414422
1	-3.4503400058	0.0115438204	-0.1701162988
2	-0.5678375449	0.0488693945	-0.0894340707
3	-0.2954293233	0.0708887298	-0.0631518912
4	-0.1925050767	0.0721518284	-0.0487184044
5	-0.1412352712	0.0650942355	-0.0391386186
6	-0.1105333637	0.0560585999	-0.0320472359
7	-0.0893756598	0.0473512591	-0.0264723638
8	-0.0734002048	0.0396625377	-0.0219548198
9	-0.0607138780	0.0330997632	-0.0182410248
10	-0.0503837893	0.0275775754	-0.0151677036
11	-0.0418725667	0.0229598516	-0.0126167608
12	-0.0348220007	0.0191090838	-0.0104965459
13	-0.0289671478	0.0159018279	-0.0087332625
14	-0.0240998874	0.0132320087	-0.0072664242
15	-0.0200516411	0.0110101129	-0.0060460440
16	-0.0166838512	0.0091611937	-0.0050306568
17	-0.0138818653	0.0076227172	-0.0041858084

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 17
NUMBER OF RESPONSE FACTORS PER SET = 18
COMMON RATIO = 0.8320619809

Figure 3.31 WALL TYPE 5

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	1.0000	0.530	37.4	0.16	0.0	12 IN. CONCRETE BLOCK
2	0.0	0.0	0.0	0.0	0.97	2 IN. AIR SPACE
3	0.0420	0.093	50.0	0.20	0.0	GYPSUM BOARD (1/2 IN. DRYWALL)
4	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.251 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	1.9842237391	0.0013665093	0.5742440112
1	-1.1634699896	0.0305178705	-0.2115710407
2	-0.1998803815	0.0562234194	-0.0370425957
3	-0.1139556846	0.0472443077	-0.0227359074
4	-0.0768145611	0.0341915641	-0.0156258208
5	-0.0535340481	0.0241323011	-0.0109292590
6	-0.0375356415	0.0169583794	-0.0076680048
7	-0.0263465724	0.0119079331	-0.0053828443
8	-0.0184963871	0.0083604474	-0.0037790557
9	-0.0129856673	0.0058696505	-0.0026531523
10	-0.0091168374	0.0041209100	-0.0018626978

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 10
NUMBER OF RESPONSE FACTORS PER SET = 11
COMMON RATIO = 0.7020701252

Figure 3.32 WALL TYPE 6

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	0.3330	0.770	125.0	0.22	0.0	4 IN. FACE BRICK
2	0.0	0.0	0.0	0.0	0.97	2 IN. AIR SPACE
3	0.5000	0.320	37.4	0.16	0.0	6 IN. CONCRETE BLOCK
4	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.274 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	5.1759344301	0.0004818795	0.7895877616
1	-3.2695424908	0.0191789005	-0.2692359761
2	-0.7587666368	0.0527768139	-0.1020456338
3	-0.3835993798	0.0572743784	-0.0570506711
4	-0.2049172310	0.0462427144	-0.0335460660
5	-0.1145446088	0.0333206219	-0.0202270343
6	-0.0664447011	0.0227347281	-0.0124061364
7	-0.0396444574	0.0150609622	-0.0076977491
8	-0.0241378000	0.0098089342	-0.0048130590
9	-0.0149030741	0.0063236006	-0.0030244890
10	-0.0092878675	0.0040513390	-0.0019067182
11	-0.0058240519	0.0025855525	-0.0012045407
12	-0.0036666203	0.0016461079	-0.0007619589
13	-0.0023143048	0.0010464140	-0.0004824007
14	-0.0014631469	0.0006645581	-0.0003055746
15	-0.0009259976	0.0004217934	-0.0001936308
16	-0.0005864364	0.0002676088	-0.0001227228
17	-0.0003715487	0.0001697446	-0.0000777922
18	-0.0002354655	0.0001076527	-0.0000493156
19	-0.0001492495	0.0000682671	-0.0000312649
20	-0.0000946118	0.0000432884	-0.0000198218
21	-0.0000599801	0.0000274482	-0.0000125673
22	-0.0000380267	0.0000174039	-0.0000079679
23	-0.0000241091	0.0000110350	-0.0000050519
24	-0.0000152856	0.0000069967	-0.0000032030
25	-0.0000096914	0.0000044362	-0.0000020308

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 25
NUMBER OF RESPONSE FACTORS PER SET = 26
COMMON RATIO = 0.6340357594

Figure 3.33 WALL TYPE 7

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	0.3330	0.770	125.0	0.22	0.0	4 IN. FACE BRICK
2	0.0	0.0	0.0	0.0	0.90	2 IN. AIR SPACE
3	0.5000	0.320	37.4	0.16	0.0	6 IN. CONCRETE BLOCK
4	0.1670	0.025	0.5	0.16	0.0	2 IN. FIBERGLAS
5	0.0420	0.093	50.0	0.20	0.0	GYPSUM BOARD (1/2 IN. DRYWALL
6	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.093 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	5.1760690615	0.0000115877	0.4439902914
1	-3.2670838588	0.0013777480	-0.3138918862
2	-0.7557869855	0.0068934014	-0.0176965466
3	-0.3843689468	0.0111441629	-0.0043407542
4	-0.2111334742	0.0119522028	-0.0029676851
5	-0.1260887556	0.0109942480	-0.0023240584
6	-0.0818863673	0.0094649507	-0.0018494570
7	-0.0571435615	0.0078925361	-0.0014793520
8	-0.0420716914	0.0064743214	-0.0011864391
9	-0.0321059989	0.0052647825	-0.0009529141
10	-0.0250532825	0.0042609730	-0.0007659763
11	-0.0198101191	0.0034396053	-0.0006159898
12	-0.0157841950	0.0027725923	-0.0004954969
13	-0.0126309912	0.0022331561	-0.0003986293
14	-0.0101323213	0.0017978824	-0.0003207239
15	-0.0081390029	0.0014470969	-0.0002580549
16	-0.0065427869	0.0011645958	-0.0002076363
17	-0.0052618399	0.0009371738	-0.0001670707
18	-0.0042326699	0.0007541313	-0.0001344313
19	-0.0034052407	0.0006068254	-0.0001081689
20	-0.0027397611	0.0004882868	-0.0000870373
21	-0.0022044236	0.0003929009	-0.0000700340
22	-0.0017737284	0.0003161472	-0.0000563524
23	-0.0014271992	0.0002543869	-0.0000453437

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 23
NUMBER OF RESPONSE FACTORS PER SET = 24
COMMON RATIO = 0.8046447957

Figure 3.34 WALL TYPE 8

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	0.0050	26.000	480.0	0.10	0.0	SHEET METAL
2	0.1670	0.033	9.0	0.24	0.0	2 IN. DENSE INSULATION
3	0.0050	26.000	480.0	0.10	0.0	SHEET METAL
4	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.174 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	0.5514184654	0.0876718792	0.4467220057
1	-0.3750153754	0.0825395979	-0.2653719297
2	-0.0021438832	0.0038427902	-0.0069272981
3	-0.0000708183	0.0001273395	-0.0002289768
4	-0.0000023434	0.0000042138	-0.0000075770
5	-0.0000000775	0.0000001394	-0.0000002507

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 5
NUMBER OF RESPONSE FACTORS PER SET = 6
COMMON RATIO = 0.0330909240

Figure 3.35 WALL TYPE 9

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	0.0050	26.000	480.0	0.10	0.0	METAL SIDING
2	0.0830	0.025	2.0	0.20	0.0	1 IN. DENSE INSULATION
3	0.6670	0.387	37.4	0.16	0.0	8 IN. CONCRETE BLOCK
4	0.0	0.0	0.0	0.0	0.97	AIR SPACE
5	0.0420	0.093	50.0	0.20	0.0	GYPSUM BOARD (1/2 IN. DRYWALL)
6	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.140 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	0.5146377460	0.0005182241	0.5690153555
1	-0.2803814402	0.0093362348	-0.2206708079
2	-0.0163803967	0.0177033926	-0.0414458546
3	-0.0126738061	0.0173869841	-0.0279549505
4	-0.0104608986	0.0150620845	-0.0224173494
5	-0.0087579868	0.0127369779	-0.0186520712
6	-0.0073543179	0.0107178747	-0.0156422697
7	-0.0061794908	0.0090096368	-0.0131399000
8	-0.0051930167	0.0075720513	-0.0110416632
9	-0.0043641390	0.0063635663	-0.0092791506
10	-0.0036675825	0.0053479039	-0.0077980941
11	-0.0030822064	0.0044943385	-0.0065534514

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 11
NUMBER OF RESPONSE FACTORS PER SET = 12
COMMON RATIO = 0.8403921062

Figure 3.36 WALL TYPE 10

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	0.0417	0.830	55.0	0.40	0.0	BUILT UP COATING (1/2 STONE)
2	0.0313	0.110	70.0	0.40	0.0	BUILT UP COATING (3/8 FELT)
3	0.1670	0.025	4.0	0.24	0.0	2 IN. FIBERGLAS
4	0.0100	26.000	480.0	0.10	0.0	METAL PAN (CORRAGATED)
5	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.130 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	1.9271711515	0.0458700543	0.5517222324
1	-1.7924270399	0.0757974472	-0.3987272481
2	-0.0046149222	0.0078098340	-0.0217505968
3	-0.0001677723	0.0004476465	-0.0012201840
4	-0.0000092404	0.0000251497	-0.0000685014
5	-0.0000005184	0.0000014120	-0.0000038458
6	-0.0000000291	0.0000000793	-0.0000002159
7	-0.0000000016	0.0000000045	-0.0000000121

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 7
NUMBER OF RESPONSE FACTORS PER SET = 8
COMMON RATIO = 0.0561417054

Figure 3.37 ROOF TYPE 1

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	0.0417	0.830	55.0	0.40	0.0	BUILT UP COATING (1/2 STONE)
2	0.0313	0.110	70.0	0.40	0.0	BUILT UP COATING (3/8 FELT)
3	0.2500	0.033	9.0	0.24	0.0	3 IN. CELLULAR GLASS
4	0.0100	26.000	480.0	0.10	0.0	METAL PAN (CORRAGATED)
5	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.116 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	2.0037117174	0.0114439795	0.6027205680
1	-1.8493309263	0.0645768947	-0.4212625309
2	-0.0311971279	0.0314422529	-0.0526715341
3	-0.0054266640	0.0071076824	-0.0098951082
4	-0.0010810060	0.0014594799	-0.0019855447
5	-0.0002185981	0.0002962520	-0.0004018748
6	-0.0000442875	0.0000600485	-0.0000814282
7	-0.0000089747	0.0000121693	-0.0000165013
8	-0.0000018187	0.0000024661	-0.0000033440

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 8
NUMBER OF RESPONSE FACTORS PER SET = 9
COMMON RATIO = 0.2026523314

Figure 3.38 ROOF TYPE 2

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	0.0417	0.830	55.0	0.40	0.0	BUILT UP COATING (1/2 STONE)
2	0.0313	0.110	70.0	0.40	0.0	BUILT UP COATING (3/8 FELT)
3	0.2500	0.033	9.0	0.24	0.0	3 IN. CELLULAR GLASS
4	0.0100	26.000	480.0	0.10	0.0	METAL PAN (CORRUGATED)
5	0.0	0.0	0.0	0.0	1.00	CEILING AIR SPACE
6	0.0625	0.035	30.0	0.30	0.0	ACOUSTICAL TILE
7	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.088 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	2.0037089916	0.0005814275	0.4544622493
1	-1.8501224313	0.0138581537	-0.2190318052
2	-0.0359361297	0.0245698197	-0.0595592957
3	-0.0123118669	0.0184312150	-0.0340522933
4	-0.0067881936	0.0116863152	-0.0207673120
5	-0.0041058603	0.0072212113	-0.0127598376
6	-0.0025194586	0.0044451137	-0.0078479502
7	-0.0015492980	0.0027347123	-0.0048276076
8	-0.0009530122	0.0016823045	-0.0029697312
9	-0.0005862486	0.0010348855	-0.0018268534
10	-0.0003606352	0.0006366185	-0.0011238037

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 10
NUMBER OF RESPONSE FACTORS PER SET = 11
COMMON RATIO = 0.6151581783

Figure 3.39 ROOF TYPE 3

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	0.0417	0.830	55.0	0.40	0.0	BUILT UP COATING (1/2 STONE)
2	0.0313	0.110	70.0	0.40	0.0	BUILT UP COATING (3/8 FELT)
3	0.1670	0.033	9.0	0.24	0.0	2 IN. CELLULAR GLASS
4	0.3330	0.100	40.0	0.20	0.0	4 IN. L.W. CONCRETE
5	0.0100	26.000	480.0	0.10	0.0	METAL PAN (CORRAGATED)
6	0.0	0.0	0.0	0.0	1.00	CEILING AIR SPACE
7	0.0625	0.035	30.0	0.20	0.0	ACOUSTICAL TILE
8	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.082 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	2.0054295783	0.0000012548	0.3975211148
1	-1.8323264692	0.0004846146	-0.1591849091
2	-0.0260346346	0.0034844179	-0.0296728986
3	-0.0107789618	0.0065281629	-0.0190244846
4	-0.0076057210	0.0074989133	-0.0144608300
5	-0.0060537888	0.0073079132	-0.0118478607
6	-0.0050793298	0.0067028375	-0.0100774103
7	-0.0043699623	0.0059991826	-0.0087252210
8	-0.0038035378	0.0053139007	-0.0076161772
9	-0.0033279475	0.0046857028	-0.0066724555
10	-0.0029186618	0.0041235914	-0.0058552050
11	-0.0025623822	0.0036257432	-0.0051417715
12	-0.0022506341	0.0031867703	-0.0045167154
13	-0.0019772194	0.0028004661	-0.0039682076
14	-0.0017371776	0.0024608041	-0.0034865295
15	-0.0015263391	0.0021622666	-0.0030634049
16	-0.0013411136	0.0018999187	-0.0026916638
17	-0.0011783750	0.0016693905	-0.0023650461

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 17
NUMBER OF RESPONSE FACTORS PER SET = 18
COMMON RATIO = 0.8766596114

Figure 3.40 ROOF TYPE 4

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	0.0050	26.000	480.0	0.10	0.0	SHEET METAL
2	0.5000	0.025	0.5	0.16	0.0	6 IN. FEBERGLAS
3	0.0420	0.470	150.0	0.20	0.0	GYPSUM BOARD
4	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.048 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	0.3025937611	0.0148770058	0.8570748184
1	-0.2539873396	0.0224091788	-0.5519189919
2	-0.0003130877	0.0074079602	-0.1752942566
3	-0.0000995360	0.0023553142	-0.0557336777
4	-0.0000316468	0.0007488569	-0.0177201632
5	-0.0000100619	0.0002380942	-0.0056340116

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 5
NUMBER OF RESPONSE FACTORS PER SET = 6
COMMON RATIO = 0.3179435476

Figure 3.41 ROOF TYPE 5

DESCRIPTION OF CONSTRUCTION

LAYER NUMBER	THICKNESS FT	CONDUCTIVITY BTU PER (HR)(FT)(F)	DENSITY LB PER CU FT	SPECIFIC HEAT BTU PER (LB)(F)	RESISTANCE (HR)(SQ FT)(F) PER BTU	
1	0.0100	2.300	70.0	0.35	0.0	ASPHALT SHINGLE (PITCHED ROOF)
2	0.0420	0.067	34.0	0.29	0.0	1/2 IN. PLYWOOD SHEATHING
3	0.0	0.0	0.0	0.0	1.00	ATTIC AIR SPACE
4	0.5000	0.025	0.5	0.16	0.0	6 IN. INSULATION
5	0.0420	0.470	150.0	0.20	0.0	GYPSUM BOARD
6	0.0	0.0	0.0	0.0	0.68	INSIDE AIR

THERMAL CONDUCTANCE = 0.045 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

HOUR	X	Y	Z
0	0.7041712189	0.0100444126	0.8569121506
1	-0.6588926193	0.0224665553	-0.5530683028
2	-0.0004555153	0.0082561150	-0.1764214705
3	-0.0001234544	0.0026371985	-0.0563432318
4	-0.0000394216	0.0008422350	-0.0179941836
5	-0.0000125900	0.0002689823	-0.0057467531
6	-0.0000040208	0.0000859041	-0.0018353248

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 6
NUMBER OF RESPONSE FACTORS PER SET = 7
COMMON RATIO = 0.3193672610

Figure 3.42 ROOF TYPE 6

SUN1

A subroutine to calculate the daily solar radiation data.

INPUT

IDOY	:	Day of Year, 1 to 366
TL	:	Tangent of Latitude angle

OUTPUT

SUNRAS	:	Hourly angle (radians) when solar altitude is zero
DEABC(1)	:	Tangent of declination angle, TANδ
DEABC(2)	:	Equation of time, ET, hours
DEABC(3)	:	Apparent solar constant, A, BTU/hr-sq ft
DEABC(4)	:	Atmospheric extinction coefficient, B
DEABC(5)	:	Sky diffuse factor, C

Table 3.8 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; and sky diffuse factor, C.

Table 3.8 VALUES OF δ, ET, A, B AND C FOR NORTHERN HEMISPHERE

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

Table 3.8 could be stored in the computer memory, but this would necessitate an interpolation procedure. In order to avoid such a problem and to save computer core, Tanδ, ET, A, B and C are expressed in Fourier Series form and the values are calculated as a function of the day of the year, d, from the following truncated Fourier series.

$$\left.\begin{array}{l}\text{Tan } \delta \\ \text{ET} \\ \text{A} \\ \text{B} \\ \text{C}\end{array}\right\} = \begin{array}{l} A_0 + A_1 * \text{Cos}(\omega * d) + A_2 * \text{Cos}(2 * \omega * d) + A_3 * \text{Cos}(3 * \omega * d) \\ \quad + B_1 * \text{Sin}(\omega * d) + B_2 * \text{Sin}(2 * \omega * d) + B_3 * \text{Sin}(3 * \omega * d) \end{array}$$

where $\omega = 2*\pi/366. = 0.01721$

$d = \text{IDOY}$

The proper Fourier coefficients are given in Tabel 3.9.

Table 3.9 FOURIER COEFFICIENTS

	A_0	A_1	A_2	A_3	B_1	B_2	B_3
Tanδ	-.00527	-.4001	-.003996	-.00424	.0672	0.0	0.0
ET	0.696×10^{-4}	.00706	-0.0533	-0.00157	-0.122	-0.156	-.00556
A	368.44	24.52	-1.14	-1.09	.58	-0.18	.28
B	.1717	-.0344	.0032	.0024	-.0043	0.0	-.0008
C	.0905	-.0410	.0073	.0015	-.0034	.0004	-.0006

CALCULATION SEQUENCE

1. Calculate Tanδ, ET, A, B and C using the following equation where I varies from 1 to 5 and coefficients take on values shown in Table 3.9.

$$\text{DEABC(I)} = A_0 + A_1 * \text{C1} + A_2 * \text{C2} + A_3 * \text{C3} + B_1 * \text{S1} + B_2 * \text{S2} + B_3 * \text{S3}$$

Where

$\text{C1} = \cos(\omega * d)$

$\text{S1} = \sin(\omega * d)$

and by trigometric identity

$$C2 = \cos(2*\omega*d) = C1*C1-S1*S1$$

$$C3 = \cos(3*\omega*d) = C1*C2-S1*S2$$

$$S2 = \sin(2*\omega*d) = 2*S1*C1$$

$$S3 = \sin(3*\omega*d) = C1*S2+S1*C2$$

2. Calculate sun rise angle

$$SUNRAS = \cos^{-1}(-TL*DEABC(1))$$

which is obtained from general equation

$$\sin(h) = \sin(\delta)*\sin(L)+\cos(\delta)*\cos(L)*\cos(t)$$

(this equation is RAYCOS(3); see subroutine SUN2 for derivation)

where

h = solar altitude, radians

L = latitude, radians

t = hour angle, radians

and where SUNRAS is gotten by setting h=0, and solving for t.

SUN2

A subroutine to calculate the hourly solar radiation data.

INPUT

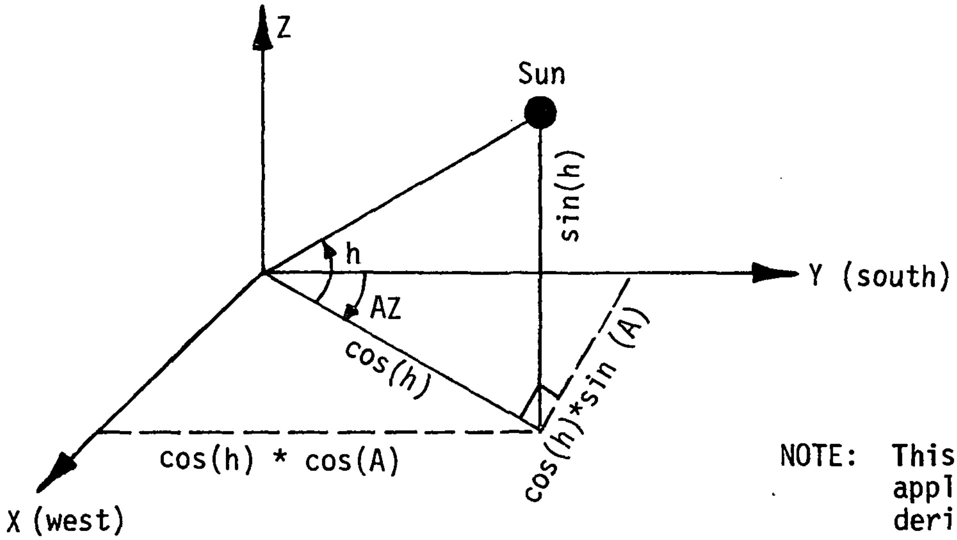
H	:	Hour angle, radians (calculated in main program)	
DEABC(1)	:	Tangent of declination angle	Calculated in SUN1
DEABC(2)	:	Equation of time, hours	Calculated in SUN1
DEABC(3)	:	Apparent solar constant, Btu/hr-sq ft	Calculated in SUN1
DEABC(4)	:	Atmospheric extinction coefficient	Calculated in SUN1
DEABC(5)	:	Sky diffuse factor	Calculated in SUN1
SL	:	Sin of latitude angle	
CL	:	Cosine of latitude angle	
CN	:	Clearness number	
SA	:	Sin of building azimuth angle	
CA	:	Cos of building aximuth angle	

OUTPUT

RAYCOS(1)	:	Direction cosine of sun in x-direction (WEST)
RAYCOS(2)	:	Direction cosine of sun in y-direction (SOUTH)
RAYCOS(3)	:	Direction cosine of sun in z-direction (UPWARD)
RDN	:	Intensity of direct normal solar radiation, Btu/hr-sq ft
BS	:	Brightness of sky, Btu/hr-sq ft.

CALCULATION SEQUENCE

1. Calculate direction cosines of sun



NOTE: This coordinate system applies only to this derivation

From the schematic presented above, the direction cosines are as follows:

RAYCOS(1) = cos(w) = cos(h)*sin(AZ)

RAYCOS(2) = cos(s) = cos(h)*cos(AZ)

RAYCOS(3) = SIN(h)

where h = altitude of sun measured from horizontal, degrees

AZ = azimuth of sun measured from south towards west, degrees

From spherical trigonometry++, the following relationships hold

$$\sin(h) = \sin(\delta)*\sin(L)+\cos(\delta)*\cos(L)*\cos(t)$$

$$\cos(AZ)=-(\sin(\delta)*\cos(L)-\cos(\delta)*\sin(L)*\cos(t))/\cos(h)$$

$$\sin(AZ)= +(\cos(\delta)*\sin(t))/\cos(h)$$

++ J. L. Threlkeld, "Thermal Environmental Engineering", Chapter 14 - Solar Radiation, Prentice-Hall Inc., 1962.

where δ = declination of sun, degrees

L = station latitude, degrees

t = hour angle of sun measured from south towards west, degrees

Substitution gives

RAYCOS(1) = +cos(δ)*sin(t)

RAYCOS(2) =-sin(δ)*cos(φ)+cos(δ)*sin(φ)*cos(t)

RAYCOS(3) = sin(δ)*sin(φ)+cos(δ)*cos(φ)*cos(t)

We must build into these equations the ability to account for building rotation, which is represented by the building azimuth angle, A. *This rotation correction is about the z-axis and therefore will only* affect RAYCOS(1) and RAYCOS(2). From trigonometry, the new values after rotation can be found by using the relationships

x =-x'*cos(A) + y'*sin(A)

y =-x'*sin(A) - y'*cos(A)

Substitution yeilds

RAYCOS(1) = -(cos(δ)*sin(t))*cos(A)

-(sin(δ)*cos(φ)-cos(δ)*sin(φ)*cos(t))*sin(A)

RAYCOS(2) = -(cos(δ)*sin(t))*sin(A)

+(sin(δ)*cos(φ)-cos(δ)*sin(φ)*cos(t))*cos(A)

RAYCOS(3) = sin(δ)*sin(φ)+cos(δ)*cos(φ)cos(t)

To get into form in subroutine let

cos(δ) = CD
sin(δ) = SD
cos(A) = CA
sin(A) = SA
cos(φ) = cos(L) = CL
sin(φ) = sin(L) = SL
cos(t) = cos(h) = CH
sin(t) = sin(h) = SH

Finally, by substitution of these identities,

RAYCOS(1) = -CD*SH*CA-SD*CL*SA+CD*SL*CH*SA

RAYCOS(2) = -CD*SH*SA+SD*CL*CA-CD*SL*CH*CA

RAYCOS(3) = SD*SL+CD*CL*CH

2. Calculate intensity of direct normal solar radiation

   a) If RAYCOS(3) is $\leq$ 0.001, sun has not risen yet, and therefore set

      RAYCOS(3) = 0.0
      RDN = 0.0
      BS = 0.0

   b) If RAYCOS(3) is greater than 0.001, sun is up, and therefore

      RDN = DEABC(3)*CN*EXP(-DEABC(4)/RAYCOS(3))

      BS = DEABC(5)*RDN/(CN*CN)

   Value of clearness number, CN, can be gotten from Figure 3.43

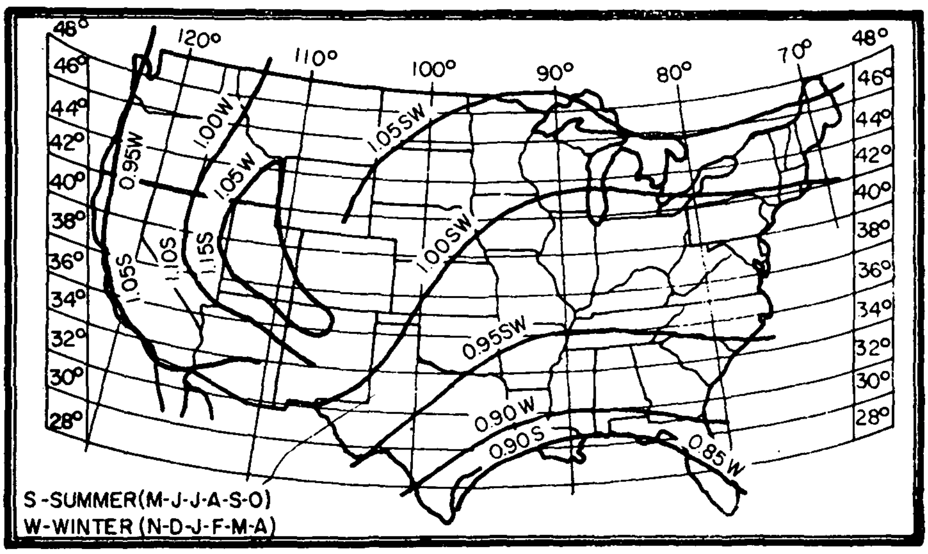


Figure 3.43 CLEARNESS NUMBERS OF NON-INDUSTRIAL ATMOSPHERE IN UNITED STATES

SUN3

A subroutine which calculates solar data depending upon orientation of a surface.

INPUT

WT	:	Surface tilt angle from horizontal, radians
WA	:	Surface azimuth angle, radians, clockwise from y-axis of building
RAYCOS	:	Direction cosines of sun's ray
RDN	:	Intensity of direct normal solar radiation, Btu/hr-sq ft (already corrected for cloud cover)
BS	:	Brightness of sky (diffuse sky radiation on horizontal surface, Btu/hr-sq ft
ROG	:	Ground reflectivity

OUTPUT

GAMMA	:	Cosine of angle between zenith and outward normal of surface
ETA	:	Cosine of the solar angle of incidence, η
RDIR	:	Intensity of direct solar radiation on surface, Btu/hr-sq ft
RDIF	:	Intensity of diffuse radiation on surface, Btu/hr-sq ft
RTOT	:	Intensity of total radiation on surface, Btu/hr-sq ft
BG	:	Brightness of ground, Btu/hr-sq ft

For a pictorial illustration of the various angles referred to in SUN1, SUN2 and SUN3, see Figures 3.44 and 3.45.

CALCULATION SEQUENCE

1. Calculate brightness of ground

   BG = ROG * (BS+RDN*RAYCOS(3))

2. Calculate the direction cosines (α, β and γ) of the normal to the surface. By definition

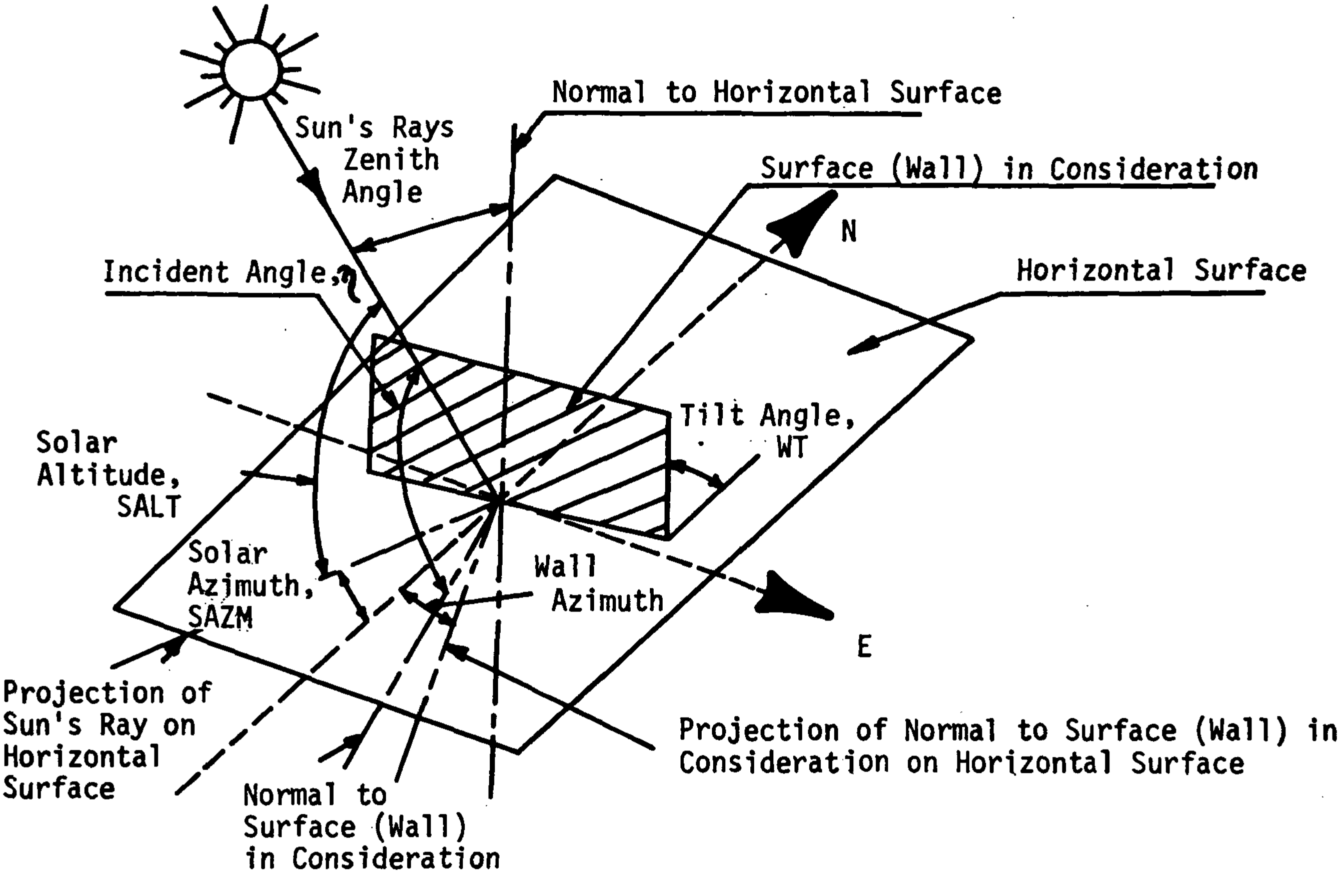


Figure 3.44 DEFINITION OF ANGLES

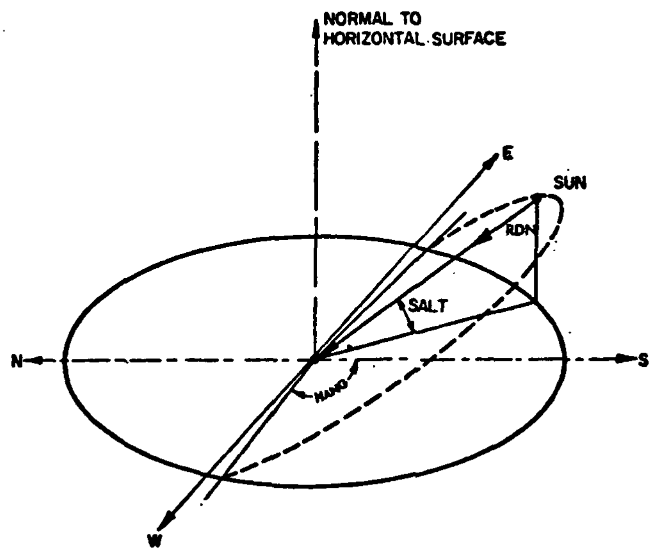


Figure 3.45 SCHEMATIC SHOWING APPARENT PATH OF SUN AND HOUR ANGLE

α = cos(WT) = CWT

β = sin(WA)*sin(WT) = SWA*SWT

γ = cos(WA)*sin(WT) = CWA*SWT

Since most building surfaces have tilt angles that are generally either 0° (roofs) or 90° (walls) and azimuth angles that generally coincide with the four cardinal directions of the compass (0°, 90°. 180° and 270°) much computer computation time can be saved by checking for these conditions and setting the values of the sin(WT), cos(WT), sin(WA) and cos(WA) directly instead of letting the computer software evaluate the sine and cosine.

Therefore, the following preliminary checks have been made part of SUN3.

a) If WT = 0.0 RAD (0°), surface is horizontal facing upward

CWT = cos (0) = 1.0
SWT = sin (0) = 0.0

b) If WT = 1.5708 RAD (90°), surface is vertical

CWT = cos (90) = 1.0
SWT = sin (90) = 0.0

c) For all other tilt angles

CWT = cos (WT)
SWT = sin (WT)

d) If WA = 0.0 RAD (0°)

CWT = cos (0) = 1.0
SWT = sin (0) = 0.0

e) If WA = 1.5708 RAD (90°)

CWT = cos (90) = 0.0
SWT = sin (90) = 1.0

f) If WA = 3.1416 RAD (180°)

CWT = cos (180) = -1.0
SWT = sin (180) = 0.0

g) If WA = 4.7114 RAD (270°)

CWT = cos (270) = 0.0
SWT = sin (270) = -1.0

h) For all other azimuth angles

$$CWT = \cos(WA)$$
$$SWT = \sin(WA)$$

3. Calculate ETA, the cosine of the incident radiation on the surface

$$ETA = \cos(\eta) = \alpha*RAYCOS(3)+\beta*RAYCOS(1) +\gamma*RAYCOS(2)$$

4. Calculate the intensity of the direct normal solar radiation

a) If ETA $\leq$ 0.0, sun is not up yet

RDIR = 0.0

b) If ETA > 0.0, sun is up

RDIR = RDN * ETA

5. Calculate the intensity of diffuse radiation

a) If WT $\leq$ 0.7854 RAD (45°) surface is oriented toward sky

RDIF = BS

b) If WT > 2.35619 RAD (135°), surface is oriented toward ground

RDIF = BG

c) If WT between 45° and 135°, diffuse radiation is estimated using curve shown in Figure 3.46++.

