NECAP - NASA'S ENERGY-COST ANALYSIS PROGRAM
Part II - Engineering Manual

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Nites, Ill. 60648
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D.C.
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 account 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 with 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 barriers, etc., during the design phase. After installation, users can optimize operating schedules, most economical temperature settings for components, and other valuable data.
This version of NASA's Energy-Cost Analysis Program (NECAP) is for internal NASA use.

The National Aeronautics and Space Administration (NASA) can not assume any responsibility for the application of the manual or the program beyond the control of its engineers. Users that apply the program do so without recourse to the Government.
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1.2 Input ........................................ 6-1
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1.4 Main Routine Algorithms ......................... 6-1
IN ORDER TO MINIMIZE THE AMBIGUITIES INVOLVED IN MATHEMATICAL OPERATIONS, THE FOLLOWING FORTRAN OPERATIONAL SYMBOLS ARE USED PARTICIALLY 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 usage 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

1-3
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 therefore 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:

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

\[
\begin{align*}
X_i \\
Y_i \\
Z_i
\end{align*}
\]

Response factors series for \( j = 1, 2, \ldots, M \) 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

\[
CR = X_{M+1}/X_M = Y_{M+1}/Y_M = Z_{M+1}/Z_M
\]

2-3
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 \( Q_B \).

![A WALL](image)

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, \( X_0, X_1, X_2, \ldots \) and the values of \( Q_B \) at times 0, 1, 2, ... are called, respectively \( Y_0, Y_1, Y_2, \ldots \).

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, \( Z_0, Z_1, Z_2, \ldots \) and the values of \( Q_A \) at times 0, 1, 2, ... are called, respectively \( Y_0, Y_1, Y_2, \ldots \).

Therefore:

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

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

The time series \( Y_0, Y_1, Y_2, Y_3, \ldots \), 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

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<table>
<thead>
<tr>
<th>Name of the Subroutine</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>APOL</td>
<td>Calculates area and orientation of an irregular surface</td>
</tr>
<tr>
<td>CCM</td>
<td>Calculates cloud cover modifier</td>
</tr>
<tr>
<td>CENTER</td>
<td>Centers the headings of output</td>
</tr>
<tr>
<td>DAYMO</td>
<td>Determines the day of month</td>
</tr>
<tr>
<td>DESDY</td>
<td>Determines design day temperature correction factors</td>
</tr>
<tr>
<td>DST</td>
<td>Determines Daylight Savings Time</td>
</tr>
<tr>
<td>FILM</td>
<td>Calculates outside heat transfer film coefficient</td>
</tr>
<tr>
<td>HD</td>
<td>Calculates heat gain through slowly responding surfaces (Delayed surfaces)</td>
</tr>
<tr>
<td>HL</td>
<td>Calculates sensible and plenum return air heating and cooling load due to a space</td>
</tr>
<tr>
<td>HOLIDAY</td>
<td>Determines holidays of year</td>
</tr>
<tr>
<td>HQ</td>
<td>Calculates heat gain through quickly responding surfaces (Quick surfaces)</td>
</tr>
<tr>
<td>INF</td>
<td>Calculates space infiltration air loads</td>
</tr>
<tr>
<td>INPUT1</td>
<td>Reads surface geometric data for shading surfaces</td>
</tr>
<tr>
<td>INPUT2</td>
<td>Reads surface geometric data for delayed, quick and window surfaces</td>
</tr>
<tr>
<td>LEEP</td>
<td>Determines whether the year is a leap-year</td>
</tr>
<tr>
<td>MATCON</td>
<td>Converts shadow picture matrix for pictorial display</td>
</tr>
<tr>
<td>MONFIN</td>
<td>Determines name of month for printing in reports</td>
</tr>
<tr>
<td>NDOW</td>
<td>Determines day of week</td>
</tr>
<tr>
<td>PPWVMS</td>
<td>Calculates water vapor pressure of saturated air</td>
</tr>
<tr>
<td>PSY</td>
<td>Calculates psychrometric data</td>
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<tr>
<td>Name of the Subroutine</td>
<td>Function</td>
</tr>
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<td>------------------------</td>
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<tr>
<td>QMAX</td>
<td>Keeps track of space peak heating and cooling loads</td>
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<td>RECTAN</td>
<td>Calculates vertex coordinates of a rectangular surface</td>
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<td>RECAP1</td>
<td>Echos initial portion of input data</td>
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<td>RECAP2</td>
<td>Echos surface geometric description data</td>
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<td>REPRT1</td>
<td>Prints title page</td>
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<td>Prints weather information page</td>
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<td>REPRT3</td>
<td>Prints load tape parameter labels</td>
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<td>REPRT5</td>
<td>Prints summary of design day weather</td>
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<td>REPRT6</td>
<td>Prints summary of design load results</td>
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<td>RMRSS</td>
<td>Calculates room hourly weighting factors</td>
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<td>SCHEDUL</td>
<td>Generates operating schedules for people, lights, and equipment</td>
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<tr>
<td>SCHED</td>
<td>Assigns proper lighting, people, and equipment schedules</td>
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<td>SEARCH</td>
<td>Limits shadow pictures to certain times and certain surfaces</td>
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<td>SHADOW</td>
<td>Calculates shadow shapes and areas</td>
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<tr>
<td>SHG</td>
<td>Calculates heat gain through windows</td>
</tr>
<tr>
<td>STNDRD</td>
<td>Generates response data for standard walls and roofs</td>
</tr>
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<td>SUN1</td>
<td>Calculates daily data on solar radiation</td>
</tr>
<tr>
<td>SUN2</td>
<td>Calculates hourly data on solar radiation</td>
</tr>
<tr>
<td>SUN3</td>
<td>Calculates solar data which depends on orientation of a surface</td>
</tr>
<tr>
<td>TAR</td>
<td>Calculates glass absorption and transmission factors</td>
</tr>
<tr>
<td>WBF</td>
<td>Calculates wet-bulb temperature</td>
</tr>
<tr>
<td>WEATHER</td>
<td>Decodes weather tape</td>
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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 struc-
ture 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](image-url)
Were it necessary to compute $Q$ for each hour, on the basis of the hourly history of $\Delta T$, 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 ($r_0, r_1, r_2, \ldots$) of the wall (see Figure 3.3).

Any arbitrary schedule of $\Delta T$ may be squared off to give a schedule of approximate temperature differences, $\Delta T'$, whose values agree with those of $\Delta T$ at integral multiples of the time interval, $\delta$. This schedule of approximate temperature differences, $\Delta T'$, may be resolved into a series of triangular pulses ($\Delta T_1, \Delta T_2, \Delta T_3, \Delta T_4,$ and $\Delta T_5$) which, when added together, give exactly $\Delta T'$. Each of these component pulses has a base width, or duration, of $2\delta$, a peak occurring at each integral multiple of $\delta$, 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 $\Delta T_2$ 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, $Q_1 \ldots Q_5$, 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, $\Delta T$ and $\Delta T'$ give nearly the heat gain schedule elicited by the original temperature difference schedule, $\Delta T$. 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.

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

where $Q_j$ equals the heat gain at the hour $j$; $\Delta T_{j-i}$ equals the temperature difference $i$ hours previous to hour $j$; $r_i$ equals the $i$th response

3-7
\[ T = \text{OUTSIDE SURFACE TEMPERATURE} \]
\[ T_0 = \text{INSIDE AIR TEMPERATURE} \]
\[ \Delta T = T - T_0 \]

Figure 3.3 HEAT GAIN SCHEDULE FOR A TRIANGULAR TEMPERATURE PULSE SHOWING RESPONSE FACTORS
Figure 3.4 THE CONVOLUTION PRINCIPLE

3-9
factor for the wall; and \( n \) equals the number of hours of the temperature difference history which significantly effect \( Q_j \). 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

3-10
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

3-11
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 \( Q_{IHTS_i} \)

\[
Q_{IHTS_i} = \sum_{j=1}^{NIHTS_i} \left[ FIHTS_{jj} \times (TSPAC_{adj} - TSPAC_i) \right]; \quad jj = 1, NIHTS_i
\]

where

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

3.3.3 Job Processing Control Segment

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.

\[
\begin{align*}
BHMAX &= 0 \\
BCMAX &= 0 \\
SSHMAX_i &= 0 \\
STCMAX_i &= 0 \\
QCBLDG_{\&1} &= 0 \\
QHBLDG_{\&1} &= 0 \\
QSUM_{\&1,\&2} &= 0 \\
QWIN_{\&1,\&2} &= 0
\end{align*}
\]

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\textsubscript{i} = 0 \ (delayed \ surfaces) \\
ICALQ\textsubscript{i} = 0 \ (quick \ surfaces) \\
ICALW\textsubscript{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 \\

\begin{align*}
QCCOMP_{icc} &= 0 \\
QHCOMP_{icc} &= 0 \ (where \ icc = 1,17)
\end{align*}

- 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\textsuperscript{2}) 
   - DEABC(4) - atmospheric extinction coefficient (air mass\textsuperscript{-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 H₂O/lbm-dry air)
  - ENTH - Enthalpy (Btu/lbm-air)
  - DENS - Density (lbsm/ft³)

- if | HANG | ≤ | SUNRAS |, sun above horizon
  
  J1 = 0
  
  Call subroutine SUN2 to calculate:

  - RAYCOSₓᵧz - solar angle direction cosines (X,Y,Z)
  - RDN - direct normal radiation (Btu/hr-ft²)
  - 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 | HANG | > | 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,
  \[ T_{GROND} = T_{GRND}_{\text{month}} + 460.0 \]

• underground wall heat transfer
  \[ QW_i = \sum [F_{W_i} \times (T_{GROND} - T_{SPAC_i})] \text{ for } i = 1, \text{NUM}_i \]

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

If \(| HANG | < | SUNRAS |\), 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-ft²)

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 $|\text{HANG}| > |\text{SUNRAS}|$, 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 $|\text{HANG}| < |\text{SUNRAS}|$, sun above horizon.

Call subroutine SUNS 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 ($\text{XA}, \text{YA}, \text{ZA}$) 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 $|\text{HANG}| > |\text{SUNRAS}|$, 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 $|\text{HANG}| < |\text{SUNRAS}|$, 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

     \[ QPS = 28 + Qp(266.4 - 10.25 \times Qp) + (T-460.) \times (1.2-\text{Qp} \times (3.07 - 0.128 \times Qp) ) \]

   People, latent

     \[ QPL = 206. - Qp(214.9 - 13.8 \times Qp) - (T-460.) \times (6.7 - Qp \times (4.44 - 0.222 \times Qp) ) \]

   where Qp - activity levels of occupants (Btu/hr)
   \( T \) - space temperature (°F)

- Sum thermal loads entering zone at current hour.

   Solar radiation (H1NEW)

     \[ H1NEW = QRAD \]

   where QRAD - sum of instantaneous solar radiation into zone.

3-20
Transmission and internal loads (H2NEW)

\[ H2NEW = Q_{eqs} \times SCHED_{eq} + Q_{dwall} + Q_{qwall} + Q_{dceil} + Q_{qceil} \]
\[ + Q_u + Q_{int} + QPS \times SCHED_{peo} \times NFOLK + Q_{gc} \]

where
- \( Q_{eqs} \) - 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)

\[ H3NEW = 3413 \times SCHED_{lit} \times PLITE \]

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 \( (Q_{S_{inf}}, Q_{L_{inf}}) \)

Sum latent space loads (HLAT)

\[
HLAT = QPL \times SCHED_{peo} \times NFOLK + QL_{eq} \times SCHED_{eq} + QL_{inf}
\]

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.

3-22
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

\[ \begin{align*}
  n & : \text{Number of vertices} \\
  x_i, y_i, z_i & : \text{Coordinates of vertices, ft} \\
  x_j, y_j, z_j & : \text{Coordinates of vertices, ft}
\end{align*} \]

OUTPUT

\[ \begin{align*}
  \text{AREA} & : \text{Area of polygon, ft}^2 \\
  \text{TILT} & : \text{Tilt angle (angle from zenith), degrees} \\
  \text{AZIM} & : \text{Azimuth angle of the right-handed normal, degrees,}
  \text{clockwise from y axis}
\end{align*} \]

CALCULATION SEQUENCE

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

where \[ \begin{align*}
  j & = i + 1 \quad \text{when } i < n \\
  j & = 1 \quad \text{when } i = n \\
  \mathbf{V}_i, \mathbf{V}_j, \ldots & \text{position vectors of the vertices}
\end{align*} \]
2. \[ XCOMP = \frac{1}{2} \sum_{i=1}^{n} (y_iz_j - y_jz_i) \]
\[ YCOMP = \frac{1}{2} \sum_{i=1}^{n} (z_ix_j - z_jx_i) \]
\[ ZCOMP = \frac{1}{2} \sum_{i=1}^{n} (x_iz_j - x_jz_i) \]

3. \[ TILT = \cos^{-1} \left( \frac{ZCOMP}{A} \right) \]

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

5. If \( PROJ \ll A \), \( AZIM = 0.0 \)

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**

<table>
<thead>
<tr>
<th>SIGN OF XCOMP</th>
<th>SIGN OF YCOMP</th>
<th>EQUATIONS FOR THE CALCULATION OF AZIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>[ \Pi + \sin^{-1}\left(\frac{-XCOMP}{PROJ}\right) ]</td>
</tr>
<tr>
<td>0 or +</td>
<td>-</td>
<td>[ \frac{\Pi}{2} + \sin^{-1}\left(\frac{-YCOMP}{PROJ}\right) ]</td>
</tr>
<tr>
<td>-</td>
<td>0 or +</td>
<td>[ 1.5\Pi + \sin^{-1}\left(\frac{YCOMP}{PROJ}\right) ]</td>
</tr>
<tr>
<td>0 or +</td>
<td>0 or +</td>
<td>[ \sin^{-1}\left(\frac{XCOMP}{PROJ}\right) ]</td>
</tr>
</tbody>
</table>

**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

3-24
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

<table>
<thead>
<tr>
<th>ICLTP</th>
<th>STRATUS</th>
<th>CIRRUS, CIRROSTRATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AL ≤ 45°</td>
<td>AL &gt; 45°</td>
</tr>
<tr>
<td>ICLD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>.60</td>
<td>.88</td>
</tr>
<tr>
<td>2</td>
<td>.60</td>
<td>.88</td>
</tr>
<tr>
<td>3</td>
<td>.58</td>
<td>.88</td>
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<td>.35</td>
<td>.61</td>
</tr>
<tr>
<td>10</td>
<td>.27</td>
<td>.46</td>
</tr>
</tbody>
</table>