If ETA < -0.2,
y = 0.45

If ETA $\geq$ -0.2,
y = 0.55 + 0.437*ETA + 0.313*ETA**2

Then RDIF = y*BS + 0.5*BG

6. Calculate total radiation incident upon surface

RTOT = RDIR + RDIF

++ J.L. Threlkeld, "Thermal Environmental Engineering", Chapter 14, Solar Radiation, Figure 14.18, Prentice-Hall Inc., 1962.

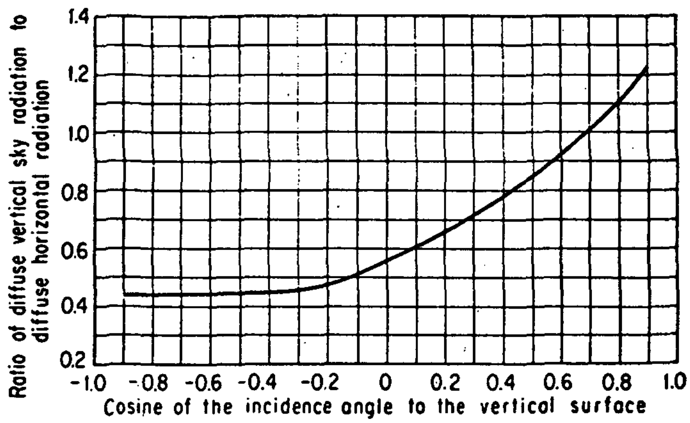


Figure 3.46 RATIO OF DIFFUSE SKY RADIATION INCIDENT UPON A VERTICAL SURFACE TO THAT INCIDENT UPON A HORIZONTAL SURFACE DURING CLEAR DAYS

TAR

A subroutine which calculates transmission, absorption and reflection factors for windows.

INPUT

L	:	Code for thickness times extinction coefficient ($k*\ell$), see Table 3.10 and Figure 3.47
C	:	Cosine of angle of incidence, η
NPANE	:	Number of panes (1 or 2)

Note: In some cases, glass manufacturers use value of transmission at Normal incidence. In this case, using the curve given in Figure 3.47, it is possible to obtain the value of $k*\ell$. The data for the curve are taken from National Research Council of Canada Report No. 7104

OUTPUT

TDIR	:	Transmission factor for direct solar radiation
TDIF	:	Transmission factor for diffuse solar radiation
ADIRO ADIRI	: :	Absorption factors for direct solar radiation through outer and inner window pane
ADIFO ADIFI	: :	Absorption factors for diffuse radiation through outer and inner window pane

The data for the polynominal coefficients a_j and t_j are given in Table 3.11. These coefficients are curve-fitted and the equation forms used in the subroutine.

CALCULATION SEQUENCE

1. Compute transmission factors for direct solar and diffuse radiation.

$$TDIR = \sum_{j=0}^{5} t_j * (C**j)$$

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

Table 3.10

CODE FOR THICKNESS TIMES
EXTINCTION COEFFICIENT

CODE	MEANING
1	1/8" sheet
2	$k^*\ell$ = 0.10
3	$k^*\ell$ = 0.15
4	$k^*\ell$ = 0.20
5	$k^*\ell$ = 0.40
6	$k^*\ell$ = 0.60
7	50% transparent H.A. plate
8	$k^*\ell$ = 1.00

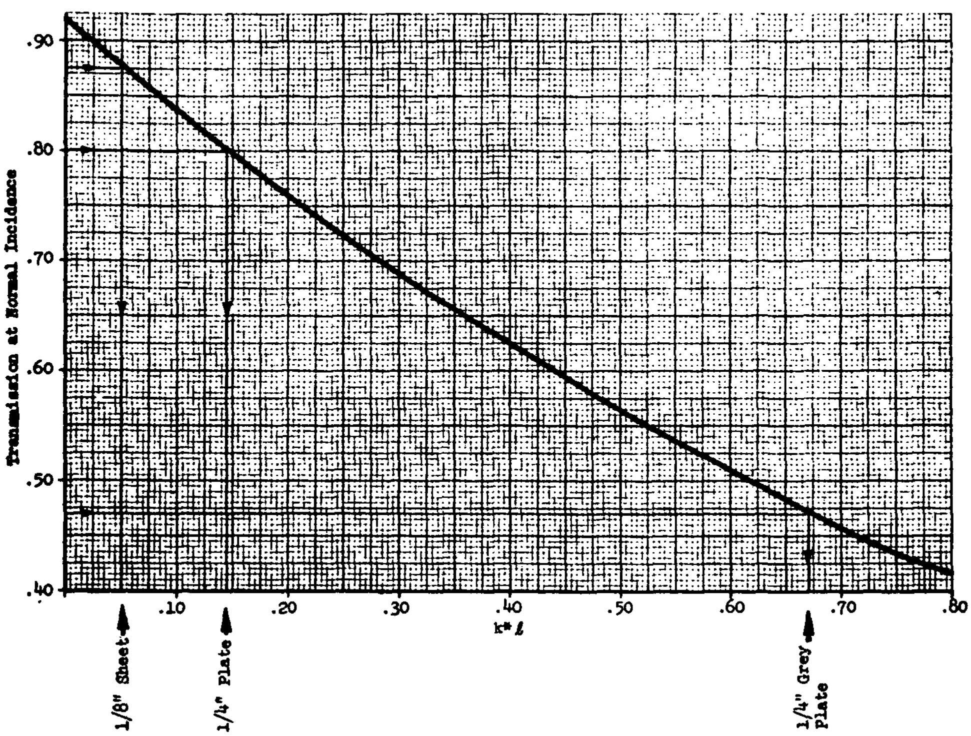


Figure 3.47 $k^*\ell$ VS TRANSMISSION AT NORMAL INCIDENCE FOR SINGLE SHEET GLASS

Table 3.11

POLYNOMIAL COEFFICIENTS FOR USE IN CALCULATION OF TRANSMITTANCE AND ABSORPTANCE OF GLASS

k*ℓ	j	Single Glazing a_j	Single Glazing t_j	Double Glazing $a_{j,outer}$	Double Glazing $a_{j,inner}$	Double Glazing t_j
0.05 1/8" Sheet	0	0.01154	-0.00885	0.01407	0.00228	-0.00401
	1	0.77674	2.71235	1.06226	0.34559	0.74050
	2	-3.94657	-0.62062	-5.59131	-1.19908	7.20350
	3	8.57881	-7.07329	12.15034	2.22366	-20.11763
	4	-8.38135	9.75995	-11.78092	-2.05287	19.68824
	5	3.01188	-3.89922	4.20070	0.72376	-6.74585
0.10	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
	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
0.15 1/4" Reg. Plate	0	0.01837	-0.01200	0.01905	0.00067	-0.00428
	1	1.92497	2.13036	2.47900	0.26017	0.45797
	2	-8.89134	1.13833	-11.74266	-0.72713	7.41367
	3	18.40197	-10.07925	24.14037	1.14950	-19.92004
	4	-17.48648	12.44161	-22.64299	-0.97138	19.40969
	5	6.17544	-4.83285	7.89954	0.32705	-6.66603
0.20	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
	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
0.40	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
	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
0.60	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
	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
0.80 50% Trans. H.A. Plate	0	0.01153	-0.00646	0.00819	-0.00015	-0.00136
	1	4.55946	0.68256	5.01768	0.07717	0.04419
	2	-15.43294	1.82499	-17.21228	-0.09059	3.87529
	3	26.70568	-6.95325	29.46388	0.00050	-9.59069
	4	-22.87993	7.80647	-24.76915	0.06711	9.16022
	5	7.57795	-2.94454	8.05040	-0.03394	-3.12776
1.00	0	0.00962	-0.00496	0.00670	-0.00012	-0.00098
	1	4.81911	0.51043	5.18781	0.05746	0.02576
	2	-15.47137	1.47607	-16.84820	-0.05878	3.00400
	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

2. Compute absorption factors for direct solar and diffuse radiation.

$$ADIRO = \sum_{j=0}^{5} a_{j,outer} * (C**j)$$

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

$$ADIRI = \sum_{j=0}^{5} a_{j,inner} * (C**j)$$

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

WBF

A subroutine for calculating the wet-bulb temperature of moist air given the enthalpy and barometric pressure

INPUT

H	:	Enthalpy, Btu/lb
PB	:	Barometric pressure, inches of mercury

OUTPUT

WBF	:	Wet-bulb temperature, °F

CALCULATION SEQUENCE

1. If PB = 29.92 and H > 0

   Let Y = log(H)

   For $H < 11.758$

   WBF = 0.6040 + 3.4841 * Y + 1.3601 * (Y**2) + 0.9731 * (Y**3)

   For $H \geq 11.758$

   WBF = 30.9185 - 39.682 * Y + 20.5841 * (Y**2) - 1.758 * (Y**3)

2. If PB ≠ 29.92, or $H \leq 0$ solve the following equation by iterating WBF

   H = 0.24 * WBF + (1061 + 0.444 * WBF) * W2

   Where W2 = 0.622 * PV2/(PB - PV2)

   PV2 = PPWVMS (WBF)

WEATHER

The weather subroutine obtains the hourly values of the data listed below, together with Station Number, Year, Month, Day and Hour (Standard Time) from "1440 Magnetic Tapes" of the National Weather Record Center, which are required by the hourly load calculation procedure.

DBT	:	Dry-bulb temperature, °F
DPT or WBT	:	Dew point or wet-bulb temperature, °F
TCA	:	Total cloud amount index
TOC	:	Cloud type index
V	:	Wind velocity, knots
PATM	:	Atmospheric pressure, in. Hg

The hourly values of the data listed above can be obtained either in punch card or magnetic tape form from the National Weather Record Center, NWRC, Asheville, N.C. Detailed information on these data may be found in:

(1) Reference Manual WBAN Hourly Surface Observations 144, April, 1966.

(2) Reference Manual WBAN Solar Radiation-Hourly 280, April 1967.

(3) Tape Reference Manual, Airways Surface Observations, TDF 14.

See Appendix C of Volume I, User's Manual for Decoding Algorithms.

SECTION 4
VARIABLE TEMPERATURE PROGRAM

4.1 OBJECTIVE AND DESCRIPTION

The space loads calculated by the Thermal Load Analysis Program described in Section 3 are determined on the basis of the following two assumptions:

1. space heating and/or cooling is available any time it is required.
2. space temperature is always maintained at its specified set point.

In reality, however, the space temperature is not maintained at a constant, but rather varies from its set point from time to time due to:

1. throttling range and deadband of thermostat
2. undersized space heating and/or cooling capacity
3. shutdown of equipment during specified periods.

If the user wishes to investigate the effects of the above items on building performance and energy usage, he can do so with the use of the Variable Temperature Program.

Utilizing such information as the type of thermostat, operating characteristics of thermostat, heating and cooling capacity available to each space, and seasonal start-up/shutdown dates for the heating and cooling plant, the Variable Temperature Program corrects the basic loads calculated by the Thermal Load Analysis Program for these effects and generates a new output tape containing corrected hourly space loads.

4.2 INPUT

The Variable Temperature Program requires two forms of input:

1. the output tape generated by the Thermal Load Analysis Program and containing hourly weather and basic space loads.
2. the card input data described in Table 5.1 of User's Manual.

In attempting to simulate the effect of varying space temperature, all surfaces and objects having mass, and therefore thermal inertia, have their influence on the room's response to that effect. For this reason, the Variable Temperature Program requires the user to define some additional information that may not have been required by the Thermal Load Analysis Program, i.e., the types of floors, ceilings and furnishings that are part of each space. If, however, the user desires not to go into this kind of detail, an alternative approach can be used, i.e., make use of typical default values built into the program. The default values set by the program are determined as follows:

1. For floors, the default parameters are a function of the weight of floor (lbs per sq. ft.) which are specified in Table 4.3 of User's Manual, Reading Order LC-57, and passed along to the Variable Temperature Program via the input tape.

2. For ceilings, the default parameters are a function of the weight of ceiling (lbs per sq. ft.) which is assumed to be one-half of the weight of floor.

3. For furnishings, the default parameters are a function of the weight of furnishings (lbs per sq. ft.) called for in Table 5.1 of User's Manual, Reading Order VT-16.

The more detailed solution requires that the make-up of the floors, ceilings and furnishings be known and use be made of the Response Factor Program (Section 2) to generate the response factors corresponding to each.

4.3 OUTPUT

Results of the variable temperature analysis are summarized in a one-page report (Report V1) entitled "Summary of Variable Temperature Load Calculations" (see Figure 4.1). At the user's option, additional reports can be called for which echo input data and detail results for various phases of the analysis. The optional reports include:

1. Report V2 - Hourly Summary of Results (Figure 4.2)

2. Report V3 - Echo of Building Description Data Read From Tape (Figure 4.3)

3. Report V4 - Echo of Floor, Ceiling and Furnishing Input Data (Figure 4.4)

4. Report V5 - Echo of Space Description Input Data (Figure 4.5)

5. Report V6 - Echo of Thermostat Scheduling Input Data (Figure 4.6)

6. Report V7 - Summary of Internal Surface Data and Calculation (Figure 4.7)

7. Report V8 - Summary of Calculated Space Response Factors (Figure 4.8)

SUMMARY OF VARIBLE TEMPERATURE LOAD CALULATIONS

LRC SYSTEMS ENGINEERING BUILDING

SPACE NO.	*******HEATING******** MAX. HEAT ADDITION (BTU/HR)	HOUR/DAY/MO	********COOLING******** MAX. HEAT EXTRACTED (BTU/HR)	HOUR/DAT/MO	***LOWEST SPACE TEMP.*** TEMP. (F)	HOUR/DAY/MO	***HIGHEST SPACE TEMP.*** TEMP. (F)	HOUR/DAY/MO
1	-422349.	7/ 4/ 1	781727.	16/ 2/ 7	65.0	22/ 7/ 1	79.8	20/ 2/ 7
2	-84546.	7/ 4/ 1	37410.	7/ 2/ 6	52.9	7/ 5/ 1	82.5	17/ 7/ 7
3	-68535.	7/ 4/ 1	28594.	7/ 2/ 6	53.6	7/ 5/ 1	80.9	18/ 7/ 7
4	-80411.	7/ 4/ 1	35203.	7/ 2/ 6	52.9	7/ 5/ 1	83.1	18/ 1/ 6
5	-67267.	7/ 4/ 1	30003.	7/ 2/ 6	55.4	7/ 5/ 1	81.4	18/ 7/ 7
6	0.	1/ 3/ 1	0.	1/ 3/ 1	85.0	1/ 3/ 1	85.0	1/ 3/ 1

TOTAL BUILDING HEAT EXTRACTIONS AND ADDITIONS
HEATING= -808810723.
COOLING= 1041576949.

Figure 4.1 REPORT V1

DATE= 1/15	SPACE NO.	SPACE TEMP.	HIGH TEMP.	LOW TEMP.	TEMP. CORR.	HEATING CAPACITY	COOLING CAPACITY	SYSTEM LOAD	CONSTANT TEMP. SYSTEM LOAD	THERMOSTAT TYPE	SCHEDULE TYPE
HOUR OF DAY= 1	DBT= -9		WBT= -9		SUN= 1	HOA= -1.9	PATM=	29.72	VEL= 11.0	CC= 0.724	
	1	69.1	10.0	-10.0	-5.91	422349.	895829.	0.	-421184.	2	1
	2	63.5	10.0	-10.0	-11.52	84546.	37410.	-84546.	-118811.	2	1
	3	63.0	10.0	-10.0	-11.97	68535.	28594.	-68535.	-95900.	2	1
	4	62.7	10.0	-10.0	-12.27	80411.	35203.	-80411.	-112715.	2	1
	5	64.2	10.0	-10.0	-10.83	67267.	30003.	-67267.	-93706.	2	1
	6	85.0	0.0	-20.0	0.0	0.	0.	0.	0.	2	1
HOUR OF DAY= 2	DBT= -8		WBT= -9		SUN= 1	HOA= -1.7	PATM=	29.73	VEL= 10.0	CC= 0.724	
	1	68.4	10.0	-10.0	-6.59	422349.	895829.	0.	-439885.	2	1
	2	63.2	10.0	-10.0	-11.77	84546.	37410.	-84546.	-118321.	2	1
	3	62.8	10.0	-10.0	-12.17	68535.	28594.	-68535.	-95516.	2	1
	4	62.5	10.0	-10.0	-12.47	80411.	35203.	-80411.	-112242.	2	1
	5	64.0	10.0	-10.0	-11.05	67267.	30003.	-67267.	-93588.	2	1
	6	85.0	0.0	-20.0	0.0	0.	0.	0.	0.	2	1
HOUR OF DAY= 3	DBT= -9		WBT=-10		SUN= 1	HOA= -1.9	PATM=	29.76	VEL= 10.0	CC= 0.724	
	1	67.8	10.0	-10.0	-7.23	422349.	895829.	0.	-453325.	2	1
	2	63.0	10.0	-10.0	-12.04	84546.	37410.	-84546.	-119437.	2	1
	3	62.6	10.0	-10.0	-12.38	68535.	28594.	-68535.	-96369.	2	1
	4	62.3	10.0	-10.0	-12.69	80411.	35203.	-80411.	-113246.	2	1
	5	63.7	10.0	-10.0	-11.29	67267.	30003.	-67267.	-94665.	2	1
	6	85.0	0.0	-20.0	0.0	0.	0.	0.	0.	2	1
HOUR OF DAY= 4	DBT=-10		WBT=-10		SUN= 1	HOA= -2.1	PATM=	29.78	VEL= 9.0	CC= 0.724	
	1	67.2	10.0	-10.0	-7.82	422349.	895829.	0.	-464116.	2	1
	2	62.7	10.0	-10.0	-12.28	84546.	37410.	-84546.	-119629.	2	1
	3	62.4	10.0	-10.0	-12.57	68535.	28594.	-68535.	-96522.	2	1
	4	62.1	10.0	-10.0	-12.88	80411.	35203.	-80411.	-113416.	2	1
	5	63.5	10.0	-10.0	-11.51	67267.	30003.	-67267.	-95010.	2	1
	6	85.0	0.0	-20.0	0.0	0.	0.	0.	0.	2	1
HOUR OF DAY= 5	DBT=-11		WBT=-11		SUN= 1	HOA= -2.4	PATM=	29.78	VEL= 7.0	CC= 0.724	
	1	66.6	10.0	-10.0	-8.38	422349.	895829.	0.	-473562.	2	1
	2	62.6	10.0	-10.0	-12.40	84546.	37410.	-84546.	-118135.	2	1
	3	62.7	10.0	-10.0	-12.65	68535.	28594.	-68535.	-95387.	2	1
	4	62.1	10.0	-10.0	-12.97	80411.	35203.	-80411.	-112052.	2	1
	5	63.4	10.0	-10.0	-11.63	67267.	30003.	-67267.	-94041.	2	1
	6	85.0	0.0	-20.0	0.0	0.	0.	0.	0.	2	1
HOUR OF DAY= 6	DBT=-11		WBT=-11		SUN= 1	HOA= -2.4	PATM=	29.78	VEL= 6.0	CC= 0.724	
	1	66.1	10.0	-10.0	-8.90	422349.	895829.	0.	-481983.	2	1
	2	62.6	10.0	-10.0	-12.44	84546.	37410.	-84546.	-116604.	2	1
	3	62.3	10.0	-10.0	-12.68	68535.	28594.	-68535.	-94229.	2	1
	4	62.0	10.0	-10.0	-12.98	80411.	35203.	-80411.	-110661.	2	1
	5	63.3	10.0	-10.0	-11.70	67267.	30003.	-67267.	-93028.	2	1
	6	85.0	0.0	-20.0	0.0	0.	0.	0.	0.	2	1
HOUR OF DAY= 7	DBT=-11		WBT=-11		SUN= 1	HOA= -2.4	PATM=	29.79	VEL= 5.0	CC= 0.724	
	1	69.1	2.0	-2.0	-5.91	422349.	895829.	-422349.	-236032.	1	1
	2	62.7	2.0	-2.0	-12.27	84546.	37410.	-84546.	-112185.	1	1
	3	62.5	2.0	-2.0	-12.49	68535.	28594.	-68535.	-90280.	1	1
	4	62.2	2.0	-2.0	-12.81	80411.	35203.	-80411.	-106420.	1	1
	5	63.4	2.0	-2.0	-11.56	67267.	30003.	-67267.	-89206.	1	1
	6	85.0	-8.0	-12.0	0.0	0.	0.	0.	0.	1	1

Figure 4.2 REPORT V2

```
***IBU61=1***

     IDEN1=      LRC SYSTEMS ENGINEERING
     IDEN2=          HAMPTON, VIRGINIA
     IDEN3=R.JENSEN
     IDEN4=SZ, 4W, 3IN
     IDEN5=NOV 26, 1973

NRF=  2

RESPONCE FACTOR INDEX=  1    NRFT= 30      RATIO=0.870676
               5.223269       0.000000        5.223269
              -3.110390       0.000074       -3.110390
              -0.582690       0.001356       -0.582690
              -0.326882       0.004783       -0.326882
              -0.216421       0.008151       -0.216421
              -0.154776       0.010043       -0.154776
              -0.116290       0.010613       -0.116290
              -0.090706       0.010364       -0.090706
              -0.072871       0.009685       -0.072871
              -0.059897       0.008819       -0.059897
              -0.050082       0.007905       -0.050082
              -0.042399       0.007014       -0.042399
              -0.036213       0.006184       -0.036213
              -0.031119       0.005429       -0.031119
              -0.026856       0.004753       -0.026856
              -0.023243       0.004154       -0.023243
              -0.020156       0.003625       -0.020156
              -0.017502       0.003162       -0.017502
              -0.015211       0.002756       -0.015211
              -0.013228       0.802401       -0.013228
              -0.011508       0.002092       -0.011508
              -0.010014       0.001822       -0.010014
              -0.008716       0.001587       -0.008716
              -0.007587       0.001382       -0.007587
              -0.006604       0.001203       -0.086604
              -0.005750       0.001048       -0.005750
              -0.005006       0.000912       -0.005006
              -0.004358       0.000794       -0.004358
              -0.003794       0.000691       -0.003794
              -0.003304       0.000602       -0.003304

RESPONCE FACTOR INDEX=  2    NRFT=  8      RATIO=0.393645
               0.292150       0.086481        0.292150
              -0.161527       0.037536       -0.161527
              -0.028397       0.024278       -0.028397
              -0.010872       0.009824       -0.010872
              -0.004274       0.003872       -0.004274
              -0.001682       0.001524       -0.001682
              -0.000662       0.000600       -0.000662
              -0.000261       0.000236       -0.000261

HDB= 17
     SURFACE INDEX=  1      RESPONCE FACTOR TYPE=  1      AREA AD=   1680.00
     SURFACE INDEX=  2      RESPONCE FACTOR TYPE=  1      AREA AD=     22.00
     SURFACE INDEX=  3      RESPONCE FACTOR TYPE=  1      AREA AD=     88.00
     SURFACE INDEX=  4      RESPONCE FACTOR TYPE=  1      AREA AD=   1470.00
     SURFACE INDEX=  5      RESPONCE FACTOR TYPE=  1      AREA AD=     22.00
     SURFACE INDEX=  6      RESPONCE FACTOR TYPE=  1      AREA AD=     88.00
```

Figure 4.3 REPORT V3

```
***IBUG2=1***

PRINTOUT OPTION= 2     BOILER-CHILLER START-STOP OPTION=1

     PRINT START DATE= 1/15/66      PRINT STOP DATE= 1/15/66
     PRINT START DATE= 8/15/66      PRINT STOP DATE= 8/15/66
     BOILER SPRING OFF DATE= 4/ 1/66      BOILER FALL ON DATE  = 9/ 1/66
     CHILLER SPRING ON DATE= 4/ 1/66      CHILLER FALL OFF DATE= 9/ 1/66


     ********************************************************************************
     SYSTEM SIMULATION INPUT DATA.
           5833  BON   - HOUR OF SEASONAL BOILER START-UP.
           2161  BOFF  - HOUR OF SEASONAL BOILER SHUT-DOWN.
           2161  CON   - HOUR OF SEASONAL CHILLER START-UP.
           5833  COFF  - HOUR OF SEASONAL CHILLER SHUT-DOWN.
     ********************************************************************************


     NO. OF DELAYED FLOOR TYPES NDF=  0


     NO. OF DELAYED CEILING TYPES NDC=  0


     NO. OF DELAYED FURNISHING TYPES NDFU=  0
```

Figure 4.4 REPORT V4

```
***IBUG3=1***     NO. OF SPACES NS=  6

   SPACE INDEX=  1     NO. OF DELAYED FLOORS NF=  0     NO. DELAYED CEILINGS NC=  0     NO. OF FURNISHINGS NFUR=  0
                                                                                        WEIGHT OF FURNISHINGS=  1.0

   SPACE INDEX=  2     NO. OF DELAYED FLOORS NF=  0     NO. DELAYED CEILINGS NC=  0     NO. OF FURNISHINGS NFUR=  0
                                                                                        WEIGHT OF FURNISHINGS=  1.0

   SPACE INDEX=  3     NO. OF DELAYED FLOORS NF=  0     NO. DELAYED CEILINGS NC=  0     NO. OF FURNISHINGS NFUR=  0
                                                                                        WEIGHT OF FURNISHINGS=  1.0

   SPACE INDEX=  4     NO. OF DELAYED FLOORS NF=  0     NO. DELAYED CEILINGS NC=  0     NO. OF FURNISHINGS NFUR=  0
                                                                                        WEIGHT OF FURNISHINGS=  1.0

   SPACE INDEX=  5     NO. OF DELAYED FLOORS NF=  0     NO. DELAYED CEILINGS NC=  0     NO. OF FURNISHINGS NFUR=  0
                                                                                        WEIGHT OF FURNISHINGS=  1.0

   SPACE INDEX=  6     NO. OF DELAYED FLOORS NF=  0     NO. DELAYED CEILINGS NC=  0     NO. OF FURNISHINGS NFUR=  0
                                                                                        WEIGHT OF FURNISHINGS=  0.0
```

Figure 4.5 REPORT V5

IBUG5=1 NO. OF DIFFERENT SCHEDULES= 1

SCHD. TYPE	DAY TYPE	HOUR OF DAY	THERM TYPE	HI LIMIT	LOW LIMIT	SET POINT
1	WEEKDAY					
		1	2	85.0	65.0	75.0
		2	2	85.0	65.0	75.0
		3	2	85.0	65.0	75.0
		4	2	85.0	65.0	75.0
		5	2	85.0	65.0	75.0
		6	2	85.0	65.0	75.0
		7	1	77.0	73.0	75.0
		8	1	77.0	73.0	75.0
		9	1	77.0	73.0	75.0
		10	1	77.0	73.0	75.0
		11	1	77.0	73.0	75.0
		12	1	77.0	73.0	75.0
		13	1	77.0	73.0	75.0
		14	1	77.0	73.0	75.0
		15	1	77.0	73.0	75.0
		16	1	77.0	73.0	75.0
		17	1	77.0	73.0	75.0
		18	2	85.0	65.0	75.0
		19	2	85.0	65.0	75.0
		20	2	85.0	65.0	75.0
		21	2	85.0	65.0	75.0
		22	2	85.0	65.0	75.0
		23	2	85.0	65.0	75.0
		24	2	85.0	65.0	75.0
1	SAT./SUN./HOL.					
		1	2	85.0	65.0	75.0
		2	2	85.0	65.0	75.0
		3	2	85.0	65.0	75.0
		4	2	85.0	65.0	75.0
		5	2	85.0	65.0	75.0
		6	2	85.0	65.0	75.0
		7	2	85.0	65.0	75.0
		8	2	85.0	65.0	75.0
		9	2	85.0	65.0	75.0
		10	2	85.0	65.0	75.0
		11	2	85.0	65.0	75.0
		12	2	85.0	65.0	75.0
		13	2	85.0	65.0	75.0
		14	2	85.0	65.0	75.0
		15	2	85.0	65.0	75.0
		16	2	85.0	65.0	75.0
		17	2	85.0	65.0	75.0
		18	2	85.0	65.0	75.0
		19	2	85.0	65.0	75.0
		20	2	85.0	65.0	75.0
		21	2	85.0	65.0	75.0
		22	2	85.0	65.0	75.0
		23	2	85.0	65.0	75.0
		24	2	85.0	65.0	75.0

SPACE INDEX	THERMOSTAT TYPE	HEATING CAPACITY	COOLING CAPACITY	PLENUM	OVER SPACE	CFM	SCHEDULES			
1	1	-422349.	895829.	0	0	0.	0	0	0	0
2	1	-84546.	37410.	0	0	0.	0	0	0	0
3	1	-68535.	28594.	0	0	0.	0	0	0	0
4	1	-80411.	35203.	0	0	0.	0	0	0	0
5	1	-67267.	30003.	0	0	0.	0	0	0	0
6	1	0.	0.	0	0	0.	0	0	0	0

Figure 4.6 REPORT V6

```
***IBUG6=1***

     SPACE=  1     NO. OF INTERNAL HEAT TRANSFER SURFACES=  1                SIHTC(I)=      728.

     SPACE=  2     NO. OF INTERNAL HEAT TRANSFER SURFACES=  0

     SPACE=  3     NO. OF INTERNAL HEAT TRANSFER SURFACES=  0

     SPACE=  4     NO. OF INTERNAL HEAT TRANSFER SURFACES=  0

     SPACE=  5     NO. OF INTERNAL HEAT TRANSFER SURFACES=  0

     SPACE=  6     NO. OF INTERNAL HEAT TRANSFER SURFACES=  0
```

Figure 4.7 REPORT V7

```
***IBUG8=1***

     FINAL SPACE RESPONSE FACTORS FOR SPACE=  1

             -193348.2500
              230321.2500
              -47098.8398
               -1295.9922
                -291.2617
                 -89.9453
                 -45.1621
                 -19.4460
                  -6.1973
                   0.0002

     FINAL SPACE RESPONSE FACTORS FOR SPACE=  2

              -20560.8438
               30025.5469
               -8276.4219
                -701.3948
                -271.9626
                -136.7441
                 -76.1282
                 -43.8718
                 -25.5769
                 -14.9590
                  -8.7492
                  -5.0947
                  -2.9479
                  -1.6875
                  -0.9495
                  -0.5185
                  -0.2689
                  -0.1251
                  -0.0443
                   0.0000

     FINAL SPACE RESPONSE FACTORS FOR SPACE=  3

              -18623.4492
               27197.7734
               -7496.5586
                -634.9932
                -246.9197
                -124.4336
                 -69.4050
                 -40.0513
                 -23.3769
                 -13.6886
                  -8.0146
                  -4.6724
                  -2.7069
                  -1.5514
                  -0.8740
                  -0.4779
                  -0.2481
```

Figure 4.8 REPORT V8

4.4 MAIN ROUTINE ALGORITHMS

The calculations performed by the Variable Temperature Program are as follows:

1. Read building description data from basic load input tape. Order of data is as follows:

   a) IDEN1 - Facility name

   b) IDEN2 - Facility location

   c) IDEN3 - Engineer's name

   d) IDEN4 - Project number

   e) IDEN5 - Date

   f) NRF - Number of types of response factor surfaces

   g) For each surface type

      NRFT - Number of response factor terms

      R1 - Common ratio

      RX, RY, RZ - Surface response factors

   h) NDB - Number of delayed surfaces

   i) For each delayed surface

      IRF - Response factor type index

      AD - Surface area, sq. ft.

   j) NQB - Number of quick surfaces

   k) For each quick surface

      ISQ - Surface roughness index

      UQ - Surface U-factor less outside film coefficient, Btu/hr-sq ft-^{o}F

      AQ - Surface area, sq.ft.

   l) NWB - Number of windows

m) For each window

NPW - Number of panes of glass

AW - Window area, sq. ft.

n) NIHT - Number of internal heat transfer surfaces

o) For each internal heat transfer surface

ISPC1, ISPC2 - Spaces connected to surface

FIHTS - Surface V*A, Btu/hr. °F

p) NUWB - Number of underground walls

q) For each underground wall

AUW - Underground wall area, sq. ft.

FUW - U-factor, Btu/hr-sq ft-°F

r) NUFB - Number of underground floors

s) For each underground floor

AUF - Underground floor area, sq. ft.

FUF - U-factor, Btu/hr-sq ft-°F

t) NS - Number of spaces in building

u) For each space

ND - Number of delayed surfaces in space

NQ - Number of quick surfaces in space

NW - Number of windows in space

NIHTS - Number of internal H.T. surfaces in space

NUW - Number of underground walls in space

NUF - Number of underground floors in space

MULT - Space repetition factor

FLORB - Floor area, sq. ft.

VOL - Space volume, cu. ft.

TSPAC - Set point temperature, ^{o}F

WOF - Weight of floor, lbs/sq. ft.

ID - Index associated with each of ND delayed surfaces

IQ - Index associated with each of NQ quick surfaces

IW - Index associated with each of NW windows

IHTS - Index associated with each of NIHTS internal H.T. surfaces

IUW - Index associated with each of NUW underground walls

IUF - Index associated with each of NUF underground floors

v) JMONT - Starting month, 1 to 12

LENGH - Number of days

NOHIE - Number of hours in each month

ISTRT - Starting hour of analysis, 1 to 8760

IEND - Ending hour of analysis, 1 to 8760

2. Write all of the data read above onto the output tape in the same order as above.

3. For each window, calculate the resistance and U-factor (less the outside film coefficient).

   a) For single pane windows

      REI = 0.5 inside film resistance

      REA = 0.0 interpane resistance

      R = REI + REA total resistance

      UGW = 1.0/R U-factor

   b) For multi-pane windows

      REI = 0.5 inside film resistance

      REA = 1.6 interpane resistance

R = REI + REA total resistance

UGW = 1.0/R U-factor

4. Read card input data as outlined in Table 5.1 of User's Manual.

5. Calculate hour of year that boiler and chiller are to be turned on and off.

   IBS = IHOY (MONS, IDAYS, NOHIE)

   IBE = IHOY (MONE, IDAYE, NOHIE)

   ICS = IHOY (MONS, IDAYS, NOHIE)

   ICE = IHOY (MONE, IDAYE, NOHIE)

6. Calculate each space's set of response factors by accounting for heat storage effect of delayed surfaces, underground walls and floors, ceilings, intermediate floors, and furnishings. Effects of quick surfaces and windows will be added within the hour loop, where the outside film coefficient can be calculated as a function of wind speed. For each space I = 1 to NS, perform the following:

   a) Determine the highest number of response factor terms that any delayed surface in the space has.

      - MNRF = 1 (initialization)
      - If ND(I) = 0, go to (6b).
      - For each delayed surface J4 = 1 to ND(I),

        J1 = ID(I,J4) (delayed surface index)

        J3 = IRF(J1) (response factor surface type index)

        MNRFT = IR(J3)

        If MNRF < MNRFT, reset MNRF = MNRFT.

   b) Limit the minimum number of response factor terms to 10.

      If MNRF < 10, reset MNRF = 10.

   c) Set index J=1 (first term of space response factor set).

d) Initialize space response factor variable corresponding to J.

SRMRT(J) = 0.0

e) Underground Walls - calculate and add into SRMRT a correction factor to correct the underground wall load for space temperatures other than that assumed in basic load calculation.

- This correction factor should only be added in one time; therefore if J > 1, skip to calculation (6g).

- If NUW(I) $\leq$ 0, space has no underground walls; therefore skip to calculation (6f).

- For each underground wall J1 = 1 to NUW(I),

  SRMRT(J) = SRMRT(J) - AUW(J2) * FUW(J2)

  where J2 = IUW(I,J1).

f) Underground Floors - calculate and add into SRMRT a correction factor to correct the underground floor load for space temperatures other than that assumed in basic load calculation.