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

1. $$SQ = ICLD \times ICLD$$

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

$$CC = 0.598 + 0.00026 \times ICLD + 0.00021 \times SQ - 0.00035 \times ICLD \times SQ$$

2b. STRATUS CLOUDS, AL > 45°

$$CC = 0.908 - 0.03214 \times ICLD + 0.0102 \times SQ - 0.00114 \times ICLD \times SQ$$
3a. CIRRUS, CIRROSTRATUS CLOUDS, AL \leq 45^\circ \\
\quad CC = 0.849 - 0.01277 * ICLD + 0.00360 * SQ - 0.00059 
\quad \quad * ICLD * SQ \\
3b. CIRRUS, CIRROSTRATUS CLOUDS, AL > 45^\circ \\
\quad CC = 1.010 - 0.01394 * ICLD + 0.00553 * SQ - 0.00068 
\quad \quad * 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
\begin{itemize}
\item IDEN : Left-justified title, name, etc.
\item KODE : processing indicator
\item KAGIT : print output device
\end{itemize}

OUTPUT
\begin{itemize}
\item IDEN : Centered title, name, etc.
\end{itemize}

CALCULATION SEQUENCE
\begin{enumerate}
\item Check IDEN column-by-column to determine number of blanks at righthand.
\item Reallocation of IDEN in field with half of blanks of either side.
\item Print IDEN on output device KAGIT.
\item If KODE > 3, write IDEN onto output device 2.
\end{enumerate}

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

3-26
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

3=27
11. If \((304 + \text{LEAP}) < \text{IDOY} \leq (334 + \text{LEAP})\), \text{MONTH} = 11, \\
\text{IDAY} = \text{IDOY} - 304 - \text{LEAP}
12. IF \((334 + \text{LEAP}) < \text{IDOY}\), \text{MONTH} = 12 \text{IDAY} = \text{IDOY} - 334 - \text{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 Daylight Saving Time indicator

\[
\begin{cases} 
0 & \text{Standard Time} \\
1 & \text{Daylight Saving Time} 
\end{cases}
\]

DSTS : The day when Daylight Saving Time commences

DSTF : The day when Standard Time resumes

**CALCULATION SEQUENCE**

1. If \text{MONTH} is less than 4 and greater than 10, IDST = 0
2. If \text{MONTH} is greater than 4 and less than 10, IDST = 1
3. If \text{MONTH} = 4 and \text{IDAY} is less than 24, IDST = 0
4a. If \text{MONTH} = 4 and \text{IDAY} is greater than 23, find \text{JDAY} > 23 for which \text{DAY OF THE WEEK} = \text{NDOW (JAHR, 4, IDAY)} is equal to 1, DSTS = \text{JDAY}.
4b. If \text{IDAY} is less than DSTS, IDST = 0; otherwise, IDST = 1
5. If \text{MONTH} = 10 and \text{IDAY} is less than 25, IDST = 1
6a. If \text{MONTH} = 10 and \text{IDAY} is greater than 24, find \text{JDAY} > 24 for which \text{DAY OF THE WEEK} = \text{NDOW (JAHR, 10, IDAY)} is equal to 1, DSTF = \text{JDAY}.
6b. If \text{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, °F
- **TMIN**: Minimum dry-bulb temperature for summer design day, °F
- **TDEW**: Average dew point temperature for summer design day, °F
- **TWIN**: Minimum dry-bulb temperature for winter design day, °F
- **PATM**: Atmospheric pressure, inches of mercury

**OUTPUT**

- **TDB**: Hourly dry-bulb temperature for design day, °F
- **TWB**: Hourly wet-bulb temperature for design day, °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.

3-29
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

3-30
2. Initialize correction factors

\[ CORM1 = 0.0 \quad \text{Month correction for DBT} \]
\[ CORM2 = 0.0 \quad \text{Month correction for WBT} \]
\[ CORD1 = 0.0 \quad \text{Day correction for DBT} \]
\[ CORD2 = 0.0 \quad \text{Day correction for WBT} \]

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
\( RD \leq 45 \), \( K = 8 \)
\( 3-31 \)
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.
      \[ H = 0.24 \times TMAX + (1061. + 0.444 \times TMAX) \times W \]
   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 \times TDB(I) + (1061. + 0.444 \times TDB(J) \times W
      TWB(I) = WBF(H,PATM)
      If (TWB(J)+3) \leq 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 \( \pi = 3.14 \)
      \[ \alpha = \pi/12.0 \]
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-°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

<table>
<thead>
<tr>
<th>IS</th>
<th>A(IS)</th>
<th>B(IS)</th>
<th>C(IS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0.535</td>
<td>2.04</td>
</tr>
<tr>
<td>2</td>
<td>0.001329</td>
<td>0.369</td>
<td>2.20</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0.380</td>
<td>1.90</td>
</tr>
<tr>
<td>4</td>
<td>-0.002658</td>
<td>0.363</td>
<td>1.45</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0.281</td>
<td>1.80</td>
</tr>
<tr>
<td>6</td>
<td>-0.001661</td>
<td>0.302</td>
<td>1.45</td>
</tr>
</tbody>
</table>
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 \( T_{O_i} \) includes the present temperature, \( T_{O_1} \), 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
- \( T_{O_i} \): Outside wall surface temperature history, \( (T_{O_i} \) 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;
- \( SUMR \): Used to accomplish the recursive summation of the response factors and outside surface temperature
- \( QN \)
- \( QR \)
Space heat gain (+) or loss (-) per unit area of surface, BTU/HR - Sq. ft.

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:

\[ Q_{\text{OUTSIDE}} = \sum_{i=1}^{t} (T_{0i} - T_M)X_i \]  \hspace{1cm} (EQ. 1)^

\[ Q_{\text{INSIDE}} = \sum_{i=1}^{t} (T_{0i} - T_M)Y_i \]  \hspace{1cm} (EQ. 2)^

^ Note that the response factors include the inside convection film coefficient.
Outside Wall Surface Heat Balance:

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

where

\[ q_1 = AB \times S0LI \]  
(EQ. 4)

\[ q_2 = F0 \times (TDB - TO) \]  
(EQ. 5)

\[ q_3 = 2.0 \times A \times (10.0 - CC) \]  
(EQ. 6)

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

\[ \sum_{i=1}^{n} (TO_i - TM)X_i = AB \times S0LI + FO \times (TDB - TO) \]

\[ - 2.0 \times A \times (10.0 - CC) \]  
(EQ. 7)

Equation 7 is the heat balance equation of the outside wall surface at the time in question. Since \( T0_2, T0_3, \text{ etc.} \) are known from past calculations, \( T0_1 \) may be solved from this equation.

Rearranging equation 7 as:

\[ TO_1 \times (X_i + FO) = X_i \times TM + AB \times S0LI + FO \times TDB - 2.0 \]

\[ \times A \times (10.0 - CC) - \sum_{i=2}^{n} (TO_i - TM)X_i \]  
(EQ. 8)

and solving equation 8 for \( TO_1 \) gives:

\[ TO_1 = \frac{X_1 \times TM + AB \times S0LI + FO \times TDB - 2.0 \times A \times (10.0 - CC) - \sum_{i=2}^{n} (TO_i - TM)X_i}{X_1 + FO} \]

Now that \( TO_1 \) is known, equation 2 may be used to compute \( Q_{\text{INSIDE}} \) 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 : Window solar load weighing factors
RATRG :
RMRX1 :
RMRXC : Space sensible load weighing factors
RATRX :
RMRIS1 :
RMRISC : Space lighting load weighing factors
RATRIS :
RMRPS1 :
RMRPSC : Return plenum lighting load weighting factors
RATRPS :
HRLDS : Total space sensible load for present hour, BTU/HR
HRLDL : Total plenum sensible load for present hour, BTU/HR
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA</td>
<td>Weighted window solar load for present hour, BTU/HR</td>
</tr>
<tr>
<td>SB</td>
<td>Weighted space sensible load for present hour, BTU/HR</td>
</tr>
<tr>
<td>SC</td>
<td>Weighted space lighting load for present hour, BTU/HR</td>
</tr>
<tr>
<td>H2P</td>
<td>Components of sensible load from previous hour, BTU/HR</td>
</tr>
<tr>
<td>H2NEWP</td>
<td>Components of sensible load for present hour, BTU/HR</td>
</tr>
<tr>
<td>SBP(I)</td>
<td>Components of weighted sensible load for present hour, BTU/HR, where</td>
</tr>
</tbody>
</table>

\[
I = 1 \text{ equipment} \\
2 \text{ quick walls} \\
3 \text{ delayed walls} \\
4 \text{ underground floors} \\
5 \text{ underground walls} \\
6 \text{ internal walls} \\
7 \text{ people} \\
8 \text{ window conduction} \\
9 \text{ quick ceilings} \\
10 \text{ delayed ceilings} \\
\]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTPUT</td>
<td></td>
</tr>
<tr>
<td>H1</td>
<td>Window solar load from previous hour, BTU/HR</td>
</tr>
<tr>
<td>H2</td>
<td>Total transmission and internal load from previous hour, BTU/HR</td>
</tr>
<tr>
<td>H3</td>
<td>Plenum return air load from previous hour, BTU/HR</td>
</tr>
<tr>
<td>HRLDS</td>
<td>Total space sensible load for present hour, BTU/HR</td>
</tr>
<tr>
<td>HRLDL</td>
<td>Total plenum sensible load for present hour, BTU/HR</td>
</tr>
<tr>
<td>SA</td>
<td>Weighted window solar load for present hour, BTU/HR</td>
</tr>
<tr>
<td>SB</td>
<td>Weighted space sensible load for present hour, BTU/HR</td>
</tr>
<tr>
<td>SC</td>
<td>Weighted space lighting load for present hour, BTU/HR</td>
</tr>
<tr>
<td>SBP</td>
<td>Components of weighted sensible load for present hour, BTU/HR</td>
</tr>
<tr>
<td>H2P</td>
<td>Components of sensible load for previous hour, BTU/HR</td>
</tr>
</tbody>
</table>

3-39
(SPACE SENSIBLE LOAD)_{i} = \sum_{j=0}^{\infty} \sum_{i=1}^{n} (LOAD)_{t-j} \cdot (WEIGHTING FACTOR)_{t-j}^{i}

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

HOLIDAY

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 =

\[ JOL = \begin{cases} 
0 & \text{Not holiday} \\
1 & \text{Holiday} 
\end{cases} \]

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 \( NDAY = 2 \)
- \( MO = 1, JAY \) is greater than 23, and \( NDAY = 5 \)

2. Otherwise, set \( JOL \) equal to 0.
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:

\[ Q_{OUTSIDE} = Q_{INSIDE} = U \times (T_0 - TM) \]  

(EQ. 1)

where \( U \) is the overall heat transfer coefficient.

The heat balance equation of the outside wall surface becomes:

\[ U \times (T_0 - TM) = AB \times SOLI + FO \times (TDB - T_0) - 2.0 \times A \times (10.0 - CC) \]  

(EQ. 2)

Solving this equation for \( T_0 \) gives:

\[ T_0 = \frac{U \times TM + AB \times SOLI + FO \times TDB - 2.0 \times A \times (10.0 - CC)}{U + FO} \]  

(EQ. 3)

Now that \( T_0 \) is known, equation 9 may be used to compute \( Q_{INSIDE} \) directly.
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**

- **XX**: coordinates of vertices
- **YY**: coordinates of vertices
- **ZZ**:

**CALCULATION SEQUENCE**

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

2. Short form input for rectangular surface
   a) Read the following card input data:
      - **XCORN**: coordinates of lower lefthand vertex, ft
      - **YCORN**: coordinates of lower lefthand vertex, ft
      - **ZCORN**: 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

3-42
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

<table>
<thead>
<tr>
<th>KARD</th>
<th>Logical unit number for card input device</th>
</tr>
</thead>
<tbody>
<tr>
<td>KAGIT</td>
<td>Logical unit number for line printer</td>
</tr>
</tbody>
</table>

OUTPUT

| NV          | Number of vertices contained in surface |
| XX          | coordinates of vertices                 |
| YY          |                                           |
| ZZ          |                                           |
| 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   |

3-43
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.
   \[
   \begin{align*}
   NV &= FNV + 0.1 \\
   NX &= FNX + 0.1 \\
   NY &= FNY + 0.1 \\
   ND &= FND + 0.1 \\
   NA &= FNA + 0.1 \\
   ISR &= FISR + 0.1 \\
   IRF &= FIRF + 0.1
   \end{align*}
   \]
   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 ≥ 3, go to calculation 5.
4. Short form input for rectangular surface
   a) Read the following card input data:
      \[
      \begin{align*}
      \{ \text{XCORN, YCORN, ZCORN} \} & \quad \text{coordinates of lower lefthand vertex, ft} \\
      \text{HT} & \quad \text{height, ft} \\
      \text{WD} & \quad \text{width, ft}
      \end{align*}
      \]
3-44
AZIM - azimuth angle, degrees
TILT - tilt angle, degrees

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

\[
\text{AZIM} = 0.01745 \times \text{AZIM} \\
\text{TILT} = 0.01745 \times \text{TILT} \\
\text{AREA} = \text{HT} \times \text{WD}
\]

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.
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:

   \[
   WRA = \frac{53.2 + 0.245 \times (DB - 50.0)}{7000.0} 
   \]

   ![Dew Point Temperature Diagram](image)

   \(DPT = \text{dew point temperature of air leaving cooling coil}\)

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

   \[WRA = \text{HUMRA}\]

3-46
3. \[ QSIN = 14.4 \times DEN \times VO \times (DB + 460.0 - TSPA) \times CODE / 60.0 \]
\[ QLIN = 63300.0 \times DEN \times VO \times (HUMRA - WRA) \times CODE \]

**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 ≠ 1 or MM or J ≠ 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 asterisk 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 insights into the mechanics of performing such calculations.

![Figure 3.8](image-url)

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

3-48
Step 2 - Surface broken into grid elements with 1 indicating portion that is shaded

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

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

3-51
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 \( JDAY/7 \)
   \( NDX = JDAY - 7 \times NTX + IWK \)
   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, °F
   - **WBT** : Outside air wet-bulb temperature, °F
   - **DPT** : Outside air dew point temperature, °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 subroutine.