- This correction factor should only be added in one time; therefore if J > 1, skip to calculation (6g).

- If NUF(I) $\leq$ 0, space has no underground floors; therefore skip to calculation (6g).

- For each underground floor J1 = 1 to NUF(I),

  SRMRT(J) = SRMRT(J) - AUF(J2) * FUF(J2)

  where J2 = IUF(I,J1).

g) Delayed Surfaces - calculate response factor term for all delayed heat transfer surfaces and add their contribution into SRMRT(J).

- Let number of delayed surfaces in space ND1 = ND(I).

- If ND1 $\leq$ 0, skip to calculation (6h).

- For each delayed surface J2 = 1 to ND1, J1 = ID(I,J2) (delayed surface index)

A = AD(J1) (area)

J3 = IRF(J1) (response factor index)

If J > IR(J3), use common ratio to determine response factor.

RZ(J3,J) = RATOS(J3) * RZ(J3,J-1)

SRMRT(J) = SRMRT(J) - A * (RZ(J3,J))

h) Ceilings - calculate response factor term for all ceilings, if any, in space and add their contribution into SRMRT.

- Let number of ceiling surfaces in space NC1 = NC(I).
- If NC1 $\leq$ 0, skip to calculation (6i).
- For each ceiling surface J1 = 1 to NC1,

J2 = ICD(I,J1) (ceiling index type)

A = ACEIL(I,J1) (area)

If J > IRC(J2), use common ratio to determine response factor.

CRX(J2,J) = CRC(J2) * CRX(J2,J-1)

CRZ(J2,J) = CRC(J2) *CRZ(J2,J-1)

SRMRT(J) = SRMRT(J) + A * (CRX(J2,J) - CRZ(J2,J))

i) Non-underground Floors - calculate response factor term for all non-underground floors, if any, in space and add their contribution into SRMRT(J).

- Let number of non-underground floors in space NF1 = NF(I).
- If NF1 $\leq$ 0, skip to calculation (6j).
- For each non-underground floor J1 = 1 to NF1,

J2 = IFD(I,J1) (floor index type)

A = AFLOR(I,J1) (area)

If J > IRFL(J2), use common ratio to determine response factor.

FLRX(J2,J) = CRFL(J2) * FLRX(J2,J-1)

FLRZ(J2,J) = CRFL(J2) * FLRZ(J2,J-1)

SRMRT(J) = SRMRT(J) + A * (FLRX(J2,J) - FLRZ(J2,J)

j) Furnishings - calculate response factor term for all furnishings in space, if any, and add their contribution into SRMRT(J).

- Let area of furnishings in space AFN1 = AFN(I).
- If AFN1 $\leq$ 0.0, skip to calculation (6k).
- If J > IRFU(J2), use common ratio to determine response factor.

  FURZ(J2,J) = CRFU(J2) * FLRZ(J2,J-1)

  where J2 = IFND(I).
- SRMRT(J) = SRMRT(J) - AFN1 * FURZ(J2,J).

k) Add in default values for floors and ceilings, if required.

- Check to see if default values for floor and ceiling are required.

  If user entered his own floor and ceiling via input data, (i.e., NC(I) + NF(I) > 0, then skip to calculation (6o).

l) Underground Floors - using default values (DFURZ)[++] built into program for underground floors, calculate the response factor term to account for heat storage effect; add its contribution into SRMRT.

- If space has no underground floors (i.e., NUF(I) $\leq$ 0, skip to calculation (6m).
- For each underground floor J1 = 1 to NUF(I):

  J2 = IUF(I,J1) (underground floor number)

[++] Default values taken from Dr. T. Kusuda, "Thermal Response Factors for Multi-layer Structures of Various Heat Condition Systems", p.V.3.23, "Basement Floor", ASHRAE Semiannual Meeting, January, 1969.

If J > 10, use common ratio to calculate default value.

DFURZ(J) = DFURZ(J-1) * DFUCR

Update SRMRT and adjust response factor for U-factor other than the 0.665 (6" concrete on soil) upon which default values are based.

SRMRT(J) = SRMRT(J) - AUF(J2) * DFURZ(J) *

(FUF(J2)/0.665)

m) Underground Walls - using default values (DFURZ) built into program for underground walls, calculate the response factor term to account for heat storage effect; add its contribution into SRMRT.

- If space has no underground walls (i.e., NUW(I)$\leq$0), skip to calculation (6p).

- For each underground wall, J1 = 1 to NUW(I).

  J2 = IUW(I) (underground wall number)

  If J > 10, use common ratio to calculate default value.

  DFURZ(J) = DFUCR * DFURZ(J-1)

  Update SRMRT and adjust response factor for U-factor other than the 0.791 (6" concrete wall against soil) upon which default values are based (see same reference as used in (6 l).

  SRMRT(J) = SRMRT(J) - AUW(J2) * DFURZ(J) *

  (FUF(J2)/0.791)

n) Ceilings - using default values (DFFRZ) built into program for ceilings, calculate the response factor term and add its contribution into SRMRT.

- There is no bypass around this calculation since each space is assumed to have a ceiling and since the user did not define one, i.e., NC(I) = 0, a default value must be entered.

- If J > 7, use common ratio to calculate default value.

  DFFRZ(J) = DFFCR * DFFRZ(J-1)

- Update SRMRT and adjust response factor term for weights other than the 70 lbs/sq. ft. upon which default values are based.++ (It is assumed that the ceiling is also serving as a floor to the space above, therefore the total weight of surface (140 lbs/sq. ft.) is being split between a floor and a ceiling.)

  SRMRT(J) = SRMRT(J) - FLORB(I) + DFFRZ(J) *

  (WOF(I)/70.0) * 1.26

  where 1.26 is the correction to the overall U-factor for a ceiling.

o) Non-underground Floor - using default values (DFFRZ) built into program for non-underground floors, calculate the response factor term and add its contribution into SRMRT.

- Check to see if a floor has been previously defined, i.e., NUF(I) > 0, and if so, skip to calculation (6p).

- If J > 7, use common ratio to calculate default value.

  DFFRZ(J) = DFFCR * DFFRZ(J-1)

- Update SRMRT and adjust response factor term for weights other than 70 lbs/sq. ft. upon which default values are based++.

  SRMRT(J) = SRMRT(J) - FLORB(I) * DFFRZ(J) *

  (WOF(I)/70.0)

p) Furnishings - using default values (DFNRZ) built into program for furnishings, calculate the response factor term and add its contribution into SRMRT.

- Check to see if user entered his own furnishing data, i.e., IFND(I) > 0, and if so, skip to calculation (6q).

- If J > 10, use common ratio to calculate default value.

++ Default values taken from Dr. T. Kusuda, "Thermal Response Factors for Multi-layer Structures of Various Heat Condition Systems", p. V.3.22, "Concrete Floor", ASHRAE Semiannual Meeting, January, 1969.

DFNRZ(J) = DFNCR * DFNRZ(J-1)

- Update SRMRT and adjust response factor term for weights other than the 20 lbs/sq. ft. upon which default values are based.++ (It is assumed that the heat storage capacity of furnishings is equivalent to approximately 3" paper.)

  SRMRT(J) = SRMRT(J) - FLORB(I) * DFNRZ(J) *

  (WOFN(I)/20.0)

q) Store the space response factor into a matrix for later use.

   SRF(I,J) = SRMRT(J)

r) Check to ensure at least 3 space response factor terms have been calculated, and if not, go to calculation (6w) and proceed to next term calculation.

s) Perform check to determine if space is fast responding, i.e., J = 3 and |SRMRT(J)| ≤ 1.0 * E-15, and if so, go to calculation (6x).

t) Check to determine if all space response factor terms have been calculated. If J ≤ MNRF, go to calculation (6w).

u) Perform the relative end test. If |SRF(I,J)/SRF(I,1)| ≤ 1.0*E-3, go to calculation (6x).

v) Limit the number of space response factor terms to 100. If J ≥ 100, go to calculation (6x).

w) Increment J = J + 1 and go to calculation (6d) to begin calculation for next term.

x) Set the number of terms defined for space in question.

   NSRF(I) = J

7. Calculate the sum of U * A for all internal heat transfer surfaces in each space. For each space I = 1 to NS,

   JLIM = NIHTS(I) (number of surfaces)

++ Default values taken from Dr. T. Kusuda, "Thermal Response Factors for Multi-layer Structures of Various Heat Condition Systems", p. V.3.23, "Solid Slab", ASHRAE Semiannual Meeting, January, 1969.

$SIHTC(I) = \Sigma\, FIHTS(J2)$ for $J1 = 1$ to JLIM

$J2 = IHTS(I,J1)$ (surface index)

8. Initialize run parameters for each space I = 1 to NS.

SMH(I)	=	1.0E10	space maximum heating
SMC(I)	=	-1.0E10	space maximum cooling
SLT(I)	=	1.0E10	space lowest temperature
SHT(I)	=	-1.0E10	space highest temperature
ESHT(I)	=	0.0	heat extraction difference
ETEMP(I,J)	=	0.0	space temperature deviation

where J = 1 to NSRF(I)

9. Initialize run parameters for building.

TCOOL = 0.0 total building cooling consumption

THEAT = 0.0 total building heating consumption

10. Begin hourly analysis, perform following for each day JDAY = ISTRT to IEND incrementing 24 hours each time.

a) Check condition of boiler. If

$$\left\{\begin{array}{l} IBE > JDAY \\ IBS < JDAY \\ IBC = 1 \end{array}\right\}$$

boiler should be off, therefore set IBOF = 0. Otherwise, set IBOF = 1.

b) Check condition of chiller. If

$$\left\{\begin{array}{l} ICS < JDAY \\ ICE > JDAY \end{array}\right\}$$

chiller should be ON, therefore set ICOF = 1. Otherwise, set ICOF = 0.

c) For each hour of day, i.e.,

IHOUR = JDAY to JDAYE

JDAYE = JDAY + 23

perform following calculations.

d) Read from the input the hour's time and weather parameters.

IDUMY	-	hour of year 1 to 8760
MONTH	-	month of year 1 to 12
IDAY	-	day of month 1 to 31
NDAY	-	day of week 1 to 7 (1=Sunday)
ITIME	-	hour of day, 1 to 24 corrected for DST
J1	-	sun flag, 0 = up, 1 = down
KA	-	dry-bulb temperature, ^{o}F
LA	-	Wet-bulb temperature, ^{o}F
IWS	-	wind speed, knots
HUMRAT	-	humidity ratio, lbs/lbs
PATM	-	barometric pressure, inches of mercury
DEN	-	density, lbs/cu. ft.
ENTH	-	enthalpy, Btu/lb
JSC	-	type of day, 1 to 9
CC	-	cloud cover modifier.

e) Set type of day indicator for thermostat operation schedule.

If JSC = 1 or JSC > 7, set IDT = 2.

If JSC = 2 to 6, set IDT = 1.

f) Begin space calculation repeating the following calculations for I = 1 to NS.

g) Initialize space parameters.

UQT = 0.0 sum of U * A for quick surfaces (outside film included)

UGWT= 0.0 sum of U * A for glass surfaces (outside film included)

PIHT= 0.0 partial internal heat transfer term

SUM1= 0.0 response factor sum for space

h) Read from the input tape the space load set.

IDUMY - space number

HRLDS - sensible load, Btu/hr

HLAT - latent load, Btu/hr

HRLDL - plenum return air load, Btu/hr

SPOW - space power consumption by lights and equipment, KW

QSINF - sensible infiltration load, Btu/hr

QLINF - latent infiltration load, Btu/hr

i) Calculate the sum of U * A for quick surfaces. For each quick surface in space J1 = 1 to NQ(I), perform following calculations:

JQ = IQ(I,J1) (quick surface index)

U = UQ(JQ) (surface U-factor)

IRUF = ISQ(JQ) (roughness factor index)

CALL FILM (VEL,IRUF,F)

where VEL = IWS

F = outside film resistance

UQT = UQT + AQ(JQ) * (U/(1.0 + F * U))

j) Calculate the sum U * A for window surfaces. For each window in space J1 = 1 to NW(I) perform following calculations:

JW = IW(I,J1) (window index)

U = UGW(JW) (U-factor)

ITYPE = 6

CALL FILM (VEL,ITYPE,F)

where VEL = IWS

F = outside film resistance

UGWT = UGWT + AW(JW) * (U/(1.0 + F * U))

k) Calculate the internal surface load correction factor. For each internal surface in space J1 = 1 to NIHTS(I), perform following calculations:

J2 = IHTS(I,J1) (surface index)

J3 = ISPC1(J2) (adjacent space number)

If J3 = I, set J3 = ISPC2(J2)

PIHT = PIHT + FIHTS(J2) * ETEMP(J3,1)

l) Calculate final space response factors and set value of ETEMP. For J1 = 1 to JL1M1 where JL1M1 = NSRF(I)-1, perform the following calculations:

J2 = JL1M - J1

ETEMP(I,J2+1) = ETEMP(I,J2)

SUM1 = SUM1 + SRF(I,J2+1) * ETEMP(I,J2+1)

m) Initialize plenum variables.

CFM1 = 0.0

CFM2 = 0.0

UCFM = 0.0

n) Check if space is a ceiling plenum, and if so, perform the following calculations:

- If IPLS(I) = 0, space is not a plenum, therefore skip to calculation (10 o).

- Check if fan is operating. If

  ITIME ≤ IVON(I,IDT)

  or ITIME > IVOFF(I,IDT)

  fan is off; therefore skip to calculation (10 o).

- Fan is operating; therefore perform the following:

  J1 = IVS(I)

  UCFM = CFM(I)

  CFM1 = 1.08 * CFM(I)

  CFM2 = 1.08 * CFM(I) * (TSPAC(I) -

  ETEMP(J1,1) - TSPAC(J1) + HRLDL(J1)

o) Calculate temperature difference between outside dry-bulb and constant space temperature assumed in basic load calculation.

   TOMCS = LA - TSPAC(I)

   If $|TOMCS| \leq 0.1$, set TOMCS = 1.0E35

p) Define various terms to be used in equations later.

   SUM3 = UQT + UGWT

   SUM4 = SUM1 + PIHT + HRLDS + CFM2

   SUM5 = -SRF(I,1) + SUM3 + SIHTC(I)

   + QSINF/TOMCS + CFM1

q) Set space thermostat type and check for no thermostat, i.e., floating space temperature. Also set thermostat schedule that applies.

   IJUMP = ISTT(I)

   If IJUMP = 0, skip to calculation (10u).

   JUMP = IVTSD(IJUMP,IDT,ITIME)

r) Set the high and low thermostat limits deviations and space heating and cooling capacity.

   TL = VTSD2(IJUMP,IDT,ITIME) - TSPAC(I)

   TH = VTSD1(IJUMP,IDT,ITIME) - TSPAC(I)

   HEAT = -HCAP(I) * IBOF

   COOL = CCAP(I) * ICOF

s) Analysis for a Type 1 thermostat (linear or proportional control) (see Table 4.1).

- Calculate slope of thermostat function line.

  D = (HEAT + COOL)/(TH - TL)

- Calculate intercept of thermostat function line.

  C = -(HEAT + D * TL)

- Calculate space temperature deviation from TSPAC(I) that exists at end of hour.

  TEMPS = (SUM4 - C)/(SUM5 + D)

- Calculate heat extracted from or supplied to space during hour.

  HE = TEMPS * D + C

- Check if more heat is required than the space has capacity for.

  If TEMPS < TL, set

    HE = -HEAT

    TEMPS = (SUM4 + HEAT)/SUM5

- Check if more cooling is required than the than the space has capacity for.

  If TEMPS > TH, set

    HE = COOL

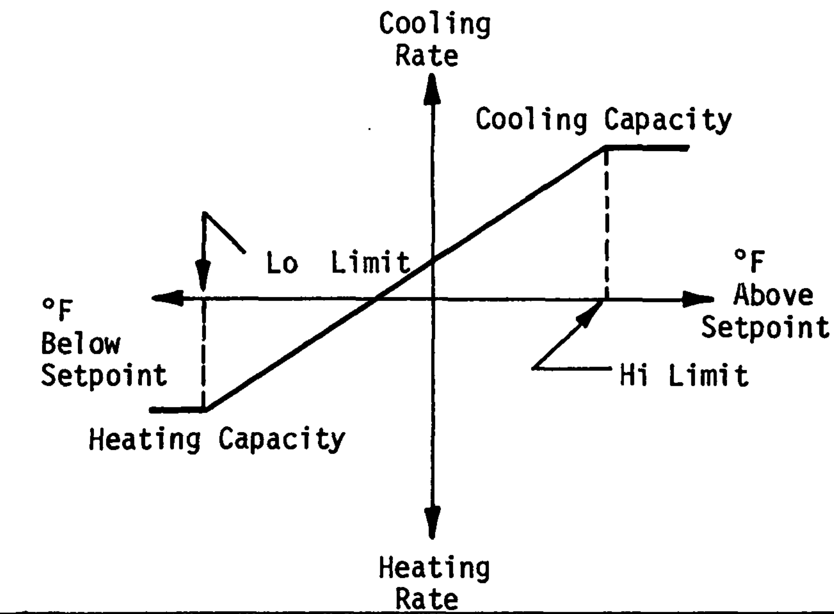
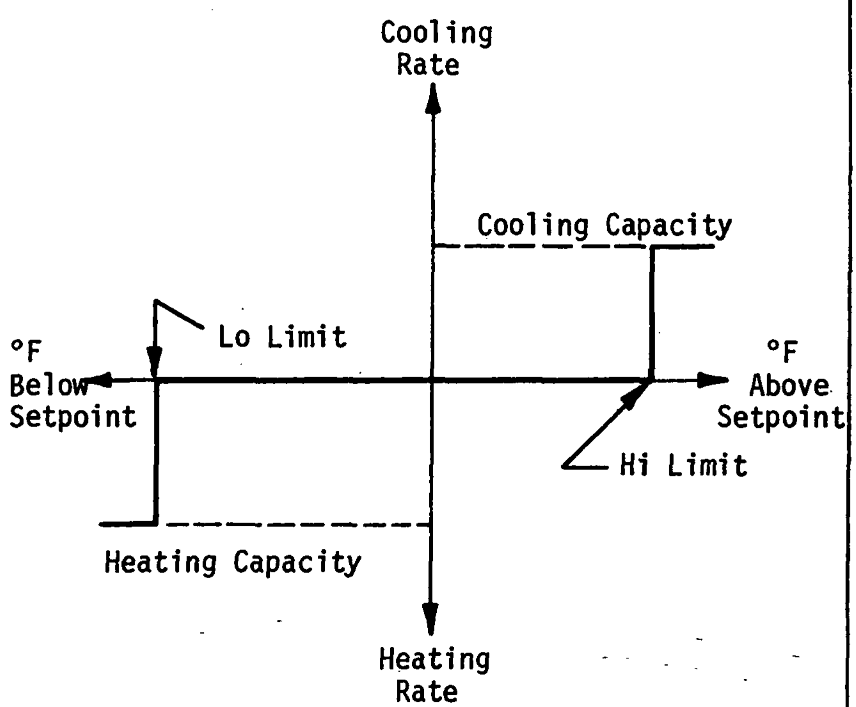
    TEMPS = (SUM4 - COOL)/SUM5

- Go to calculation (10v).

t) Analysis for a Type 2 thermostat (hi-low or on-off control) (see Table 4.1). This thermostat supplies no heating or cooling between the high and low limits. If the limits are hit, the extraction rate (+ or -) at that temperature is calculated and compared to the heating or cooling capacity of the space. If the space capacity is exceeded, the temperature is allowed to float the necessary amount to satisfy heat balance equation.

Table 4.1

TYPES OF THERMOSTATS

TYPE	DESCRIPTION	ACTION
1	LINEAR OR PROPORTIONAL CONTROL	
2	HI-LOW OR ON-OF CONTROL	

- Calculate space temperature deviation from TSPAC(I) that exists at end of hour.

  TEMPS = SUM4/SUM5

- Initialize heat extraction rate.

  HE = 0.0

- Check if lower thermostat temperature limit is exceeded and if so, reset TEMPS and HE.

  If TEMPS < TL, set

  TEMPS = TL

  HE = SUM4 - TEMPS * SUM5

- Check if space heating capacity has been exceeded and if so, reset TEMPS and HE.

  If |HE| > HEAT, set

  TEMPS = (SUM4 + HEAT)/SUM5

  HE = -HEAT

- Check if high thermostat temperature limit is exceeded and if so, reset TEMPS and HE.

  If TEMPS > TH, set

  TEMPS = TH

  HE = SUM4 - TEMPS * SUM5

- Check if space cooling capacity has been exceeded and if so, reset TEMPS and HE.

  If |HE| > COOL, set

  TEMPS = (SUM4 - COOL)/SUM5

  HE = COOL

- Go to calculation (10v).

u) Analysis for a Type 0 thermostat (floating control or no thermostat at all). This will be simulated using a Type 2 thermostat analysis, but with high and low limit set at extremely large values.

- Set limit values at quantities that will never be exceeded.

  TL = -1.0E10

  TH = 1.0E10

- Zero out space heating and cooling capacities.

  HEAT = 0.0

  COOL = 0.0

- Proceed to calculation (10t).

v) Store space end-of-hour temperature deviation for use next hour.

   ETEMP(I,1) = TEMPS

w) Calculate end-of-hour space temperature.

   STEMP = TEMPS + TSPAC(I)

x) Write out space data onto output tape.

IDUMY	-	space number
HE	-	system sensible load, Btu/hr
HLAT	-	system latent load, Btu/hr
ZERO	-	plenum return air load
SPOW	-	space power consumption, KW
ZERO	-	sensible infiltration load, Btu/hr
QLINF	-	latent infiltration load, Btu/hr
STEMP	-	resulting space temperature, ^{o}F
UCFM	-	CFM being circulated through a plenum space when fan is operating.

y) Keep track of space maximum heating and cooling rates and their time of occurrence.

- Maximum heating check

  If SMH(I) > HE , reset maximum

SMH(I) = HE

ITSMH(I,1) = ITIME

ITSMH(I,2) = IDAY

ITSMH(I,3) = MONTH

- Maximum cooling check

  If SMC(I) < HE, reset maximum

  SMC(I) = HE

  ITSMC(I,1) = ITIME

  ITSMC(I,2) = IDAY

  ITSMC(I,3) = MONTH

z) Keep track of maximum and minimum space temperatures and their time of occurrence.

- Lowest space temperature check

  If SLT(I) > STEMP, reset minimum

  SLT(I) = STEMP

  ITSLT(I,1) = ITIME

  ITSLT(I,2) = IDAY

  ITSLT(I,3) = MONTH

- Highest space temperature check

  If SHT(I) < STEMP, reset maximum

  SHT(I) = STEMP

  ITSHT(I,1) = ITIME

  ITSHT(I,2) = IDAY

  ITSHT(I,3) = MONTH

aa) Update consumption totals for building.

If HE < 0.0, THEAT = THEAT + HE * MULT(I)

If HE > 0.0, TCOOL + HE * MULT(I)

bb) END OF SPACE LOOP

cc) END OF HOUR LOOP

11. Write final report. See Figure 4.1.

NOTE: For further information on the algorithms contained within the Variable Temperature Program refer to the following additional references.

1. K. Kimura, "Simulation of Cooling and Heating Loads Under Intermittent Operation of Air Conditioning, ASHRAE Semiannual Meeting, New Orleans, January 1972.

2. G. Mitalas and D. Stephenson, "Room Thermal Response Factors", ASHRAE Semiannual Meeting, Detroit, January 1967.

3. ASHRAE Handbook of Fundamentals, Chapter 22, Air Conditioning Cooling Loads Part II - Extension of Cooling Load Calculation For Intermittent and Variable Operating Conditions, P. 425, 1972.

SECTION 5
SYSTEM AND EQUIPMENT SIMULATION PROGRAM

5.1 OBJECTIVE AND DESCRIPTION

Due to outside air requirements and the limitations imposed by various component control schedules, the hourly heating and cooling requirements of a building's boilers and chillers may differ markedly from the summation of hourly heating and cooling space loads. The System and Equipment Simulation Program, therefore, performs two functions. First, it translates hourly space loads, including the ventilation air requirements, by means of the individual performance characteristics of each fan system, into the hourly thermal requirements imposed upon the heating and cooling plants. Second, it converts these hourly thermal requirements into energy requirements based upon the part-load characteristics of the heating and cooling plant equipment.

The System and Equipment Simulation Program is made up of a number of functions and subroutines. (See Table 5.1 for a description of these routines.) The main routine, SYSIM, directs the flow of logic through the program and controls the order in which calculations are to be performed. The sequence of the calculations is as follows. First, the zone air flows are determined using the peak hourly heating and cooling zone loads. Next, fans and fan motors are sized based on air flows and system pressures. In this segment, central equipment is also sized. Then, an hour-by-hour analysis of the building's energy distribution systems is performed. Each system is examined each hour and the hourly heating and/or cooling loads calculated and summed to give the building's heating and/or cooling requirements. At the end of an hour's calculations, after the last thermal distribution system has been examined and any snow-melting load accounted for, the EQUIP subroutine is called upon to convert the hourly building thermal requirements into hourly heating, cooling and on-site generation (if applicable) energy requirements. This series of calculations is repeated hourly for the length of time called for (up to 1 year). The output is organized in terms of monthly energy and resource requirements for the building equipment combination in question. An annual summary of the energy and resource consumption is then printed out as a permanent record.

The sequence of calculations outlined above is the same for a heat conservation equipment combination, except that: 1) zone air flows are sized differently, 2) other supplemental heating requirements must be accounted for, and 3) specialized treatment of the double-bundled condenser refrigeration machines is necessary.

In order to follow the notations of the engineering manual, an understanding of variable organization as it pertains to zone labeling is required (see Figure 5.1). The re-numbering of zones internally by the program has resulted in increased flexibility to the user and a reduction of computer storage requirements. As regards assigning zones to energy distribution systems, the user need not be concerned with zone sequence when generating the load tape. They may be specified in any order. Zones may be omitted or repeated.

Regarding the program structure, a storage requirement savings is realized since variables which were once doubly-subscripted may now be singly subscrpted. An example of this potential savings using the example of Figure 5.1 zone/system relationships is illustrated in Figure 5.2. Input tape variables ("ℓ" numbers) are assigned via variable $SPACN_{k,j}$. Each zone "j" of system "k" has a corresponding "i". Thus one doubly-subscripted variable ($SPACN_{k,j}$) is used to identify the particular "ℓ" variable location of a given zone on a given system.

LOAD PROGRAM SPACE NUMBERING	(ℓ)	1	2	3	4	5	6	7	8	9	10				
SIMULATION PROGRAM INTERNAL NUMBERING	(i)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
LOAD PROGRAM NUMBERING	($SPACN_{k,j}=\ell$)	4	10	1	3	5	5	8	7	6	2	4	6	4	3
ZONE NUMBERING	(j)	1	2	3	4	5	1	2	3	1	2	3	1	2	1
SYSTEM NUMBERING	(k)	1					2			3			4		5

Figure 5.1 SYSTEM SIMULATION PROGRAM NUMBERING ORGANIZATION w/example

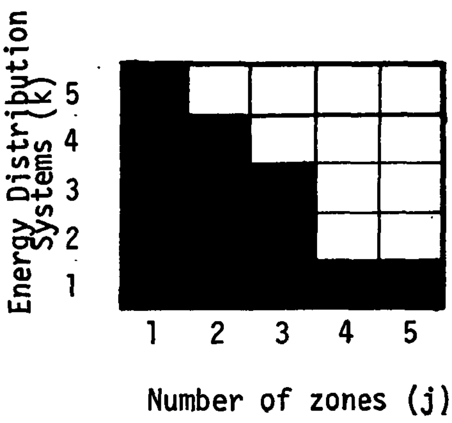


Figure 5.2 SYSTEM/ZONE MATRIX using doubly-subscripted variables (k,j)

TABLE 5.1

SYSTEM AND EQUIPMENT SIMULATION SUBROUTINES AND FUNCTIONS

NAME	FUNCTION
SYSIM	Main routine
HTCON	Heat conservation
TDATA	Reads off header data from LOAD tape
CDATA	Reads card input
FSIZE	Fan sizing
MZDD	Multi-zone and dual duct fan system simulation
SZRHT	Single-zone/sub-zone reheat fan system
FHTG2	Floor panel heating systems
FCOIL	Fancoil unit simulation (2- and 4-pipe)
INDUC	Induction unit fan system simulation (2- and 4-pipe)
VARVL	Variable volume fan system simulation
RHFS2	Simulation of: Single-zone fan system w/face and bypass dampers, Unit ventilator, Unit heater, Constant volume reheat fan system.
FANOF	Load handler when fan system is off
ZLO3	Zone load organizer: calculates reheating and recooling loads
BRAD2	Baseboard radiation simulation
AHU	Air Handling Unit simulation
MXAIR	Mixed air calculation
ECONO	Economizer cycle simulation
CCOIL	Cooling coil simulation
TRSET	Linear interpolation routine
PTLD	Part load fan power calculation
TEMP	Temperature calculation
PSYCH	Psychrometrics
PSY1	Psychrometrics
PSY2	Psychrometrics
PPWVM	Psychrometrics

TABLE 5.1 (CONT'D)

NAME	FUNCTION
ALOG1	Base 10 logarithms
HUM1	Humidity ratio calculation
DENSY	Air density calculation
ERROR	Prints error messages
MAX	Maximum value calculation
H2OZN	Zone moisture change and requirement calculation
WZNEW	Humidity ratio calculation
EQUIP	Boilers, chillers and on-site generation systems
STTUR	Steam turbine
CENT	Centrifugal water chiller
RECIP	Reciprocating water chiller
ABSOR	Steam absorption water chiller
SNOWM	Snow melting
ENGYC	Energy consumption output table

5.2 MAIN ROUTINE ALGORITHMS

The main routine of the System and Equipment Simulation Program. SYSIM controls the flow through the program. This routine is divided roughly into three sections.

- Initial Sizing. Subroutines are called to read card input data (CDATA) and to read off header data from the LOAD tape (TDATA). A third subroutine (FSIZE) is then called to size zone and system air flows. Finally, central system power consuming equipment (i.e., pumps, fans, cooling towers, motors, engine generators, steam turbines) are sized.

- Hourly Calculations. The function of this mode is to first read hourly weather data and zone loads from the LOAD tape. Secondly, the appropriate energy distribution subroutines are called to calculate energy conversion system loads (heating, cooling, water and power requirements). Thirdly, subroutine EQUIP is called to calculate resource requirements necessary to satisfy heating, cooling and power needs. An account of energy distribution and conversion system loads not met is kept and printed in this mode at the end of each month.

- Monthly summaries. The third mode indicates the activity of the program by printing a central equipment size summary and a table of energy and resource requirements (demand and consumption) for each month.

INPUT

Cards - A description of card input variables may be found in Section 6 of the User's Manual (Vol. I).

Tape - Hourly data required by the program is defined in Table 5.2. This includes both weather and zone load information.

OUTPUT

Printer - Printed output is discussed in Table 5.3. Also refer to Section 6 of the User's Manual for examples of the program's output.

COMMON

The System and Equipment Simulation Program is organized such that use of common by second-, third-, etc. order subroutines and functions is the exception rather than the norm. However, most of the variables required by first-order subroutines are located in COMMON. These variables are defined in Table 5.4.

TABLE 5.2

ORGANIZATION OF INPUT LOAD TAPE TO SYSTEM AND EQUIPMENT SIMULATION PROGRAM

On the input tape, after the header data, the following variables appear for each hour:

IHOUR	:	Hour number, hour of year
IMOY	:	Month of year
IDOM	:	Day of month
NDOW	:	Day of the week
IHOD	:	Hour of the day
ISUN	:	Sun index which indicates whether or not the sun is up (0 = sun up; 1 = sun not up)
TOA	:	Outside air dry-bulb temperature (^{o}F)
TWB	:	Outside air wet-bulb temperature (^{o}F)
VEL	:	Wind velocity (knots)
WOA	:	Outside air humidity ratio (lb water/lb dry air)
PATM	:	Barometric pressure (inches of mercury)
DOA	:	Outside air density (lbm/ft^3)
HOA	:	Enthalpy of outside air (Btu/lb dry air)
JSC	:	Day type (i.e., weekday, Saturday, Sunday, Holiday, Xmas)
CCM	:	Cloud cover modifier

For each zone, the following variables appear on the input tape:

IS	:	Space number
QS_{ℓ}	:	Zone sensible load (Btu/hr)
QL_{ℓ}	:	Zone latent load (Btu/hr)
$QLITE_{\ell}$	:	Zone lighting load picked up by return air (Btu/hr)
$SLPOW_{\ell}$	:	Zone internal lighting and machinery power consumption (KW)

TABLE 5.2 (CONT'D)

$QSINF_\ell$	:	Zone sensible infiltration load (Btu/hr)
$QLINF_\ell$	:	Zone latent infiltration load (Btu/hr)
$STEMP_\ell$	:	Zone temperature (^oF) (calculated in Variable Temperature Program)
$UCFM_\ell$	:	Air flow if zone is a ceiling plenum (ft^3/min) (calculated in Variable Temperature Program)

TABLE 5.3

OUTPUT OF SYSTEM AND EQUIPMENT SIMULATION PROGRAM

(NOTE: optional printout not covered here)

PROGRAM VARIABLE		DESCRIPTION
Input Recap		
Recapitulation of input card data		
Energy Analysis Header		
FAC	-	Building or project name
CITY	-	Location
ENGR	-	Name of user
PROJ	-	Project number
DATE	-	Date
Energy Distribution System Summary		
$FBHPS_k$	-	Supply fan brake horsepower, system k
$FBHPR_k$	-	Return fan brake horsepower, system k
$FBHPE_k$	-	Exhaust fan brake horsepower, system k
$JMAX_k$	-	Number of zones on system k
$CFMAX_k$	-	Supply air, system k (CFM)
$CFMIN_k$	-	Minimum outside air, system k (CFM)
$CFMEX_k$	-	Exhaust air, system k (CFM)
$ALPCT_k$	-	Minimum outside air percent of supply air, system k
Zone Air Flow Summary		
$CFMS_i$	-	Supply air, zone i (CFM)
$CFMX_i$	-	Exhaust air, zone i (CFM)
TSP_i	-	Set point temperature, zone i (^oF)

TABLE 5.3 (CONT'D)

PROGRAM VARIABLE		DESCRIPTION
Loads Not Met		
$QCLNM_i$	-	Monthly accumulation of cooling loads not met, zone i (MBTU)
$QCPNM_i$	-	Peak cooling load not met, zone i (MBH)
$IHCNM_i$	-	Number of hours in month cooling load not met, zone i
$QHLNM_i$	-	Monthly accumulations of heating loads not met, zone i (MBTU)
$QHPNM_i$	-	Peak heating load not met, zone i (MBH)
$IHHNM_i$	-	Number of hours in month heating load not met, zone i
QRCNM	-	Monthly accumulation of central cooling system loads not met due to undersized equipment (MBTU)
QRCNM	-	Peak central cooling system load not met (MBH)
IHRNM	-	Number of hours in month central cooling system load not met
QBCNM	-	Monthly accumulations of boiler loads not met due to undersized equipment (MBTU)
QBPNM	-	Peak boiler load not met (MBH)
IHBNM	-	Number of hours in month boiler load not met

NOTE: Loads not met are tabulated only once (i.e., zone loads not met are not carried over into central equipment loads not met).

TABLE 5.3 (CONT'D)

PROGRAM VARIABLE		DESCRIPTION
Summary of Equipment Sizes		
NUMC	:	Number of chillers
SZC	:	Size of chillers (tons)
NUMB	:	Number of boilers
SZB	:	Size of boilers (MBH)
NUMT	:	Number of steam turbines
SZT	:	Size of steam turbines (HP)
M4	:	Number of on-site generation engines
SZE	:	Size of on-site generation engines (KW)
CAPH	:	Total heating capacity (MBH)
CAPC	:	Total cooling capacity (tons)
CFMCT	:	Cooling tower air flows (CFM)
HPCTF	:	Horsepower of cooling tower fan motor (HP)
HPBLA	:	Horsepower of boiler auxiliaries (HP)
GPMCL	:	Chilled water flow (gpm)
HPCLP	:	Chilled water pump horsepower (HP)
GPMCN	:	Condenser water flow (gpm)
HPCNP	:	Condenser water pump horsepower (HP)
GPMBL	:	Boiler water flow (gpm)
HPBLP	:	Boiler water pump horsepower (HP)

TABLE 5.3 (CONT'D)

PROGRAM VARIABLE		DESCRIPTION
ENGY	:	Monthly resource consumptions and demands. A 12 x 2 x 18 matrix with indices defined as indicated below. This variable is transferred to subroutine ENGYC where the monthly tabulation is printed. FIRST SUBSCRIPT: MONTH 1 is January 2 is February 3 is March 4 is April 5 is May 6 is June 7 is July 8 is August 9 is September 10 is October 11 is November 12 is December SECOND SUBSCRIPT: MODE OF ENERGY 1 is Demand 2 is Consumption THIRD SUBSCRIPT: TYPE OF ENERGY 1 is Maximum monthly heating 2 is Maximum monthly cooling 3 is Electric, internal lights and building equipment 4 is Electric, external lights 5 is Electric heat (boiler and auxiliaries, and hot water pumps) 6 is Electric cool (chillers, chilled water pumps, and cooling tower fan) 7 is Gas heat 8 is Gas cooling 9 is Gas generation 10 is Steam heat 11 is Steam cooling 12 is Oil heat 13 is Oil cooling 14 is Diesel fuel generation 15 and 16 not used 17 is City water 18 is Fan power

TABLE 5.4
DEFINITION OF
VARIABLES IN COMMON

IPRT1	-	Optional print flag-1
IPRT2	-	Optional print flag-2
IPRT3	-	Optional print flag-3
KO	-	Line printer unit number
IC	-	Card reader unit number
IT	-	Input tape unit number
IBOIL	-	Boiler on/off flag (1=on; 0=off)
ICHIL	-	Chiller on/off flag (1=on; 0=off)
IFAN	-	Fan system shut-off flag (0=fans run continuously, 1=fans may be shut off) 2=fans and baseboard radiators may be shut off)
QS_{ℓ}	-	Zone sensible load (Btu/hr)
QL_{ℓ}	-	Zone latent load (Btu/hr)
$QLITE_{\ell}$	-	Light heat into ceiling plenum above zone (Btu/hr)
$SLPOW_{\ell}$	-	Space light and power (KW)
$QSINF_{\ell}$	-	Zone sensible loss due to infiltration (Btu/hr)
$QLINF_{\ell}$	-	Zone latent loss due to infiltration (Btu/hr)
$STEMP_{\ell}$	-	Space temperature at a given hour (^oF)
$UCFM_{\ell}$	-	Air flow through zone if it is a plenum space (ft^3/min)
TSP_{ℓ}	-	Zone set point temperature (^oF)
VOL_{ℓ}	-	Zone volume (ft^3)
TOA	-	Outside air dry-bulb temperature (^oF)
WOA	-	Outside air humidity ratio $(\frac{lbm\text{-}H20}{lbm\text{-}dry\ air})$
HOA	-	Outside air enthalpy (Btu/lbm)
DOA	-	Outside air density (lbm/ft^3)
PATM	-	Barometric pressure (in.Hg.)
TCO	-	Changeover temperature (^oF)
KBLDG	-	Heat conservation building flag
KMAX	-	Number of energy distribution systems
IZNMX	-	Number of zones to be studied
MSTRT	-	Month in which study begins

TABLE 5.4 (CONT'D)

NDAYS	-	Length of study (days)
MEND	-	Last month of study
$IMAX_m$	-	Number of hours in month m (m = 1,12)
$KFAN_k$	-	Energy distribution system index
$JMAX_k$	-	Number of zones on system k
$CFMAX_k$	-	Design supply air of system k (ft^3/min)
$CFMEX_k$	-	Exhaust air, system k (ft^3/min)
$ALFAM_k$	-	Minimum fraction outside air, system k
OACFM	-	Minimum ventilation air, system k (ft^3/min)
$RHSP_k$	-	Relative humidity set point, system k (% R.H.)
WSP_k	-	Humidity ratio set point, system k ($\frac{lbm\text{-}H2O}{lbm\text{-}dry\ air}$)
$DAVE_k$	-	Average air density, system k (lbm/ft^3)
WRA_k	-	Return air humidity ratio, system k ($\frac{lbm\text{-}H2O}{lbm\text{-}dry\ air}$)
DRA_k	-	Return air density, system k (lbm/ft^3)
$PWGAL_k$	-	Process water volume, system k (gals)
$FMASS_k$	-	Supply air mass, system k (lbm-air/hr)
$FMASR_k$	-	Return air mass, system k (lbm-air/hr)
$FMASX_k$	-	Exhaust air mass, system k (lbm-air/hr)
$TFNPS_k$	-	Total supply fan pressure, system k (inches)
$TFNPR_k$	-	Total return fan pressure, system k (inches)
$TFNPE_k$	-	Total exhaust fan pressure, system k (inches)
$FBHPS_k$	-	Supply fan brake horsepower, system k (bhp)
$FBHPR_k$	-	Return fan brake horsepower, system k (bhp)
$FBHPE_k$	-	Exhaust fan brake horsepower, system k (bhp)
$DTFNS_k$	-	Air temperature rise across supply fan, system k, at full load (°F)
$DTFNR_k$	-	Air temperature rise across return fan, system k, at full load (°F)
$MXAO_k$	-	Mixed air option, system k
$IVVRH_k$	-	Variable volume reheat option, system k

TABLE 5.4 (CONT'D)

$ICZN_k$	-	Zone in which humidistat is located, system k, (a "j" number)
$ITMPC_{k,1}$	-	Air temperature control mode, system k
$ITMPC_{k,2}$	-	Air temperature control mode, system k
$NVFC_k$	-	Type of fan damper control, system k
$VVMIN_k$	-	Minimum air flow through variable volume boxes, system k
$TCOFC_k$	-	Two-pipe induction unit fan system changeover temperature or floor panel heating system hot water shut-off temperature, system k (^oF)
$TFIX1_k$	-	Fixed hot deck or AHU discharge temperature, system k (^oF)
$TFIX2_k$	-	Fixed cold deck temperature, system k (^oF)
$RIPA_k$	-	Ratio of induced to primary air, system k
CFM_i	-	Supply air flow rate, zone i (constant)(cu ft/min)
$CFMS_i$	-	Supply air flow rate, zone i (variable) (cu ft/min)
$CFMR_i$	-	Return air flow rate, zone i (cu ft/min)
$CFMX_i$	-	Exhaust air flow rate, zone i (cu ft/min)
$ZMASS_i$	-	Supply air mass flow, zone i (constant)(lbm-air/hr)
$ZMAS_i$	-	Supply air mass flow, zone i (variable)(lbm-air/hr)
$ZMASR_i$	-	Return air mass flow, zone i (lbm-air/hr)
$ZMASX_i$	-	Exhaust air mass flow, zone i (lbm-air/hr)
QSI_i	-	Sensible heating load, zone i (Btu/hr)
TS_i	-	Supply air temperature, zone i (^oF)
WZ_i	-	Calculated humidity ratio, zone i (lbm-H2O/lbm-dry air)
$WREQD_i$	-	Required humidity ratio , zone i (lbm-H_2O/lbm-dry air)
$ALFBR_i$	-	Active length baseboard radiation, zone i (lin.ft)
$CBTU_i$	-	Baseboard radiation heat output per linear foot at standard conditions, zone i (Btu/hr-lin.ft)
$QCLNM_i$	-	Monthly accumulation of cooling loads not met, (zone i) * $MULT_i$ (Btu)
$QCPNM_i$	-	Monthly peak cooling load not met, zone i (Btu/hr)
$IHCNM_i$	-	Number of hours cooling load not met, zone i (hrs)
$QHLNM_i$	-	Monthly accumulation of heating loads not met,(zone i)* $MULT_i$ (Btu)

TABLE 5.4 (CONT'D)

$QHPNM_i$	-	Monthly peak heating load not met, zone i (Btu/hr)
$IHHNM_i$	-	Number of hours heating load not met, zone i (hrs)
$IPLEN_i$	-	LOAD program space number of plenum above zone i
$SPACN_{k,j}$	-	Number of space as per LOAD program, applied to system k, zone j
$MULT_i$	-	Multiplication factor,zone i
I	-	Variable subscript i
$TOALO_n$	-	Low outside air temperature at which system temperature is THI_n, reset schedule n (^oF)
$TOAHI_n$	-	High outside air temperature at which system temperature is TLO_n, reset schedule n (^oF)
TLO_n	-	Low system fluid temperature, reset schedule n (^oF)
THI_n	-	High system fluid temperature, reset schedule n (^oF)
$ISET_{k,m}$	-	Reset temperature schedule index, system k, reset item m (an "n" number) ("m" is defined in Table 6.4, User Manual)
TFBHP	-	Total fan brake horsepower (bhp)
EFF	-	Pump and fan motor efficiency
$PLOC_k$	-	Location of floor heating panels, system k
$PAREA_k$	-	Floor area covered by heating panels, system k (ft^2)
$PERIM_k$	-	Exposed perimeter of floor, system k (lin.ft)
KFLCV	-	Type of floor covering (1=bare concrete; 2=tile; 3=carpeting)
CINSL	-	Floor insulation conductance (Btu/hr-sq-ft-^oF)
DINSL	-	Floor insulation thickness (ft)
TLCHL	-	Chilled water set point temperature (^oF)
TPS	-	Steam turbine entering steam temperature (^oF)
PPS	-	Steam turbine entering steam pressure (psig)
TESTM	-	Boiler supply and absorption chiller entering steam temperature (^oF)
PESTM	-	Boiler supply and absorption chiller entering steam pressure (psig)
SZT	-	Steam turbine size (hp)

TABLE 5.4 (CONT'D)

NUMT	-	Number of steam turbines
RPM	-	Steam turbine speed (rpm)
SZE	-	Engine/Generator set size (KW)
FFLMN	-	Minimum part load cut-off for chillers
KREHT	-	Source of reheat coil energy
HVDF	-	Heating value of diesel fuel (Btu/gal)
HVHO	-	Heating value of heating oil (Btu/gal)
CFMBN	-	Building total minimum outside air (cu ft/min)
CFMBX	-	Building total design load supply air (cu ft/min)
CFMBE	-	Building total exhaust air (cu ft/min)
PWBIL	-	Building peak base power load (KW)
PWOL	-	Power of external lighting (KW)
TLCNM	-	Maximum allowable condenser water temperature (^oF)
TLCMN	-	Well or city water design return water temperature (^oF)
TCWIN	-	City water supply temperature (^oF)
TWWIN	-	Well water supply temperature (^oF)
TECMN	-	Cooling tower water low limit temperature (^oF)
HDCLP	-	Total chilled water pump head (ft)
HDCNP	-	Total condenser water pump head (ft)
HDBLP	-	Total boiler water pump head (ft)
HDWWP	-	Total well water pump head (ft)
GPMCL	-	Chilled water flow rate (gpm)
GPMCN	-	Condenser water flow rate (gpm)
GPMBL	-	Boiler water flow rate (gpm)
GPMWW	-	Well water flow rate (gpm)
HPCLP	-	Chilled water pump power (bhp)
HPCNP	-	Condenser water pump power (bhp)

TABLE 5.4 (CONT'D)

HPBLP	-	Boiler water pump power (bhp)
HPWWP	-	Well water pump power (bhp)
HPCTF	-	Cooling tower fan power (bhp)
HPBLA	-	Boiler accessory power (bhp)
CFMCT	-	Cooling tower air flow (cu ft/min)
IHSRT	-	Hour of year at which simulation may begin
IHSTP	-	Hour of year at which simulation may end
NCASE	-	Number of cases to be run
NRSET	-	Number of reset schedules to be read
KHCST	-	Heat conservation system flag
NUMB	-	Number of boilers
SZB	-	Size of each boiler (MBH)
BON	-	Hour of seasonal boiler start-up (hour of year)
BOFF	-	Hour of seasonal boiler shut-down (hour of year)
NUMC	-	Number of chillers
SZC	-	Size of each chiller (tons)
CON	-	Hour of seasonal chiller start-up (hour of year)
COFF	-	Hour of seasonal chiller shut-down (hour of year)
KSNOW	-	Type of snow melting system
QSNOW	-	Snow melting system design load (Btu/hr)
SAREA	-	Snow melting slab area (sq ft)
$ASYS_{nc}$	-	System identification number, run nc
$ABLDG_{nc}$	-	Heat conservation flag (1=no; 2=yes), run nc
$AM1_{nc}$	-	Type of chiller, run nc
$AM2_{nc}$	-	Source of chiller energy, run nc
$AM3_{nc}$	-	Source of general heating energy, run nc
$AREHT_{nc}$	-	Source of reheat coil energy, run nc

TABLE 5.4 (CONT'D)

$AM6_{nc}$	-	Type of auxiliary chiller, run nc
$AM7_{nc}$	-	Type of supplemental heat, run nc
$AM4_{nc}$	-	Number of engine/generator sets, run nc
$AM5_{nc}$	-	Type of engine/generator set, run nc
QRCNM	-	Monthly accumulation of chiller loads not met due to undersizing (MBTU)
QRPNM	-	Monthly peak chiller load not met (MBH)
IHRNM	-	Number of hours chiller load not met
QBCNM	-	Monthly accumulation of boiler loads not met due to undersizing (Btu)
QBPNM	-	Monthly peak boiler load not met (Btu)
IHBNM	-	Number of hours boiler load not met

CALCULATION SEQUENCE

1. Call subroutine CDATA to read and recap card input data.

2. Call subroutine TDATA to read off input tape header data stopping before hourly weather and building load information is encountered.

3. Read daily snowfall data, if snow-melting system is used.

4. Call subroutine FSIZE to calculate the following quantities:

PWBIL	: Peak building base power (KW)
CFM_i	: Peak supply air volume for zone i (CFM)
$CFMR_i$	: Return air volume for zone i (CFM)
$CFMAX_k$	: Total air supplied by fan system k
$CFMEX_k$	: Auxiliary exhaust air removed from zones served by system k (CFM)
$CFMIN_k$	: Minimum outside air required for fan system k (CFM)
$ALFAM_k$	: Percent of minimum outside air required for fan system k
$OACFM_k$	: Minimum outside air for system k
DRA_k	: Initialize return air density for system k
WRA_k	: Initialize return air humidity ratio, system k (lbm-H_2O/lbm-dry air)
$FBHPS_k$	: Supply fan brake horsepower required for fan system k (bhp)
$FBHPR_k$	: Return fan brake horsepower required for fan system k (bhp)
$FBHPE_k$	: Exhaust fan brake horsepower required for fan system k (bhp)
TFBHP	: Summation of fan brake horsepowers for all systems (bhp)

$DTFNS_k$: Temperature rise across supply fan, system k

$DTFNR_k$: Temperature rise across return fan, system k

$ZMAS_i$: Supply air mass flow to zone i at design load (lbm/hr)

$ZMASX_i$: Exhaust air mass flow from zone i (lbm/hr)

$ZMASR_i$: Return air mass flow from zone i at design load (lbm/hr)

$FMASS_k$: Total supply air mass flow of system k at design conditions (lbm/hr)

$FMASX_k$: Total exhaust air mass flow of system k (lbm/hr)

$FMASR_k$: Total return air mass flow of system k at design conditions (lbm/hr)

CFMBE : $\sum_{k=1,kmax} CFMEX_k$

CFMBX : $\sum_{k=1,kmax} CFMAX_k$

CFMBN : $\sum_{k=1,kmax} CFMIN_k$

5. Check type of system

If conventional or on-site generation, go to calculation 6.
If heat conservation, call HTCON and then go to 31.

6. Size Central Equipment

6.1 Heating and cooling capacities

CAPH = SZB * NUMB

CAPC = SZC * NUMC

SZT = SZC

NUMT = NUMC

6.2 Steam turbines (to drive centrifugal chillers).

If M1=5, determine number of steam turbines required.

NUMT = NUMC

Determine size of steam turbines required, if used, assuming 1 HP per ton of cooling.

$$SZT = SZC$$

6.3 Compute total heating capacity required.

If M1 = 4 (steam absorption chiller),

Check boiler size with steam turbine requirements for possible updating. Steam turbine requirements based upon peak cooling hour assuming 20 lbs steam per ton of cooling

$$CAPH1 = CAPC * 20.0 * 33.472/34.5$$

If CAPH < CAPH1,

$$CAPH = CAPH1$$

$$SZB = CAPH/NUMB$$

6.4 Size all pump water flows.

Chilled water flow rate (gpm)

$$GPMCL = 2.4 * CAPC$$

Condenser water flow rate (gpm)

If M1 $\neq$ 4, GPMCN = 3.0 * CAPC

If M1 = 4 (steam absorption chiller),

$$GPMCN = 3.5 * CAPC$$

Boiler water flow rate (gpm)

$$GPMBL = CAPH * 1000.0/(500.0 * 20.0)$$

6.5 Size pump motors assuming a pump efficiency of 60%.

Chilled water pump horsepower

$$HPCLP = GPMCL * HDCLP/(3962.0 * 0.6 * EFF)$$

Condenser water pump horsepower

$$HPCNP = GPMCN * HDCNP/(3962.0 * 0.6 * EFF)$$

Boiler water pump horsepower

HPBLP = GPMBL * HDBLP/(3962.0 * 0.6 * EFF)

6.6 Horsepower requirement for motors running boiler auxiliary equipment such as fans, blowers, pumps, etc. should be computed. From American Standard catalog for packaged boilers ranging in size from 20 to 750 HP, the auxiliary horsepower requirement was approximately 1/20 of the total boiler horsepower capacity; therefore

HPBLA = CAPH * 1000.0/(33472.0 * 20.0)

6.7 Size cooling tower fan.

Cooling tower air flow requirement

For all chillers except steam absorption, use 300 cfm per ton of cooling; therefore

CFMCT = 300.0 * CAPC

For steam absorption system, use 350 cfm per ton of cooling; therefore

CFMCT = 350.0 * CAPC

Cooling tower fan horsepower requirement assuming 1.0 inch water total pressure

HPCTF = CFMCT * 1.0/(6346.0 * EFF)

6.8 Sum heating and cooling equipment brake horsepower demand.

HPHEQ = HPBLA + HPBLP where HPHEQ has units of horsepower

HPCEQ = HPCTF + HPCLP + HPCNP where HPCEQ has units of horsepower

6.9 Size on-site generation plants.

Calculate maximum building electrical demand assuming all electrical equipment operating (electric resistance heating and electrically-driven compressive cooling not allowable with on-site generation).

BKWDM = PWBIL + PWOL + (TFBHP + HPCEQ + HPHEQ) * 0.7457

Calculate number and size of on-site generation units.

If M4 ≠ 0, set

NUME = M4 where NUME is number of engines.

Size of engines is then

SZE = BKWDM/NUME

If SZE > 500 KW, increase the number of engines until SZE ≤ 500 KW.

Finally, set M4 = NUME.

If M4 = 0, set

NUME = 2 where NUME is number of engines

Size of engines is then

SZE = BKWDM/NUME

If SZE > 500 KW, increase NUME until SZE ≤ 500 KW.

Finally, set M4 = NUME.

7. Begin hourly energy consumption analysis repeating calculations 7 through 14 for every hour of the analysis.

Read hourly weather data which includes:

IHOUR	: Hour number, hour of year
IMOY	: Month of year
IDOM	: Day of month
NDOW	: Day of the week
IHOD	: Hour of the day
ISUN	: Sun index which indicates whether or not the sun is up
TOA	: Outside air dry-bulb temperature (^{o}F)
TWB	: Outside air wet-bulb temperature (^{o}F)
VEL	: Wind velocity (knots)

WOA : Outside air humidity ratio (lb water/lb dry air)

PATM : Barometric pressure (inches of mercury)

DOA : Outside air density (lbm/ft^3)

HOA : Enthalpy of outside air (Btu/lb dry air)

JSC : Day type (i.e., weekday, Saturday, Sunday, holiday, Xmas)

CCM : Cloud cover modifier (0=opaque, 1=clear)

Read zone load data for all zones on tape.

IS_ℓ : Space number

QS_ℓ : Zone sensible load (Btu/hr)

QL_ℓ : Zone latent load (Btu/hr)

$QLITE_\ell$: Zone lighting load picked up by return air (Btu/hr)

$SLPOW_\ell$: Zone internal lighting and machinery power consumption (KW)

$QSINF_\ell$: Zone sensible infiltration load (Btu/hr)

$QLINF_\ell$: Zone latent infiltration load (Btu/hr)

$STEMP_\ell$: Zone temperature (^oF)

Initialize total net fan brake horsepower (TNFBP).

TNFBP = TFBHP

8. Call energy distribution systems.

Check type of fan system.

If $KFAN_k$ = 1, call RHFS2
2, call MZDD
3, call MZDD
4, call SZRHT
5, call RHFS2
6, call RHFS2
7, call FHTG2
8, call FCOIL
9, call FCOIL
10, call INDUC
11, call INDUC
12, call VARVL
13, call RHFS2

Each of the above subroutines simulates the performance of a given system and returns the following quantities:

$QFPC_k$	- system cooling requirement (Btu/hr)
$QFPH_k$	- system primary heating requirement (Btu/hr
$QFPRH_k$	- system reheat coil heating requirement (Btu/hr)
$QFPPH_k$	- system preheat coil heating requirement (Btu/hr)
TQB_k	- heating requirement of baseboard radiation in zones served by system k (Btu/hr)
$WATER_k$	- steam humidifier water requirement (lbm/hr)
PWL_k	- base power (KW)
TNFBP	- total net fan brake horsepower, all fan systems (bhp)

9. Sum building hourly cooling, heating, reheat, zone power, and water resource requirements.

$$QHBC = \sum_{k=1,kmax} QFPC_k$$

$$QHBH = \sum_{k=1,kmax} QFPH_k + QFPPH_k + TQB_k + \left(\frac{-WATER_k}{1000.0}\right)$$

$$QHBRH = \sum_{k=1,kmax} QFPRH_k$$

$$PWILM = \sum_{k=1,kmax} PWL_k$$

$$H2O = \sum_{k=1,kmax} WATER_k$$

10. Determine if cooling tower fan is operating.

If chiller is off (ICHIL=0), set KCTF=0, and go to calculation 11.

If chiller is on (ICHIL=1), assume a 7^oF approach for tower, therefore temperature of water entering condenser is

TECON = TWB + 7.0

If from previous hour,tower is on (KCTF=1), and if (TECON $\geq$ TECMN + 10), set KCTF=1; otherwise KCTF=0.

If from previous hour, tower is off (KCTF=0), and if (TECON < TECMN), set KCTF=0; otherwise KCTF=1.

11. Determine hourly electrical demand of the building (ELDEM) for on-site generation, if used.

If ISUN = 0, exterior lights are OFF; therefore, set

PWEL = 0.0

If ISUN = 1, exterior lights are ON; therefore, set

PWEL = PWOL

If cooling equipment only is ON,

ELDEM = PWILM + PWEL + (TNFBP + HPCLP + HPCNP + HDCTF * KCTF) * 0.7457

If heating equipment only is ON,

ELDEM = PWILM + PWEL + (TNFBP + HPHEQ) * 0.7457

If heating and cooling equipment are ON,

ELDEM = PWILM + PWEL + (TNFBP + HPCLP + HPCNP + HDCTF * KCTF + HPHEQ) * 0.7457

12. Check type of snow-melting system.

If KSNOW = 0, no snow-melting system. Go to calculation 13.

If KSNOW = 1 or 2, snow-melting considered.

Calculate amount of snowfall for the hour, assuming that 1/24 of the day's total fell during the hour.

SNOW = 0.1 * SNOWF(ID)/24.0

where SNOW has units of equivalent inches of water, SNOWF(ID) has units of inches of snow and ID is the day number of the year, calculated as follows:

ID = 1 + IHOUR/24

Call SNOWM subroutine which calculates QTOT, the snow-melting load.

Add QTOT to heating requirement of building.

If KSNOW = 1, liquid type snow-melting system; therefore,

QHBH = QHBH - QTOT

If KSNOW = 2, electric type snow-melting system; therefore,

ELEH = ELEH + QTOT/3413.0

13. Calculate hourly energy consumption.

    Call EQUIP which calculates the following:

    GASC
    GASH
    GASG
    OILC
    OILH
    STMC
    STMH
    ELEC
    ELEH
    FUEL
    Chiller loads not met due to undersized equipment
    Boiler loads not met due to undersized equipment

    See subroutine EQUIP algorithms for explanation of these variables

14. Keep running total of hourly energy consumption for each month. Update the following quantities each hour.

    ENGY (M,2,3)
    ENGY (M,2,4)
    ENGY (M,2,5)
    ENGY (M,2,6)
    ENGY (M,2,7)
    ENGY (M,2,8)
    ENGY (M,2,8)
    ENGY (M,2,9)
    ENGY (M,2,10)
    ENGY (M,2,11)
    ENGY (M,2,12)
    ENGY (M,2,13)
    ENGY (M,2,14)
    ENGY (M,2,15)
    ENGY (M,2,16)
    ENGY (M,2,17)
    ENGY (M,2,18)

    See subroutine ENGTG algorithms for explanation of ENGY matrix.

15. Keep a record of maximum hourly energy demands by checking, at the end of each hour's calculation, and updating the following energy demand quantities.

    ENGY (M,1,1)
    ENGY (M,1,2)
    ENGY (M,1,3)
    ENGY (M,1,4)

ENGY (M,1,5)
ENGY (M,1,6)
ENGY (M,1,7)
ENGY (M,1,8)
ENGY (M,1,9)
ENGY (M,1,10)
ENGY (M,1,11)
ENGY (M,1,12)
ENGY (M,1,13)
ENGY (M,1,14)
ENGY (M,1,15)
ENGY (M,1,16)
ENGY (M,1,17)
ENGY (M,1,18)

END OF HOURLY ANALYSIS FOR ENTIRE YEAR

16. Write out summary of equipment sizes. See Table 5.3 for list of the items printed out.

17. Call ENGYC to write out annual summary of building monthly energy consumption and demands.

18. Check to see if there is another case to be run.

    If YES, go to calculation 5 and continue.

    If NO, PROGRAM FINISHED.

5.3 ALGORITHMS OF SUBROUTINES

CDATA

A subroutine to read card input data and assign default values. See Volume I, System and Equipment Simulation Input Tables for reading order and default values of card input variables.

TDATA

A subroutine to read off load tape header data (building description information). This advances the tape to the hourly analysis data.

Building description information read in this subroutine used by the system simulation program is as follows:

Facility Name

Facility Location

Name of User

Project Number

Date

Number of zones on load tape

Volume of each zone (cu ft)

Set point temperature of each zone (°F)

Month in which analysis begins

Length of study (days)

Number of hours per month

FSIZE

A subroutine to size energy distribution system characteristics. These properties include:

- Zone peak heating and cooling loads
- Zone air flows
- Fan system air quantities and motor brake horsepower
- Fan system
- Minimum outside air percentage

INPUT

FAC	:	Name of facility
CITY	:	Name of city in which facility is located
ENGR	:	Name of user
PROJ	:	Project number
DATE	:	Date of computer run
MSTRT	:	First month on LOAD tape
MEND	:	Last month on LOAD tape
$IMAX_m$	:	Number of hours in month m
$SPACN_{k,j}$	:	Variable relating load program zone numbering with system simulation zone numbering
$MULT_j$	:	Zone duplication factor
IZNMX	:	Number of fan zones in building
VOL_ℓ	:	Volume of load program, zone ℓ, fan system k (cu ft)
QS_ℓ	:	Hourly zone sensible load, zone ℓ (Btu/hr)
QL_ℓ	:	Hourly zone latent load, zone ℓ (Btu/hr)
$QLITE_\ell$	:	Hourly zone lighting load picked up by return air, zone ℓ (Btu/hr)
$SLPOW_\ell$	:	Hourly zone internal lighting and machinery power consumption, zone ℓ (KW)
KMAX	:	Total number of fan systems within the building

INPUT (CONT'D)

$KFAN_k$	:	Type of energy distribution system, system k
TSP_ℓ	:	Set point temperature, zone ℓ (^oF)
$JMAX_k$	:	Number of zones on system k
$TFNPS_k$	:	Total supply fan pressure of system k
$TFNPR_k$	:	Total return fan pressure of system k
$TFNPE_k$	:	Total exhaust fan pressure of system k
$OACFM_k$	:	Minimum outside ventilation air of system k (cfm)
$RHSP_k$	:	Relative humidity set point of system k (% RH)
$RIPA_k$	:	Ratio of induced to primary air for induction units of system k
EFF	:	Efficiency of fan and pump motors (decimal)
KBLDG	:	Type of building system (1.-conventional; 2.-heat conservation)
$CFMX_i$	:	Auxiliary exhaust air quantity for zone i (cfm)

OUTPUT

CFM_i	:	Supply air volume required for zone i (cfm at standard density)
$CFMR_i$	:	Return air volume for zone i at standard density
$ZMASS_i$	:	Supply air mass flow of zone i (lbm/hr)
$ZMASR_i$	:	Return air mass flow of zone i (lbm/hr)
$ZMASX_i$	:	Exhaust air mass flow of zone i (lbm/hr)
$CFMAX_k$	:	Total air supplied by fan system k (cfm)
$CFMIN_k$	:	Minimum outside air required for fan system k (cfm)
$ALFAM_k$	:	Percent of minimum outside air required for fan system k (fraction)
$FBHPS_k$	:	Supply fan brake horsepower required for fan system k (bhp)

OUTPUT (CONT'D)

$FBHPR_k$: Return fan brake horsepower required for fan system k (bhp)

$FBHPE_k$; Exhaust fan brake horsepower required for fan system k (bhp)

$CFMEX_k$: $\sum_{j=1,jmax} CFMX_i$ (cfm)

WSP_k : Humidity ratio set point for system k ($lbm-H_2O/lbm$-dry air)

CFMBX : $\sum_{k=1,kmax} CFMAX_k$ (cfm)

CFMBN : $\sum_{k=1,kmax} CFMIN_k$ (cfm)

CFMBE : $\sum_{k=1,kmax} CFMEX_k$ (cfm)

PWBIL : Maximum hourly building internal lighting and machinery power consumption (KW)

$DTFNS_k$: Temperature rise across supply fan at full load, system k (^oF)

$DTFNR_k$: Temperature rise across return fan at full load, system k (^oF)

CALCULATION SEQUENCE

1. Segment One. Read through the load input tape and find the following quantities:

   $QSZCM_i$ Maximum zone sensible cooling load for each zone, i

   $QSZHM_i$ Maximum zone sensible heating load for each zone, i

   PWBIL Maximum hourly building internal lighting and machinery power consumption

2. Segment Two. Calculate zone and system peak load air quantities and system peak load power requirements for each zone within the building.

   2.1 Calculate cooling and heating temperature differences.

$$TDC = TSP_X - \frac{(TPAC_{kf} + TIAC * ARIPA_k)}{(1. + ARIPA_k)}$$

$$TDH = TSP_{\ell} - \frac{(TPAH_{kf} + TIAH * ARIPA_k)}{(1. + ARIPA_k)}$$

where TDC : terminal unit cooling design temperature difference (^oF)

TDH : terminal unit heating design temperature difference (^oF)

$ARIPA_k$: ratio of induced to primary air (equals zero for all but induction unit fan systems), system k

TIAC : design dry-bulb temperature of induced air after passing through coil, cooling mode = 62^oF

TIAH : design dry-bulb temperature of induced air after passing through coil, heating mode = 120^oF

$TPAC_{kf}$: primary air design temperature, cooling mode, for system type kf. See table below.

$TPAH_{kf}$: primary air design temperature, heating mode, for system type kf. See table below.

TABLE 5.5 HEATING & COOLING PRIMARY AIR DESIGN TEMPERATURE

SYSTEM TYPE (kf)	SYMBOL	PRIMARY AIR COOLING DESIGN (^oF)	PRIMARY AIR HEATING DESIGN (^oF)	INDUCED AIR HEATING (^oF)	INDUCED AIR COOLING (^oF)
1	SZFB	55.	120.	-	-
2	MZS	55.	120.	-	-
3	DDS	55.	120.	-	-
4	SZRH	52.	95.	-	-
5	UVT	55.	120.	-	-
6	UHT	55.	120.	-	-
7	FPH	0.	0.	-	-
8	2PFC	55.	110.	-	-
9	4PFC	55.	110.	-	-
10	2PIU	53.	53.	120.	62.
11	4PIU	53.	53.	120.	62.
12	VAVS	55.	120.	-	-
13	RHFS	55.	120.	-	-

2.2 Calculate zone supply air quantities

If $\left|\frac{QSZCM_i}{TDC}\right| < \left|\frac{QSZHM_i}{TDH}\right|$,

$$CFM_i = \frac{QSZHM_i}{(0.245*0.075*60.*TDH)(1.+ARIPA_k)}$$

If $\left|\frac{QSZHM_i}{TDH}\right| < \left|\frac{QSZCM_i}{TDC}\right|$,

$$CFM_i = \frac{QSZHM_i}{(0.245*0.075*60.*TDC)(1.+ARIPA)}$$

If $CFMX_i > CFM_i$

$$CFM_i = CFMX_i$$

2.3 Calculate zone return air

$$CFMR_i = CFM_i - CFMX_i$$

2.4 Sum system supply and exhaust air flows

$$CFMAX_k = \sum_{j=1,jmax} CFM_i^{**}$$

$$CFMEX_k = \sum_{j=1,jmax} CFMX_i^{**}$$

2.5 Average system temperature -$TAVE_k$

$$TAVE_k = \frac{\sum_{j=1,jmax} (CFM_i * TSP * MULT_i)}{\sum_{j=1,jmax} (CFM_i * MULT_i)}$$

2.6 Minimum outside air fraction - $ALFAM_k$

If $CFMEX_k < OACFM_k > CFMAX_k$,

$$CFM_i = CFM_i * (OACFM_k/CFMAX_k)$$

$$CFMAX_i = OACFM_k$$

$$ALFAM_k = OACFM_k/CFMAX_k = 1.0$$

** NOTE: There is a corresponding j for each i; a relationship defined by the variable $SPACN_{k,j}$.

If $CFMEX_k < OACFM_k < CFMAX_k$,

$$ALFAM_k = OACFM_k / CFMAX_k$$

If $CFMEX_k > OACFM_k < CFMAX_k$,

$$OACFM_k = CFMEX_k$$

$$ALFAM_k = CFMEX_k / CFMAX_k$$

2.7 Calculate fan power.

Supply Fan:

$$FBHPS_k = \frac{CFMAX_k * TFNPS_k}{6346 * EFF}$$

Return Fan:

$$FBHPR_k = \frac{(CFMAX_k - CFMEX_k) * TFNPR_k}{6346 * EFF}$$

Exhaust Fan:

$$FBHPE_k = \frac{CFMEX_k - TFNPE_k}{6346 * EFF}$$

2.8 Sum building fan power

$$TFBHP = \sum_{j=1,kmax} (FBHPS_k + FBHPR_k + FBHPE_k)$$

2.9 Calculate temperature rise across fans at full load

Supply Fan:

$$DTFNS_k = \frac{(TFNPS * 0.4014)}{(0.245 * 0.075 * 60.0)}$$

Return Fan:

$$DTFNR_k = \frac{(TFNPR_k * 0.4014)}{(0.245 * 0.075 \quad 60.0)}$$

2.10 Calculate mass flows

Zones:

$$ZMASS_i = CFM_i * 0.075 * 60.0$$

$$ZMASX_i = CFMX_i * 0.075 * 60.0$$

$ZMASR_i = ZMASS_i - ZMASY_i$

Systems:

$FMASS_k = CFMAX_k * 0.075 * 60.0$

$FMASX_k = CFMEX_k * 0.075 * 60.0$

$FMASR_k = FMASS_k - FMASX_k$

3. Segment Three. Write FSIZE information.

3.1 For each fan system, write out the following:

K
FAN_{kf}
$FBHPS_k$
$FBHPR_k$
$FBHPE_k$
$JMAX_k$
$CFMAX_k$
$CFMIN_k$
$CFMEX_k$
$ALFAM_k$

3.2 For each zone, write out the following:

k
j
λ
$MULT_i$
CFM_i
$CFMX_i$
TSP_λ

MZDD

A subroutine to simulate the performance of a multi-zone or dual duct fan system.