   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

\[
PPWV = PPWVMS(WBT) - 0.000367 \times PATM \times (DBT - WBT)/
(1.0 + (WBT - 32.0)/1571.0)
\]

3. \(HUMRAT = 0.622 \times PPW/(PATM - PPW)\)

4. \(ENTH = 0.24 \times DBT + (1061.0 + 0.444 \times DBT) \times HUMRAT\)

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

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

1. Let \(t\) be either DBT, WBT or DPT.

2. Let \(A(1) = -7.90298\)
   \(A(2) = 5.02808\)
   \(A(3) = -1.3816 \times 10^{-7}\)
   \(A(4) = 11.344\)
   \(A(5) = 8.1328 \times 10^{-3}\)
   \(A(6) = -3.49149\)

3. Let \(T = (t + 459.688)/1.8\)
   If \(T\) is less than 273.16, go to 4.
   Otherwise
   \[
z = 373.16/T
\]
   \(P1 = A(1) \times (z-1)\)
   \(P2 = A(2) \times \log_{10}(z)\)
   \(P3 = A(3) \times (10^{(A(4) \times (1-1/z))-1})\)
   \(P4 = A(5) \times (10^{(A(6) \times (z-1))-1})\)
   Go to 5.

4. Let \(z = 273.16/T\)
   \(P1 = B(1) \times (x-1)\)
   \(P2 = B(2) \times \log_{10}(z)\)
   \(P3 = B(3) \times (1-1/z)\)
   \(P4 = \log_{10}(B(4))\)

5. \(PVS = 29.921 \times 10^{(P1 + P2 + P3 + P4)}\)
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**

<table>
<thead>
<tr>
<th>I</th>
<th>: Space Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRLDS</td>
<td>: Space sensible load for hour, Btu/hr</td>
</tr>
<tr>
<td>SSHMAX</td>
<td>: Maximum space sensible heating load, Btu/hr</td>
</tr>
<tr>
<td>TOTAL</td>
<td>: Space total load for hour, Btu/hr</td>
</tr>
<tr>
<td>STCMAX</td>
<td>: Maximum space total cooling load, Btu/hr</td>
</tr>
<tr>
<td>SUMA</td>
<td>: Space window solar load, Btu/hr</td>
</tr>
<tr>
<td>SUMBP(L)</td>
<td>: Space sensible load components, Btu/hr</td>
</tr>
</tbody>
</table>

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

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

3-54
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 building 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

3-55
\( M = 1 \) 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

\[ Q\text{SUM}(M,I) : \text{Components of space peak cooling load, Btu/hr; } M \text{ and } I \text{ have same definition as for } Q\text{WIN} \]

**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

   \[ \text{BHEATT} = \text{BHEATT} + \text{HRLDS} + \text{QOA} \]

   \[ \text{QOA} = 14.4 \times \text{DENS} \times \text{CFMSF} \times \text{FLORA}(I) \times (\text{DBT} - \text{TROOM}(I)) \]

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

   \[
   \begin{align*}
   \text{QHCOMP}(1) &= \text{QHCOMP}(1) + \text{SUMBP}(I,3) \times \text{MULT}(I) \\
   (2) &= (2) + \text{SUMBP}(I,8) \times \text{MULT}(I) \\
   (3) &= (3) + \text{SUMA}(I) \times \text{MULT}(I) \\
   (4) &= (4) + \text{SUMBP}(I,2) \times \text{MULT}(I) \\
   (5) &= (5) + \text{SUMBP}(I,6) \times \text{MULT}(I) \\
   (6) &= (6) + \text{SUMBP}(I,5) \times \text{MULT}(I) \\
   (7) &= (7) + \text{SUMBP}(I,4) \times \text{MULT}(I) 
   \end{align*}
   \]
(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)

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

3-57
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 \(|\text{TOTAL}| > |\text{STCMAX}|\), 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**

\[
\begin{align*}
X & : \\
Y & : \text{Coordinates of one vertex, ft} \\
Z & : \\
H & : \text{Height of surface, ft} \\
W & : \text{Width of surface, ft} \\
A & : \text{Azimuth angle, degrees} \\
B & : \text{Tilt angle, degrees}
\end{align*}
\]

**OUTPUT**

\[
\begin{align*}
XV(I) & : \\
YV(I) & : \text{Coordinates of 4 vertices} \\
ZV(I) & :
\end{align*}
\]

**CALCULATION SEQUENCE**

1. Let 
   \[
   \begin{align*}
   CA & = \cos(A) \\
   CB & = \cos(B) \\
   SA & = \sin(A) \\
   SB & = \sin(B)
   \end{align*}
   \]

2. \[
   \begin{align*}
   XV(1) & = X - H \times CB \times SA \\
   YV(1) & = Y - H \times CB \times CA \\
   ZV(1) & = Z + H \times SB
   \end{align*}
   \]

3-58
$X_V(2) = X$
$X_V(2) = Y$
$Z_V(2) = Z$

$X_V(3) = X - W \times CA$
$Y_V(3) = Y + W \times SA$
$Z_V(3) = Z$

$X_V(4) = X - W \times CA - H \times CB \times SA$
$Y_V(4) = Y + W \times SA - H \times CB \times CA$
$Z_V(4) = Z + H \times SB$

---

**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, °F
DTH : Hot air supply temperature, °F
ALTUD : Building altitude, ft.
TDBS : Summer maximum DBT, °F
RANGS : Summer daily range of DBT, °F
TDPS : Summer dew point temperature, °F
WINDS : Summer wind speed, mph
TDBW : Winter minimum DBT, °F
RANGW : Winter daily range of DBT, °F
TDPW : Winter dew point temperature, °F
WINDW : Winter wind speed, mph
JAHR : Weather year
JMONTH : Starting month of analysis

3-60
LENGTH : Length of analysis, days
IXMAS : Length of Christmas period, days
TDB : Initial temperature of exterior surfaces, °F
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
X : 
Y : Coordinates of lower left-hand vertex, ft.
Z : 
HT : Height, ft.
WD : Width, ft.
AZIM : Azimuth angle, radians
TILT : Tilt angle, radians
X : 
Y : Coordinates of all surface vertices, ft.
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 ****

<table>
<thead>
<tr>
<th>Description</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
<th>Value 4</th>
<th>Value 5</th>
<th>Value 6</th>
<th>Value 7</th>
<th>Value 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASIC DATA</td>
<td>37.00</td>
<td>76.50</td>
<td>5.00</td>
<td>0.98</td>
<td>0.98</td>
<td>325.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PROCESSING DATA</td>
<td>1.00</td>
<td>0.13</td>
<td>2.00</td>
<td>52.00</td>
<td>55.00</td>
<td>100.00</td>
<td>120.00</td>
<td></td>
</tr>
<tr>
<td>DESIGN LOAD DATA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALTITUDE SUMMER DAY</td>
<td>15.00</td>
<td>94.00</td>
<td>16.00</td>
<td>73.00</td>
<td>8.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20.00</td>
<td>3.00</td>
<td>17.00</td>
<td>10.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRINT CODE</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO. OF SCHEDULE TYPES</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.13 SAMPLE OUTPUT FROM RECAP1
### DELAYED SURFACE NO. 11

<table>
<thead>
<tr>
<th>ABSORBANCE</th>
<th>REFLECTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.70</td>
<td>0.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INDICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT</th>
</tr>
</thead>
<tbody>
<tr>
<td>106.00</td>
</tr>
</tbody>
</table>

### DELAYED SURFACE NO. 12

<table>
<thead>
<tr>
<th>ABSORBANCE</th>
<th>REFLECTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.70</td>
<td>0.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INDICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT</th>
</tr>
</thead>
<tbody>
<tr>
<td>106.00</td>
</tr>
</tbody>
</table>

### DELAYED SURFACE NO. 13

<table>
<thead>
<tr>
<th>ABSORBANCE</th>
<th>REFLECTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.70</td>
<td>0.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INDICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.00</td>
</tr>
</tbody>
</table>

### DELAYED SURFACE NO. 14

<table>
<thead>
<tr>
<th>ABSORBANCE</th>
<th>REFLECTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.70</td>
<td>0.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INDICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
</tr>
</tbody>
</table>

### DELAYED SURFACE NO. 15

<table>
<thead>
<tr>
<th>ABSORBANCE</th>
<th>REFLECTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.70</td>
<td>0.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INDICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
</tr>
</tbody>
</table>

### DELAYED SURFACE NO. 16

<table>
<thead>
<tr>
<th>ABSORBANCE</th>
<th>REFLECTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>0.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INDICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
</tr>
</tbody>
</table>

### DELAYED SURFACE NO. 17

<table>
<thead>
<tr>
<th>ABSORBANCE</th>
<th>REFLECTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>0.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INDICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.00</td>
</tr>
</tbody>
</table>

### DELAYED SURFACE NO. 18

<table>
<thead>
<tr>
<th>ABSORBANCE</th>
<th>REFLECTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>0.10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INDICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT</th>
</tr>
</thead>
<tbody>
<tr>
<td>106.00</td>
</tr>
</tbody>
</table>

There are 0 delayed surface pictorial outputs desired.
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.
      
      \[ AA = \text{AZIM}/0.01745 \]
      
      \[ BB = \text{TILT}/0.01745 \]
   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

<table>
<thead>
<tr>
<th>IDEN1</th>
<th>Facility name</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDEN2</td>
<td>Facility location</td>
</tr>
<tr>
<td>IDEN3</td>
<td>Analyst's name</td>
</tr>
<tr>
<td>IDEN4</td>
<td>Project number</td>
</tr>
<tr>
<td>IDEN5</td>
<td>Date</td>
</tr>
<tr>
<td>KODE</td>
<td>Print code indicating if writing on output computer tape is desired</td>
</tr>
<tr>
<td>KAGIT</td>
<td>Logical unit number for line printer.</td>
</tr>
</tbody>
</table>

OUTPUT

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

3-65
Figure 3.16 SAMPLE OUTPUT

ANALYSIS OF ENERGY UTILIZATION FOR

LRC SYSTEMS ENGINEERING

HAMPTON, VIRGINIA

ENGINEER = R. JENSEN
PROJECT NO = 52, 4W, 3IN
DATE = NOV 26, 1973
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.

REPR2

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

INPUT

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>JSTAT</td>
<td>Weather station number</td>
</tr>
<tr>
<td>JHOUR</td>
<td>Hour of day when analysis is to start</td>
</tr>
<tr>
<td>LMONTH</td>
<td>Month when analysis is to start</td>
</tr>
<tr>
<td>LDAY</td>
<td>Day of month when analysis is to start</td>
</tr>
<tr>
<td>JAHHR</td>
<td>Year when analysis is to start</td>
</tr>
<tr>
<td>LENGTH</td>
<td>Length of analysis in days</td>
</tr>
<tr>
<td>ITDB</td>
<td>Initial estimate of exterior surface temperature, OF</td>
</tr>
<tr>
<td>KAGIT</td>
<td>Logical unit number for line printer</td>
</tr>
</tbody>
</table>
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, °F
- **RANGS**: Daily swing of dry-bulb temperature for summer design day, °F
- **TDPS**: Average dew point temperature for summer design day, °F
- **WINDS**: Wind speed for summer design day, mph
- **TDBW**: Minimum winter dry-bulb temperature, °F
- **RANGW**: Daily swing of dry-bulb temperature for winter design day, °F
- **TDPW**: Average dew point temperature for winter design day, °F
- **WINDW**: Wind speed for winter design day, mph
- **PATM**: Atmospheric pressure, inches of mercury
- **IPRNT**: Logical unit number for line printer.

3-68
** Figure 3.17 SAMPLE OUTPUT 3-69

* 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.

*
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

************
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.

REPT6

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

INPUT

<table>
<thead>
<tr>
<th>IPRNT</th>
<th>Logical unit number for line printer</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAC</td>
<td>Facility name</td>
</tr>
<tr>
<td>CITY</td>
<td>Facility location</td>
</tr>
<tr>
<td>PROJ</td>
<td>Project number</td>
</tr>
<tr>
<td>ENGR</td>
<td>Engineer name</td>
</tr>
</tbody>
</table>
### 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°F
3. Daily Swing of Dry-Bulb Temperature = 18°F
4. Average Dew-Point Temperature = 72°F
5. Average Wind Speed = 5 mph

#### Winter Day Input Parameters
1. Month Assumed to be December
2. Minimum Dry-Bulb Temperature = 20°F
3. Daily Swing of Dry-Bulb Temperature = 3°F
4. Average Dew-Point Temperature = 5°F
5. Average Wind Speed = 7 mph

<table>
<thead>
<tr>
<th>Month</th>
<th>A.M.</th>
<th>P.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBT</td>
<td>62.5</td>
<td>61.5</td>
</tr>
<tr>
<td>WBT</td>
<td>59.5</td>
<td>58.5</td>
</tr>
<tr>
<td>April</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBT</td>
<td>67.5</td>
<td>66.5</td>
</tr>
<tr>
<td>WBT</td>
<td>64.5</td>
<td>63.5</td>
</tr>
<tr>
<td>May</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBT</td>
<td>72.5</td>
<td>71.5</td>
</tr>
<tr>
<td>WBT</td>
<td>69.5</td>
<td>68.5</td>
</tr>
<tr>
<td>June</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBT</td>
<td>75.5</td>
<td>74.5</td>
</tr>
<tr>
<td>WBT</td>
<td>72.5</td>
<td>71.5</td>
</tr>
<tr>
<td>July</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBT</td>
<td>76.5</td>
<td>75.5</td>
</tr>
<tr>
<td>WBT</td>
<td>73.5</td>
<td>72.5</td>
</tr>
<tr>
<td>August</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBT</td>
<td>76.5</td>
<td>75.5</td>
</tr>
<tr>
<td>WBT</td>
<td>73.5</td>
<td>72.5</td>
</tr>
<tr>
<td>September</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBT</td>
<td>73.5</td>
<td>72.5</td>
</tr>
<tr>
<td>WBT</td>
<td>70.5</td>
<td>69.5</td>
</tr>
<tr>
<td>October</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBT</td>
<td>69.5</td>
<td>68.5</td>
</tr>
<tr>
<td>WBT</td>
<td>66.5</td>
<td>65.5</td>
</tr>
<tr>
<td>November</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBT</td>
<td>61.5</td>
<td>60.5</td>
</tr>
<tr>
<td>WBT</td>
<td>58.5</td>
<td>57.5</td>
</tr>
<tr>
<td>December</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBT</td>
<td>21.5</td>
<td>20.5</td>
</tr>
<tr>
<td>WBT</td>
<td>17.5</td>
<td>16.5</td>
</tr>
</tbody>
</table>