INPUT

K - Energy distribution system number

Various items held in COMMON (see Table 5.4 for definitions of variables in COMMON).

OUTPUT

QCC - Cooling coil load (Btu/hr)

QHC - AHU heating coil load (Btu/hr)

QRHC - Reheat coil load (Btu/hr)

QPHC - Preheat coil load (Btu/hr)

TQB - Baseboard heating load (Btu/hr)

WATER - Steam humidification supplied at air handling unit (lbm-H_2O/hr)

BPKW - Base power (KW)

TNFBP - Total net [updated] fan brake horsepower (bhp)

Various items held in COMMON.

CALCULATION SEQUENCE

1. Fan off/on check.

   Using subroutine FANOF, determine whether the fan has been turned off for the current hour.

   If the system is off, terminate MZDD simulation for the current hour.

   If the system is on, continue.

2. Identify sensible thermal load of each zone on this system.

$$QSI_i = QS_\ell{}^{**}$$

3. Baseboard radiation.

If boiler on, call subroutine BRAD2 to calculate baseboard radiation heat (QB_j) and to adjust QSI_i for QB_j.

Sum baseboard radiation heat,

$$TQB = \sum_{j=1,jmax} QB_j$$

If boiler off, continue.

4. Calculate base power (KW); includes internal power, lights receptacles, equipment, misc.

$$BPKW = \sum_{j=1,jmax} SLPOW_\ell * MULT_i{}^{**}$$

5. System and zone mass flows remain constant.

$$FMAS_k = \sum_{j=1,jmax} ZMASS_i * MULT_i$$

$$FMR_k = \sum_{j=1,jmax} ZMASR_i * MULT_i$$

6. Calculate return air temperature (TRA_k).

NOTE: Since the System and Equipment Simulation Program is capable of using LOAD or VARIABLE TEMPERATURE tapes as input, the following logic sequence is required.

If ceiling plenum is calculated as a separate zone,

If LOAD tape is used,

$$DTL2_i = 0.$$

$$QLITI = QLITE_\ell + QS_{p\ell} + QLITE_{p\ell} + QSINF_{p\ell}{}^{**}$$

If VARIABLE TEMPERATURE tape is used,

$$DTL2_i = STEMP_{p\ell} - TSP_\ell$$

$$QLITI = QLITE_\ell$$

**There is a corresponding ℓ for each i; a relationship defined by the variable $SPACN_{k,j}$. Hence, i and ℓ are defined by system number (k) and zone number(j). See Para. 5.1 for zone labeling organization.

If ceiling plenum is not calculated as a separate zone,

$$DTL2_i = 0.$$

$$QLITI = QLITE_\ell$$

$$DTL_i = QLITI/(0.245 * \overline{ZMASR_i})$$

$$TRA_k = \frac{\sum_{j=1,jmax} (TSP\ell + DTL_i + DTL2_i) * ZMASR_i * MULT_i}{\sum_{j=1,jmax} ZMASR_i * MULT_i} + DTFNR_k$$

where $DTL2_i$ - difference between zone and plenum temperatures as calculated by VARIABLE TEMPERATURE program.

QLITI - thermal load of plenum $p\ell$ above zone ℓ as calculated by LOAD program.

$p\ell$ - LOAD program space number of plenum above zone ℓ.

7. Calculate required supply air temperature of each zone.

$$TS_i = TSP\ell - QSI/(0.245 * ZMASS_i)$$

8. Calculate zone humidification requirements.

Using subroutine H2OZN, calculate total moisture requirements including set point recovery load ($H2OAD_i$) and moisture changes in current hour due to environmental and room effects ($H2OAD_i$).

9. Calculate hot deck and cold deck air temperatures. Generally, three control options are available:

   1. Fixed settings for both hot and cold decks.

   2. Fixed cold deck temperature but allowing hot deck temperature to vary inversely with outside air temperature.

   3. Reset temperature control as governed by the spaces. Control for this mode involves setting the hot deck leaving air temperature equal to that of air supplied to the space requiring warmest air. The cold deck leaving air temperature is set equal to the temperature of air supplied to the space requiring coolest air.

Call subroutine TEMP to calculate hot and cold deck leaving air temperatures (THC and TCC).

10. Calculate desired economizer approach temperature entering supply fan.

$$EAT = TCC - DTFNS_k$$

11. Calculate mixed air conditions.

Call subroutine MXAIR to simulate the performance of:

1. Fixed outside and return air dampers.
2. An enthalpy/temperature type economizer cycle.

or

3. A temperature type economizer cycle.

Subroutine MXAIR also calculates the thermal properties (temperature, humidity ratio, and density) of the mixed air stream.

12. Calculate preheat coil load by comparing to mixed air temperature desired.

If boiler on,

If TMA < EAT,

$$QPHC = 0.245 * FMASS_k * (TMA-EAT)$$

$$TMABF = EAT$$

If TMA $\geq$ EAT,

$$QPHC = 0.$$

$$TMABF = TMA$$

(TMABF = temperature of mixed air before fan (^{o}F))

If boiler off,

$$QPHC = 0.$$

$$TMABF = TMA$$

13. Calculate mixed air temperature after supply fan.

$$TMAAF = TMABF + DTFNS_k$$

14. Check boiler and chiller operation to update deck temperatures.

If chiller off,

$$TCC = TMAAF$$

If boiler off,

$$THC = TMAAF$$

15. Calculate air mass through hot and cold decks.

15.1 Calculate fraction of cold deck air required by zone.

$PCTC_i = (THC - TS_i)/(THC - TCC)$

If $PCTC_i \leq 0.0$, heating load not met.

$PCTC_i = 0.$

$QLNM_i = 0.245 * ZMASS_i * (THC - TS_i)$ ($QLNM_i$=load not met)

Update as required the following variables:

$QHLNM_i$ -

$QHPNM_i$ -

$IHHNM_i$ -

$TS_i = THC$

IF PCTC > 1.0, cooling load not met.

$QLNM_i = 0.245 * ZMASS_i * (TCC - TS_i)$

Update as required the following variables:

$QCLNM_i$ -

$QCPNM_i$ -

$IHCNM_i$ -

$TS_i = TCC.$

16. Sum cold and hot deck mass flows.

$$CMASS = \sum_{j=1,jmax} ZMASS_i * PCTC_i$$

$$HMASS = FMASS_k - CMASS$$

17. Calculate heating coil load.

$$QHC = HMASS * 0.245 * (TMAAF - THC)$$

$$WHC = WMA$$

18. Calculate cooling coil load.

Call subroutine CCOIL to calculate cooling coil load (QCC), cold deck humidity ratio (WCC), and sensible heat ratio (SHR).

19. Calculate humidification requirements.

19.1 Calculate required hot deck humidity ratio (WHRQD).

$$CMESS = ZMASS_{icz} * PCTC_{icz}$$

$$HMESS = ZMASS_{icz} * (1. - PCTC_{icz})$$

$$WZRQD = WZ_{icz} - H2ORD_{icz}/ZMASS_{icz}$$

$$WHRQD = (ZMASS_{icz} * WZRQD - WCC * CMESS)/HMESS$$

where:

icz - zone in which humidistat is located.

19.2 Check that WHRQD does not exceed a high limit of 80% R.H. within the duct. Call subroutine HUM1 to do this.

19.3 Hot deck humidity ratio.

If $WHRQD \leq WMA$

$$WHC = WMA$$

If $WHRQD > WMA$

$$WHC = WHRQD.$$

19.4 Calculate amount of humidification water required.

$$WATER = HMASS * (WHC - WMA)$$

20. Calculate zone humidity ratio.

Using function WZNEW, calculate the humidity ratio of each zone (WZ_i).

21. Calculate return air humidity ratio and density.

$$WRA_k = \frac{\sum_{j=1,jmax} WZ_j * ZMASR_j * MULT_j}{\sum_{j=1,jmax} ZMASR_j * MULT_j}$$

$$DRA_k = \frac{PATM}{(0.745 * (TRA_k + 460.)(1.0 + 7000.0 * WRA_k/4360.)}$$

SZRHT

A subroutine to simulate the operation of a single-zone fan system with sub-zone reheat.

INPUT

K	-	Energy distribution system number

Various items held in COMMON (see Table 5.4 for definitions of variables in COMMON).

OUTPUT

QCC	-	Cooling coil load (Btu/hr)
QHC	-	AHU heating coil load (Btu/hr)
QTRHC	-	Reheat coil load (Btu/hr)
QPHC	-	Preheat coil load (Btu/hr)
TQB	-	Baseboard heating load (Btu/hr)
WATER	-	Steam humidification supplied at air handling unit (lbm-H_2O/hr)
BPKW	-	Base power (KW)
TNFBP	-	Total net [updated] fan brake horsepower (bhp)

Various items held in COMMON.

CALCULATION SEQUENCE

1. Fan off/on check.

   Using subroutine FANOF, determine whether the fan has been turned off for the current hour.

   If the system is off, terminate SZRHT simulation for the current hour.

   If the system is on, continue.

2. Identify sensible thermal load of each zone on this system.

$QSI_i = QS_\ell$ **

3. Baseboard radiation.

If boiler on, call subroutine BRAD2 to calculate baseboard radiation heat (QB_j) and to adjust QSI_i for QB_j.

Sum baseboard radiation heat,

$$TQB = \sum_{j=1,jmax} QB_j$$

If boiler off, continue.

4. Calculate required supply air temperature to each zone,

$TS_i = TSP - QSI_i/(0.245 * ZMAS_i)$

5. Calculate AHU discharge temperature.

$TLVG = TS_i$ (equals supply air temperature of air to central zone which in "j" sequence is assumed to be No. 1)

6. Calculate fraction of primary air required.

$BETA_i = (TS_i - TRPRI)/(TLVG - TRPRI)$

If $BETA_i \leq 0.5$, reheat coil required.

$QZRHC_i = 0.245 * ZMASS_i * (0.5 * (TRPRI + TLVG) - TS_i)$

If $BETA_i > 0.5$,

If BETA ≥ 1.0, cooling load not met.

Call subroutine CCOIL to calculate cooling load not met ($QLNM_i$).

Update as required the following variables:

$QCLNM_i$ -

$QCPNM_i$ -

$IHCNM_i$ -

$TS_i = TLVG$

**NOTE: There is a corresponding ℓ for each i; a relationship defined by the variable $SPACN_{k,j}$. Hence, i and ℓ are defined by system number (k) and zone number (j). See Para. 5.1 for zone labeling organization.

If BETA $\leq$ 1.0, continue.

7. Calculate zone mass flows.

$$ZMAS_i = ZMASS_i * BETA_i$$

$$ZMASR_i = ZMAS_i - ZMASX_i$$

If ZMASR < 0.0,

ZMASR = 0.

8. Calculate system mass flows.

$$FMAS = \sum_{j=1,jmax} ZMAS_i * MULT_i$$

$$FMAR = \sum_{j=1,jmax} ZMASR_i * MULT_i$$

9. Calculate percent of full load.

$$PCTSA = FMAS/FMASS_k$$

$$PCTRA = FMAR/FMASR_k$$

10. Calculate return air temperature (TRA_k).

NOTE: Since the System and Equipment Simulation Program is capable of using LOAD or VARIABLE TEMPERATURE tapes as input, the following logic sequence is required.

If ceiling plenum is calculated as a separate zone,

If LOAD tape is used,

$$DTL2_i = 0.$$

$$QLITI = QLITE_\ell + QS_{p\ell} + QLITE_{p\ell} + QSINF_{p\ell} \quad **$$

If VARIABLE TEMPERATURE tape is used,

$$DTL2_i = STEMP_{p\ell} - TSP_\ell$$

$$QLITI = QLITE_\ell$$

If ceiling plenum is not calculated as a separate zone,

$$DTL2_i = 0.$$

$$QLITI = QLITE_\ell$$

DTL_i = QLITI/(0.245 $ZMASR_i$)

$$TRA_k = \frac{\sum_{j=1,jmax} (TSP_\ell + DTL_i + DTL2_i) * ZMASR_i * MULT_i}{\sum_{j=1,jmax} ZMASR_i * MULT_i}$$

$$+ DTFNR_k * PTLD(NVFC_k, PCTRA)$$

where $DTL2_i$ - difference between zone and plenum temperatures as calculated by VARIABLE TEMPERATURE program.

QLITI - thermal load of plenum $p\ell$ above zone ℓ as calculated by LOAD program.

$p\ell$ - LOAD program space number of plenum above zone ℓ.

11. Calculate desired economizer approach temperature (EAT).

$$EAT = TLVG - DTFNS_k * PTLD(NVFC_k, PCTSA)$$

12. Calculate mixed air conditions entering preheat coil.

Call subroutine MXAIR to simulate the performance of:

1. Fixed outside and return air dampers.

2. An enthalpy/temperature type economizer cycle.

or

3. A temperature type economizer cycle.

Subroutine MXAIR also calculates the thermal properties (temperature, humidity ratio, and density) of the mixed air stream.

13. Air Handling Unit (AHU).

13.1 If boiler and chiller on, if chiller on and cooling called, or if boiler and heating called,
Call subroutine AHU (mode 2) to simulate the operation of a central system air handling unit. Calculate heating and cooling coil operation (QHC and QCC), the effect of fan heat, and the addition of steam (WATER) by a humidifier on the discharge side of the unit.

Go to 14.

13.2 If boiler off and heating required at AHU,

$$TLVG = TMA + DTFNS_k * PTLD(NVFC_k, PCTSA)$$

Go to 13.4.

13.3 If chiller off and cooling required at AHU,

$$TLVG = TMA + DTFNS_k * PTLD(NVFC_k, PCTSA)$$

Go to 13.4.

13.4 If $\frac{TLVG-TLVG2}{TLVG} < 0.001$,

Call subroutine AHU (mode 2) to simulate the operation of a central system air handling unit. Calculate heating and cooling coil operation (QHC and QCC), the effect of fan heat, and the addition of steam (WATER) by a humidifier on the discharge side of the unit.

Go to 14.

If $\frac{TLVG-TLVG2}{TLVG} \geq 0.001$,

$$TLVG = TLVG2 = TLVG.$$

Go to Step 2.

14. Adjust total fan brake horsepower.

$$PCTSA = SMCFM/CFMAX_i$$

$$TNFBP = TNFBP + (PTLD(NVFC_k, PCTSA) - 1.0) * FBHPS_k$$
$$+ (PTLD(NVFC_k, PCTRA) - 1.0) * FBHPR_k$$

15. Calculate base power (KW); includes internal power, lights receptacles, equipment, misc.

$$BPKW = \sum_{j=1,jmax} SLPOW_{\ell} * MULT_i$$

16. Calculate zone humidity ratio.

Using function WZNEW, calculate the humidity ratio of each zone (WZ_i).

17. Calculate return air humidity ratio and density.

$$WRA_k = \frac{\sum_{j=1,jmax} WZ_j * ZMASR_j * MULT_j}{\sum_{j=1,jmax} ZMASR_j * MULT_j}$$

$$DRA_k = \frac{PATM}{(0.754 * (TRA_k + 460.)(1.0 + 7000.0 * WRA_k/4360.)}$$

FHTG2

A subroutine for simulating the system performance of the floor panel heating system.

INPUT

TOA	:	Dry-bulb temperature of outside air, ^{o}F
K	:	Fan system number
JMAXK	:	Number of zones on fan system No. K
QS_{ℓ}	:	Hourly sensible load for zone No. ℓ Btu/hr
QL_{ℓ}	:	Hourly latent load for zone No. ℓ Btu/hr
$QLITE_{\ell}$	:	Hourly lighting load picked up by return air in zone No. ℓ Btu/hr.
$SLPOW_{\ell}$	:	Hourly zone internal lighting and machinery power consumption, KW, for zone No. ℓ
TCO	:	Building changeover temperature, ^{o}F
$PERIM_{k}$	:	Exposed perimeter of floor for distribution system No. k, ft.
$PAREA_{k}$	:	Floor area available for heating panels, system k sq. ft.
$PLOC_{k}$	:	Location of floor heating panel for system No. k
CINSL	:	Floor insulation conductance, Btu/hr-sq.ft.-^{o}F
DINSL	:	Floor insulation thickness, ft.
TSP_{ℓ}	:	Set point temperature of zone No. ℓ, ^{o}F
KFLCV	:	Type of floor covering

OUTPUT

QFPC	:	Hourly cooling requirement, Btu/hr
QFPH	:	Hourly heating requirement, Btu/hr
QFPRH	:	Hourly reheat requirement, Btu/hr
BPKW	:	Total internal lights and machinery power consumption for zones served by system under consideration, KW

CALCULATION SEQUENCE*

1. Read load input tape for zones required and calculate:

   $BPKW = \sum SLPOW_{\ell} * MULT_{i}$, for J = 1 to JMAXK

   $QSI_{i} = QS_{\ell} + QLITE_{\ell}$

   $QSSUM = \sum QSI_{i}$, for all zones on this system requiring heating

2. If $TOA > TOACO_{k}$, go to calculation 2.1, otherwise go to calculation 2.2

   2.1 No heating available since building system is operating in cooling mode, therefore set

   QFPC = 0.0

   QFPH = 0.0

   QFPRH = 0.0

   Go to 3.

   2.2 Heating available within building, therefore perform the following:

   2.2.1 Calculate panel temperature, TPAN, required for desired heating flux, QPAN.

   $QPAN = QSSUM/PAREA_{k}$

   Calculate set point temperature of system $TSPJ1 = TSP_{\ell}$ where TSP_{ℓ} is the set point of the first zone.

   Initially, set TPAN = 76.0

   QCALC = 0.15 * ((TPAN + 460.0)/100.0)

   ** 4.0 - 0.15 ((TSPJ1 + 460.0)/100.0)

   ** 4.0 + 0.32 * (TPAN - TSPJ1) ** 1.31

   If (QPAN - QCALC) is greater than (0.01 * QPAN), calculate a new TPAN

   TPAN = TPAN + 0.5 * (QPAN - QCALC)

   and repeat above calculation. If necessary, repeat again until QCALC is within (0.01 * QPAN).

*See 1967 ASHRAE Guide and Data Book, Systems and Equipment Volume, Chapter 58, for derivation of all equations.

2.2.2 Calculate surface temperature of floor required as a function of the type of floor covering.

2.2.2.1 If KFLCV = 1, bare concrete floor, therefore

TSUR = TPAN

2.2.2.2 If KFLCV = 2, tile covering, therefore

TSUR = TPAN + QPAN * 0.05

2.2.2.3 If KFLCV = 3, carpeting, therefore

TSUR = TPAN + QPAN * 1.4

2.2.3 If TSUR as calculated above is greater than 85.0^{o}F, reset

TSUR = 85.0

2.2.4 Calculate the downward and edgewise loss coefficient, C3.

2.2.4.1 If CINSL = 0.0, no insulation, therefore

C3 = 1.8

2.2.4.2 If CINSL > 0.0, and DINSL = 0.0, then only perimeter insulation, therefore

C3 = 1.32 + 0.25 * CINSL

2.2.4.3 If CINSL > 0.0 and DINSL > 0.0, then

C3 = 0.932 + 0.523 * CINSL
- 0.479 * CINSL ** 2.0
- 0.271 * DINSL + 0.046 * DINSL
** 2.0 + 0.786 * CINSL * DINSL
- 0.72 * DINSL * CINSL ** 2.0
- 0.182 * CINSL * DINSL ** 2.0
+ 0.24 * (DINSL * CINSL) ** 2.0

2.2.5 Calculate downward and edgewise heat loss, QLOSS.

2.2.5.1 If $PLOC_k$ = 1, then

$$QLOSS = PERIM_k * C3 * (TPAN - TOA)/PAREA_k$$

2.2.5.2 If PLOC (K) = 2, then

QLOSS = 0.15 * ((TPAN + 460.0)/100.0)

** 4.0 - 0.15 * (TSPJ1 + 460.0)/

100.0) ** 4.0 + 0.021

* (TPAN - TSPJ1) ** 1.25

2.2.6 Calculate heating requirement of system.

$QFPH = 1.0 * (QPAN + QLOSS) * PAREA_k$

QFPC = 0.0

QFPRH = 0.0

3. Distribute unmet heating and cooling loads, finding:

Heating and cooling peak, consumption, and number of hours heating and cooling loads were not met.

FCOIL

A subroutine to simulate the operation of two- and four-pipe fancoil systems consisting of blow-through type fancoil units.

INPUT

k : Energy distribution system number

Various items held in COMMON (see Table 5.4 for definition of variables in COMMON).

OUTPUT

QC : Cooling load (BTU/HR) ($QC = \sum_{j=1,\, jmax} QC_i$) **

QH : Heating load (BTU/HR) ($QH = \sum_{j=1,\, jmax} QH_i$) **

TQB : Baseboard heating load (BTU/HR)

BPKW : Base power (KW)

TNFBP : Total net (updated) fan brake horsepower (BHP)

CALCULATION SEQUENCE

1. Fan off/on check.

   Using subroutine FANOF, determine whether fancoil units have been turned off for the current hour.

   If fancoil units are off, terminate fancoil simulation.

   If fancoil units are on, continue.

2. For two-pipe fancoil units, use subroutine TEMP to determine process water mode (i.e., hot water, chilled water, or changeover) for the current hour.

**NOTE: There is a corresponding ℓ for each i, a relationship defined by the variable $SPACN_{k,j}$. Hence, i and ℓ are defined by system number (k) and zone number of system (j). See Para. 5.1 for zone labeling organization.

3. Calculate base power (KW), includes internal power, lights, receptacles, equipment, miscellaneous.

$$BPKW = \sum_{j=1,\ jmax} SLPOW_{\ell} * MULT_i \ **$$

Calculation sequence 4 through 12 is repeated for each fancoil zone on system k.

4. Calculate sensible thermal load.

$$QSI_i = QS_{\ell} + QLITE_{\ell} \ **$$

5. Baseboard radiation.

If boiler is on, call subroutine BRAD2 to calculate baseboard radiation heat (QB_j) and adjust QSI.

Sum baseboard radiation heat.

$$TQB = \sum_{j=1,\ jmax} QB_j$$

If boiler is off, continue.

6. Calculate mixed air conditions.

Call subroutine MXAIR to calculate thermal properties (temperature, humidity ratio, and density) of mixing outside air and room air by the fancoil unit.

7. Calculate mass flow through fancoil unit.

$$ZMAS = CFM_i * DMA * 60.0$$

where DMA = mixed air density (LBM/FT^3)

8. Calculate required supply air temperature.

$$TSA_i = TSP_1 - QSI_i/(0.245 * ZMAS_i) \ **$$

**NOTE: There is a corresponding ℓ for each i, a relationship defined by the variable $SPACN_{k,j}$. Hence, i and ℓ are defined by system number (k) and zone number of system (j). See Para. 5.1 for zone labeling organization.

9. Calculate fan heat and mixed air temperature downstream of blower.

$$QFAN = CFM_i \quad TFNPS_k * 0.4014$$

$$TMA = TMA + QFAN/(0.245 * ZMAS_i)$$

10. Zone humidity calculations.

Using subroutine H2ØZN, calculate total moisture requirements including set point recovery load ($H2ØRD_i$) and moisture changes in current hour due to environmental and room effects ($H2ØAD_i$).

11. Calculate fancoil performance and distribute thermal loads.

11.1 <u>Two-Pipe Fancoil System</u>

11.1.1 <u>Heating Mode (IPW = -1)</u>

If TMA $\leq$ TSA, heating required.

If boiler on, call subroutine ZLØ3 to calculate QH and distribute unmet load, if any.

If boiler off, heating load not met,

$$QLNM_i = ZMAS_i * 0.245 * (TMA - TSA)$$

Update as required:

$QHLNM_i$: Sum of all heating loads not met, zone i.

$QHPNM_i$: Peak heating load not met, zone i.

$IHHNM_i$: Hours heating load not met, zone i.

If TMA > TSA, cooling load not met.

Call subroutine CCOIL to calculate cooling load not met.

Update as required the following variables:

$QCLNM_i$: Sum of all cooling loads not met, zone i.

$QCPNM_i$: Peak cooling load not met, zone i.

$IHCNM_i$: Hours cooling load not met, zone i.

11.1.2 Changeover Mode (IPW = 0)

During the changeover hour, it is assumed that both heating and cooling loads may be met. Therefore, the four-pipe fancoil system zone analysis is used (see 11.2). In addition, there is a thermal load due to changing the tempdrature of the hydronic system (see 13.).

11.1.3 Cooling Mode (IPW = +1)

If TMA $\leq$ TSA, cooling required.

If chiller on, call subroutine ZLØ3 to calculate QC_i and distribute unmet load, if any.

If chiller off, cooling load not met. Call subroutine CCOIL to calculate cooling loads not met.

Update as required:

$QCLNM_i$: Sum of all cooling loads not met, zone i.

$QCPNM_i$: Peak cooling load not met, zone i.

$IHCNM_i$: Hours cooling load not met, zone i.

If TMA > TSA, heating load not met.

$$QLNM_i = ZMAS_i * 0.245 * (TMA - TSA)$$

Update as required:

$QHLNM_i$: Sum of all heating loads not met, zone i.

$QHPNM_i$: Peak heating load not met, zone i.

$IHHNM_i$: Hours heating load not met, zone i.

11.2 Four-Pipe Fancoil System

If TMA $\leq$ TSA, heating required.

If boiler on, call subroutine ZLØ3 to calculate QH_i and distribute unmet load, if any.

If boiler off, heating load not met.

$$QLNM_i = ZMAS_i * 0.245 * (TMA - TSA)$$

Update as required the following variables:

$QHLNM_i$: Sum of all heating loads not met, zone i.

$QHPNM_i$: Peak heating load not met, zone i.

$IHHNM_i$: Hours heating load not met, zone i.

If TMA > TSA, cooling required.

If chiller on, call subroutine ZLØ3 to calculate QC_i and distribute unmet load, if any.

If chiller off, cooling load not met. Call subroutine CCOIL to calculate cooling load not met.

Update as required the following variables:

$QCLNM_i$: Sum of all cooling loads not met, zone i.

$QCPNM_i$: Peak cooling load not met, zone i.

$IHCNM_i$: Hours cooling load not met, zone i.

12. Calculate zone humidity ratio.

Using function WZNEW, calculate the humidity ratio of each zone.

13. Calculate heat of changeover (for two-pipe fancoil systems only).

If IPW = 0, changeover.

Calculate hot water temperature (THW) using function TRSET.

Calculate changeover heat : QCO

$$QCO = PWGAL_k * 8.3 * (THW - TLCHL)$$

where $PWGAL_k$: Water volume of two-pipe system (GALS)

TLCHL : Chilled water temperature (°F)

If heating-to-cooling changeover:

$$QC = QC + QCO$$

If cooling-to-heating changeover:

$$QC = QH - QCO$$

If IPW ≠ 0, continue.

INDUC

A subroutine to simulate the operation of two and four pipe induction unit fan systems having induction units whose primary and induced room air streams mix after induced air is tempered. Induction unit cooling coil limited to sensible cooling only.

INPUT

K : Energy distribution system number.

Various items held in COMMON (See Table 5.4 for definition of variables in COMMON).

OUTPUT

QCC : Total cooling load (Btu/hr) ($QCC = \sum_{J=1,\ jmax} QC_i$)

QHC : Heating load at AHU (Btu/hr) ($QHC = \sum_{j=1,\ jmax} QH_i$)

QTRHC : Heating load at induction unit (Btu/hr) ($QTRHC = \sum_{j=1,\ jmax} QRHC_i$)**

TQB : Baseboard heating load (Btu/hr)

WATER : Steam humidification supplied at air handling unit (lbs-H_2O/hr).

BPKW : Base power (KW)

TNFBP : Total net [updated] fan brake horsepower (Bhp)

Various items held in COMMON.

CALCULATION SEQUENCE

1. Fan off/on check.

Using subroutine FANOF, determine whether air handler has been turned off for the current hour

If the system is off, terminate induction system simulation.

If the system is on, continue.

2. Calculate temperature leaving air handler (TLVG).

If two-pipe induction unit fan system, call subroutine TEMP to calculate primary air temperature and induction unit water mode indicator (IPW). This is graphically represented as follows:

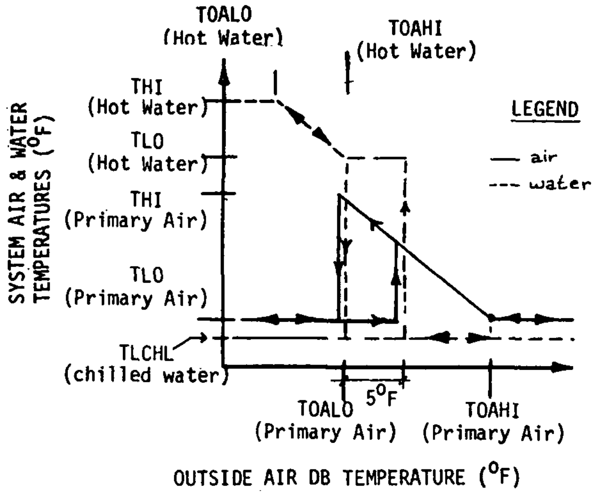


Figure 5.3 TWO-PIPE INDUCTION UNIT AIR AND WATER SCHEDULING

NOTE: TOAHI [hot water] should be set equal to TOALO (primary air).

If four-pipe induction unit fan system, primary air is held constant (set equal to $TFIX1_k$).

3. Calculate fraction of primary to total air (ALFIU)

$$ALFIU = 1.0/(1.0 + RIPA_k)$$

4. Calculate base power (KW); includes internal power, lights, receptacles, equipment, miscellaneous.

$$BPKW = \sum_{j=1,\ jmax} SLPOW_{\ell} * MULT_i \ **$$

5. Identify sensible thermal load of each zone on this system.

$$QSI_i = QS_{\ell} \ **$$

**NOTE: There is a corresponding ℓ for each i, a relationship defined by the variable $SPACN_{k,j}$. Hence, i and ℓ are defined by system number (k) and zone number of system (j). See Table 5.1 for zone labeling organization.

6. Baseboard radiation.

If boiler on, call subroutine BRAD2 to calculate baseboard radiation heat (QB_j) and adjust QSI_i for QB_i.

Sum baseboard radiation heat.

$$TQB = \sum_{j=1,\ jmax} QB_j$$

If boiler off, continue.

7. Calculate return air temperature (TRA_k).

NOTE: Since the system and equipment simulation program is capable of using LOAD or VARIABLE TEMPERATURE tapes as input, the following logic sequence is required.

If ceiling plenum is calculated as a separate zone,

If LOAD tape is used,

$$DTL2_i = 0.0$$

$$QLITI = QLITE_{\ell} + QS_{p\ell} + QLITE_{p\ell} + QSINF_{p\ell} \; **$$

If VARIABLE TEMPERATURE tape is used,

$$DTL2_i = STEMP_{p\ell} - TSP_{\ell}$$

$$QLITI = QLITE_{\ell}$$

If ceiling plenum is not calculated as a separate zone,

$$DTL2_i = 0.0$$

$$QLITI = QLITE_{\ell}$$

$$DTL_i = QLITI/(0.245 * ZMASR_i)$$

$$TRA_k = \left[\frac{\left(\sum_{j=1,\ jmax} (TSP_{\ell} + DTL_i + DTL2_i) * ZMASR_i * MULT_i\right)}{\left(\sum_{j=1,\ jmax} ZMASR_i * MULT_i\right)}\right] + DTFNR_k$$

where $DTL2_i$ -- Difference between zone and plenum temperatures as calculated by VARIABLE TEMPERATURE program.

QLITI -- Thermal load of plenum $p\ell$ above zone ℓ as calculated by LOAD program.

8. Zone humidity calculations.

Using subroutine H2OZN, calculate total moisture requirements including set point recovery load ($H2ORD_i$) and moisture changes in current hour due to environmental and room effects ($H2OAD_i$).

9. Calculate economizer approach temperature (EAT).

If TLVG > 125.0°F,

TLVG = 125.0°F

$EAT = TLVG - DTFNS_k$

If EAT < 40.0°F

EAT = 40.0°F

$TLVG = EAT + DTFNS_k$

10. Calculate mixed air conditions.

Call subroutine MXAIR to simulate the performance of:

1. Fixed outside and return air dampers
2. An enthalpy/temperature type economizer cycle.
3. A temperature type economizer cycle

Subroutine MXAIR also calculates the thermal properties (temperature, humidity ratio, and density) of the mixed air stream.

11. Air handling unit.

Call subroutine AHU (mode 1) to simulate the functioning of a central system air handling unit. Calculate heating and cooling coil thermal response (QHC and QCC) of fan heat, and operation of steam humidifier on discharge side of unit (WATER).
The heating coil is locked out when the boiler scheduled off.
The cooling coil is locked out when the chiller scheduled off.
The humidifier is locked out when the cooling coil is functioning.

12. Calculate induction unit coil sensible thermal load and induced air mass flow.

$$QSIU_i = QSI_i + ZMASS_i * 0.245 * (TLVG - TSP_\ell)$$

$$ZMAS_i = ZMASS_i * RIPA_k$$

13. Induction unit simulation.

13.1 Two-pipe induction unit.

13.1.1 Hot water mode (IPW = -1).

If $QSIU_i \leq 0.0$,

If boiler on,

$$TLC_i = -QSIU_i/(ZMAS_i * 0.245) + TSP_\ell$$

where TLC_i - Temperature of induced air after coil (°F).

Call subroutine ZL03 to calculate induction unit heating load and distribute an unmet load, if any.

If boiler off, heating load not met.

$$QLNM_i = QSIU_i$$

Update as required the following variables:

$QHLNM_i$ -
$QHPNM_i$ -
$IHHNM_i$ -

If $QSIU_i > 0.0$, cooling load not met.

$$QLNM_i = QSIU_i$$

Update as required the following variables:

$QCLNM_i$ -
$QCPNM_i$ -
$IHCNM_i$ -

13.1.2 Changeover mode (IPW = 0).

During the changeover hour, it is assumed that both heating and cooling loads may be met. Therefore, the four-pipe fan-coil system zone analysis is used (see 13.2.). In addition, there is a thermal load due to changing the temperature of the hydronic system (see 17.).

13.1.3 Cooling mode (IPW = +1)

If $QSIU_i > 0.0$, cooling required.

If chiller on,

$TLC_i = -QSIU_i/(ZMAS_i * 0.245) + TSP_\ell$

Call subroutine ZL03 to calculate cooling load and distribute an unmet load, if any.

If chiller off, cooling load not met.

$QLNM_i = QSIU_i$

Update as required the following variables:

$QCLNM_i$ -
$QCPNM_i$ -
$IHCNM_i$ -

If $QSIU_i < 0.0$, heating load not met.

$QLNM_i = QSIU_i$

Update as required the following variables:

$QHLNM_i$ -
$QHPNM_i$ -
$IHHNM_i$ -

13.2 Four-pipe induction unit.

If $QSIU_i \leq 0.0$, heating required.

If boiler on,

$TLC_i = -QSIU_i/(ZMAS_i * 0.245) + TSP_\ell$

Call subroutine ZL03 to calculate induction unit heating load and distribute an unmet load, if any.

If boiler off, heating load not met.

$QLNM_i = QSIU_i$

Update as required the following variables:

$QHLNM_i$ -
$QHPNM_i$ -
$IHHNM_i$ -

If $QSIU_i > 0.0$, cooling required,

If chiller on,

$TLC_i = -QSIU_i/(ZMAS_i * 0.245) + TSP_\ell$

Call subroutine ZL03 to calculate cooling load and distribute an unmet load, if any.

If chiller off, cooling load not met.

$QLNM_i = QSIU_i$

Update as required the following variables:

$QCLNM_i$ -
$QCPNM_i$ -
$IHCNM_i$ -

14. Calculate thermal properties (temperature and humidity ratio) of air leaving the induction unit.

$TTLVG_i = (TLVG * ZMASS_i + TLC * ZMAS_i)/(ZMASS_i + ZMAS_i)$

$WTLVG_i = (WSUP * ZMASS_i + WCLVG * ZMAS_i)/(ZMASS_i + ZMAS_i)$

15. Calculate zone humidity ratio.

Using function WZNEW, calculate the humidity ratio of each zone (WZ_i).