**Note**: Temperature correction factors based on Canmet System Design Manual pages 18-19. WBT is set at least 3 deg. F below DBT.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATE</td>
<td>Date</td>
</tr>
<tr>
<td>NSPAC</td>
<td>Number of spaces in building</td>
</tr>
<tr>
<td>AREA</td>
<td>Space floor areas, sq ft</td>
</tr>
<tr>
<td>VOL</td>
<td>Space volumes, cu ft</td>
</tr>
<tr>
<td>TSPAC</td>
<td>Space set point temperature, °F</td>
</tr>
<tr>
<td>DENS</td>
<td>Outside air density for summer peak load hour, lbs/cu ft</td>
</tr>
<tr>
<td>DENW</td>
<td>Outside air density for winter peak load hour, lbs/cu ft</td>
</tr>
<tr>
<td>QSUM(I,N)</td>
<td>Components of space peak cooling load, Btu/hr, where N is the space number and I takes on the following definition:</td>
</tr>
<tr>
<td></td>
<td>I = 1   delayed walls</td>
</tr>
<tr>
<td></td>
<td>2   window conduction</td>
</tr>
<tr>
<td></td>
<td>3   Window solar</td>
</tr>
<tr>
<td></td>
<td>4   quick walls</td>
</tr>
<tr>
<td></td>
<td>5   internal walls</td>
</tr>
<tr>
<td></td>
<td>6   underground walls</td>
</tr>
<tr>
<td></td>
<td>7   underground floors</td>
</tr>
<tr>
<td></td>
<td>8   people sensible</td>
</tr>
<tr>
<td></td>
<td>9   people latent</td>
</tr>
<tr>
<td></td>
<td>10   lighting</td>
</tr>
<tr>
<td></td>
<td>11   equipment sensible</td>
</tr>
<tr>
<td></td>
<td>12   infiltration sensible</td>
</tr>
<tr>
<td></td>
<td>13   infiltration latent</td>
</tr>
<tr>
<td></td>
<td>14   plenum return air</td>
</tr>
<tr>
<td></td>
<td>15   equipment latent</td>
</tr>
<tr>
<td></td>
<td>16   month</td>
</tr>
<tr>
<td></td>
<td>17   ambient DBT</td>
</tr>
<tr>
<td></td>
<td>18   ambient WBT</td>
</tr>
<tr>
<td></td>
<td>19   ambient humidity ratio</td>
</tr>
<tr>
<td></td>
<td>20   hour of day</td>
</tr>
<tr>
<td></td>
<td>21   quick ceilings</td>
</tr>
<tr>
<td></td>
<td>22   delayed ceilings</td>
</tr>
<tr>
<td></td>
<td>23   day of month</td>
</tr>
<tr>
<td>QWIN(I,N)</td>
<td>Components of space peak heating load, Btu/hr; I and N have same definition as for QSUM.</td>
</tr>
<tr>
<td>T1(I)</td>
<td>Components of building peak cooling load, Btu/hr; I has same definition as for QSUM.</td>
</tr>
<tr>
<td>T2(I)</td>
<td>Components of building peak heating load, Btu/hr; I has same definition as for QSUM.</td>
</tr>
</tbody>
</table>
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:

   \[
   CFM1 = \frac{TOT1}{(14.4\times DENS\times (TSPAC(N) - DTC(1))}
   \]

3-74
**Figure 3.20 SAMPLE OUTPUT**

**DEVELOPMENT LOAD CALCULATION RESULTS FOR**
**LRC SYSTEMS ENGINEERING**
**HAMPTON, VIRGINIA**

**SPACE NO.**
4

**SPACE REPELITON FACTOR**
1

**AREA (SQ.FT.)**
500

**VOLUME (CU.FT.)**
4700

**SUMMER COOLING PEAK**
OUT/WAT/HR OF DAY/DATE 98 / 75 / 18 / JULY 1

**WINTER HEATING PEAK**
OUT/WAT/HR OF DAY/DATE -14 / -15 / 21 / JAN. 23

<table>
<thead>
<tr>
<th>Component</th>
<th>Sensible Load (BTUH)</th>
<th>Latent Load (BTUH)</th>
<th>Winter Load (BTUH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WALLS</td>
<td>5800</td>
<td>0</td>
<td>-35586</td>
</tr>
<tr>
<td>CEILINGS</td>
<td>1709</td>
<td>0</td>
<td>-3570</td>
</tr>
<tr>
<td>WINDOW CONJUNCTANCE</td>
<td>20660</td>
<td>0</td>
<td>-96917</td>
</tr>
<tr>
<td>WINDOW SOLAR</td>
<td>20270</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>QUICK SURFACES</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>INTERNAL SURFACES</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>UNDERGROUND WALLS</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>UNDERGROUND FLOORS</td>
<td>185</td>
<td>0</td>
<td>-1690</td>
</tr>
<tr>
<td>OCCUPANTS</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>LIGHT TO SPACE</td>
<td>5529</td>
<td>0</td>
<td>1474</td>
</tr>
<tr>
<td>EQUIPMENT TO SPACE</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>INfiltration</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>54264</td>
<td>0</td>
<td>-136271</td>
</tr>
</tbody>
</table>

**TOTAL SPACE COOLING**
475264 BTUH

**TOTAL SPACE HEATING**
-136271 BTUH

**SUPPLY AIR AT 50 F AT DIFFUSER**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>CFM</th>
<th>CFM/SQ.FT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2223</td>
<td>4.45</td>
<td></td>
</tr>
<tr>
<td>2779</td>
<td>5.56</td>
<td></td>
</tr>
<tr>
<td>2376</td>
<td>4.75</td>
<td></td>
</tr>
<tr>
<td>1645</td>
<td>3.29</td>
<td></td>
</tr>
</tbody>
</table>
## 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**  
93 / 81 / 17 / Aug 2

**Winter Heating Peak**  
-15 / -15 / 6 / Jan 23

### Figure 3.21 SAMPLE OUTPUT

#### Sensible Load and Load (BTUH) (BTUH) (BTUH)

|walls | 4536. | 0. | -109526. |
|ceiling | 106015. | 0. | -337968. |
|window conductance | 54813. | 0. | -344317. |
|window solar | 38064. | 0. | |
|quick surfaces | 0. | 0. | 0. |
|internal surfaces | 7260. | 0. | 7260. |
|underground walls | 0. | 0. | 0. |
|underground floors | 13738. | 0. | -178599. |
|occupants | 85080. | 67716. | 75. |
|light to space | 57918. | 0. | 16470. |
|equipment to space | 0. | 0. | 0. |
|infiltration | 0. | 0. | 0. |
|sum | -946104. | 67716. | -729336. |

#### Total

|total building cooling | 1554714. | 374504. | -1605210. |
|total building heating | -1605210. | 374504. | -1605210. |

#### Constant Volume System

|supply air at 70°F at diffuser | 36497. | 0.69 CFM/SQ.FT. MAX. |
|supply air at 55°F at diffuser | 46521. | 0.86 CFM/SQ.FT. MAX. |
|supply air at 72°F at diffuser | 16500. | 0.31 CFM/SQ.FT. MAX. |
|supply air at 140°F at diffuser | 11423. | 0.22 CFM/SQ.FT. MAX. |

#### Constant Volume System

<p>|supply air at 70°F at diffuser | 42370. | 0.80 CFM/SQ.FT. CONST. |
|supply air at 55°F at diffuser | 52962. | 1.00 CFM/SQ.FT. CONST. |
|supply air at 72°F at diffuser | 17608. | 0.33 CFM/SQ.FT. CONST. |
|supply air at 140°F at diffuser | 12190. | 0.23 CFM/SQ.FT. CONST. |</p>
<table>
<thead>
<tr>
<th>SPACE NO.</th>
<th>HEATING EXTRACTION RATE (BTU/HR)</th>
<th>COOLING EXTRACTION RATE (BTU/HR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-500389.</td>
<td>861499.</td>
</tr>
<tr>
<td>2</td>
<td>-43732.</td>
<td>45320.</td>
</tr>
<tr>
<td>3</td>
<td>-115744.</td>
<td>35014.</td>
</tr>
<tr>
<td>4</td>
<td>-136271.</td>
<td>54264.</td>
</tr>
<tr>
<td>5</td>
<td>-113510.</td>
<td>38009.</td>
</tr>
<tr>
<td>6</td>
<td>0.</td>
<td>0.</td>
</tr>
</tbody>
</table>
CFM2 = \frac{TOT1}{14.4 \times DENS \times (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 = \frac{TOT3}{14.4 \times DENW \times (DTH(1) - TSPAC(N))}

CFM4 = \frac{TOT3}{14.4 \times DENW \times (DTH(2) - TSPAC(N))}

where TOT3 is total winter sensible load.

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

SQFT1 = \frac{CFM1}{AREA(N)}

SQFT2 = \frac{CFM2}{AREA(N)}

SQFT3 = \frac{CFM3}{AREA(N)}

SQFT4 = \frac{CFM4}{AREA(N)}

2. Calculate following summations for building.

a) Total floor area

TAREA = \sum (AREA(N) \times MULT(N)), for N=1 to NSPAC

b) Total volume

TVOL = \sum (VOL(N) \times MULT(N)), for N=1 to NSPAC

c) Total cooling cfm at both temperature conditions

TCFM1 = \sum (CFM1 \times MULT(N)), for N=1 to NSPAC

TCFM2 = \sum (CFM2 \times MULT(N)), for N=1 to NSPAC

d) Total heating cfm at both temperature conditions

TCFM3 = \sum (CFM3 \times MULT(N)), for N=1 to NSPAC

TGFM4 = \sum (CFM4 \times 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

\[ Q_{\text{FAN}} = 0.4014 \times T_{\text{CFM1}} \times F_{\text{PRESS}} \]

h) Ventilation air load for summer peak cooling hour

\[ Q_{\text{SOAS}} = 14.4 \times D_{\text{ENS}} \times C_{\text{FMSF}} \times T_{\text{AREA}} \times (T_1(17) - 75.0) \]

\[ Q_{\text{LOA}} = 63000. \times D_{\text{ENS}} \times C_{\text{FMSF}} \times T_{\text{AREA}} \times (T_1(19) - 0.0093) \]

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

\[ Q_{\text{SOAW}} = 14.4 \times D_{\text{EW}} \times C_{\text{FMSF}} \times T_{\text{AREA}} \times (T_2(17) - 75.0) \]

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.
1) 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
  \[ TCFM_5 = \frac{SUMT1}{14.4 \cdot DENS \cdot (75.0 - DTC(1))} \]
  \[ TCFM_6 = \frac{SUMT1}{14.4 \cdot DENS \cdot (75.0 - DTC(2))} \]
  \[ TSQFT_5 = \frac{TCFM_5}{TAREA} \]
  \[ TSQFT_6 = \frac{TCFM_6}{TAREA} \]

- Heating
  \[ TCFM_7 = \frac{-SUMT2}{14.4 \cdot DENW \cdot (DTH(1) - 75.0)} \]
  \[ TCFM_8 = \frac{-SUMT2}{14.4 \cdot DENW \cdot (DTH(2) - 75.0)} \]
  \[ TSQFT_7 = \frac{TCFM_7}{TAREA} \]
  \[ TSQFT_8 = \frac{TCFM_8}{TAREA} \]

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
  \[ TCFM_1 = \text{see 2c.} \]
  \[ TCFM_2 = \text{see 2c.} \]
  \[ TSQFT_1 = \frac{TCFM_1}{TAREA} \]
  \[ TSQFT_2 = \frac{TCFM_2}{TAREA} \]

- Heating
  \[ TCFM_3 = \text{see 2d.} \]
  \[ TCFM_4 = \text{see 2d.} \]
  \[ TSQFT_3 = \frac{TCFM_3}{TAREA} \]
  \[ TSQFT_4 = \frac{TCFM_4}{TAREA} \]

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

RMRISC : }

RATRIS :

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

RMRPSC : }

RATRPS :

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

RMRXC : }

RATRX :

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

RMRGC : }

RATRG :

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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

<table>
<thead>
<tr>
<th>WEIGHTING FACTOR</th>
<th>TYPE OF CONSTRUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYMBOL</td>
<td>LIGHT</td>
</tr>
<tr>
<td>RMRGI</td>
<td>0.224</td>
</tr>
<tr>
<td>RMRGC</td>
<td>-0.044</td>
</tr>
<tr>
<td>RATRG</td>
<td>0.82</td>
</tr>
</tbody>
</table>


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

   Table 3.6

<table>
<thead>
<tr>
<th>WEIGHTING FACTOR</th>
<th>TYPE OF CONSTRUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYMBOL</td>
<td>LIGHT</td>
</tr>
<tr>
<td>RMRXI</td>
<td>0.703</td>
</tr>
<tr>
<td>RMRXC</td>
<td>-0.523</td>
</tr>
<tr>
<td>RATRX</td>
<td>0.82</td>
</tr>
</tbody>
</table>


3-83
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:

\[
\begin{align*}
\text{RMRIS1} &= \text{RMRIS1} \times \frac{\text{PERCT}}{100.} \\
\text{RMRISC} &= \text{RMRISC} \times \frac{\text{PERCT}}{100.}
\end{align*}
\]

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

\[
\begin{align*}
\text{RMRPS1} &= 0.0 \\
\text{RMRPSC} &= 0.0 \\
\text{RATRPS} &= 0.0
\end{align*}
\]

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

\[
\begin{align*}
\text{RMRPS1} &= \text{RMRIS1} \times \frac{100. - \text{PERCT}}{100.} \\
\text{RMRPSC} &= \text{RMRISC} \times \frac{100. - \text{PERCT}}{100.} \\
\text{RATRPS} &= \text{RATRIS}
\end{align*}
\]
<table>
<thead>
<tr>
<th>WEIGHTING FACTOR SYMBOL</th>
<th>TYPE OF CONSTRUCTION</th>
<th>LIGHT</th>
<th>MEDIUM</th>
<th>HEAVY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1 - Fluorescent fixture recessed into suspended ceiling, ceiling plenum not vented.</td>
<td>RMRIS1</td>
<td>0.53</td>
<td>0.53</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>RMRISC</td>
<td>-0.35</td>
<td>-0.40</td>
<td>-0.44</td>
</tr>
<tr>
<td></td>
<td>RATRIS</td>
<td>0.82</td>
<td>0.87</td>
<td>0.91</td>
</tr>
<tr>
<td>Type 2 - Fluorescent fixture recessed into suspended ceiling, return air through ceiling plenum.</td>
<td>RMRIS1</td>
<td>0.59</td>
<td>0.59</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td>RMRISC</td>
<td>-0.41</td>
<td>-0.46</td>
<td>-0.50</td>
</tr>
<tr>
<td></td>
<td>RATRIS</td>
<td>0.42</td>
<td>0.87</td>
<td>0.91</td>
</tr>
<tr>
<td>Type 3 - Fluorescent fixture recessed into suspended ceiling, supply and return air through fixtures.</td>
<td>RMRIS1</td>
<td>0.87</td>
<td>0.87</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>RMRISC</td>
<td>-0.69</td>
<td>-0.74</td>
<td>-0.78</td>
</tr>
<tr>
<td></td>
<td>RATRIS</td>
<td>0.82</td>
<td>0.87</td>
<td>0.91</td>
</tr>
<tr>
<td>Type 4 - Incandescent lights exposed in the room air</td>
<td>RMRIS1</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>RMRISC</td>
<td>-0.32</td>
<td>-0.37</td>
<td>-0.41</td>
</tr>
<tr>
<td></td>
<td>RATRIS</td>
<td>0.82</td>
<td>0.87</td>
<td>0.91</td>
</tr>
</tbody>
</table>