16. Calculate return air humidity ratio and density.

$WRA_k = (\Sigma_{j=1,jmax} WZ_i * ZMASR_i * MULT_i)/(\Sigma_{j=1,jmax} ZMASR_i * MULT_i)$

$DRA_k = PATM/((0.754 * (TRA_k + 460.0)*(1.0 + 7000.0 * WRA_k/4360.0))$

17. Calculate heat of changeover (for two-pipe induction systems only).

If IPW = 0 (changeover),

Calculate hot water temperature using function TRSET.

Calculate changeover heat, QCO

$QCO = PWGAL_k * 8.3 * (THW - TLCHL)$

where, $PWGAL_k$ - Water volume of two-pipe induction unit system (gal.)
TLCHL - Chilled water temperature (°F)

If heating to cooling changeover:

$$QC = QC + QCO$$

If cooling to heating changeover:

$$QH = QH - QCO$$

If IPW $\neq$ 0, continue.

VARVL

A subroutine to simulate the operation of a variable volume fan system with optional reheat.

INPUT

K - Energy distribution system number

Various items held in COMMON (see Table 5.4 for definitions of variables in COMMON).

OUTPUT

QCC - Cooling coil load (Btu/hr)

QHC - AHU heating coil load (Btu/hr)

QTRHC - Reheat coil load (Btu/hr)

TQB - Baseboard heating load (Btu/hr)

WATER - Steam humidification supplied at air handling unit (lbm-H_2O/hr)

BPKW - Base power (KW)

TNFBP - Total net [updated] fan brake horsepower (bhp)

Various items held in COMMON.

CALCULATION SEQUENCE

1. Fan off/on check.

   Using subroutine FANOF, determine whether the fan has been turned off for the current hour.

   If the system is off, terminate VARVL simulation for the current hour.

   If the system is on, continue.

2. Identify leaving AHU air temperature,

   $$TLVG = TFIX1_k$$

   $$TLVG2 = TLVG$$

3. Identify sensible thermal load of each zone on this system.

$$QSI_i = QS_\ell \;**$$

4. Baseboard radiation.

If boiler on, call subroutine BRAD2 to calculate baseboard radiation heat (QB_j) and to adjust QSI_i for QB_j.

Sum baseboard radiation heat,

$$TQB = \sum_{j=1,jmax} QB_j$$

If boiler off, continue.

5. Calculate air mass flow and temperature to each zone,

$$ZMAS_i = QSI_i/(0.245 * (TSP_\ell - TLVG))$$

If $ZMAS_i > ZMASS_i$

$$ZMAS_i = ZMASS_i$$

If $ZMAS_i < ZMASS_i * VVMIN_k$

$$ZMAS_i = ZMASS_i * VVMIN_k$$

$$ZMASR_i = ZMAS_i - ZMASX_i$$

If $ZMASR_i < 0.0$,

$$ZMASR_i = 0.$$

$$TS_i = TSP_\ell - QSI_i/(0.245 * ZMAS_i)$$

6. Calculate system mass flows.

$$FMAS_k = \sum_{j=1,jmax} ZMAS_i * MULT_i$$

$$FMR_k = \sum_{j=1,jmax} ZMASR_i * MULT_i$$

7. Calculate supply and return air full load flows.

$$PCTSA = FMAS_k/FMASS_k$$

$$PCTRA = FMR_k/FMASR_k$$

** There is a corresponding ℓ for each i; a relationship defined by the variable $SPACN_{k,j}$. Hence, i and ℓ are defined by system number (k) and zone number (j). See Para. 5.1 for zone labeling organization.

8. Calculate return air temperature (TRA_k).

NOTE: Since the System and Equipment Simulation Program is capable of using LOAD or VARIABLE TEMPERATURE tapes as input, the following logic sequence is required.

If ceiling plenum is calculated as a separate zone,

If LOAD tape is used,

$$DTL2_i = 0.$$

$$QLITI = QLITE_\ell + QS_{p\ell} + QLITE_{p\ell} + QSINF_{p\ell} \quad **$$

If VARIABLE TEMPERATURE tape is used,

$$DTL2_i = STEMP_{p\ell} - TSP_\ell$$

$$QLITI = QLITE_\ell$$

If ceiling plenum is not calculated as a separate zone,

$$DTL2_i = 0.$$

$$QLITI = QLITE_\ell$$

$$DTL_i = QLITI/(0.245 * ZMASR_i)$$

$$TRA_k = \frac{\sum_{j=1,jmax} (TSP_\ell + DTL_i + DTL2_i) * ZMASR_i * MULT_i}{\sum_{j=1,jmax} ZMASR_i * MULT_i}$$

$$+ DTFNR_k * PTLD(NVFC_k, PCTRA)$$

where $DTL2_i$ - difference between zone and plenum temperatures as calculated by VARIABLE TEMPERATURE program.

QLITI - thermal load of plenum $p\ell$ above zone ℓ as calculated by LOAD program.

$p\ell$ - LOAD program space number of plenum above zone ℓ.

9. Zone humidity calculations.

Using subroutine H2OZN, calculate total moisture requirements including set point recovery load $(H2OAD_i)$ and moisture changes in current hour due to environmental and room effects $(H2OAD_i)$.

10. Calculate economizer approach temperature (EAT).

If $TLVG > 125.^{o}F$

$$TLVG = 125.^{o}F$$

$$EAT = TLVG - DTFNS_k$$

If $EAT < 40.^{o}F$

$$EAT = 40.^{o}F$$

$$TLVG = EAT + DTFNS_k$$

11. Calculate mixed air conditions.

Call subroutine MXAIR to simulate the performance of:

1. Fixed outside and return air dampers.
2. An enthalpy/temperature type economizer cycle.

or

3. A temperature type economizer cycle.

Subroutine MXAIR also calculates the thermal properties (temperaure, humidity ratio, and density) of the mixed air stream.

12. Air Handling Unit (AHU).

12.1 If boiler and chiller on, if chiller on and cooling called, or if boiler and heating called,
Call subroutine AHU (mode 1) to simulate the operation of a central system air handling unit. Calculate heating and cooling coil operation (QHC and QCC), the effect of fan heat, and the addition of steam (WATER) by a humidifier on the discharge side of the unit.

Go to 13.

12.2 If boiler off and heating required at AHU,

$$TLVG = TMA + DTFNS_k * PTLD(NVFC_k, PCTSA)$$

Go to 12.4.

12.3 If chiller off and cooling required at AHU,

$$TLVG = TMA + DTFNS_k * PTLD(NVFC_k, PCTSA)$$

Go to 12.4.

12.4 If $\frac{TLVG-TLVG2}{TLVG} < 0.001$,

Call subroutine AHU (mode 1) to simulate the operation of a central system air handling unit. Calculate heating and cooling coil operation (QHC and QCC), the effect of fan heat, and the addition of steam (WATER) by a humidifier on the discharge side of the unit.

Go to 13.

If $\frac{TLVG-TLVG2}{TLVG} \geq 0.001$,

TLVG = TLVG2 = TLVG.

Go to Step 3.

13. Adjust total fan brake horsepower.

$$PCTSA = SMCFM/CFMAX_k$$

$$TNFBP = TNFBP + (PTLD(NVFC_k, PCTSA)-1.0)*FBHPS_k$$
$$+ (PTLD(NVFC_k, PCTRA)-1.0)*FBHPR_k$$

14. Calculate base power (KW); includes internal power, lights receptacles, equipment, misc.

$$BPKW = \sum_{j=1,jmax} SLPOW_\ell * MULT_i$$

15. Terminal unit performance.

$$QT_i = ZMAS_i * 0.245 * (TLVG - TS_i)$$

If no reheat coils,

If $QT_i < 0.0$, heating load not met.

$QLNM_i = QT_i$

Update as required the following variables:

$QHLNM_i$ -

$QHPNM_i$ -

$IHHNM_i$ -

TS_i = TLVG

WTLVG = WSUP (WSUP = supply air humidity ratio. It is calculated in subroutine AHU.)

If $QT_i = 0.0$,

WTLVG = WSUP

If $QT_i > 0.0$, cooling load not met.

$QLNM_i = QT_i$

Update as required the following variables:

$QCLNM_i$ -

$QCPNM_i$ -

$IHCNM_i$ -

TS_i = TLVG

$WTLVG_i$ = WSUP

If terminal has reheat coil,

If $QT_i < 0$,

If boiler on,

Call subroutine ZL03 to calculate and sum reheat coil loads and distribute loads not met, if any.

If boiler off, heating load not met.

$QLNM_i = QT_i$

Update as required the following variables:

$QHLNM_i$ -

$QCLNM_i$ -

$IHHNM_i$

TS_i = TLVG

$WTLVG_i$ = WSUP

If $QT_i = 0.0$,

$WTLVG = WSUP$

If $QT_i > 0.0$, cooling load not met.

Call subroutine CCOIL to calculate cooling load not met ($QLNM_i$).

Update as required the following variables:

$QCLNM_i$ -

$QCPNM_i$ -

$IHCNM_i$ -

$TS_i = TLVG$

$WTLVG_i = WSUP$

Go to 13.

16. Calculate zone humidity ratio.

Using function WZNEW, calculate the humidity ratio of each zone (WZ_i).

17. Calculate return air humidity ratio and density.

$$WRA_k = \frac{\sum_{j=1,jmax} WZ_i * ZMASR_i * MULT_i}{\sum_{j=1,jmax} ZMASR_i * MULT_i}$$

$$DRA_k = \frac{PATM}{(0.754 * (TRA_k + 460.)(1.0 + 7000.0 * WRA_k/4360.)}$$

A subroutine to simulate the operation of a single-zone fan system with face and bypass dampers, a unit ventilator, a unit heater, or a constant volume reheat fan system.

INPUT

K - Energy distribution system number.

Various items held in COMMON (see Table 5.4 for definitions of variables in COMMON).

OUTPUT

QCC - Cooling coil load (Btu/hr.)

QHC - AHU heating coil load (Btu/hr.)

QTRHC - Reheat coil load (Btu/hr.)

TQB - Baseboard heating load (Btu/hr.)

WATER - Steam humidification supplied at air handling unit (lbm-H_2O/hr.)

BPKW - Base power (Kw)

TNFBP - Total net [updated] fan brake horsepower (bhp)

Various items held in COMMON.

CALCULATION SEQUENCE

1. Fan off/on check.

   Using subroutine FANOF, determine whether the fan has been turned off for the current hour.

   If the system is off, terminate RHFS2 simulation for the current hour.

   If the system is on, continue.

2. Identify sensible thermal loss of each zone on this system.

   $QSI_i = QS_\ell$ **

3. Baseboard radiation.

If boiler on, call subroutine BRAD2 to calculate baseboard radiation heat (QB_j) and to adjust QSI_i for QB_j.

Sum baseboard radiation heat,

$$TQB = \sum_{j=1,jmax} QB_j$$

If boiler off, continue.

4. Calculate required zone supply air temperatures.

$$TS_i = TSP_\ell - QSI_i/(0.245 - ZMASS_i)$$

5. Calculate base power (Kw); includes internal power, lights receptacles, equipment, misc.

$$BPKW = \sum_{j=1,\ jmax} SLPOW_\ell * MULT_i \ **$$

6. Calculate return air temperature, TRA_k

NOTE: Since the System and Equipment Simulation Program is capable of using LOAD or VARIABLE TEMPERATURE tapes as input, the following logic sequence is required.

If ceiling plenum is calculated as a separate zone,

If LOAD tape is used,

$$DTL2_i = 0.$$

$$QLITI = QLITE_\ell + QS_{p\ell} + QLITE_{p\ell} + QSINF_{p\ell} \ **$$

If VARIABLE TEMPERATURE tape is used,

$$DTL2_i = STEMP_{p\ell} - TSP_\ell$$

$$QLITI = QLITE_\ell$$

If ceiling plenum is not calculated as a separate zone,

$$DTL2_i = 0$$

$$QLITI = QLITE_\ell$$

**NOTE: There is a corresponding ℓ for each i; a relationship defined by the variable $SPACN_{k,j}$. Hence, i and ℓ are defined by system number (k) and zone number (j). See Para. 5.1 for zone labeling organization.

$$DTL_i = QLITI/(0.245 * ZMASR_i)$$

$$TRA_k = \left[\frac{\sum_{j=1,jmax} (TSP + DTL_i + DTL2_i) * ZMASR_i * MULT_i}{\sum_{j=1,jmax} ZMASR_i * MULT_i} \right] + DTFNR_k$$

where $DTL2_i$ - difference between zone and plenum temperatures as calculated by VARIABLE TEMPERATURE program.

QLITI - thermal load of plenum $p\lambda$ above zone λ as calculated by LOAD program.

$p\lambda$ - load program space number of plenum above zone λ

7. Zone humidity calculations

Using subroutine H2OZN, calculate total moisture requirements including setpoint recovery load ($H2OAD_i$) and moisture changes in current hour due to environmental and room effects ($H2OAD_i$)

8. Calculate air temperature leaving unit.

8.1 For single-zone fan system, unit ventilator, and unit heater,

$TLVG = TS_1$ (one)

8.2 For constant volume heat fan system, air handler discharge temperature (TLVG) is controlled in one of three ways:

1. constant leaving air temperature

2. set equal to lowest TS_i

3. reset as an inverse function of ambient air temperature.

Call subroutine TEMP to calculate TLVG for one of the above control modes.

9. Calculate economizer approach temperature (EAT).

If TLVG 125.^{o}F

$TLVG = 125.^{o}F$

$EAT = TLVG-DTFNS_k$

If EAT 40.^{o}F

$EAT = 40.^{o}F$

$TLVG = EAT + DTFNS_k$

10. Calculate mixed air conditions.

Call subroutine MXAIR to simulate the performance of:

1. Fixed outside and return air dampers.

2. An enthalpy/temperature type economizer cycle.

or

3. A temperature type economizer cycle.

Subroutine MXAIR also calculates the thermal properties (temperature, humidity ratio, and density) of the mixed air stream.

11. Air handling unit.

11.1 Single-zone system with face and bypass dampers around cooling coil.

Call subroutine AHU (mode 2) to simulate the functioning of this air handling unit. Calculate bypass damper operation, heating and cooling coil thermal response (QHC and QCC), effect of fan heat, and steam humidifier functioning (WATER).

11.2 Unit ventilator.

Heating and the addition of outside air are provided by this system type.

Call subroutine AHU (mode 1) to calculate the functioning of the heating coil (QHC) and effect of fan heat.

11.3 Unit heater.

Same as unit ventilator, without outside air option.

11.4 Constant volume reheat fan system.

Call subroutine AHU (mode 1) to simulate the operation of a central system air handling unit. Calculate heating and cooling coil operation (QHC and QCC), the effect of fan heat, and the addition of steam (WATER) by a humidifier on the discharge side of the unit.

11.5 Controls applicable to all system types.

The heating coil is locked out when the boiler is scheduled off.

The cooling coil is locked out when the chiller is scheduled off.

The humidifier is locked out when the cooling coil is functioning.

12. Calculate reheat coil loads (QT_i) and distribute loads not met.

12.1 Single-zone fan system and constant volume reheat fan systems.

$$QT_i = ZMASS_i \quad 0.245 \quad (TLVG_i - TS_i)$$

If $QT_i < 0.0$,

If boiler on,

Call subroutine ZL03 to calculate and sum reheat coil loads and distribute loads not met, if any.
Go to 13.

If boiler off, heating load not met.

$QLNM_i = QT_i$

Update as required the following variables:

$QHLNM_i$ -

$QHPNM_i$ -

$IHHNM_i$ -

$TS_i = TLVG$

$WTLVG_i = WSUP$ (WSUP = supply air humidity ratio. It is calculated in subroutine AHU.)

If $QT_i = 0.0$,

$WTLVG_i = WSUP$
Go to 13.

If $QT_i > 0.0$, cooling load not met.

Call subroutine CCOIL to calculate cooling load not met ($QLNM_i$).
Update as required the following variables:

$QCLNM_i$ -

$QCPNM_i$ -

$IHCNM_i$ -

$TS_i = TLVG$

$WTLVG_i$ = WSUP

Go to 13.

12.2 Unit ventilator and unit heat systems.

$$QT_i = ZMASS_i * 0.245 * (TLVG_i - TS_i)$$

If $QT_i < 0.0$, heating load not met.

$QLNM_i = QT_i$

Update as required the following variables:

$QHLNM_i$ -

$QHPNM_i$ -

$IHHNM_i$ -

TS_i = TLVG

$WTLVG_i$ = WSUP

Go to 13.

If $QT_i > 0.0$, cooling load not met.

$QLNM_i = QT_i$

Update as required the following variables:

$QCLNM_i$ -

$QCPNM_i$ -

$IHCNM_i$ -

TS_i = TLVG

$WTLVG_i$ = WSUP

Go to 13.

13. Calculate zone humidity ratio.

Using function WZNEW, calculate the humidity ratio of each zone (WZ_i).

14. Calculate return air humidity ratio and density.

$$WRA_k = \frac{\sum_{j=1,\ jmax} WZ_j * ZMASR_j * MULT_j}{\sum_{j=1,jmax} ZMASR_j * MULT_j}$$

$$DRA_k = \frac{PATM}{(0.754 * (TRA_k+460.)(1.0+7000.0*WRA_k/4360.)}$$

FANOF

A subroutine to handle loads for a given hour when a fan system is off. This routine should only be called when IFAN = 1.

INPUT

k : Energy distribution system number.

Various items held in COMMON (see Table 5.4 for definition of variables in COMMON).

OUTPUT

IOO : Fan operation indicator (0, fan on; 1, fan off).

QCC : Cooling load (Btu/hr).

QHC : Heating load (Btu/hr).

QTRHC : Reheat coil load (Btu/hr).

QPHC : Preheat coil load (Btu/hr).

TQB : Baseboard radiation load (Btu/hr).

WATER : Steam humidification supplied at air handling unit ($lbm-H_2O/hr$).

BPKW : Base power (KW).

TNFBP : Total net [updated] fan brake horsepower (Bhp).

Various items held in COMMON.

CALCULATION SEQUENCE

1. Check for zero sensible zone load.

$$\text{If} \sum_{j=1,\ jmax} |QS_i| \neq 0, \text{**}$$

RETURN.

**NOTE: There is a corresponding for each i; a relationship defined by the variable $SPACN_{k,j}$. Hence, i and are defined by system number (k) and zone number (j). See Para. 5.1 for zone labeling organization.

If $\sum_{j=1,\,jmax} |QS_i| = 0$, **

CONTINUE.

2. Fan system turned off, distribute loads not met.

2.1 Initialize general variables.

QCC = 0.

QHC = 0.

WATER = 0.

QTRHC = 0.

QPHC = 0.

TQB = 0.

2.2 Zone load distribution.

2.2.1 Sum base power requirements.

$$BPKW = \sum_{j=1,\,jmax} SLPOW_i * MULT_i$$

2.2.2 Sum baseboard radiation heat.

$QLNM_i = QS_\ell + QLITE_\ell$

If boiler on, call subroutine BRAD2 to calculate baseboard radiation heat (QB_i) and adjust $QLNM_i$.

If boiler off, CONTINUE.

2.2.3 Distribute sensible load not met ($QLNM_i$).

If $QLNM_i < 0.0$, heating load not met.

Update the following variables as required:

$QHLNM_i$

$QHPNM_i$

$IHHNM_i$

GO TO 2.2.4

If $QLNM_i = 0.0$,

GO TO 2.2.4

If $QLNM_i > 0.0$, cooling load not met.

Update the following variables as required:

$QCLNM_i$

$QCPNM_i$

$IHCNM_i$

GO TO 2.2.4

2.2.4 Turn off all system fans.

$TNFBP = TNFBP - FBHPS_k - FBHPR_k - FBHPE_k$

$IOO = 1.$

ZL03

Zone load organizer. A subroutine to calculate terminal unit thermal loads to reheat and recooling coils. These are then checked against maximum and minimum leaving coil temperatures. Thermal loads met and unmet, positive and negative are broken out and summed.

INPUT

IQ : Coil type index (1 = heating; 2 = cooling).

AMULT : Zone multiplication factor.

TLC : Desired leaving coil temperature (°F).

TEC : Entering coil temperature (°F).

WEC : Entering coil humidity ratio (lbm-H_2O/lbm-dry air).

TLCMX : Maximum allowable leaving coil temperature (°F).

TLCMN : Minimum allowable leaving coil temperature (°F).

Variables in COMMON. See Table 5.4 for definitions.

OUTPUT

WLVG : Leaving humidity ratio (lbm-H_2O/lbm-dry air).

QTRHC : System reheat load (Btu/hr).

QTRCC : System recooling load (Btu/hr).

Also, some variables in COMMON.

CALCULATION SEQUENCE

1. Heating supplied.

If TLC > TLCMX,

TDIF = TLCMX - TLC

TLC = TLCMX

$QTDIF = ZMAS_i * 0.245 * (TDIF - TLC)$

$QLNM_i$ = QTDIF

Update as required the following variables:

$QHLNM_i$

$QHPNM_i$

$IHHNM_i$

QT = $ZMAS_i$ * 0.245 * (TEC - TLC)

QTRHC = QTRHC + QT * AMULT

WLVG = WEC

If TLC $\leq$ TLCMX,

QT = $ZMAS_i$ * 0.245 * (TEC - TLC)

QTRHC = QTRHC + QT * AMULT

WLVG = WEC

2. Cooling supplied.

If TLC < TLCMN,

Call subroutine CCOIL to calculate cooling load (QCTLC) if TLC were allowed to be met.

Call subroutine CCOIL to calculate cooling load (QT) with TLC limited to TLCMN.

TLC = TLCMN

QTDIF = QCTLC - QT

$QLNM_i$ = QTDIF

Update the following variables as required:

$QCLNM_i$

$QCPNM_i$

$IHCNM_i$

QTRCC = QTRCC + QT * AMULT

If TLC $\geq$ TLCMN,

Call subroutine CCOIL to calculate cooling load QT

QTRCC = QTRCC + QT * AMULT

BRAD2

A subroutine to calculate the heat (QB) added to a zone by a baseboard radiation heating system and to correspondingly adjust the zone's base sensible heat load (QS).

INPUT

QS - Base sensible heating load (Btu/hr)

TSP - Set point temperature of zone (^{o}F)

CBTU - Heat output of baseboard radiation at standard conditions (215^{o}F avg. water temp., 65^{o}F entering air temp.) (Btu/hr-lin.ft.)

ALFBR - Active length baseboard radiation (lin.ft.)

TOA - Dry-bulb temperature outside air (^{o}F)

THWHI - (^{o}F)

THWLO - (^{o}F)

TOAHI - (^{o}F)

TOALO - (^{o}F)

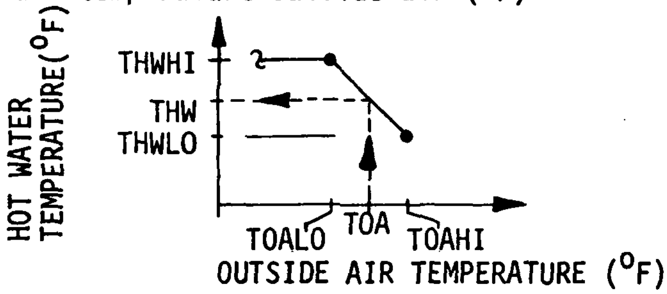


Figure 5.4 Graphic illustration of baseboard hot water temperature reset as function of outside air temperature

OUTPUT

QB - Heat given off by baseboard radiation (Btu/hr)

CALCULATION SEQUENCE

1. Baseboard heating off.

   If TOA $>$ TOAHI,

   QB = 0.

2. Baseboard heating on.

   If TOA $\leq$ TOAHI,

   TAIR = TSP - 10.

Calculate THW using function TRSET.

$$QB = -\left[\frac{(THW - TAIR)}{(215. - 65.)}\right]^{1.4} * (CBTU * ALFBR)$$

3. Adjust QS.

$$QS = QS - QB$$

A routine to simulate the performance of air handling units calculating thermal requirements of coils, fan heat, and humidifier.

INPUT

NAHU : Air handling unit type:

1) Draw-through unit--heating coil, cooling coil, fan, discharge
2) Draw-through unit--heating coil, cooling coil with face and bypass dampers, fan, discharge.
   When heating required, bypass full open and heating coil modulates to meet load, cooling coil off. When cooling required, heating coil locked out, cooling coil runs wild, dampers modulate to meet required dry bulb temperature.

PATM : Barometric pressure (in. Hg).

MFAN : Fan mass air flow (lbm-air/hr).

NVFC : Fan volume control index (see PTLD).

PCTLD : Fan full load fraction.

DTFAN : Temperature rise across fan at full load (°F).

TLVG : Desired air temperature leaving AHU (°F).

TCD : Cold deck temperature (°F).

H2ORD : Net humidity control zone water requirement.

MZONE : Humidity control zone mass air flow (lbm-air/hr).

WZ : Humidity control zone humidity ratio (lbm-H_2O/lbm-dry air).

TMA : Inlet dry bulb temperature (°F).

WMA : Inlet humidity ratio (lbm-H_2O/lbm-dry air).

DMA : Inlet air density (lbm/ft^3).

OUTPUT

QCC : Cooling coil load (Btu/hr).

SHR : Sensible heat ratio.

QHC : Heating coil load (Btu/hr).

WLVG : Humidity ratio entering humidifier section (lbm-H_2O/lbm-dry air) air).

DLVG : Air density entering humidifier section (lbm/ft^3).

WSUP : Humidity ratio after humidifier section (lbm-H_2O/lbm).

WATER : Water added to air by humidifier (lbm-H_2O/hr).

CALCULATION SEQUENCE

1. Simple draw-through unit simulation.

TLC = TLVG - DTFAN * PTLD * (NVFC, PCTLD)

If TMA < TLC,

QHC = MFAN * 0.245 * (TMA - TLC)

QCC = 0.0

WLVG = WMA

SHR = 1.0

GO TO 3.

If TMA = TLC,

QHC = 0.0

QCC = 0.0

WLVG = WMA

SHR = 1.0

GO TO 3.

If TMA > TLC,

Call subroutine CCOIL to calculate WLVG, QCC, and SHR.

QHC = 0.0

GO TO 3.

2. Draw-through unit with bypass around cooling coil.

TLC = TLVG - DTFAN * PTLD * (NVPC, PCTLD)

If TMA < TLC,

QHC = MFAN * 0.245 * (TMA - TLC)

QCC = 0.0

WLVG = WMA

SHR = 1.0

GO TO 3.

If TMA = TLC

QHC = 0.0

QCC = 0.0

WLVG = WMA

SHR = 1.0

GO TO 3.

If TMA > TLC,

Call subroutine CCOIL to calculate cooling coil performance for 1. lbm-air/hr (QCC1).

Call subroutine MXAIR to calculate position of face and bypass dampers (ALFA = portion of air through bypass).

QCC = MFAN * (1.0 - ALFA) * QCC1

3. Humidifier simulation.

Using function DENSY, calculate DLVG.

If QCC > 0.0

WATER = 0.0

WSUP = WLVG

If QCC $\leq$ 0.0,

WSUP = -H2ORD/MZONE + WZ

(Limit WSUP by high limit switch on humidifier set at 80% R.H.)

WATER = -MFAN * (WLVG - WSUP)

MXAIR

A subroutine to calculate the thermal properties of mixed air given the properties of the two mixing air streams. The basic application of this routine is in simulating the function of three types of outside air control.

INPUT

	MXAO	:	Type of outside air control.
		1	Fixed percent outside air.
		2	Enthalpy/temperature type economizer cycle control.
		3	Temperature type economizer cycle control.
Air Stream #1	TOA	:	Outside air dry bulb temperature (°F)
	DOA	:	Outside air density (lbm/ft^3)
	HOA	:	Outside air enthalpy (Btu/lbm)
	WOA	:	Outside air humidity ratio (lbm-H_2O/lbm-dry air)
	PATM	:	Barometric pressure (in. Hg)
Air Stream #2	TRA	:	Return air temperature (°F)
	DRA	:	Return air density (lbm/ft^3)
	WRA	:	Return air humidity ratio (lbm-H_2O/lbm-dry air)
	EAT	:	Desired mixed air temperature (economizer approach temperature) (°F)
	ALFAM	:	Minimum fraction of outside air (for MXAO type 1, ALFAM is the fixed portion of outside air.

OUTPUT

ALFA : Actual portion of outside air which meets or approaches EAT.

TMA : Mixed air dry bulb temperature (°F)

WMA : Mixed air himidity ratio (lbm-H_2O/lbm-dry air)

OUTPUT (Concluded)

DMA : Mixed air density (lbm/ft^3)

CALCULATION SEQUENCE

1. Using subroutine PSYCH, calculate return air enthalpy (HRA).

2. MXAO = 1 (fixed percent outside air)

   ALFA = ALFAM

   GO TO 5.

3. MXAO = 2 (enthalpy/temperature type economizer cycle control)

   If HOA < HRA,

      Calculate ALFA using subroutine ECONO

   If HOA > HRA,

      ALFA = ALFAM

   GO TO 5.

4. MXAO = 3 (temperature type economizer cycle control)

   Calculate ALFA using subroutine ECONO.

   GO TO 5.

5. Mixed air thermal properties.

   TMA = (TOA * DOA * ALFA + TRA * DRA * (1. - ALFA))/(DOA * ALFA
      + DRA * (1. - ALFA))

   WMA = (WOA * DOA * ALFA + WRA * DRA * (1. - ALFA))/(DOA * ALFA
      + DRA * (1. - ALFA))

   DMA = PATM/((.754 * (TMA + 460.)) * (1. + (7000. * WMA/4360.)))

ECONO

A subroutine to simulate the operation of a temperature type economizer cycle, calculating that portion of outside air yielding a mixed air temperature closest to the desired mixed air dry bulb temperature.

INPUT

OA : Outside air dry bulb temperature (°F)

DOA : Outside air density (lbm/ft^3)

RA : Return air dry bulb temperature (°F)

DRA : Return air density (lbm/ft^3)

LVG : Desired mixed air dry bulb temperature (°F)

ALFAM : Minimum fraction of outside air

OUTPUT

ALFA : Portion of outside air yielding mixed temperature closest to desired mixed air temperature

CALCULATION SEQUENCE

1. Select appropriate mode.

Mode 1. Return air temperature greater than outside air temperature.

If LVG $\leq$ OA,

ALFA = 1.0

If LVG > OA,

If LVG < RA,

ALFA = (DRA * (RA - LVG))/(RA * DRA - OA * DOA + LVG * (DOA - DRA))

If LVG $\geq$ RA,

ALFA = ALFAM

GO TO 2.

Mode 2. Return air temperature equals outside air temperature.

ALFA = 1.0

RETURN

Mode 3. Return air temperature less than outside air temperature.

If LVG $\leq$ RA,

ALFA = ALFAM

If LVG > RA,

If LVG < OA,

ALFA = (DRA * (RA - LVG))/(RA * DRA - OA * DOA + LVG * (DOA - DRA))

If LVG $\geq$ OA,

ALFA = 1.0

GO TO 2.

2. Check range of ALFA.

If ALFA < ALFAM,

ALFA = ALFAM

If ALFA > 1.0,

ALFA = 1.0

CCOIL

A subroutine to simulate the performance of a cooling coil. It calculates the sensible and latent heat extracted by a cooling coil assuming it to be of adequate capacity. The coil cools air to dry bulb temperature (TDBO) and calculates the humidity ratio at that condition.

INPUT

MASS : Rate of air flow through coil (lbm-air/hr)

PATM : Barometric pressure (inches Hg.)

TDBI : Dry bulb temperature of entering air (°F)

WI : Humidity ratio of entering air (lb-H_2O/lb-dry air)

TDBO : Dry bulb temperature of leaving air (°F)

OUTPUT

WO : Humidity ratio of leaving air (lb-H_2O/lb-dry air)

QCC : Total heat extracted by coil (Btu)

SHR : Sensible heat ratio

CALCULATION SEQUENCE

1. Estimate leaving wet bulb temperature.

   TWBO = TDBO - 1.5

2. Simulate cooling coil.

   DT = TDBI - TDBO

   If DT $\leq$ 0.0,

      QCC = 0.0

      SHR = 1.0

      WO = WI

If DT > 0.0,

QSC = MASS * 0.245 * DT

Use subroutine PSY1 to calculate leaving air humidity ratio (WO)

DW = WI - WO

If DW $\leq$ 0.0,

WO = WI

QCC = QSC

SHR = 1.0

If DW > 0.0,

QLC = MASS * 1090.0 * DW

QCC = QSC + QLC

SHR = QSC/QCC

The functioning of the cooling coil simulation is illustrated graphically in Figure 5.5, where it is plotted on an HVAC equipment manufacturer's psychrometric chart.

It shows a strong correlation with the manufacturer's published cooling coil performance curves and it is also in accord with recommendations of Stoecker, et.al. (1973) (ASHRAE Publication No. 2290-RP-131), recommending cooling coil discharge air conditions to be 90% RH for simulation purposes when latent heat is being extracted.

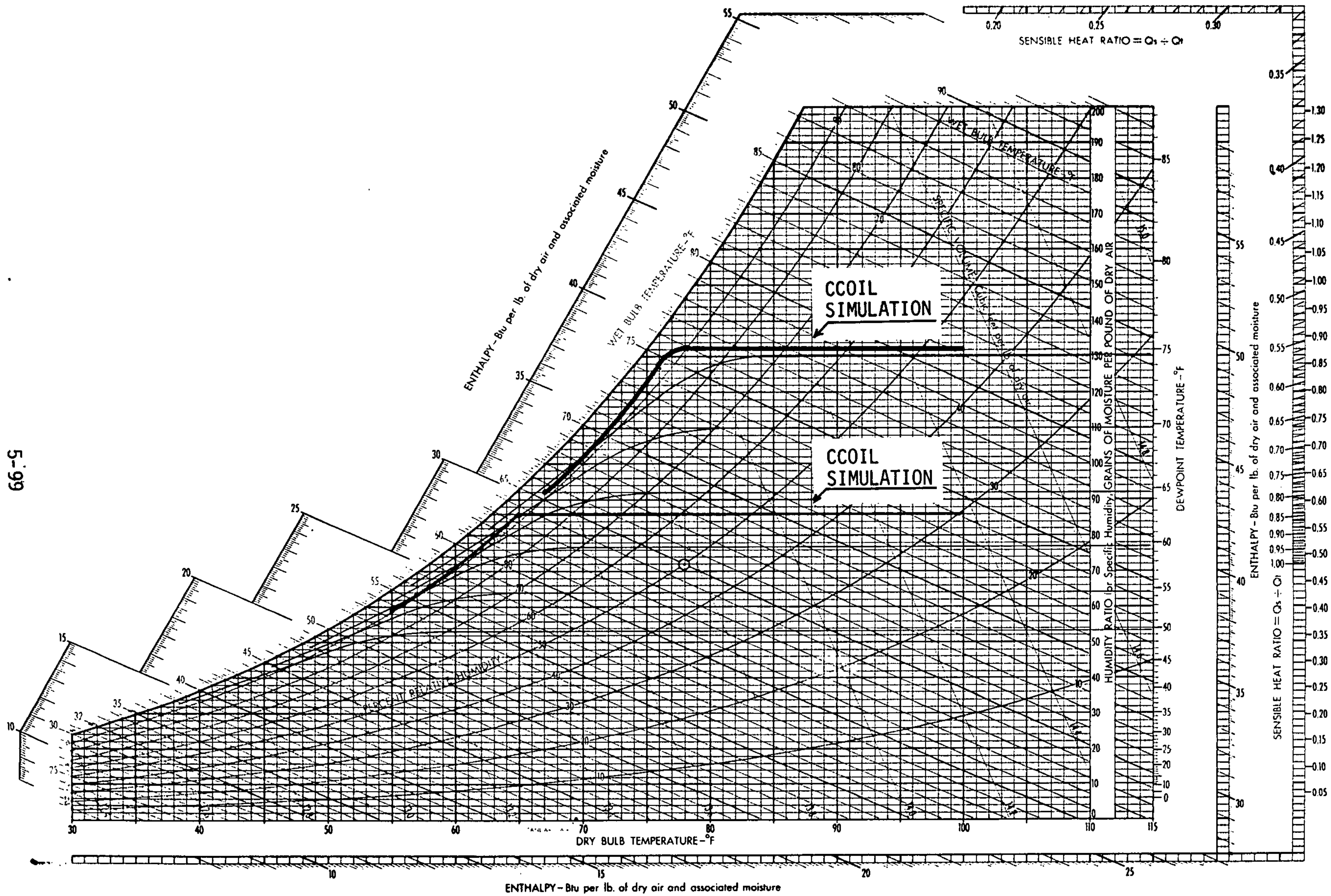


Fig.5.5 Manufacturer's psychrometric chart illustrating the performance of CCOIL.