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 £ 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

   3-87
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 \[0 \Rightarrow \text{no}\quad 1 \Rightarrow \text{yes}\]

**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 \(J = 0\)
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 window vertex |
| ZZ   | : |
| 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 \( S = \frac{SBK}{12.0} \)
   \( D = \frac{BD}{12} \)
   \( CA = \cos(A) \)
   \( CB = \cos(B) \)
   \( SA = \sin(A) \)
   \( SB = \sin(B) \)
   \( H = HH + D \)
   \( W = WW + D + D \)

2. **VERTEX 1** of the first shading surface
   
   \[
   \begin{align*}
   XV(1,1) &= XX + D \cdot CA \\
   YV(1,1) &= YY - D \cdot SA \\
   ZV(1,1) &= ZZ
   \end{align*}
   \]

3. **VERTEX 2** of the first shading surface
   
   \[
   \begin{align*}
   XV(1,2) &= XX + D \cdot CA + S \cdot SA \\
   YV(1,2) &= YY - D \cdot SA + S \cdot CA \\
   ZV(1,2) &= ZZ
   \end{align*}
   \]

4. **VERTEX 3** of the first shading surface (also vertex 2 of the second shading surface)
   
   \[
   \begin{align*}
   XV(1,3) &= XX + S \cdot SA - H \cdot CB \cdot SA \\
   YV(1,3) &= YY - D \cdot SA + S \cdot CA - H \cdot CB \cdot CA \\
   ZV(1,3) &= ZZ + H \cdot SB
   \end{align*}
   \]
VERTEX 4 of the first shading surface
(also vertice 1 of the second shading surface)

\[
\begin{align*}
XV(1,4) &= XX+D*CA-H*CB*SA \\
YV(1,4) &= YY-H*CB*CA \\
ZV(1,4) &= ZZ+H*SB
\end{align*}
\]

---and so on---

FIGURE 3.24A
DEFINITION OF SURFACE DIMENSIONS
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 icosochedron. 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**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NVERTF</td>
<td>Number of vertices on receiving Polygon (R.P.)</td>
</tr>
<tr>
<td>XVERTF</td>
<td>x-coordinates of receiving Polygon (R.P.)</td>
</tr>
<tr>
<td>YVERTF</td>
<td>y-coordinates of receiving Polygon (R.P.)</td>
</tr>
<tr>
<td>ZVERTF</td>
<td>z-coordinates of receiving Polygon (R.P.)</td>
</tr>
<tr>
<td>NUXDIV</td>
<td>Number of x-divisions</td>
</tr>
<tr>
<td>NUYDIV</td>
<td>Number of y-divisions</td>
</tr>
<tr>
<td>NPOLY</td>
<td>Number of shading Polygons (S.P.)</td>
</tr>
<tr>
<td>NVERT</td>
<td>Number of vertices of each shading Polygon (S.P.)</td>
</tr>
<tr>
<td>PERM</td>
<td>Permeability of each shading Polygon (S.P.)</td>
</tr>
<tr>
<td>XVERT</td>
<td>x-coordinates of shading Polygon vertices (S.P.)</td>
</tr>
<tr>
<td>YVERT</td>
<td>y-coordinates of shading Polygon vertices (S.P.)</td>
</tr>
<tr>
<td>ZVERT</td>
<td>z-coordinates of shading Polygon vertices (S.P.)</td>
</tr>
</tbody>
</table>
 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 \( V_{1}V_{2}V_{3} \) must be convex and the vertices must be numbered counterclockwise. The equation of transformation is written in matrix form as

\[
\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = A \begin{bmatrix} x - x_0 \\ y - y_0 \\ z - z_0 \end{bmatrix}
\]

where

\[
x_0 = \frac{x_2 + \gamma(x_3 - x_2)}{1 - \gamma}
\]

\[
\gamma, A \text{ Scalar} = (x_1 - x_2) \cdot (x_3 - x_2) / ((x_3 - x_2) \cdot (x_3 - x_2))
\]

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1st row of A = $\frac{x_3 - x_0}{|x_3 - x_0|}$
2nd row of A = $\frac{x_1 - x_0}{|x_1 - x_0|}$
3rd row of A = 1st row of A × 2nd row of A

Solar altitude, $\alpha$, and azimuth, $\beta$, must also be transformed, into the solar direction vector, as

$$x'_s = \begin{pmatrix} \sin \beta \cdot \cos \alpha \\ \sin \alpha \\ \cos \beta \cdot \cos \alpha \end{pmatrix}$$

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](image)

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 $V_1, V_2,...V_n$ 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.

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

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

$$\theta_i \sim \begin{cases} 
\frac{Y_i - Y_p}{X_i - X_p + Y_i - Y_p} & \text{in 1st quadrant} \\
1 + \frac{X_p - X_i}{X_p - X_i + Y_p - Y_i} & \text{in 2nd quadrant} \\
2 + \frac{Y_p - Y_i}{X_p - X_i + Y_p - Y_i} & \text{in 3rd quadrant} \\
3 + \frac{X_i - X_p}{X_i - X_p + Y_p - Y_i} & \text{in 4th quadrant}
\end{cases}$$

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**: Thermal resistance at outside surface, air space, and inside surface, sq ft-hr-°F/Btu
- **RI**: Thermal resistance at outside surface, air space, and inside surface, sq ft-hr-°F/Btu

**++ 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 : Transmission factors of direct and diffuse radiation

TDIF :

ADIRO,outer : Absorption factors of direct solar radiations through outer and inner window pane

ADIRI,inner :

ADIFO,outer : Absorption factors of diffuse radiation through outer and inner window pane

ADIFI,inner :

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*ε = 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.

   \[ \text{FI} = \frac{\text{RO} + \text{RA}}{\text{RO} + \text{RA} + \text{RI}} \]
   \[ \text{FO} = \frac{\text{RO}}{\text{RO} + \text{RA} + \text{RI}} \]

2. Calculate components of solar load

   a) Direct

   \[ \text{QDIR} = \text{SHAW} \times \text{RDIR} \]
b) Diffuse
\[ Q_{DIF} = B_S \times F_{WS} + B_G \times F_{WG} \]

c) Transmitted
\[ Q_{TRANS} = Q_{DIR} \times T_{DIR} + Q_{DIF} \times T_{DIF} \]

d) Absorbed
\[ Q_{ABS} = Q_{DIF} \times (F_O \times A_{DIFO} + F_I \times A_{DIFI}) + Q_{DIR} \times (F_O \times A_{DIRO} + F_I \times A_{DIRI}) \]

3. Calculate solar heat gain through glass
If \( SC = 0 \), \( Q_{RAY} = Q_{TRANS} + Q_{ABS} \)
If \( SC \neq 0 \), \( Q_{RAY} = SC \times (Q_{TRANS} + Q_{ABS}) \)

4. Calculate heat conduction through glass
\[ Q_{CON} = U \times (T_{DB} - T) \]
\[ U = \frac{1.0}{(R_O + R_A + R_I)} \]

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

<table>
<thead>
<tr>
<th>Layer Number</th>
<th>Thickness (ft)</th>
<th>Conductivity (BTU per hr-ft-F)</th>
<th>Density (lb per cu ft)</th>
<th>Specific Heat (BTU per lb-F)</th>
<th>Resistance (HR)(SQ FT)(F) Per BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0350</td>
<td>0.105</td>
<td>25.0</td>
<td>0.31</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.0600</td>
<td>0.032</td>
<td>18.0</td>
<td>0.45</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.97</td>
</tr>
<tr>
<td>4</td>
<td>0.0420</td>
<td>0.093</td>
<td>50.0</td>
<td>0.20</td>
<td>0.68</td>
</tr>
<tr>
<td>5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>Inside Air</td>
</tr>
</tbody>
</table>

**Thermal Conductance = 0.224 BTU per (HR)(SQ FT)(F)**

### Response Factors

<table>
<thead>
<tr>
<th>Hour</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.7229657863</td>
<td>0.0726557570</td>
<td>0.520790818</td>
</tr>
<tr>
<td>1</td>
<td>-0.4760762919</td>
<td>0.1280242763</td>
<td>-0.2719392817</td>
</tr>
<tr>
<td>2</td>
<td>-0.0200596977</td>
<td>0.0204772025</td>
<td>-0.0217534698</td>
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<td>3</td>
<td>-0.0021301912</td>
<td>0.0021923822</td>
<td>-0.0023144631</td>
</tr>
<tr>
<td>4</td>
<td>-0.0002285611</td>
<td>0.0002382457</td>
<td>-0.0002483478</td>
</tr>
<tr>
<td>5</td>
<td>-0.0000245366</td>
<td>0.0000255703</td>
<td>-0.0000266542</td>
</tr>
<tr>
<td>6</td>
<td>-0.0000026320</td>
<td>0.0000027444</td>
<td>-0.0000028607</td>
</tr>
</tbody>
</table>

**Number of hours required to reach common ratio = 6**
**Number of response factors per set = 7**
**Common ratio = 0.1073260628**

Figure 3.27 WALL TYPE 1
### Description of Construction

<table>
<thead>
<tr>
<th>Layer Number</th>
<th>Thickness (in)</th>
<th>Conductivity (BTU/hr ft°F)</th>
<th>Density (lb/ft³)</th>
<th>Specific Heat (BTU/lb°F)</th>
<th>Resistance (hr ft°F/BTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0330</td>
<td>0.105</td>
<td>25.0</td>
<td>0.31</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.0650</td>
<td>0.032</td>
<td>18.0</td>
<td>0.45</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.3330</td>
<td>0.027</td>
<td>0.5</td>
<td>0.16</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>0.0420</td>
<td>0.093</td>
<td>50.0</td>
<td>0.20</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.68</td>
</tr>
</tbody>
</table>

THERMAL CONDUCTANCE = 0.063 BTU per (hr)(sq ft)(°F)

### Response Factors

<table>
<thead>
<tr>
<th>Hour</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.6941580979</td>
<td>0.0113674929</td>
<td>0.4269565407</td>
</tr>
<tr>
<td>1</td>
<td>-0.5716134396</td>
<td>0.0367019877</td>
<td>-0.3426992755</td>
</tr>
<tr>
<td>2</td>
<td>-0.0050861079</td>
<td>0.0124295695</td>
<td>-0.0194638095</td>
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<td>3</td>
<td>-0.0007794799</td>
<td>0.0022810880</td>
<td>-0.0014518610</td>
</tr>
<tr>
<td>4</td>
<td>-0.0012205533</td>
<td>0.0003573323</td>
<td>-0.0001518203</td>
</tr>
<tr>
<td>5</td>
<td>-0.00001914658</td>
<td>0.0000594358</td>
<td>-0.0000020229</td>
</tr>
<tr>
<td>6</td>
<td>-0.0000050021</td>
<td>0.0000093666</td>
<td>-0.0000003035</td>
</tr>
<tr>
<td>7</td>
<td>-0.00000047177</td>
<td>0.0000014722</td>
<td>-0.0000000634</td>
</tr>
<tr>
<td>8</td>
<td>-0.00000007406</td>
<td>0.0000002312</td>
<td>-0.0000000724</td>
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<tr>
<td>9</td>
<td>-0.00000001163</td>
<td>0.0000000363</td>
<td>-0.0000000113</td>
</tr>
<tr>
<td>10</td>
<td>-0.00000000183</td>
<td>0.0000000057</td>
<td>-0.0000000018</td>
</tr>
<tr>
<td>11</td>
<td>-0.00000000029</td>
<td>0.0000000009</td>
<td>-0.0000000003</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>LAYER</th>
<th>THICKNESS (FT)</th>
<th>CONDUCTIVITY (BTU PER (HR)(FT))(F)</th>
<th>DENSITY (LB PER CU FT)</th>
<th>SPECIFIC HEAT (BTU PER (LB))(F)</th>
<th>RESISTANCE (HR)(SQ FT)(F) PER BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3330</td>
<td>0.770</td>
<td>125.0</td>
<td>0.22</td>
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</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.97</td>
</tr>
<tr>
<td>3</td>
<td>0.2650</td>
<td>0.032</td>
<td>18.0</td>
<td>0.45</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>0.3330</td>
<td>0.027</td>
<td>0.5</td>
<td>0.16</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.0420</td>
<td>0.093</td>
<td>50.0</td>
<td>0.20</td>
<td>0.0</td>
</tr>
<tr>
<td>6</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.68</td>
</tr>
</tbody>
</table>

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

RESPONSE FACTORS

<table>
<thead>
<tr>
<th>HOUR</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.1752956356</td>
<td>0.0001965101</td>
<td>0.4269400411</td>
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<tr>
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<td>-3.2898511764</td>
<td>0.0064728911</td>
<td>-0.3432131120</td>
</tr>
<tr>
<td>2</td>
<td>-0.8104616803</td>
<td>0.0152204263</td>
<td>-0.0207286954</td>
</tr>
<tr>
<td>3</td>
<td>-0.4361870018</td>
<td>0.0138525634</td>
<td>-0.0029405844</td>
</tr>
<tr>
<td>4</td>
<td>-0.2461277890</td>
<td>0.0094048978</td>
<td>-0.0007116550</td>
</tr>
<tr>
<td>5</td>
<td>-0.1404883497</td>
<td>0.0057904012</td>
<td>-0.0003196081</td>
</tr>
<tr>
<td>6</td>
<td>-0.0607613436</td>
<td>0.0034552065</td>
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<tr>
<td>7</td>
<td>-0.0465702944</td>
<td>0.0020075027</td>
<td>-0.0000914601</td>
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<td>8</td>
<td>-0.0268902259</td>
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<td>-0.0000517639</td>
</tr>
<tr>
<td>9</td>
<td>-0.0155356625</td>
<td>0.0006751731</td>
<td>-0.0000296466</td>
</tr>
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<td>-0.0089778552</td>
<td>0.0003905833</td>
<td>-0.0000170679</td>
</tr>
<tr>
<td>11</td>
<td>-0.0051867566</td>
<td>0.0002258387</td>
<td>-0.0000098835</td>
</tr>
<tr>
<td>12</td>
<td>-0.0029898589</td>
<td>0.0001505544</td>
<td>-0.0000056881</td>
</tr>
<tr>
<td>13</td>
<td>-0.0017333567</td>
<td>0.0000754649</td>
<td>-0.0000052867</td>
</tr>
<tr>
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<td>0.0000436196</td>
<td>-0.0000018994</td>
</tr>
<tr>
<td>15</td>
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</tr>
<tr>
<td>16</td>
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</tr>
<tr>
<td>17</td>
<td>-0.0001954854</td>
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<td>-0.0000003667</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>LAYER NUMBER</th>
<th>THICKNESS FT</th>
<th>CONDUCTIVITY BTU PER (HR)(FT) (F)</th>
<th>DENSITY LB PER CU FT</th>
<th>SPECIFIC HEAT BTU PER (LB)(F)</th>
<th>RESISTANCE (HR)(SQ FT)(F) PER BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.6670</td>
<td>0.387</td>
<td>57.4</td>
<td>0.16</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.68</td>
</tr>
</tbody>
</table>

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

**RESPONSE FACTORS**

<table>
<thead>
<tr>
<th>HOUR</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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</tr>
<tr>
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<tr>
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<td>-0.1631642836</td>
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<tr>
<td>3</td>
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<tr>
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</tr>
<tr>
<td>5</td>
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<td>6</td>
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<tr>
<td>7</td>
<td>-0.0022693953</td>
<td>0.0016523042</td>
<td>-0.0012030117</td>
</tr>
</tbody>
</table>

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 7
NUMBER OF RESPONSE FACTORS PER SET = 8
COMMON RATIO = 0.3276334020

**Figure 3.30 WALL TYPE 4**
## DESCRIPTION OF CONSTRUCTION

<table>
<thead>
<tr>
<th>LAYER NUMBER</th>
<th>THICKNESS (FT)</th>
<th>CONDUCTIVITY (BTU PER (HR)(FT)(F))</th>
<th>DENSITY (LB PER CU FT)</th>
<th>SPECIFIC HEAT (BTU PER (LB)(F))</th>
<th>RESISTANCE (HR)(SQ FT)(F) PER BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0000</td>
<td>1.040</td>
<td>131.0</td>
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<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.9</td>
<td>0.0</td>
<td>0.60</td>
</tr>
</tbody>
</table>

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

## RESPONSE FACTORS

<table>
<thead>
<tr>
<th>HOUR</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1.2087414422</td>
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<td>-0.0050306568</td>
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<tr>
<td>17</td>
<td>-0.0138818653</td>
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**NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 17**

**NUMBER OF RESPONSE FACTORS PER SET = 17**

**COMMON RATIO = 0.8320619809**

Figure 3.31 WALL TYPE 5
### DESCRIPTION OF CONSTRUCTION

<table>
<thead>
<tr>
<th>LAYER NUMBER</th>
<th>THICKNESS FT</th>
<th>CONDUCTIVITY BTU PER (HR)(FT)(F)</th>
<th>DENSITY LB PER CU FT</th>
<th>SPECIFIC HEAT BTU PER (LB)(F)</th>
<th>RESISTANCE (HR)(SQ FT)(F) PER BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0000</td>
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<tr>
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<td>0.0</td>
<td>0.0</td>
<td>0.97</td>
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<td>0.093</td>
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<td>4</td>
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<td>0.0</td>
<td>0.0</td>
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</tr>
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12 IN. CONCRETE BLOCK
2 IN. AIR SPACE
GIPSUM BOARD (1/2 IN. DRYWALL)
INSIDE AIR

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

### RESPONSE FACTORS

<table>
<thead>
<tr>
<th>HOUR</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.982237391</td>
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<td>0.5742440112</td>
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<td>-0.2115710407</td>
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<td>2</td>
<td>-0.199803815</td>
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<td>-0.0370425957</td>
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<td>3</td>
<td>-0.113956846</td>
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<td>-0.0227359074</td>
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<td>0.0041209100</td>
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</table>

**NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 10**
**NUMBER OF RESPONSE FACTORS PER SET = 11**
**COMMON RATIO = 0.7026701252**

Figure 3.32 WALL TYPE 6
DESCRIPTION OF CONSTRUCTION

<table>
<thead>
<tr>
<th>LAYER NUMBER</th>
<th>THICKNESS FT</th>
<th>CONDUCTIVITY BTU PER (HR)(FT)(F)</th>
<th>DENSITY LB PER FT</th>
<th>SPECIFIC HEAT BTU PER (LB)(F)</th>
<th>RESISTANCE (HR)(SQ FT)(F) PER BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3330</td>
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<td>125.0</td>
<td>0.22</td>
<td>0.0</td>
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<tr>
<td>2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.5000</td>
<td>0.320</td>
<td>37.4</td>
<td>0.16</td>
<td>0.0</td>
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<td>4</td>
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<td>0.0</td>
<td>0.0</td>
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THERMAL CONDUCTANCE = 0.274 BTU PER (HR)(SQ FT)(F)

RESPONSE FACTORS

<table>
<thead>
<tr>
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<th>Y</th>
<th>Z</th>
</tr>
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<tr>
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<td>-0.7587665366</td>
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<td>4</td>
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<td>0.0462427144</td>
<td>-0.0359606660</td>
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<td>-0.0664447011</td>
<td>0.0227347281</td>
<td>-0.0124061364</td>
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<td>-0.0058240519</td>
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<td>0.0010464140</td>
<td>-0.0004820407</td>
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<td>-0.0003055746</td>
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<td>-0.0001936308</td>
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<td>-0.0001227220</td>
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<td>0.0001697446</td>
<td>-0.0000779922</td>
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<td>0.0000493156</td>
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NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 25
NUMBER OF RESPONSE FACTORS PER SET = 26
COMMON RATIO = 0.6346337994

Figure 3.33 WALL TYPE 7
### DESCRIPTION OF CONSTRUCTION

<table>
<thead>
<tr>
<th>Layer Number</th>
<th>Layer Thickness (FT)</th>
<th>Conductivity (BTU/HR FT°F)</th>
<th>Density (LB/FT³)</th>
<th>Specific Heat (BTU/LB°F)</th>
<th>Resistance (IN² FT HR/BTU)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0.330</td>
<td>0.770</td>
<td>125.0</td>
<td>0.22</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.5000</td>
<td>0.320</td>
<td>37.4</td>
<td>0.16</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>0.1670</td>
<td>0.025</td>
<td>0.5</td>
<td>0.16</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.0420</td>
<td>0.093</td>
<td>50.0</td>
<td>0.20</td>
<td>0.0</td>
</tr>
<tr>
<td>6</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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</table>

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

### RESPONSE FACTORS

<table>
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<th>Hour</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
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</tr>
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</table>

**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**

<table>
<thead>
<tr>
<th>LAYER NUMBER</th>
<th>THICKNESS FT</th>
<th>CONDUCTIVITY BTU PER (HR)(FT)(F)</th>
<th>DENSITY LB PER CU FT</th>
<th>SPECIFIC HEAT BTU PER (LB)(F)</th>
<th>RESISTANCE (HR)(SQ FT)(F) PER BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</tr>
<tr>
<td>3</td>
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<td>0.10</td>
<td>0.0</td>
</tr>
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**THERMAL CONDUCTANCE = 0.174 BTU PER (HR)(SQ FT)(F)**

**RESPONSE FACTORS**

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<th>Z</th>
</tr>
</thead>
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</table>

**NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 5**

**NUMBER OF RESPONSE FACTORS PER SET = 6**

**COMMON RATIO = 0.0350909240**

*Figure 3.35 WALL TYPE 9*
### DESCRIPTION OF CONSTRUCTION

<table>
<thead>
<tr>
<th>LAYER NUMBER</th>
<th>THICKNESS (FT)</th>
<th>CONDUCTIVITY (BTU PER (HR)(FT)(F))</th>
<th>DENSITY (LB PER CU FT)</th>
<th>SPECIFIC HEAT (BTU PER (LB)(F))</th>
<th>RESISTANCE ((HR)(SQ FT)(F)) PER BTU</th>
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<tbody>
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THERMAL CONDUCTANCE = 0.140 BTU PER (HR)(SQ FT)(F)

### RESPONSE FACTORS

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<td>4</td>
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<td>-0.0051350167</td>
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<td>-0.0092791506</td>
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<tr>
<td>10</td>
<td>-0.0036675825</td>
<td>0.0053479039</td>
<td>-0.0077980941</td>
</tr>
<tr>
<td>11</td>
<td>-0.0030602064</td>
<td>0.0044943385</td>
<td>-0.0065934014</td>
</tr>
</tbody>
</table>

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
<table>
<thead>
<tr>
<th>LAYER NUMBER</th>
<th>THICKNESS (FT)</th>
<th>CONDUCTIVITY (BTU PER (HR)(FT)(F))</th>
<th>DENSITY (LB PER CU FT)</th>
<th>SPECIFIC HEAT (Btu Per (Lb)(F))</th>
<th>RESISTANCE (HR)(SQ FT)(F) PER BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0417</td>
<td>0.630</td>
<td>55.0</td>
<td>0.40</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.0313</td>
<td>0.110</td>
<td>70.0</td>
<td>0.40</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.1670</td>
<td>0.025</td>
<td>4.0</td>
<td>0.24</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>0.0100</td>
<td>26.000</td>
<td>480.0</td>
<td>0.10</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.68</td>
<td>Insidie Air</td>
</tr>
</tbody>
</table>

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

**RESPONSE FACTORS**

<table>
<thead>
<tr>
<th>HOUR</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.9271711515</td>
<td>0.0458700543</td>
<td>0.5517222324</td>
</tr>
<tr>
<td>1</td>
<td>-1.7924270399</td>
<td>0.0759794472</td>
<td>-0.3987272481</td>
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<tr>
<td>2</td>
<td>-0.0046149222</td>
<td>0.0078098340</td>
<td>-0.0217505969</td>
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<tr>
<td>3</td>
<td>-0.0001677723</td>
<td>0.0004476465</td>
<td>-0.0012201840</td>
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<td>4</td>
<td>-0.00000092404</td>
<td>0.0000251497</td>
<td>-0.000006851014</td>
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<td>5</td>
<td>-0.00000005184</td>
<td>0.0000019120</td>
<td>-0.0000038458</td>
</tr>
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<td>0.0000000793</td>
<td>-0.0000002159</td>
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<tr>
<td>7</td>
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<td>0.00000000045</td>
<td>-0.0000000121</td>
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</tbody>
</table>

**NUMBER OF HOURS REQUIRED TO MEACH COMMON RATIO = 7**

**NUMBER OF RESPONSE FACTORS PER SET = 8**

**COMMON RATIO = 0.0561417054**

Figure 3.37 ROOF TYPE 1
### Description of Construction

<table>
<thead>
<tr>
<th>Layer Number</th>
<th>Thickness (FT)</th>
<th>Conductivity (BTU per (HR) (FT) (F))</th>
<th>Density (LB per CU FT)</th>
<th>Specific Heat (BTU per (LR) (F))</th>
<th>Resistance (HR/FT) (F) per BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0417</td>
<td>0.830</td>
<td>55.0</td>
<td>0.40</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.0313</td>
<td>0.110</td>
<td>70.0</td>
<td>0.40</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.2500</td>
<td>0.033</td>
<td>9.0</td>
<td>0.24</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>0.0100</td>
<td>26.000</td>
<td>480.0</td>
<td>0.10</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.68</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Thermal Conductance = 0.116 BTU per (HR) (SQ FT) (F)

### Response Factors

<table>
<thead>
<tr>
<th>Hour</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.0037117174</td>
<td>0.011439795</td>
<td>0.6027205680</td>
</tr>
<tr>
<td>1</td>
<td>-1.8493309263</td>
<td>0.0645768974</td>
<td>-0.421625309</td>
</tr>
<tr>
<td>2</td>
<td>-0.0311971279</td>
<td>0.0314422529</td>
<td>-0.0526713541</td>
</tr>
<tr>
<td>3</td>
<td>-0.0054266640</td>
<td>0.0071076824</td>
<td>-0.0098951082</td>
</tr>
<tr>
<td>4</td>
<td>-0.0010810560</td>
<td>0.0014594799</td>
<td>-0.0019855447</td>
</tr>
<tr>
<td>5</td>
<td>-0.0002185981</td>
<td>0.0002962520</td>
<td>-0.0004018748</td>
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<td>6</td>
<td>-0.0000442875</td>
<td>0.0000600485</td>
<td>-0.0000819282</td>
</tr>
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<td>7</td>
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<td>0.0000216693</td>
<td>-0.0000165013</td>
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<td>-0.0000001818</td>
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<td>-0.0000034440</td>
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</tbody>
</table>

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

<table>
<thead>
<tr>
<th>LAYER NUMBER</th>
<th>THICKNESS (FT)</th>
<th>CONDUCTIVITY (BTU PER (HR)(FT)(F))</th>
<th>DENSITY (LB PER CU FT)</th>
<th>SPECIFIC HEAT (BTU PER (LB)(F))</th>
<th>RESISTANCE (HR)(SQ FT)(F) PER BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0417</td>
<td>0.830</td>
<td>55.0</td>
<td>0.40</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.0313</td>
<td>0.110</td>
<td>70.0</td>
<td>0.40</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.2500</td>
<td>0.033</td>
<td>9.0</td>
<td>0.24</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>0.0100</td>
<td>26.000</td>
<td>480.0</td>
<td>0.10</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.00</td>
</tr>
<tr>
<td>6</td>
<td>0.0625</td>
<td>0.035</td>
<td>30.0</td>
<td>0.30</td>
<td>0.0</td>
</tr>
<tr>
<td>7</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.68</td>
</tr>
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</table>

**THERMAL CONDUCTANCE = 0.086 BTU PER (HR)(SQ FT)(F)**

### RESPONSE FACTORS

<table>
<thead>
<tr>
<th>HOUR</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.0037089916</td>
<td>0.0005814275</td>
<td>0.45462293</td>
</tr>
<tr>
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<td>-1.8501224513</td>
<td>0.0138581537</td>
<td>-0.2190318052</td>
</tr>
<tr>
<td>2</td>
<td>-0.0559361297</td>
<td>0.0245698197</td>
<td>-0.0595592957</td>
</tr>
<tr>
<td>3</td>
<td>-0.0123118669</td>
<td>0.0184312150</td>
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</tr>
<tr>
<td>4</td>
<td>-0.0067881936</td>
<td>0.0116065312</td>
<td>-0.0207673120</td>
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<td>5</td>
<td>-0.0041058603</td>
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<td>6</td>
<td>-0.0025194586</td>
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<td>-0.0015492980</td>
<td>0.0027341273</td>
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<td>-0.000950122</td>
<td>0.0016823045</td>
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<td>9</td>
<td>-0.0005562486</td>
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<td>10</td>
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<td>0.0006366105</td>
<td>-0.0011230837</td>
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</tbody>
</table>