TRSET

A function to calculate TRSET as a linear function of TOA between the coordinates (THI, TOALO) and (TLO, TOAHI). TRSET is allowed to float between THI and TLO but not to exceed those bounds as illustrated in the figure below.

INPUT

TOA :

THI :

TLD :

TOAHI :

TOALO :

OUTPUT

TRSET -

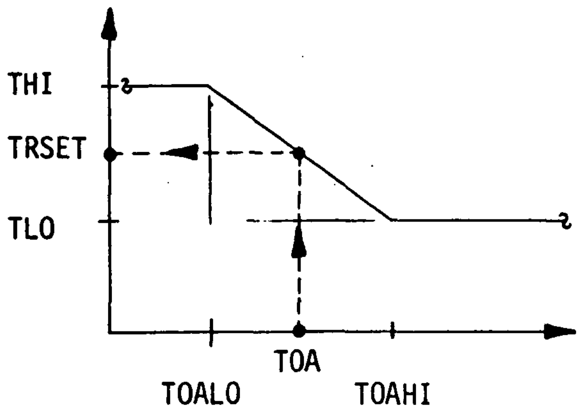


Figure 5.6 GRAPHIC ILLUSTRATION OF FUNCTION TRSET.

CALCULATION SEQUENCE

If TOA ≤ TOALO,

TRSET = THI

If TOA > TOALO,

If TOA ≥ TOAHI,

TRSET = TLO

If TOA < TOAHI,

TRSET = (THI - (THI - TLO) * (TOA - TOALO))/(TOAHI - TOALO)

PTLD

A function to calculate the part load power requirement of variable volume fans.

INPUT

NC : Curve Number

1 : Variable Speed Motor.

2 : Inlet Vane Damper

3 : Discharge Damper

PC : Fraction of full load for a volume

OUTPUT

PTLD : Percent part load power

LIMIT VALUES

$0.20 \le PC \le 1.10$

CALCULATION SEQUENCE

1. Variable Speed Motor

PTLD = 0.0015302776 + PC * (0.0052080574 + PC * (1.1086242 + PC * (-0.11635563)))

2. Inlet Vane Damper

PTLD = 0.35071223 + PC * (0.3080535 + PC * (-0.54137364 + PC * (0.87198823)))

3. Discharge Damper

PTLD = 0.37073425 + PC * (0.97250253 + PC * (-0.34240761))

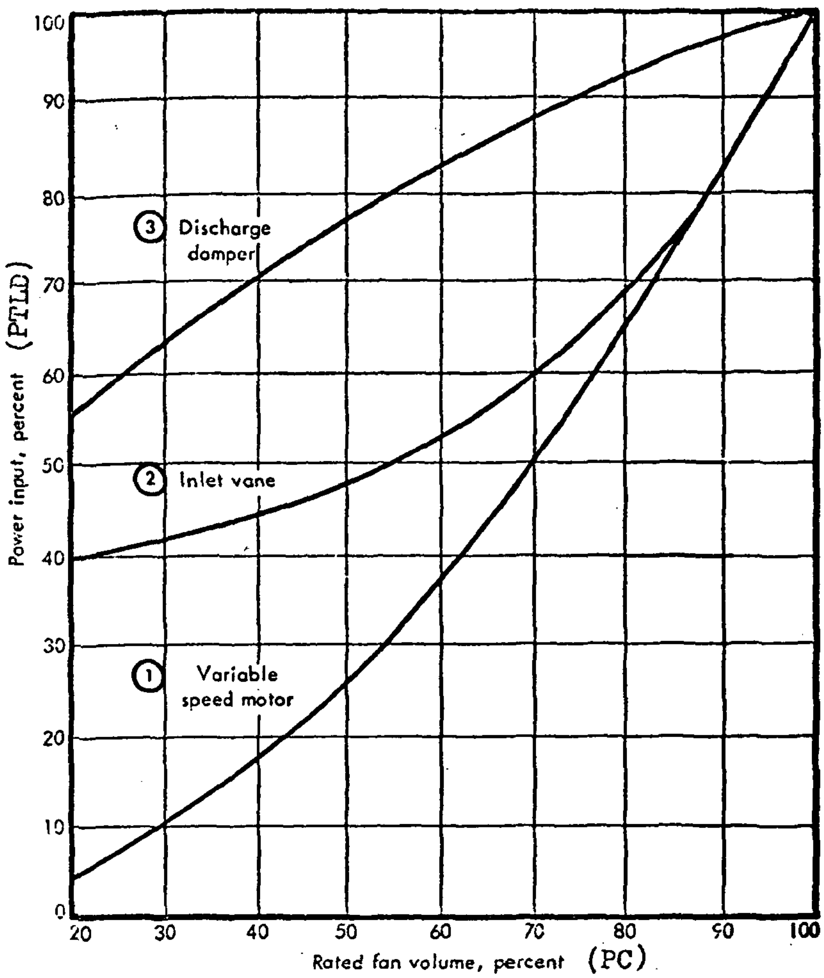


Figure 5.7 POWER SAVINGS VS AIR QUANTITY REDUCTION FOR THREE COMMON METHODS OF CONTROLLING DUCT STATIC PRESSURES

TEMP

A subroutine to calculate the dry bulb air temperature of air leaving an air handler and/or indicate the mode (heating or cooling) of process water in a two-pipe distribution system.

INPUT

ICO : Type of control option selected:

1) Fixed or predefined (constant).
2) Determined by room with coldest supply air requirement.
3) Reset as inverse function of outside air dry bulb temperature.
4) Reset as direct function of outside air dry bulb temperature to a maximum, then lower to a minimum (spike). For two-pipe induction units with waterside changeover.
5) High/low step function with hysteresis at changeover. Used for two-pipe fancoil waterside changeover.
6) Determined by room with warmest supply air requirement.

K : Fan system number.

JMAXK : Number of zones on currently analyzed system.

TOA : Dry bulb outside air temperature (°F)

TFIX : Fixed leaving air temperature for control mode one (°F)

SPACN(K,J) : Variable which defines zone/Q-distrib. system relationships.

TS(I) : Required supply air temperatures to each zone (°F)

Following variables used for control mode three:

TLAHI : Highest air temperature leaving AHU (°F)

TLALO : Lowest air temperature leaving AHU (°F)

TDBLO : Low ambient DB temperature corresponding to high leaving AHU temperature (TLAHI) (°F)

TDBHI : High ambient DB temperature corresponding to low leaving AHU temperature (TLALO) (°F)

TCOFC : Two-pipe fancoil unit changeover temperature.

OUTPUT

TLVG : Required dry bulb temperature of air leaving air handler.

TOACO : Induction unit changeover temperature.

IPW : Induction or fancoil unit process water temperature indicator: -1 = Hot water available.
0 = Changeover condition and/or hot and chilled water available.
+1 = Chilled water available.

CALCULATION SEQUENCE

1. Fixed or predefined.

TLVG = TFIX

2. Determined by room with coldest air requirement.

Scan applicable TS_i values. Set TLVG equal to lowest TS_i.

3 Reset as inverse function of outside air dry bulb temperature

Use function TRSET to calculate TLVG.

Input variables:

TOA

TLAHI

TLALO

TDBHI

TDBLO

4. Two-pipe induction unit primary air schedule and process water mode indicator. See INDUC for graph of this TEMP function.

```
If TOACO < TOA,
    If TDBHI ≤ TOA,
        TLVG = TLALO
        IPW = 1
        TOACO = TDBLO
    If TDBHI > TOA,
        Calculate TLVG using function TRSET.
        IPW = 1
        TOACO = TDBLO
If TOACO = TOA,
    Calculate TLVG using function TRSET.
    If TOACO ≤ TDBLO,
        TOACO = TDBLO + 5.0
        IPW = -1
    If TOACO > TDBLO,
        TOACO = TDBLO
        IPW = -1
If TOACO > TOA,
    TLVG = TLALO
    TOACO = TDBLO + 5.0
    IPW = -1
```

5. Two-pipe fancoil waterside changeover. Based on changeover temperature with (+) or (-) 2.5°F lag.

If TOA < TOACO,

If TOACO > TCOFC

IPW = -1

If TOACO ≤ TCOFC

TOACO = TCOFC + 2.5

IPW = 0

If TOA = TOACO,

If TOACO ≤ TCOFC

TOACO = TCOFC + 2.5

IPW = 0

If TOA > TCOFC,

TOACO = TCOFC - 2.5

IPW = 0

If TOA > TOACO,

If TOACO ≥ TCOFC

TOACO = TCOFC - 2.5

IPW = 0

If TOACO < TCOFC

IPW = +1

6. Determined by room with warmest supply air requirement.

Scan applicable TS_i values. Set TLVG equal to largest TS_i.

A subroutine for calculating the psychrometric properties of moist air.

INPUT

T : Dry-bulb temperature of moist air (°F)

W : Humidity ratio of moist air (lb water/lb dry air)

PATM : Barometric pressure (inches of mercury)

OUTPUT

DEN : Density of moist air (lb dry air/cu ft)

H : Enthalpy of moist air (Btu/lb dry air)

CALCULATION SEQUENCE

1. Calculate enthalpy.

   H = 0.24 * T + W * (1061.0 + 0.444 * T)

2. Calculate specific volume.

   V = 0.754 * (T + 459.688) * (1.0 + 7000.0 * W/4360.0)/PATM

3. Calculate specific density.

   DEN = 1.0/V

PSY1 AND PSY2

A subroutine which calculates humidity ratio, enthalpy and density of outside air.

INPUT

DBT : Outside air dry-bulb temperature (°F)

WBT : Outside air wet-bulb temperatjre (°F)

DPT : Outside air dew point temperature (°F)

PATM : Atmospheric pressure (inches of mercury)

OUTPUT

HUMRAT : Humidity ratio (lbs water/lbs dry air)

ENTH : Enthalpy (Btu/lb dry air)(PSY1 only)

DENS : Density (lbs dry air/cu ft)(PSY1 only)

CALCULATION SEQUENCE

In the calculation of psychrometric properties of moist air partial pressure of water vapor is needed. This is calculated by the PPWVM sub-function.

1. Calculate partial pressure of water vapor in moisture-saturated air for WBT and obtain partial pressure of water (applies when dewpoint temperature is greater than 32.0 °F).

   PPWV = PPWVM(WBT) - 0.000367 * PATM * (DBT - WBT)/
   (1.0 + (WBT - 32.0)/1571.0)

2. HUMRAT = 0.622 * PPWV/(PATM - PPWV)

3. ENTH = 0.24 * DBT + (1061.0 + 0.444 * DBT) * HUMRAT

4. DENS = 1.0/(0.754 * (DBT + 460.0) * (1.0 + 7000.0 * HUMRAT/
   4360.0)/PATM)

PPWVM

A function which calculates the partial pressure of water in moisture-saturated air.

INPUT

TEMP : may be a wet-bulb, dry-bulb, or dewpoint temperature (^oF)

OUTPUT

PPWVM : partial pressure of water in moisture-saturated air (in. Hg)

CALCULATION SEQUENCE

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

```
 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) * (x-1)
P2 = B(2) * Log10 (z)
P3 = B(3) * (1-1/z)
P4 = Log 10 (B(4))
```

4. PVS = 29.921 * 10 ** (P1 + P2 + P3 + P4)

HUM1

A subroutine to calculate the humidity ratio (lb-H_2O/lb-dry air) of air given

T - dry-bulb temperature (^oF)

RH - relative humidity (%)

PATM - barometric pressure (in. Hg.)

1. Using subroutine PSY2, calculate humidity ratio of saturated air (WSAT) at temperature, T.
2. Humidity ratio (W) = RH * 0.01 * WSAT

DENSY

A function to calculate the density of moist air (lb-air/cu.ft.) given

T - dry-bulb temperature (^oF)

W - humidity ratio (lb-H_2O/lb-dry air)

PATM - barometric pressure (in. Hg.)

DENSY = 1.0/(0.754 * (T+460.0) * (1.0+7000.0 * W/4360.)/PATM)

MAX

A subroutine to replace current values of A with X and IB with IY if the absolute value of X exceeds A. A and X are real numbers. IB and IY are integers.

VARIABLE ORDER

A, X, IB, IY

CALCULATION SEQUENCE

1. If $|X|$ exceeds $|A|$,

$$A = X$$

$$IB = IY$$

ERROR

A subroutine to print terminal and warning messages due to input data abnormalities.

ALOG1

A function to calculate logarithms to base 10.

$$\text{Log}_{10}(X) = 0.434294481 * \text{Log}_e(X)$$

H2OZN

A subroutine to calculate hourly moisture changes and net moisture requirements.

INPUT

- QL : Latent load from zone (Btu/hr)
- ZMASS : Mass flow through zone (lbm-air/hr)
- WSP : Zone humidity ratio set point (lbm-H_2O/lbm-dry air)
- QLINF : Latent load due to infiltration from load tape (Btu/hr)
- WZON : Current zone humidity ratio (lbm-H_2O/lbm-dry air)
- WOA : Outside air humidity ratio (lbm-H_2O/lbm-dry air)

OUTPUT

- H2OAD : Zone water change in current hour (lbm-H_2O)
- H2ORD : Net zone water requirement

CALCULATION SEQUENCE

1. Zone load water.

   H2ORM = QL/1090.0

2. Infiltration water.

   H2OIN = (QLINF/1090.0) * (WOA - WZON)/((WOA - WSP)

3. Set point recovery load.

   H2OVL = (WZON - WSP) * ZMASS

4. Summaries.

   H2OAD = H2ORM + H2OIN

   H2ORD = H2OAD + H2OVL

WZNEW

A function to calculate space humidity ratios based on a water balance of the following sources: QL moisture, infiltration moisture, supply air moisture.

INPUT

TSP : Set point tepperature (°F)

TLC : Supply air temperature (°F)

WLC : Supply air humidity ratio (lbm-H_2O/lbm-dry air)

PATM : Barometric pressure (inches Hg)

CFMS : Supply air flow rate (ft^3/min)

VOL : Zone volume (ft^3)

H2OAD : Zone water change incurrent hour (lbm-H_2O)

WZ : Current zone humidity ratio (lbm-H_2O/lbm-dry air)

OUTPUT

WZNEW : New humidity ratio (lbm-H_2O/lbm-dry air)

CALCULATION SEQUENCE

1. Calculate supply air moisture and net moisture to zone.

   Call function DENSY to calculate supply air density (DLVG)

   H2OS2 = CFMS * DLVG * 60.0 * (WLC - WZ)

   DH2O = H2OS2 + H2OAD

2. Calculate new humidity ratio.

   AIR = CFMS * 60.0

   If AIR < VOL, AIR = VOL

   WZNEW = DH2O/(AIR * DLVG) + WZ

EQUIP

A subroutine for calculating the energy consumption of conventional heating and cooling systems, on-site generation systems and conventionally operated heat conservation systems.

INPUT

M1	:	Type of chiller
M2	:	Source of chiller energy
M3	:	Source of heating energy
M4	:	Number of on-site generation engines
M5	:	Type of on-site generation engines
M6	:	Type of auxiliary chiller
M7	:	Source of supplemental heat
KREHT	:	Source of reheat coil energy
NUMC	:	Number of chillers
SZC	:	Size of chillers (tons)
NUMAC	:	Number of auxiliary chillers
SZAC	:	Size of auxiliary chillers (tons)
QHBC	:	Hourly building cooling load (Btu/hr)
QHBH	:	Hourly building heating load (Btu/hr)
QHBRH	:	Hourly building reheat load (Btu/hr)
TECON	:	Entering condensing water temperature (^{o}F)
ELDEM	:	Hourly electrical demand of the building (KW)
TLCHL	:	Chilled water set point temperature (^{o}F)
TPS	:	Temperature of high pressure purchased steam (^{o}F)
PPS	:	Pressure of high-pressure purchased steam (psig)
TESTM	:	Temperature of low pressure steam (^{o}F)
PESTM	:	Pressure of low pressure (psig)

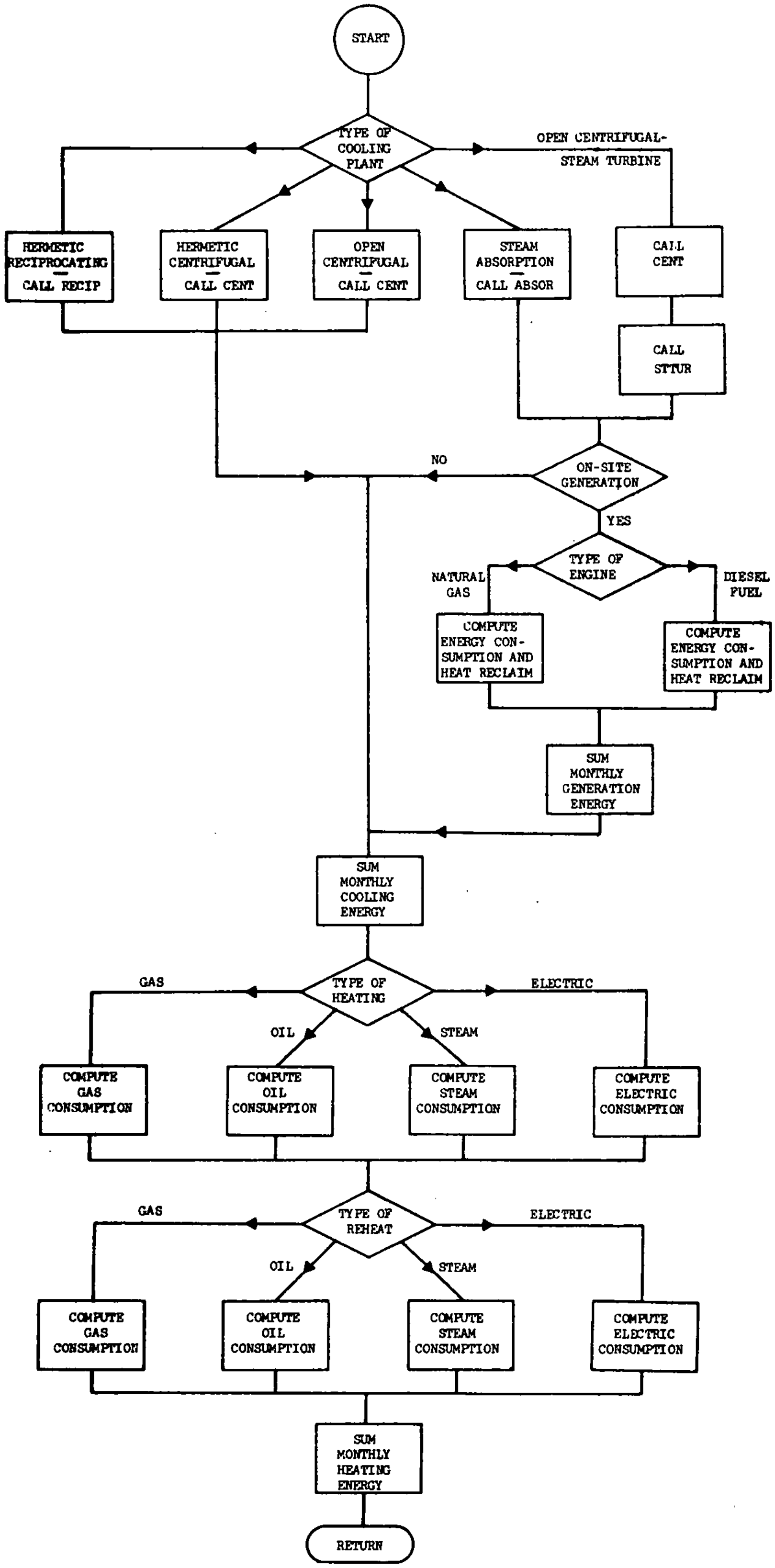


Figure 5.8 LOGIC FLOW CHART OF SUBROUTINE EQUIP

INPUT (CONT'D)

SZT	:	Size of steam turbines (HP)
NUMT	:	Number of steam turbines (rpm)
RPM	:	Speed of steam turbines (rpm)
SZE	:	Size of on-site generation engines (KW)
HVHO	:	Heating value of heating oil (Btu/gal)
HVDF	:	Heating value of diesel fuel (Btu/gal)
FFLMN	:	Minimum part load cutoff point for chillers (decimal)

OUTPUT

GASC	:	Hourly gas consumption for cooling (therms)
GASH	:	Hourly gas consumption for heating (therms)
GASG	:	Hourly gas consumption for on-site generation (therms)
OILC	:	Hourly oil consumption for cooling (gals)
OILH	:	Hourly oil consumption for heating (gals)
STMC	:	Hourly steam consumption for cooling (lbs)
STMH	:	Hourly steam consumption for heating (lbs)
ELEC	:	Hourly electrical consumption for cooling (KW)
ELEH	:	Hourly electrical consumption for heating (KW)
FUEL	:	Hourly diesel fuel consumption for on-site generation (gals)

CALCULATION SEQUENCE

1. Convert hourly building cooling load into tons.

   QHBC = QHBC/12000.0

2. Calculate the enthalpy of entering and leaving steam (for boilers and absorption chillers).

2.1 For entering condition, use

$$AH = 1068.0 - 0.485 * PESTM$$

$$BH = 0.432 + 0.000953 * PESTM$$

$$CH = 0.000036 - 0.000000496 * PESTM$$

$$HESTM = AH + BH * TESTM + CH * TESTM * TESTM$$

where HESTM is enthalpy of entering steam (Btu/lb).

2.2 For leaving conditions, assume saturated water, therefore

$$HLSTM = 180.07$$

where HLSTM is enthalpy of leaving steam (Btu/lb)

3. Check the type of building system.

If M4 = 0, then conventional system or conventionally-operated heat conservation system.

Go to calculation 4.

If M4 > 0, then on-site generation system.

Go to calculation 8.

4. Calculate the number of chillers operating.

4.1 If the quantity (1.0 - QHBC/(0.9 * NUMC * SZC)) is (+), then building system is a conventional system or a conventionally-operated heat conservation system with no auxiliary chillers needed.

Set NC = 1 (number of chillers operating).

Calculate fraction of full load.

$$FFL = QHBC/(NC * SZC)$$

If necessary, increase NC until FFL $\leq$ 0.9.

IF NC = 1, and FFL < FFLMN, then no cooling available.

If NC = NUMC, and FFL > 1.1, chiller load not met.

$$FFL = 1.1$$

$$QRNM = (QHBC - NC * SZC * FFL) * 12$$

where QRNM = chiller load not met

QHBC = NC * SZC * FFL

Update as required the following chiller load not met variables.

QRCNM -

QRPNM -

IHRNM -

4.2 If the quantity (1.0 - QHBC/(0.9 * NUMC * SZC)) is (-), then building system is a conventionally-operated heat conservation system with auxiliary chillers needed.

Set NAC = 1 (number of auxiliary chillers operating).

Calculate fraction of full load.

FFL = QHBC/(NUMC * SZC + NAC * SZAC)

If necessary, increase NAC until FFL $\leq$ 0.9.

5. Calculate the energy consumption required for cooling.

5.1 If the quantity (1.0 - QHBC/(0.9 * NUMC * SZC)) is (+), proceed as follows:

If M1 = 1, (reciprocating chiller), call RECIP, which calculates ELEC.

If M1 = 2, (hermetic centrifugal chiller), call CENT, which calculates ELEC.

If M1 = 3, (open centrifugal chiller), call CENT, which calculates ELEC, then adjust as follows:

ELEC = ELEC/(1.0 + 0.02133 * ELEC/QHBC)

If M1 = 5, (centrifugal chiller powered by steam turbine), call CENT, which calculates POWER, then call STTUR, which calculates STMC and equivalent heating requirement, QHMC.

For cases where M1 = 4 or 5, check for source of chiller energy.

If M2 = 1, GASC = QHMC/80000.0

STMC = 0.0

If M2 = 2, QILC = QHMC/(0.8 * HVHQ)

STMC = 0.0

If M2 = 3, STMC = STMC

If M2 = 4, ELEC = QHMC/3413.0

STMC = 0.0

5.2 If the quantity (1.0 - QHBC/(0.9 * NUMC * SZC)) is (-), proceed as follows:

If M1 = 1, call RECIP, which calculates PW1.

If M1 = 2, call CENT, which calculates PW1.

If M1 = 3, call CENT, which calculates PW1, then adjust as follows:

PW1 = PWL/(1.0 + 0.02133 * PW1/(FFL * NUMC * SZC))

If M6 = 1, (reciprocating auxiliary chiller), call RECIP, which calculates PW2.

If M6 = 2, (Hermetic centrifugal auxiliary chiller), call CENT, which calculates PW2.

If M6 = 3, (open centrifugal auxiliary chiller), call CENT, which calculates PW2, then adjust as follows:

PW2 = PW2/(1.0 + 0.02133 * PW2/(NAC * SZAC * FFL))

Total energy consumption for cooling

ELEC = PW1 + PW2

6. Calculate the energy consumption required for heating.

If QHBH > NUMB * SZB * 1000.0, boiler load not met.

QBNM = QHBH + SZB * NUMB * 1000.0 (QBNM = boiler load not met)

QHBH = SZB * NUMB * (-1000.0)

Update as required the following boiler load not met variables:

QBCNM -

QBPNM -

IHBNM

If M3 = 1, (gas-fired boiler), GASH = -QHBH/80000.0

If M3 = 2, (oil-fired boiler), OILH = -QHBH/(0.8 * HVHO)

If M3 = 3, (purchased steam heat, STMH = -QHBH/(HESTM-HLSTMO

If M3 = 4, (electric boiler), ELEH = -QHBH/3413.0

7. Calculate the energy consumption required for reheat.

If KREHT = 0, no reheat energy available.

If KREHT = 1, (heat from gas-fired boiler),
GASH = GASH - QHBRH/80000.0

If KREHT = 2, (heat from oil-fired boiler),
OILH = OILH - QHBRH/(0.8 *HVHO)

If KREHT = 3, (heat from purchased steam),
STMH = STMH - QHBRH/(HESTM - HLSTM)

If KREHT = 4, (heat from electric boiler),
ELEH = ELEH - QHBRH/3413.0

END OF CONVENTIONAL ANALYSIS

BEGIN ON-SITE POWER GENERATION ANALYSIS.

8. Calculate the number of on-site generation engines in operation.

Set NE = 1 (number of engines operating).

Calculate fraction of full load.

FFLE = ELDEM/(NE * SZE)

If necessary, increase NE until FFLE $\leq$ 1.1.

9. Calculate the energy consumption required for operation of engines.

If M5 = 1, (diesel), FUEL = (8900.0 + 2000.0/FFLE)/HVDF

If M5 = 2, (gas), GASG = 0.085 + 0.0289/FFLE

10. Calculate the amount of engine heat able to be reclaimed.

If M5 = 1, (diesel), QEN = (69.2 + 21.2 * FFLE) * ELDEM

If M5 = 2, (gas), QEN = (60.51 + 16.64/FFLE + 14.0 * FFLE)* ELDEM

11. Compute the number of chillers operating.

Set NC = 1 (number of chillers operating).

Calculate fraction of full load.

FFL = QHBC/(NC * SZC)

If necessary, increase NC until FFL < 0.9.

If NC = 1, and FFL < FFLMN, then no cooling available.

If NC = NUMC, and FFL > 1.1, chiller load not met.

FFL = 1.1

QRNM = (QHBC - NC * SZC * FFL) * 12

QHBC = NC * SZC * FFL

Update as required the following chiller load not met variables:

QRCNM -

QRPNM -

IHRNM -

12. Calculate the energy consumption required for cooling.

If M1 = 1, not applicable.

If M1 = 2, not applicable.

If M1 = 3, not applicable.

If M1 = 4, call ABSOR, which calculates STMC and the equivalent heating requirement, QHMC.

If M1 = 5, call CENT, which calculates POWER, then call STTUR, which calculates STMC and equivalent heating requirement, QHMC.

13. Calculate the energy consumption required for heating and cooling.

If -QHBH - QEN + QHMC > NUMB * SZB * 1000.0, boiler load not met.

QBNM = (QHBH + QEN - QHMC) + (NUMB * SZB * 1000.0)

QHBH = NUMB * SZB * (-1000.0)

Update as required the following boiler load not met variables:

QBCNM -

QBPNM -

IHBNM -

If M3 = 1, GASH = (QHMC - QHBH - QEN)/80000.0

STMC = 0.0

If GASH < 0.0, set GASH = 0.0.

If M3 = 2, OILH = (QHMC - QHBH - QEN)/(0.8 * HVHO)

STMC = 0.0

If OILH < 0.0, set OILH = 0.0.

14. Compute energy consumption required for reheat.

If KREHT = 0, not applicable.

If KREHT = 1, GASH = GASH - QHBRH/80000.0

If KREHT = 2, not applicable.

If KREHT = 3, not applicable.

END OF ON-SITE POWER GENERATION ANALYSIS.

STTUR

A subroutine for calculating the energy consumption of a single stage condensing steam turbine as a function of its power output.

INPUT

PPS : Pressure of high pressure steam (psig)

TPS : Temperature of high pressure steam (°F)

RPM : Speed of steam turbine (rpm)

SZT : Size of steam turbine, HP (taken as 1 HP/ton)

NSTON : Number of steam turbines operating; same as number of chillers operating

POWER : Total power output required by all turbines (KW)

OUTPUT

STEAM : Hourly steam consumption (lb/hr)

CALCULATION SEQUENCE

1. Find the power output for each turbine (HP)

   POWER = 1.341 * POWER/NSTON

2. Determine the enthalpy of entering steam (H1).

   H1 = AH + BH * TPS + CH * TPS * TPS

   where AH = 1068.0 - 0.485 * PPS

   BH = 0.432 + 0.000953 * PPS

   CH = 0.000036 - 0.000000496 * PPS

3. Calculate the entropy of steam.

   S = 2.385 - 0.004398 * TSAT1 + 0.000008146 * TSAT1 * TSAT1

   -0.662 * E-08 * (TSAT1 ** 3.0) + 2.0 * CH * (TPS-TSAT1)

   + (BH - 920.0 * CH) * ALOG((TPS + 460.0)/(TSAT1 + 460.0)) where

$$TSAT1 = 1.0/(0.0017887 - 0.00011429 * ALOG (PPS)) - 460.0$$

4. Find the temperature of steam after isentropic expansion and exhausting at 2 psia (condensing turbine).

$$T2 = 1.0/(0.0017887 - 0.00011429 * ALOG (2.0)) - 460.0$$

5. Find the enthalpy of leaving steam.

$$H2 = 1.0045 * T2 - 32.448 + (T2 + 460.0) * (S - 1.0045 * ALOG (T2 + 460.0) + 6.2264)$$

6. Calculate the theoretical steam rate (lb/HP-hr).

$$TSR = 3413.0/(H1 - H2)$$

7. Calculate base steam rate.

$$BSR = SLOPE * TSR + B$$

where

$$B0 = 84.0 - 0.017 * SZT + 1.5625 * ((SZT/1000.0) ** 2.0))$$

$$B1 = -19.7 + 0.001025 * SZT$$

$$B2 = 1.4$$

$$B = B0 + B1 * RPM/1000.0 + B2 * ((RPM/1000.0) ** 2.0)$$

$$S0 = 3.88 - 0.011865 * SZT + 0.1173 * ((SZT/1000.0) ** 2.0)$$

$$S1 = -1.1 + 0.000533 * SZT - 0.0581 * ((SZT/1000.0) ** 2.0)$$

$$S2 = 0.116 - 0.000057 * SZT + 0.00709 * ((SZT/1000.0) ** 2.0)$$

$$SLOPE = S0 + S1 * RPM/1000.0 + S2 * ((RPM/1000.0) ** 2.0)$$

The base steam rate calculation was made by equation-fitting the Elliott YR single stage steam turbine data.

8. Calculate the horsepower loss again determined by equation-fitting the Elliott YT single stage steam turbine catalog data for condensing turbine (2 psia).

$$HPLSS = 0.0334 * ((RPM/1000.0) ** 2.42) * ((SZT/1000.0) ** 1.47)$$

9. Calculate the superheat correction factor determined by equation-fitting the Elliott YR single stage steam turbine catalog data.

   See computer listing of STTUR subroutine for equation of SC.

10. Determine the full load steam rate (lb/HP-hr).

    FLSR = (BSR/SC) * ((SZT + HPLSS)/SZT)

11. Determine the part load steam rate for one turbine (lb/hr).

    STEAM = FLSR * SZT (PLB + PLM * POWER/SZT)

12. Calculate the total hourly steam consumption (lb/hr).

    STEAM = STEAM * NSTON

CENT

A subroutine for calculating the energy consumption of an electric hermetic centrifugal water chiller as a function of part load.

INPUT

QHBC : Hourly building cooling load (tons)

TECON : Temperature of entering condenser water (°F)

TLCHL : Temperature of leaving chilled water (°F)

FFL : Fraction of full load (decimal)

OUTPUT

POWER : Hourly electrical power consumption (kilowatt hours)

CALCULATION SEQUENCE

1. Calculate the temperature of leaving condenser water at full load.

   TLCON = TECON + 10.0

2. Calculate the full load power per ton.

   POPTN = 0.049 * ALOG (TLCON/TLCHL) * TLCHL ** 0.8

   (This equation was excerpted from personal correspondence from R. S. Arnold of Carrier to J. M. Anders of P.O.D.)

3. Determine the error correction to be applied to above equation to make it conform with Carrier catalog data (Model 19C).

   ERROR = 2.4531 - 0.041229 * TLCON - 0.0273842 * TLCHL
   + 0.000118191 * TLCON * TLCON + 0.00047537
   * TLCHL * TLCON - 0.000197535 * TLCHL * TLCHL

4. Calculate the full load power per ton.

   POPTN = POPTN - ERROR

5. Determine the total hourly part load power consumption.

$$POWER = (0.1641/FFL + 0.2543 + 0.73965 * FFL - 0.15835 * FFL * FFL) * POPTN * QHBC$$

RECIP

A subroutine for calculating the energy consumption of an electric hermetic reciprocating water chiller as a function of part load.

INPUT

QHBC : Hourly building cooling load (tons)

TECON : Temperature of entering condenser water (°F)

TLCHL : Temperature of leaving chilled water (°F)

FFL : Fraction of full load (decimal)

OUTPUT

POWER : Hourly electrical power consumption (kilowatt hours)

CALCULATION SEQUENCE

1. Calculate the power per ton as determined from an equation fit of Carrier catalog data (Model 30HR).

$$POPTN = (0.3371 + 0.01223 * TECON - 0.009749 * TLCHL) * (0.868 + 0.133 * FFL)$$

where POPTN has units of kilowatts per ton.

2. Determine total hourly power consumption.

$$POWER = POPTN * QBHC$$

ABSOR

A subroutine for calculating the energy consumption of a steam absorption water chiller.

INPUT

QHBC : Hourly building cooling load (tons)

TECON : Temperature of entering condenser water (°F)

TLCHL : Temperature of leaving chilled water (°F)

TDROP : Chilled water temperature drop at full load (°F)(set equal to 10°F in program)

FFL : Fraction of full load (decimal)

PESTM : Pressure of low pressure steam (psig)

OUTPUT

STEAM : Hourly steam consumption (lbs/hr)

CALCULATION SEQUENCE (CARRIER 16HA)

1. Determine the capacity factor which adjusts nominal capacity for operation at conditions other than the standard of 12 psig inlet steam, 85°F entering condenser water and 44°F leaving chilled water.