**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

<table>
<thead>
<tr>
<th>LAYER NUMBER</th>
<th>THICKNESS FT</th>
<th>CONDUCTIVITY BTU PER (HR)(FT)(F)</th>
<th>DENSITY LB PER CU FT</th>
<th>SPECIFIC HEAT BTU PER (LB)(F)</th>
<th>RESISTANCE (HR)(SQ FT)(F) PER BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0417</td>
<td>0.630</td>
<td>55.0</td>
<td>0.40</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.0313</td>
<td>0.110</td>
<td>70.0</td>
<td>0.40</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.1670</td>
<td>0.033</td>
<td>9.0</td>
<td>0.24</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
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<td>0.20</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.0100</td>
<td>26.000</td>
<td>480.0</td>
<td>0.10</td>
<td>0.0</td>
</tr>
<tr>
<td>6</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.00</td>
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<tr>
<td>7</td>
<td>0.00625</td>
<td>0.035</td>
<td>30.0</td>
<td>0.20</td>
<td>0.0</td>
</tr>
<tr>
<td>8</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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</tbody>
</table>

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

RESPONSE FACTORS

<table>
<thead>
<tr>
<th>HOUR</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.010</td>
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<td>0.007</td>
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<td>0.014</td>
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<td>0.060</td>
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<td>0.011</td>
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<td>6</td>
<td>0.050</td>
<td>0.067</td>
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<tr>
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<td>0.007</td>
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<td>9</td>
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<tr>
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<td>0.004</td>
<td>0.000</td>
</tr>
<tr>
<td>11</td>
<td>-0.025</td>
<td>0.003</td>
<td>0.005</td>
</tr>
<tr>
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<td>0.005</td>
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<tr>
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<td>-0.019</td>
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<td>0.003</td>
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<tr>
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<td>0.003</td>
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<td>-0.001</td>
<td>0.000</td>
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<tr>
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</table>

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

<table>
<thead>
<tr>
<th>LAYER NUMBER</th>
<th>THICKNESS (FT)</th>
<th>CONDUCTIVITY (BTU PER (HR)(FT)(F))</th>
<th>DENSITY (LB PER CU FT)</th>
<th>SPECIFIC HEAT (BTU PER (LB)(F))</th>
<th>RESISTANCE (HR)(SQ FT)(F) PER BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0050</td>
<td>26.000</td>
<td>480.0</td>
<td>0.10</td>
<td>0.0</td>
</tr>
<tr>
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<td>0.5000</td>
<td>0.025</td>
<td>0.5</td>
<td>0.16</td>
<td>0.0</td>
</tr>
<tr>
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<td>0.0420</td>
<td>0.470</td>
<td>150.0</td>
<td>0.20</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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</tr>
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</table>

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

### RESPONSE FACTORS

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<th>HOUR</th>
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<th>$Y$</th>
<th>$Z$</th>
</tr>
</thead>
<tbody>
<tr>
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<td>-0.1752942566</td>
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<td>-0.0009955360</td>
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<td>-0.0557356777</td>
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<td>-0.0000316468</td>
<td>0.0007486569</td>
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<td>-0.0000100619</td>
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</tr>
</tbody>
</table>

**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

<table>
<thead>
<tr>
<th>Layer Number</th>
<th>Thickness (ft)</th>
<th>Conductivity (BTU per (HR)(FT)(F))</th>
<th>Density (LB per CU FT)</th>
<th>Specific Heat (BTU per (LB)(F))</th>
<th>Resistance (HR)(SQ FT)(F) per BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0100</td>
<td>2.300</td>
<td>70.0</td>
<td>0.35</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.0420</td>
<td>0.067</td>
<td>34.0</td>
<td>0.29</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>0.0300</td>
<td>0.025</td>
<td>0.16</td>
<td>0.20</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.0420</td>
<td>0.470</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>6</td>
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<td>0.0</td>
<td>0.0</td>
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</table>

Thermal conductance = 0.045 BTU per (HR)(SQ FT)(F)

### Response Factors

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<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.7041712169</td>
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<tr>
<td>1</td>
<td>-0.6388926193</td>
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<td>-0.5530683926</td>
</tr>
<tr>
<td>2</td>
<td>-0.0005551533</td>
<td>0.0082561150</td>
<td>-0.1764214705</td>
</tr>
<tr>
<td>3</td>
<td>-0.0001234544</td>
<td>0.0026371985</td>
<td>-0.0563432318</td>
</tr>
<tr>
<td>4</td>
<td>-0.0000394216</td>
<td>0.0008622350</td>
<td>-0.0179991836</td>
</tr>
<tr>
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<td>-0.0000125900</td>
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<td>6</td>
<td>-0.0000040208</td>
<td>0.0000859041</td>
<td>-0.0018355248</td>
</tr>
</tbody>
</table>

Number of hours required to reach common ratio = 6
Number of response factors per set = 7
Common ratio = 0.8193672610

Figure 3.42 Roof Type 6
A subroutine to calculate the daily solar radiation data.

**INPUT**

<table>
<thead>
<tr>
<th>IDOY</th>
<th>Day of Year, 1 to 366</th>
</tr>
</thead>
<tbody>
<tr>
<td>TL</td>
<td>Tangent of Latitude angle</td>
</tr>
</tbody>
</table>

**OUTPUT**

<table>
<thead>
<tr>
<th>SUNRAS</th>
<th>Hourly angle (radians) when solar altitude is zero</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEABC(1)</td>
<td>Tangent of declination angle, TAN$\delta$</td>
</tr>
<tr>
<td>DEABC(2)</td>
<td>Equation of time, ET, hours</td>
</tr>
<tr>
<td>DEABC(3)</td>
<td>Apparent solar constant, A, BTU/hr-sq ft</td>
</tr>
<tr>
<td>DEABC(4)</td>
<td>Atmospheric extinction coefficient, B</td>
</tr>
<tr>
<td>DEABC(5)</td>
<td>Sky diffuse factor, C</td>
</tr>
</tbody>
</table>

Table 3.8 lists, as function of date, five variables related to solar radiation. These variables are declination angle, $\delta$; 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 $\delta$, ET, A, B AND C FOR NORTHERN HEMISPHERE.**

<table>
<thead>
<tr>
<th>DATE</th>
<th>$\delta$ DEGREES</th>
<th>ET HOURS</th>
<th>A Btu per (hr)(sq ft)</th>
<th>B AIR MASS$^{-1}$</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan. 21</td>
<td>-20.0</td>
<td>-.190</td>
<td>390</td>
<td>0.142</td>
<td>0.058</td>
</tr>
<tr>
<td>Feb. 21</td>
<td>-10.8</td>
<td>-.230</td>
<td>385</td>
<td>0.144</td>
<td>0.060</td>
</tr>
<tr>
<td>Mar. 21</td>
<td>0.0</td>
<td>-.123</td>
<td>376</td>
<td>0.156</td>
<td>0.071</td>
</tr>
<tr>
<td>Apr. 21</td>
<td>11.6</td>
<td>.020</td>
<td>360</td>
<td>0.180</td>
<td>0.097</td>
</tr>
<tr>
<td>May 21</td>
<td>20.0</td>
<td>.060</td>
<td>350</td>
<td>0.196</td>
<td>0.121</td>
</tr>
<tr>
<td>June 21</td>
<td>23.45</td>
<td>-.025</td>
<td>345</td>
<td>0.205</td>
<td>0.134</td>
</tr>
<tr>
<td>July 21</td>
<td>20.6</td>
<td>-.103</td>
<td>344</td>
<td>0.207</td>
<td>0.136</td>
</tr>
<tr>
<td>Aug. 21</td>
<td>12.3</td>
<td>-.051</td>
<td>351</td>
<td>0.201</td>
<td>0.122</td>
</tr>
<tr>
<td>Sept. 21</td>
<td>0.0</td>
<td>.113</td>
<td>365</td>
<td>0.177</td>
<td>0.092</td>
</tr>
<tr>
<td>Oct. 21</td>
<td>-10.5</td>
<td>.255</td>
<td>378</td>
<td>0.160</td>
<td>0.073</td>
</tr>
<tr>
<td>Nov. 21</td>
<td>-19.8</td>
<td>.235</td>
<td>387</td>
<td>0.149</td>
<td>0.063</td>
</tr>
<tr>
<td>Dec. 21</td>
<td>-23.45</td>
<td>.033</td>
<td>391</td>
<td>0.142</td>
<td>0.057</td>
</tr>
</tbody>
</table>

3-113
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.

\[
\begin{align*}
\text{Tan} \delta \\
\text{ET} \\
\text{A} \\
\text{B} \\
\text{C}
\end{align*}
\]

\[= A_0 + A_1 \cos(\omega d) + A_2 \cos(2\omega d) + A_3 \cos(3\omega d) + B_1 \sin(\omega d) + B_2 \sin(2\omega d) + B_3 \sin(3\omega d)\]

where \(\omega = 2\pi/366 = 0.01721\)

\[d = \text{IDY} \]

The proper Fourier coefficients are given in Table 3.9.

<table>
<thead>
<tr>
<th>Table 3.9 FOURIER COEFFICIENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Tanδ</td>
</tr>
<tr>
<td>ET</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>C</td>
</tr>
</tbody>
</table>

**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.

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

Where

\[C1 = \cos(\omega d)\]

\[S1 = \sin(\omega d)\]
and by trigometric identity

\[ C_2 = \cos(2\omega d) = C_1C_1 - S_1S_1 \]
\[ C_3 = \cos(3\omega d) = C_1C_2 - S_1S_2 \]
\[ S_2 = \sin(2\omega d) = 2S_1C_1 \]
\[ S_3 = \sin(3\omega d) = C_1S_2 + S_1C_2 \]

2. Calculate sun rise angle

\[ \text{SUNRAS} = \cos^{-1}(-TL*DEABC(1)) \]

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
DEABC(2) : Equation of time, hours
DEABC(3) : Apparent solar constant, Btu/hr-sq ft
DEABC(4) : Atmospheric extinction coefficient
DEABC(5) : Sky diffuse factor
SL : Sin of latitude angle
CL : Cosine of latitude angle
CN : Clearness number
SA : Sin of building azimuth angle
CA : Cos of building azimuth 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

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

\[ RAYCOS(1) = \cos(w) = \cos(h) \cdot \sin(AZ) \]
\[ RAYCOS(2) = \cos(s) = \cos(h) \cdot \cos(AZ) \]
\[ RAYCOS(3) = \sin(h) \]

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

\[ \sin(h) = \sin(\delta) \cdot \sin(L) + \cos(\delta) \cdot \cos(L) \cdot \cos(t) \]
\[ \cos(AZ) = -(\sin(\delta) \cdot \cos(L) - \cos(\delta) \cdot \sin(L) \cdot \cos(t)) / \cos(h) \]
\[ \sin(AZ) = + (\cos(\delta) \cdot \sin(t)) / \cos(h) \]


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where
\[ \delta = \text{declination of sun, degrees} \]
\[ L = \text{station latitude, degrees} \]
\[ t = \text{hour angle of sun measured from south towards west, degrees} \]

Substitution gives
\[
\text{RAYCOS}(1) = \cos(\delta) \sin(t)
\]
\[
\text{RAYCOS}(2) = -\sin(\delta) \cos(\phi) + \cos(\delta) \sin(\phi) \cos(t)
\]
\[
\text{RAYCOS}(3) = \sin(\delta) \sin(\phi) + \cos(\delta) \cos(\phi) \cos(t)
\]

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 yields
\[
\text{RAYCOS}(1) = -\left( \cos(\delta) \sin(t) \right) \cos(A)
\]
\[
\quad -\left( \sin(\delta) \cos(\phi) - \cos(\delta) \sin(\phi) \cos(t) \right) \sin(A)
\]
\[
\text{RAYCOS}(2) = -\left( \cos(\delta) \sin(t) \right) \sin(A)
\]
\[
\quad +\left( \sin(\delta) \cos(\phi) - \cos(\delta) \sin(\phi) \cos(t) \right) \cos(A)
\]
\[
\text{RAYCOS}(3) = \sin(\delta) \sin(\phi) + \cos(\delta) \cos(\phi) \cos(t)
\]

To get into form in subroutine let
\[
\cos(\delta) = CD
\]
\[
\sin(\delta) = SD
\]
\[
\cos(A) = CA
\]
\[
\sin(A) = SA
\]
\[
\cos(\phi) = \cos(L) = CL
\]
\[
\sin(\phi) = \sin(L) = SL
\]
\[
\cos(t) = \cos(h) = CH
\]
\[
\sin(t) = \sin(h) = SH
\]
Finally, by substitution of these identities,

\[ \text{RAYCOS}(1) = -CD*SH*CA-SD*CL*SA+CD*SL*CH*SA \]
\[ \text{RAYCOS}(2) = -CD*SH*SA+SD*CL*CA-CD*SL*CH*CA \]
\[ \text{RAYCOS}(3) = SD*SL+CD*CL*CH \]

2. Calculate intensity of direct normal solar radiation

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

\[ \text{RAYCOS}(3) = 0.0 \]
\[ \text{RDN} = 0.0 \]
\[ \text{BS} = 0.0 \]

b) If \( \text{RAYCOS}(3) \) is greater than 0.001, sun is up, and therefore

\[ \text{RDN} = \text{DEABC}(3)^*\text{CN}^*\text{EXP}(-\text{DEABC}(4)/\text{RAYCOS}(3)) \]
\[ \text{BS} = \text{DEABC}(5)^*\text{RDN}/(\text{CN}^*\text{CN}) \]

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

\begin{figure}
\centering
\includegraphics[width=\textwidth]{3-119.png}
\caption{CLEARNESS NUMBERS OF NON-INDUSTRIAL ATMOSPHERE IN UNITED STATES}
\end{figure}
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, $\eta$
- 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
   
   $$BG = ROG \times (BS + RDN \times RAYCOS(3))$$

2. Calculate the direction cosines ($\alpha$, $\beta$ and $\gamma$) of the normal to the surface. By definition
Normal to Horizontal Surface

Surface (Wall) in Consideration

Horizontal Surface

Sun's Rays
Zenith Angle

Incident Angle

Solar Altitude,
SALT

Solar Azimuth,
SAZM

Projection of
Sun's Ray on
Horizontal
Surface

Normal to
Surface (Wall)
in Consideration

Tilt Angle,
WT

Wall
Azimuth

E

Projection of Normal to Surface (Wall) in Consideration on Horizontal Surface

Figure 3.44 DEFINITION OF ANGLES

Figure 3.45 SCHEMATIC SHOWING APPARENT PATH OF SUN AND HOUR ANGLE
\[ \alpha = \cos(WT) = CWT \]
\[ \beta = \sin(WA) \times \sin(WT) = SWA \times SWT \]
\[ \gamma = \cos(WA) \times \sin(WT) = CWA \times SWT \]

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

\[ CWT = \cos(90) = 0.0 \]
\[ SWT = \sin(90) = 1.0 \]

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

\[
\begin{align*}
CWT &= \cos (WA) \\
SWT &= \sin (WA)
\end{align*}
\]

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

\[
\text{ETA} = \cos (\eta) = \alpha \cdot \text{RAYCOS}(3) + \beta \cdot \text{RAYCOS}(1) + \gamma \cdot \text{RAYCOS}(2)
\]

4. Calculate the intensity of the direct normal solar radiation

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

\[
\text{RDIR} = 0.0
\]

b) If ETA \( > 0.0 \), sun is up

\[
\text{RDIR} = \text{RDN} \times \text{ETA}
\]

5. Calculate the intensity of diffuse radiation

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

\[
\text{RDIF} = \text{BS}
\]

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

\[
\text{RDIF} = \text{BG}
\]

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

\[
\begin{align*}
\text{If } &\text{ ETA} < -0.2, \\
&y = 0.45 \\
\text{If } &\text{ ETA} \geq -0.2, \\
&y = 0.55 + 0.437 \times \text{ETA} + 0.313 \times \text{ETA}^2
\end{align*}
\]

Then RDIF = \( y \times \text{BS} + 0.5 \times \text{BG} \)

6. Calculate total radiation incident upon surface

\[
\text{RTOT} = \text{RDIR} + \text{RDIF}
\]

Figure 3.46 RATIO OF DIFFUSE SKY RADIATION INCIDENT UPON A VERTICAL SURFACE TO THAT INCIDENT UPON A HORIZONTAL SURFACE DURING CLEAR DAYS
A subroutine which calculates transmission, absorption and reflection factors for windows.