   RAT = -2.8246 + 0.06575 * TECON - 0.06011 * PESTM
   + 0.06433 * TLCHL + 0.0011862 * TECON * PESTM
   + 0.00023232 * TECON * TLCHL + 0.00025421 * PESTM
   * TLCHL - 0.0006438 * TECON * TECON - 0.0015887
   * PESTM * PESTM - 0.0006199 * TLCHL * TLCHL

2. Find the capacity factor which adjusts for chilled water temperature drop other than 10°F.

   CMULT = 0.9190 + 0.010333 * TDROP - 0.0002222 * TDROP
   * TDROP

3. Calculate the total capacity factor.

$$RAT = 0.91 * CMULT * RAT$$

where 0.91 is fouling factor.

4. Calculate the full load steam rate (lb/hr-ton).

$$SRATE = 22.169 + 0.592 * PESTM - 0.0196 * PESTM * PESTM - 6.9384 * RAT$$

5. Determine the part load steam consumption.

$$STEAM = SRATE * (0.0136/FFL + 0.7928 + 0.11843 * FFL + 0.0752 * FFL * FFL) * QHBC$$

A subroutine for calculating the heat required to melt snow.

INPUT

TOA	:	Dry-bulb temperature of outside air (°F)
WOA	:	Humidity ratio of outside air (lb water/lb dry air)
PATM	:	Barometric pressure (inches of mercury)
VWIND	:	Wind velocity (mph)
SAREA	:	Snow-melting slab area (sq ft)
SNOW	:	Inches of snow water equivalent (inches)

OUTPUT

QTOT	:	Total hourly heating requirement of snow-melting system (Btu/hr)

CALCULATION SEQUENCE*

1. Partial pressure of water vapor in moist air (inches of mercury)

   VP = (WOA/0.622 * PATM)/(1.0 + WOA/0.622)

2. Sensible heat required to raise temperature of snow from outside air temperature to melting point (Btu/hr-sq ft)

   QSEN = 2.6 * SNOW * (33.0 - TOA)

3. Latent heat required to melt snow (Btu/hr-sq ft)

   QLAT = 746.0 * SNOW

4. Heat required to evaporate melted snow (Btu/hr-sq ft)

   QEVAP = 1075.0 * (0.0201 * VWIND + 0.055) * (0.185 - VP)

---

*For derivation and justification of equations, see "Design of Snow-Melting Systems", Heating and Ventilating, April, 1952, by William P. Chapman, and 1967 ASHRAE Guide and Data Book, Systems and Equipment Volume, Chapter 67 entitled "Snow Melting".

5. Heat transferred by convection and radiation (Btu/hr-sq ft)

QCONV = 11.4 * (0.0201 * VWIND + 0.055) * (33.0 - TOA)

6. Determine total heat required (Btu/hr)

QTOT = (SAREA * (QSEN + QLAT + 0.5 * QEVAP + 0.5 QCONV))/

0.7

where the edge loss factor is 0.3 and the area ratio of snow-free area to slab area is 0.5.

ENGYC

A subroutine for printing the monthly energy consumption summary.

INPUT

FAC : Name of facility

CITY : Location of facility

PROJ : Project number

DATE : Date of program run

ENGR : Name of engineer

ENGY : Monthly energy consumptions and demands. A 12 x 2 x 17 matrix with indices defined as indicated below.

FIRST SUBSCRIPT: MONTH

1 January

2 February

3 March

4 April

5 May

6 June

7 July

8 August

9 September

10 October

11 November

12 December

SECOND SUBSCRIPT: MODE OF ENERGY

1 Demand

2 Consumption

THIRD SUBSCRIPT: TYPE OF ENERGY

1 Maximum monthly heating demand

2 Maximum monthly cooling demand

3 Electric, internal lights and building equipment

4 Electric, external lights

5 Electric heat (boiler and auxiliaries, and hot water pumps)

6 Electric cool (chiller, pumps and cooling tower fan)

7 Gas heat

8 Gas cool

9 Gas generation

10 Steam heat

11 Steam cool

12 Oil heat

13 Oil cool

14 Diesel fuel generation

15 Not used

16 Not used

17 City water

18 Fans

OUTPUT

Tabular summary of monthly energy consumption. See Figures 6.22 to 6.25 in the User's Manual.

A subroutine for simulating the performance of heat conservation systems. A heat conservation system is one where the refrigeration machines have double-bundled condensers. During the summer months, the system acts as a conventional refrigeration system whereby the building heat gains are picked up in the chilled water coils, returned to the refrigeration machines, and rejected through condensers and the cooling towers to the outside air. During winter months, the refrigeration machines act as a heat pump wherein the building internal heat gains are picked up by the chilled water coils and returned to the refrigeration machines. Then, instead of being rejected to the outside through the cooling tower, this heat is redistributed by the hot condenser water through the building to those areas that require heating. Supplemental heaters are provided in the chilled water return line to provide heat when the internal gains are insufficient to offset the heat loss of the building at peak heating conditions.

INPUT

VARIABLES PASSED FROM MAIN ROUTINE:

M1	:	Type of chiller
M2	:	Source of chiller energy
M3	:	Source of heating energy
M4	:	Number of on-site generation engines
M5	:	Type of on-site generation engines
M6	:	Type of auxiliary chiller
M7	:	Source of supplemental heat
NUMB	:	Heating capacity multiplier
SZB	:	Heat conservation machine heating capacity (MBH)
NUMC	:	Cooling capacity multiplier
SZC	:	Heat conservation machine cooling capacity (tons)

NOTE: Variables NUMB, SZB, NUMC, and SZC are dual functioning. They are redefined in HTCØN as given below.

CØMMØN INPUT VARIABLES:

See Table 5.4 for definitions of variables in CØMMØN.

OUTPUT

NUMHC	:	Number of heat conservation machines
SZHC	:	Size of heat conservation machines, tons
NUMC	:	Number of auxiliary chillers (In CØMMØN)
SZC	:	Size of auxiliary chillers, tons (In CØMMØN)
NUMB	:	Number of boilers (In CØMMØN)
SZB	:	Size of boilers, MBH (In CØMMØN)
CAPH	:	Total heating capacity, MBH
CAPC	:	Total cooling capacity, tons
SZSCL	:	Size of supplementary heating unit in chilled water circuit, MBH
ENGY	:	Energy resource peak and consumption matrix (See Table 5.3).

CALCULATION SEQUENCE

1. Calculate cooling capacity required.

   QCR = NUMC * SZC * 12000

   where QCR has unit of Btu/hr.

2. Calculate heating capacity required.

   QHR = -1000. * NUMB * SZB

   where QHR has units of MBH.

The input variable QSNOW should be set equal to 0.0 if snow-melting is not to be considered or if snow-melting is considered, but the engineer does not wish to have a snow-melting load added to the capacity of the boiler. If a snow-melting load is to be added to the capacity of the boiler, QSNOW can be obtained from the 1967 ASHRAE Guide and Data Book, Systems and Equipment Volume, Chapter 27, Table 2.

3. Compare peak cooling requirement to the peak heating requirement expressed as equivalent cooling and size heat conservation machines based upon the smaller of the two. Assume 1.3 heat rejection ratio between condenser and evaporator, and a 0.5 ratio of winter cooling capacity to summer cooling capacity.

If QCR $\geq$ |QHR/(1.3 * 0.5)|, go to calculation 3.2.

If QCR < |QHR/(1.3 * 0.5)|, go to calculation 3.1.

3.1 Size heat conservation machine based upon peak cooling load.

3.1.1 Compute total cooling capacity required.

CAPC = QCR/12000.0

where CAPC has units of tons.

3.1.2 Set NUMHC = 2 (number of heat conservation machines).

SZHC = CAPC * 1.3 * 0.5/NUMHC

where SZHC is the heat rejected at the condenser expressed in tons during winter operation of heat conservation machines.

If necessary, increase NUMHC until SZHC < 600.0.

3.1.3 Compute heat conservation machine heating capacity (MBH).

CAPH = SZHC * NUMHC * 12000./1000.

3.1.4 Compute total heating requirements (MBH).

QHR = NUMB * SZB

3.1.5 Compute size of boilers required in <u>condenser</u> water circuit. This is for supplemental heat.

SZB = (QHR - CAPH)/NUMB

where SZB has units of MBH. Note that the <u>definitions</u> of SZB and NUMB have changed from those at entry to HTCØN. The <u>number</u> value of NUMB does not change.

3.1.6 Compute size of supplementary heat element required in chilled water circuit.

SZSCL = CAPH/1.3

where SZSCL has units of MBH.

Go to calculation 4.

3.2 Size heat conservation machine based upon peak heating load.

3.2.1 Compute the total heating capacity required.

CAPH = -QHR/1000.0

where CAPH has units of MBH.

3.2.2 Set NUMHC = 2 (number of heat conservation machines).

SZHC = CAPH/(12.0 * NUMHC)

where SZHC is the heat rejected at the condenser expressed in tons during winter operation of heat conservation machines.

If necessary, increase NUMHC until SZHC < 600.0.

3.2.3 Compute amount of cooling available from heat conservation machines during summer operation, Btu/hr.

QCA = (SZHC * NUMHC) * 12000.0/(1.3 * 0.5)

3.2.4 Compute amount of cooling which must be provided by auxiliary chillers, Btu/hr.

QDIF1 = QCR - QCA

3.2.5 Compute size of auxiliary chillers.
Set NUMC = 1 (number of auxiliary chillers).

SZC = QDIF1/(12000.0 * NUMC)

where SZC has units of tons. Note that the definitions and number values of SZC and NUMC have changed from those at HTCØN entry.

3.2.6 Compute total cooling capacity.

$$CAPC = QCA/12000.0 + NUMC * SZC$$

where CAPC has units of tons.

3.2.7 Compute size of supplementary heating element in chilled water circuit, MBH.

$$SZSCL = CAPH/1.3$$

4. Size all pump water flows.

4.1 Chilled water flow rate, gpm.

$$GPMCL = 2.4 * CAPC$$

4.2 Condenser water flow rate, gpm.

$$GPMCN = 3.0 * CAPC$$

4.3 Boiler water flow rate, gpm.

$$GPMBL = CAPH * 1000.0/(500.0 * 20.0)$$

4.4 Well water flow rate, if used, gpm.

$$GPMWW = SZSCL * 1000.0/(60.0 * 8.3 * 1.0 * (TWWIN - TCLMN))$$

5. Size all pump motors assuming pump efficiency of 60%.

5.1 Chilled water pump horsepower.

$$HPCLP = GPMCL * HDCLP/(3962.0 * 0.6 * EFF)$$

5.2 Condenser water pump horsepower.

$$HPCNP = GPMCN * HDCNP/(3962.0 * 0.6 * EFF)$$

5.3 Boiler water pump horsepower.

$$HPBLP = GPMBL * HDBLP/(3962.0 * 0.6 * EFF)$$

5.4 Well water pump horsepower.

$$HPWWP = GPMWW * HDWWP/(3962.0 * 0.6 * EFF)$$

6. Calculate the horsepower requirement for motors running boiler auxiliary equipment such as fans, blowers, pumps, etc. From American Standard Catalog for packaged boilers ranging in size from 20 to 750 horsepower, the auxiliary horsepower requirement was approximately 1/20 of the total boiler horsepower capacity. Therefore,

HPBLA = CAPH * 1000.0/(33472.0 * 20.0)

7. Size cooling tower fan.

7.1 Cooling tower air flow requirement, cfm.

CFMCT = 300.0 * CAPC

7.2 Cooling tower fan horsepower requirement assuming 1.0 inch of water total pressure.

HPCTF = CFMCT * 1.0/(6346.0 * EFF)

8. Begin hourly energy consumption analysis, repeating calculations 9 through 20 for every hour of the year.

9. Read hourly weather and space load data. See Table 5.2 for description of variables.

10. Calculate wind velocity in units of mph.

VWIND = 1.151 * VEL

11. Determine if external lights are ON.

11.1 If ISUN = 0, set PWEL = 0.0.

11.2 If ISUN = 1, set PWEL = PWOL.

12. Check outside air temperature to determine if summer or winter operation.

If TOA $\geq$ TCO, summer operation; therefore, go to calculation 13.

If TOA < TCO, winter operation; therefore, go to calculation 14.

13. Summer operation of heat conservation machines.

13.1 Begin fan system analysis repeating the following calculations for each fan system within the building.

13.1.1 Check type of fan system.

If KFAN(K) = 1, call RHFS2 = 8, call FCØIL

= 2, call MZDD = 9, call FCØIL

= 3, call MZDD = 10, call INDUC

= 4, call SZRHT = 11, call INDUC

= 5, call RHFS2 = 12, call VARVL

= 6, call RHFS2 = 13, call RHFS2

= 7, call FHTG2

13.1.2 Keep running total of building cooling, heating, and power loads.

$$QHBC = \sum_{k=1,\ kmax} QFPC_k$$

$$QHBH = \sum_{k=1,\ kmax} QFPH_K + QFPPH_K + TQB_k$$

$$QHBRH = \sum_{k=1,\ kmax} QFPRH_k$$

$$PWILM = \sum_{k=1,\ kmax} PWL_k$$

13.2 Calculate hourly energy consumption. Call EQUIP, which the following:

GASC

GASH

GASG

OILC

OILH

STMC

STMH

ELEC

ELEH

FUEL

See subroutines ENGYC for explanation of these variables.

13.3 Go to calculation 15.

14. Winter operation of heat conservation machines.

14.1 Begin fan system analysis repeating calculation 14.1.1 through 14.1.6 for each fan system K.

14.1.1 Read zone loads from input tape and form the following summations:

$$QSUMC = \sum_{j=1,\ jmax_k} QS(L)(pos) * MULT_i^{**}$$

$$QSUMH = \sum_{j=1,\ jmax_k} QS(L)(pos) * MULT_i$$

14.1.2 Calculate supply air temperature required for each zone,

$$TS(I) = TS(L) - QS(L)/(1.08 * CFM(I))^{**}$$

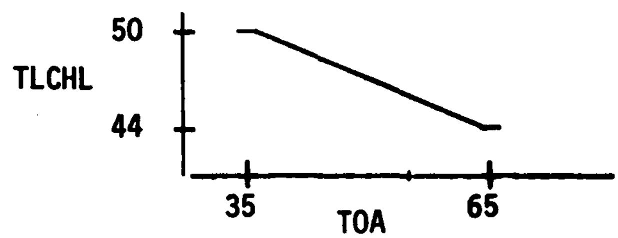
14.1.3 Form the summation.

$$SUMCT = \sum_{j=1,\ jmax_k} (CFM(I) * TS(I))^{**}$$

14.1.4 Calculate required leaving-condenser water temperature assuming schedule below which is a function of the hourly heating requirement of the building.

$$TLCON = TLCNM - 22.5 * (1.0 - QSUMH/QHR)$$

14.1.5 Calculate leaving-chilled water temperature assuming the schedule shown below.



This schedule can be expressed in equation form as:

$$TLCHL = 44.0 + (65.0 - TOA)/5.0$$

** NOTE: There is a corresponding L for each I, a relationship defined by the variable SPACN(K,J).

If TLCHL as calculated by above equation is greater than 50°F, set TLCHL = 50.0.

If TLCHL as calculated by above equation is less than 44°F, set TLCHL = 44.0.

14.1.6 Determine the ratio of cold air cfm to total cfm circulated by fan system K. Let this ratio be called GAMA(K). By definition, therefore,

$$GAMA(K) = \frac{\sum(BETA(J) + CFM(I))}{CFMAX(K)}$$

where BETA(J) is the fraction of total air flowingg through the cold duct to zone J.

A heat balance around any fan zone J yields

$$TS(I) = TCD * BETA(J) + THD(1 - BETA(J))$$

where TS(I) is the zone supply air temperature required, °F

TCD is the temperature of air leaving cooling coil, °F

THD is the temperature of air leaving heating coil, °F

Solving for BETA(J) gives

$$BETA(J) = \frac{THD - TS(I)}{THD - TCD}$$

The heating and cooling coils used in heat conservation systems are deep coils and it is therefore assumed that the discharge air temperature approaches to within 5°F the entering water temperature at maximum air flow. At partial air flow, it is further assumed that the discharge air temperature varies linearly with the air flow rate through the coil.

The temperature of air leaving the heating coil (THD) is then

$$THD = TLCON - 5.0 * (1 - GAMA(K))$$

The temperature of air leaving the cooling coil (TCD) is then

$$TCD = TLCHL + 5.0 * GAMA(K)$$

Substituting the equation for BETA(J), THD and TCD into the equation for GAMA(K) results in

$$GAMA(K) = \frac{CFMAX(K) * (TLCON - 5.0) - SUMCT}{CFMAX(K) * (TLCON - TLCHL - 10.0)}$$

where

$$SUMCT = \sum_{j=1,\ jmax_k} (CFM(I) * TS(I) * MULT(I))$$

14.2 Calculate the quantity

$$SUMGX = (GAMA(K) * CFMAX(K)) \quad \text{for } K=1 \text{ to } KMAX$$

14.3 Calculate fraction of total air circulated within building that is passing through cooling coils.

$$GAMAB = SUMGX/CFMBX$$

14.4 Determine a weighted average return air temperature for the building.

$$TPLB = 75.0 + QL1TB/(1.08 * (CFMBX - CFMEX))$$

14.5 Determine a weighted average cooling coil leaving air temperature for building.

$$TCDB = TLCHL + 5.0 * GAMAB$$

14.6 Calculate a weighted average heating coil leaving air temperature for the building.

$$THDB = TLCON - 5.0 * (1.0 - GAMAB)$$

14.7 Determine the amount of outside air required to create a cooling load that will produce the required heating at the condenser.

A heat balance about the building's heating coils, cooling coils, and outside air-return air damper systems yields the following three equations:

$$QHBC = 1.08 * CFMBX * GAMAB * (TMA - TCDB)$$
$$QHBH = 1.08 * CFMBX * (1.0 - GAMAB) * (THDB - TMA)$$
$$TMAB = TPLB * (1.0 - ALFA) + TOA * ALFA$$

where

QHBC is hourly building cooling load

QHBH is hourly building heating load

TMAB is mixed air temperature

ALFA is fraction of outside air mixing with return air

Since the heat rejection ratio at the condenser of a heat conservation machine is approximately 1.3 times the cooling load, find the fraction of outside air, ALFA, required such that

QHBH = 1.3 * QHBC

Substituting the equations for QHBC, QHBH, and TMAB into the equation yields

ALFA = TPLB/(TPLB - TOA) - (THDB * (1.0 - GAMAB)

+ 1.3 * GAMAB * TCDB)/((TPLB - TOA)

* (1.0 + 0.3 * GAMAB))

If ALFA > 1.0, the heating requirement can be obtained with 100% outside air; therefore, reset ALFA = 1.0.

If 0.0 ≤ ALFA ≤ 1.0, the heating requirement can be obtained with no need for supplementary heat.

If ALFA < 0.0, supplementary heat is required; therefore, reset ALFA = 0.0.

14.8 Calculate actual building mixed air temperature, °F.

TMAB = TOA * ALFA + TPLB * (1.0 - ALFA)

14.9 Calculate actual building heating load, Btu/hr.

QHBH = 1.08 * CFMBX * (1.0 - GAMAB) * (TMAB - THDB)

14.10 Calculate any snow-melting load, if applicable, Btu/hr.

14.10.1 If KSNOW = 0, no snow-melting system.
Go to calculation 14.11.

14.10.2 If KSNOW = 1 or 2, snow-melting is to be considered.

14.10.2.1 Calculate amount of snowfall for the hour assuming that 1/24 of the day's total fell during the hour.

SNOW = 0.1 * SNOWF(ID)/24.0

where SNOW has units of equivalent inches of water, SNOWF(ID) has units of inches of snow, and ID is the day number of the year, calculated as follows:

ID = 1 + IHOUR/24

14.10.2.2 Call SNOWM subroutine which calculates QTOT, the now-melting load.

14.10.2.3 Add QTOT to the heating requirement of the building.

If KSNOW = 1, liquid-type snow-meltingng system; therefore,

QHBH = QHBH - QTOT

If KSNOW = 2, electric-type snow melting system; therefore,

ELEH = QTOT/3413.0

14.11 Calculate actual building cooling load, Btu/hr.

QHBC = 1.08 * CFMBX * GAMAB * (TMAB - TCDB)

14.12 Calculate energy required to produce the building heating and cooling required.

14.12.1 If |QHBH| > |SZHC * NUMHC * 12000.0|, supplementary heat in condenser water line is required.

14.12.1.1 Calculate condenser water supplementary heat requirement, Btu/hr.

QSHCN = QHBH + CAPHC

where

CAPHC = SZHC * NUMHC * 12000.0

and QHBH is negative.

14.12.1.2 If $|QHBC| \geq |CAPHC/1.3|$, then no supplementary heating is required in chilled water line; therefore, set

$$QSHCL = 0.0$$

If $|QHBC| < |CAPHC/1.3|$, then calculate supplementary heat required in chilled water line, Btu/hr.

$$QSHCL = -(CAPHC/1.3 - QHBC)$$

14.12.1.3 Heat conservation machines are operating at 100% capacity, therefore

$$FFL = 1.0$$

14.12.1.4 Calculate energy consumption required by heat conservation machines.

For SZHC < 200 tons:

$$\begin{aligned} POWER = {} & QEVAP * (0.3371 + 0.01233 \\ & * TECON - 0.00974 * TLCHL) \\ & * (0.868 + 0.0133 * FFL \\ & * 16.0) \end{aligned}$$

For SZHC $\geq$ 200 tons:

$$\begin{aligned} POWER = {} & QEVAP * (1.74 - 1.0234 \\ & * FFL + 0.3707 * FFL \\ & * FFL - 0.010025 * TDIF \\ & + 0.000175 * TDIF * TDIF) \end{aligned}$$

where

$$QEVAP = QHBC/12000.0$$

$$TECON = TLCON + 16.0$$

$$TDIF = TECON - TLCHL$$

14.12.1.5 Update monthly electric heat energy consumption totals.

$$ELEH = ELEH + POWER$$

Go to calculation 14.13.

14.12.2 If $|QHBH| \leq |SZHC * NUMHC * 12000.0|$, then heat conservation machines are operating at part load.

14.12.2.1 Calculate chilled water supplementary heat requirement.

For $|QHBH| > |1.3 * QHBC|$, then

$$QSHCL = QHBH/1.3 + QHBC$$

For $|QHBH| \leq |1.3 * QHBC|$, then

$$QSHCL = 0.0$$

14.12.2.2 Calculate the number of heat conservation machines operating.

Estimated number operating is

$$ENHCM = -QHBH/(1.3 * (12000.0 * 0.9 * SZHC))$$

Round ENHCM up to next whole number and set equal to NHCON.

14.13.2.3 Calculate fraction of full load on each machine operating.

$$FFL = QEVAP/(NHCON * SZHC/1.3)$$

where $QEVAP = QHBC/12000.0 + QDIF2$

$$QDIF2 = (-QHBH/1.3 - QHBC)/12000.0$$

14.12.2.4 Calculate energy consumption of heat conservation machines operating.

For SZHC < 200 tons:

$$POWER = QEVAP * (0.3371 + 0.01223 * TECON - 0.00974 * TLCHL) * (0.868 + 0.133 * FFL * 16.0)$$

For SZHC $\geq$ 200 tons:

$$POWER = QEVAP * (1.74 - 1.0234 * FFL + 0.3707 * FFL * FFL - 0.010025 * TDIF + 0.000175 * TDIF * TDIF)$$

14.12.2.5 Calculate condenser heat available based upon evaporator load and work done.

$$QWORK = 0.2844 * POWER$$

$$QCOND = QEVAP + QWORK$$

14.12.2.6 Compare actual condenser heat available, QCOND, to that required, QHBH.

$$ERROR = 0.5 * (-QHBH/12000.0 - QCOND)$$

If |ERROR| > |0.005 * SZHC|, set QDIF2 = QDIF2 + ERROR and return to calculation 14.12.2.3 and repeat procedure until

$$|ERROR| \leq |0.005 * SZHC|$$

14.12.2.7 Check to see if FFL is below FFLMN.

If FFL $\geq$ FFLMN, then go to calculation 14.13.

If FFL < FFLMN, heat conservation machine not allowed to operate; therefore, set

QSHCL = 0.0

QHBH = 0.0

QHBC = 0.0

QHBRH = 0.0

Go to calculation 14.13.

14.13 Convert condenser supplementary heat requirement into energy requirements.

If M3 = 1, gas heating; therefore

GASH = GASH - QSHCN/80000.0

If M3 = 2, oil heating; therefore

OILH = OILH - QSHCN/(0.8 * HVHO)

If M3 = 3, steam heating; therefore

STMH = STMH - QSHCN/(HESTM - HLSTM)

If M3 = 4, electric heating; therefore

ELEH = ELEH - QSHCN/3413.0

14.14 Convert chilled water supplementary heat requirement into energy requirements.

If M7 = 1, gas heating source; therefore

GASH = GASH - QSHCL/80000.0

If M7 = 2, oil heating source; therefore

OILH = OILH - QSHCL/(0.8 * HVHO)

If M7 = 3, electric heating source; therefore

ELEH = ELEH - QSHCL/3413.0

If M7 = 4, well water heating source; therefore

ELEH = ELEH + HPWWP * 0.7457

If M7 = 5, city water heating source; therefore

GALCW = -QSHCL/(8.3 * (TCWIN - TCLMN))

15. Update the running totals of the following monthly energy consumption variables.

ENGY (M,2,3)
ENGY (M,2,4)
ENGY (M,2,5)
ENGY (M,2,6)
ENGY (M,2,7)
ENGY (M,2,10)
ENGY (M,2,12)
ENGY (M,2,15)
ENGY (M,2,16)
ENGY (M,2,17)
ENGY (M,2,18)

See subroutine ENGY for an explanation of these quantities.

16. Keep a record of maximum hourly energy demands by checking and updating if necessary the following monthly demand variables.

ENGY (M,1,1)
ENGY (M,1,2)
ENGY (M,1,3)
ENGY (M,1,4)
ENGY (M,1,5)
ENGY (M,1,6)
ENGY (M,1,7)
ENGY (M,1,10)
ENGY (M,1,12)
ENGY (M,1,15)
ENGY (M,1,16)
ENGY (M,1,17)
ENGY (M,1,18)

See subroutine ENGY for explanation of these quantities.

END OF HOURLY ANALYSIS

17. Return command to SYSIM.

SECTION 6
OWNING AND OPERATING COST ANALYSIS PROGRAM

6.1 OBJECTIVE AND DESCRIPTION

The Owning and Operating Cost Analysis Program performs a life cycle cost analysis for each building heating and cooling system analyzed by the System and Equipment Simulation Program. Life cycle costs are those expenditures which occur singularly or periodically over the life of the building and includes cost of energy, cost of equipment in terms of first costs and replacement costs which occur if the expected life of the equipment is less than that of the building, cost of maintenance (material and labor), salvage value of equipment at end of building life, and opportunity costs for floor space occupied by equipment.

Most of the burden of assembling the cost data required by the program is placed upon the user. During these times of escalating costs for energy, fuel, material and labor, it is impractical to expect the Owning and Operating Cost Analysis Program to accurately and automatically account for these factors.

6.2 INPUT

Only the punched card form of input data is required for the Owning and Operating Cost Analysis Program. Instructions for the preparation of this data are given in Table 7.1 of User's Manual.

6.3 OUTPUT

An owning and operating cost report similar to that shown in Figures 6.1 through 6.3 is received for each set of input data given to the program. Most of the information appearing on this report is simply a recap of input data. The real results of the analysis are the annuities for each equipment category and for the total HVAC system. These annuities are calculated utilizing present worth techniques.

6.4 MAIN ROUTINE ALGORITHMS

The calculations performed sequentially by the Owning and Operating Cost Analysis Program are summarized below:

1. Read all card input data as follows:

   a) FAC - name of facility

   b) CITY - location of facility

```
            OWNING AND OPERATING COST ANALYSIS FOR

                  LRC SYSTEMS ENGINFERING

                         BUILDING

                       HAMPTON, VA

ENGINEER    - R. JENSEN
PROJECT NO  - NAS1-12843
DATE        - JULY 10, 1974
```

Figure 6.1 OWNING AND OPERATING COST ANALYSIS PROGRAM OUTPUT REPORT

```
***************** INPUT  ASSUMPTIONS *************

BUILDING LIFE                                      40.00 YEARS

ANNUAL INTEREST RATE                               12.00 PERCENT

ESTIMATED LABOR WAGE ANNUAL INCREASE                8.00 PERCENT

ESTIMATED MATERIAL COST ANNUAL INCREASE            15.00 PERCENT

ESTIMATED FLOOR SPACE COST ANNUAL INCREASE         10.00 PERCENT

ESTIMATED ENERGY COST ANNUAL INCREASE              10.00 PERCENT
```

Figure 6.2 OWNING AND OPERATING COST ANALYSIS PROGRAM OUTPUT REPORT

ANALYSIS FOR - SYSTEM NO. 1 - MULTI ZONE W/BASEBOARD, CENTRIFUGAL CHILLERS, STEAM HEAT OC-10

ENERGY COST SUMMARY

	UNIT COST ($)	CONSUMPTION	TOTAL COST ($)	ANNUITY ($)
ELECTRICITY				
LIGHTING	0.03	520000. KW	15600.	
HEATING-BOILER PUMPS, CONTROLS	0.03	57658. KW	1729.	
COOLING-CHILLER, PUMPS, TOWER	0.03	205446. KW	6163.	
FANS-SUPPLY, RETURN, EXHAUST	0.03	359160. KW	10774.	
		1142264. KW	34267.	117423.
STEAM				
HEATING	1.50	1830. K LBS	2745.	9406.
WATER				
TOWER MAKE-UP	0.75	389. K GALS	291.	999.
		GRAND TOTALS	37304.	127829.

SYSTEMS AND EQUIPMENT COST

	INITIAL COST	ANTICIPATED LIFE	SALVAGE CONSID.	MAJOR OVERHAUL PERIOD	MAJOR OVERHAUL LABOR	MAJOR OVERHAUL MATERIAL	ANNUAL MAINTENANCE LABOR	ANNUAL MAINTENANCE MATERIAL	FLOOR SPACE COST	ANNUITY
CHILLER, TOWER, PUMPS, PIPING	80000.	40	YES	10	800.	200.	16000.	8000.	8000.	147538.
BOILER, PUMPS, PIPING	20000.	40	YES	10	200.	50.	1000.	1000.	2000.	20617.
DISTRIBUTION SYSTEMS, CONTROLS	175000.	40	YES	10	1750.	440.	8750.	8750.	10000.	154702.
TOTAL SYSTEMS AND EQUIPMENT ANNUITY										322857.

*TOTAL OWNING AND OPERATING ANNUITY 450687. DOLLARS *

NOTE -- ANNUITY IS CONSTRUED TO MEAN THE UNIFORM ANNUAL COST, CONSIDERING ALL THE LISTED COSTS, TO THE OWNER DURING THE LIFE TIME OF THE BUILDING.

Figure 6.3 OWNING AND OPERATING COST ANALYSIS PROGRAM OUTPUT REPORT

c) ENGR - engineer's name

d) PROJ - project number

e) DATE - date of program run

f) BLGLF - building life, years

g) RINT - annual interest rate, %

h) RINL - annual increase of labor cost, %

i) RINM - annual increase of material cost, %

j) RINF - annual increase of floor space cost, %

k) RINE - annual increase of energy and fuel cost, %

l) CELE - unit cost of electricity, $/KW

m) CGAS - unit cost of gas, $/therm

n) COIL - unit cost of oil, $/gal

o) CSTM - unit cost of steam, $/1000 lbs

p) CWAT - unit cost of water, $/1000 gals

q) CFUL - unit cost of diesel fuel, $/gal

r) CASES - number of cases or equipment combinations to be analyzed

For "CASES" number of combinations, repeat (1s) through (1ah).

s) DESC - system description label

t) ENCAT - number of energy categories

For "ENCAT" number of energy categories, repeat (1u) through (1w).

u) ETYPE - energy type coded as follows:

1 electricity
2 gas
3 oil
4 steam
5 water
6 diesel fuel

v) ECONS - annual consumption

w) ENLAB - energy category label

x) EQCAT - number of equipment categories

For each of "EQCAT" equipment categories, repeat (1y) through (1ah).

y) EQLAB - equipment category label

z) COST - installed cost of equipment, $

aa) LIFE - expected life of equipment, years

ab) SV - is resale value to be considered at end of building life?, 0 = no, 1 = yes

ac) OHPD - major overhaul period, years

ad) AML - estimated annual maintenance labor cost, $

ae) AMM - estimated annual maintenance material cost, $

af) OHL - estimated major overhaul labor cost, $

ag) OHM - estimated major overhaul material cost, $

ah) FLR - estimated cost of floor space occupied by equipment, $

2. Print title page as indicated in Figure 6.1.

3. Echo constants to be used for all analyses (see Figure 6.2).

4. Print first part of final report (Figure 6.3) summarizing energy cost results.

   a) Print system description label.

   b) For each type of energy J = 1 to 6, and each category (I = 1 to ENCAT) entered for each type, calculate and print the following:

      - ENLAB(I,N) - energy category label

      - UCOST(J) - unit cost

- ECONS(I) - energy consumption
- Total cost of energy for category

  TOTAL = UCOST(J) * ECONS(I)
- Total consumption of J energy type

  TCONS(J) = Σ ECONS(I)
- Total cost of energy type J

  TENGY(J) = Σ TOTAL
- Annuity for energy type J

  AE(J) = PE *((RINT * 100)/(1.0-1.0/(1.0+RINT * 100) ** BLGLF))

where PE the present value is

PE = Σ (TENGY(J) *((1.0 + RINE * 100)/ (1.0 + RINT)) ** L) for L = 1 to BLGLF

c) Grand total cost for all energy consumed

UA = ΣTENG(J) for J = 1 to 6

d) Grand total annuity for all energy consumed

UE = Σ AE(J) for J = 1 to 6

5. Print second part of final report (Figure 6.3) summarizing equipment cost results. For each equipment category I = 1 to EQCAT, calculate the following:

a) Present-value of installed equipment cost

PC = Σ [COST(I) * ((1.0 + RINM)/(1.0 + RINT)) ** ((J-1) * LIFE(I))] for J = 1 to L

where L = BLGLF/LIFE(I) + 1

If salvage value is considered, adjust the present-value, PC, as follows:

PC = PC-COST(I) * (L-AL)/((1.0+RINT)**BLGLF) where AL = BLGLF/LIFE(I)

b) Present-value of floor space cost

PF = Σ[FLR(I) * ((1.0 + RINF)/(1.0 + RINT))

** J] for J = 1 to LF

where LF = BLGLF

c) Present-value analysis of annual maintenance labor cost

PAML = Σ[AML(I) * ((1.0 + RINL)/(1.0 + RINT)) ** J]

for J = 1 to LF

d) Present-value analysis of annual maintenance material cost

PAMM = Σ[AMM(I) * ((1.0 + RINM)/(1.0 + RINT)) ** J]

for J = 1 to LF

e) Present-value analysis of major overhaul labor cost

POHL = Σ[OHL(I) * ((1.0 + RINL)/(1.0 + RINT))

** (J * OHPD(I))] for J = 1 to K

where K = BLGLF/OHPD(I)

f) Present-value analysis of major overhaul material cost

POHM = Σ[OHM(I) * ((1.0 + RINM)/(1.0 + RINT))

** (J * OHPD(I))] for J = 1 to K

g) Total present-value of system

P(I) = PC + PF + PAML + PAMM + POHL + POHM

h) Total owning and operating annuity for equipment I

A(I) = P(I) * (RINT/(1.0 - 1.0/(1.0 + RINT ** BLGLF))

6. Print total owning and operating annuity for entire system.

TOOA = Σ A(I) + UE

7. If there is another system combination to be analyzed, return to calculation (4) and repeat calculations 4 through 6 with the new set of data.

NOTES AND COMMENTS

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NOTES AND COMMENTS

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