**INPUT**

- **L**: Code for thickness times extinction coefficient \((k \times \ell)\), see Table 3.10 and Figure 3.47
- **C**: Cosine of angle of incidence, \(\eta\)
- **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 \(k \times \ell\). 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
- **ADIRI**: Absorption factors for direct solar radiation through outer and inner window pane
- **ADIFO**: 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.

\[
TDIR = \sum_{j=0}^{5} t_j \times (C^{2j})
\]

\[
TDIF = 2 \times \sum_{j=0}^{5} \frac{t_j}{(j + 2)}
\]
Table 3.10
CODE FOR THICKNESS TIMES
EXTINCTION COEFFICIENT

<table>
<thead>
<tr>
<th>CODE</th>
<th>MEANING</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1/8&quot; sheet</td>
</tr>
<tr>
<td>2</td>
<td>$k^* = 0.10$</td>
</tr>
<tr>
<td>3</td>
<td>$k^* = 0.15$</td>
</tr>
<tr>
<td>4</td>
<td>$k^* = 0.20$</td>
</tr>
<tr>
<td>5</td>
<td>$k^* = 0.40$</td>
</tr>
<tr>
<td>6</td>
<td>$k^* = 0.60$</td>
</tr>
<tr>
<td>7</td>
<td>50% transparent H.A. plate</td>
</tr>
<tr>
<td>8</td>
<td>$k^* = 1.00$</td>
</tr>
</tbody>
</table>

Figure 3.47 $k^*\ell$ VS TRANSMISSION AT NORMAL INCIDENCE FOR SINGLE SHEET GLASS
<table>
<thead>
<tr>
<th>k*g</th>
<th>j</th>
<th>Single Glazing</th>
<th>Double Glazing</th>
<th>H.A. Plate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>( a_j )</td>
<td>( b_j )</td>
<td>( a_j, \text{outer} )</td>
</tr>
<tr>
<td>0.05</td>
<td>0</td>
<td>0.01154</td>
<td>-0.00885</td>
<td>0.01407</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>0.77674</td>
<td>2.71235</td>
<td>1.06226</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-3.94657</td>
<td>-0.62062</td>
<td>-5.59131</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>8.57681</td>
<td>-7.07329</td>
<td>12.15034</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>-8.38135</td>
<td>9.75995</td>
<td>-11.78092</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>3.01188</td>
<td>-3.89922</td>
<td>4.20070</td>
</tr>
<tr>
<td>0.10</td>
<td>0</td>
<td>0.01636</td>
<td>-0.01111</td>
<td>0.01819</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1.34783</td>
<td>2.39371</td>
<td>1.86277</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-6.79030</td>
<td>0.42978</td>
<td>-9.24831</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>14.37378</td>
<td>-8.98262</td>
<td>19.49443</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>-13.83357</td>
<td>11.51798</td>
<td>-18.56094</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4.92439</td>
<td>-4.52064</td>
<td>6.53940</td>
</tr>
<tr>
<td>0.15</td>
<td>0</td>
<td>0.01837</td>
<td>-0.01200</td>
<td>0.01905</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1.92497</td>
<td>2.13036</td>
<td>2.47900</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-8.89134</td>
<td>1.13833</td>
<td>-11.74666</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>18.40197</td>
<td>-10.07925</td>
<td>24.14037</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>-17.48648</td>
<td>12.14461</td>
<td>-22.64299</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>6.17544</td>
<td>-4.83285</td>
<td>7.89954</td>
</tr>
<tr>
<td>0.20</td>
<td>0</td>
<td>0.01902</td>
<td>-0.01218</td>
<td>0.01862</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2.35177</td>
<td>1.90950</td>
<td>2.96400</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-10.17151</td>
<td>1.61391</td>
<td>-13.48701</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>21.24322</td>
<td>-10.64872</td>
<td>27.13020</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>-19.95978</td>
<td>12.83698</td>
<td>-25.11877</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>6.99964</td>
<td>-4.95199</td>
<td>8.68895</td>
</tr>
<tr>
<td>0.40</td>
<td>0</td>
<td>0.01712</td>
<td>-0.01056</td>
<td>0.01423</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>3.50839</td>
<td>1.29711</td>
<td>4.14384</td>
</tr>
<tr>
<td></td>
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Table 3.11
POLYNOMIAL COEFFICIENTS FOR USE IN CALCULATION OF TRANSMITTANCE AND ABSORPTANCE OF GLASS
2. Compute absorption factors for direct solar and diffuse radiation.

\[
\begin{align*}
\text{ADIRO} &= \sum_{j=0}^{5} a_{j,\text{outer}} \times (C^{*j}) \\
\text{ADIFO} &= 2 \times \sum_{j=0}^{5} \frac{a_{j,\text{outer}}}{(j + 2)} \\
\text{ADIRI} &= \sum_{j=0}^{5} a_{j,\text{inner}} \times (C^{*j}) \\
\text{ADIFI} &= 2 \times \sum_{j=0}^{5} \frac{a_{j,\text{inner}}}{(j + 2)}
\end{align*}
\]

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 \(H < 11.758\)
   
   \[
   WBF = 0.6040 + 3.4841 \times Y + 1.3601 \times (Y^{*2}) + 0.9731 \times (Y^{*3})
   \]
   
   For \(H > 11.758\)
   
   \[
   WBF = 30.9185 - 39.682 \times Y + 20.5841 \times (Y^{*2}) - 1.758 \times (Y^{*3})
   \]

2. If \(PB \neq 29.92\), or \(H < 0\) solve the following equation by iterating \(WBF\)
   
   \[
   H = 0.24 \times WBF + (1061 + 0.444 \times WBF) \times W2
   \]
   
   Where \(W2 = 0.622 \times PV2/(PB - PV2)\)
   
   \(PV2 = PPWVMS(WBF)\)
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:


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 VI) 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 Variable Temperature Load Calculations

LRC SYSTEMS ENGINEERING BUILDING

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TOTAL BUILDING HEAT EXTRAC TIONS AND ADDITIONS
- HEATING: -808810723.
- COOLING: 1041576949.

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Figure 4.1 REPORT VI
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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
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SYSTEM SIMULATION INPUT DATA.

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Figure 4.4 REPORT V4
### Figure 4.5 REPORT V5

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### SPACE INDEX  THERMOSTAT TYPE  HEATING CAPACITY  COOLING CAPACITY  PLENUM  OVER SPACE  CFM  SCHEDULES

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Figure 4.6 REPORT V6
### Table

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Figure 4.7 REPORT V7
FINAL SPACE RESPONSE FACTORS FOR SPACE= 1

-193340.2500
250321.2500
-47965.6698
-12959.9922
-291.2617
-69.9453
-45.1621
-19.4460
-6.1973
0.0002

FINAL SPACE RESPONSE FACTORS FOR SPACE= 2

-20560.8438
30025.5469
-8276.4219
-701.3948
-271.3626
-136.7441
-76.1282
-45.8718
-25.0569
19.9590
-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

-10625.4492
27197.7734
-7496.5586
-634.9932
-246.9197
-124.4336
-69.4050
-40.0913
-23.3769
-13.6866
-8.0146
-4.6724
-2.7069
-1.5514
-0.8740
-0.4779
-0.2401

Figure 4.8 REPORT V8
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 \} Surface response factors
      RZ
   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-°F
      AQ - Surface area, sq.ft.
   l) NWB - Number of windows

4-11
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 - Spaces connected to surface
   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) NUF - 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.

4-12
TSPAC - Set point temperature, °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
      \[ \text{REI} = 0.5 \text{ inside film resistance} \]
      \[ \text{REA} = 0.0 \text{ interpane resistance} \]
      \[ \text{R} = \text{REI} + \text{REA} \text{ total resistance} \]
      \[ \text{UGW} = 1.0 / \text{R} \text{ U-factor} \]
   
b) For multi-pane windows
      \[ \text{REI} = 0.5 \text{ inside film resistance} \]
      \[ \text{REA} = 1.6 \text{ interpane resistance} \]
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.

\[ \text{SRMRT}(J) = 0.0 \]

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 \( \text{NUW}(I) < 0 \), space has no underground walls; therefore skip to calculation (6f).

- For each underground wall \( J_1 = 1 \) to \( \text{NUW}(I) \),

\[ \text{SRMRT}(J) = \text{SRMRT}(J) - \text{AUW}(J_2) \times \text{FUW}(J_2) \]

where \( J_2 = \text{IUW}(I,J_1) \).

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 \( \text{NUF}(I) < 0 \), space has no underground floors; therefore skip to calculation (6g).

- For each underground floor \( J_1 = 1 \) to \( \text{NUF}(I) \),

\[ \text{SRMRT}(J) = \text{SRMRT}(J) - \text{AUF}(J_2) \times \text{FUF}(J_2) \]

where \( J_2 = \text{IUF}(I,J_1) \).

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 \( ND_1 = ND(I) \).

- If \( ND_1 < 0 \), skip to calculation (6h).

- For each delayed surface \( J_2 = 1 \) to \( ND_1 \),
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 NCI = NC(I).
- If NCI < 0, skip to calculation (6i).
- For each ceiling surface J1 = 1 to NCI,
  J2 = ICD(I,J1) (ceiling index type)
  A = ACEIL(I,J1) (area)
  If J > IRC(J2), use common ratio to determine response factor.
  \[ CRX(J2,J) = CRC(J2) \times CRX(J2,J-1) \]
  \[ CRZ(J2,J) = CRC(J2) \times CRZ(J2,J-1) \]
  \[ SRMRT(J) = SRMRT(J) + A \times (CRX(J2,J) - CRZ(J2,J)) \]

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 < 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)
  \[ 4-16 \]
If $J > IRFL(J2)$, use common ratio to determine response factor.

$$FLRX(J2,J) = CRFL(J2) \cdot FLRX(J2,J-1)$$

$$FLRZ(J2,J) = CRFL(J2) \cdot FLRZ(J2,J-1)$$

$$SRMRT(J) = SRMRT(J) + A \cdot (FLRX(J2,J) - FLRZ(J2,J))$$

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.

$$FURZ(J2,J) = CRFU(J2) \cdot FLRZ(J2,J-1)$$

where $J2 = IFND(I)$.

- $SRMRT(J) = SRMRT(J) - AFN1 \cdot FURZ(J2,J)$.

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 $NUF(I)$:

$$J2 = IUF(I,J1)$$


4-17
If \( J > 10 \), use common ratio to calculate default value.

\[
DFURZ(J) = DFURZ(J-1) \cdot DFUCR
\]

Update SRMRT and adjust response factor for U-factor other than the 0.665 (6" concrete on soil) upon which default values are based.

\[
SRMRT(J) = SRMRT(J) - AU(J2) \cdot DFURZ(J) \cdot \left( \frac{F(J2)}{0.665} \right)
\]

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., \( NUW(I) < 0 \)), skip to calculation (6p).
- For each underground wall, \( J_1 = 1 \) to \( NUW(I) \).
  
  \( J_2 = IUW(I) \) (underground wall number)

  If \( J > 10 \), use common ratio to calculate default value.

\[
DFURZ(J) = DFUCR \cdot DFURZ(J-1)
\]

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 1)).

\[
SRMRT(J) = SRMRT(J) - AUW(J2) \cdot DFURZ(J) \cdot \left( \frac{F(J2)}{0.791} \right)
\]

n) Ceilings - using default values (DFFTZ) 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.

\[
DFFRZ(J) = DFFCR \cdot DFFRZ(J-1)
\]
• 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.)

\[
SRMRT(J) = SRMRT(J) - \text{FLORB}(I) + DFFRZ(J) \times \left( \frac{\text{WOF}(I)}{70.0} \right) \times 1.26
\]

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.

\[
DFFRZ(J) = DFFCR \times DFFRZ(J-1)
\]

• Update SRMRT and adjust response factor term for weights other than 70 lbs/sq. ft. upon which default values are based++.

\[
SRMRT(J) = SRMRT(J) - \text{FLORB}(I) \times DFFRZ(J) \times \left( \frac{\text{WOF}(I)}{70.0} \right)
\]

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.


4-19
DFNRZ(O) = 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 \( |SRMRT(J)| \leq 1.0 \times 10^{-15} \), and if so, go to calculation (6x).

t) Check to determine if all space response factor terms have been calculated. If \( J \leq MNRF \), go to calculation (6w).

u) Perform the relative end test. If \( |SRF(I,J)/SRF(I,1)| \leq 1.0 \times 10^{-3} \), go to calculation (6x).

v) Limit the number of space response factor terms to 100. If \( J \geq 100 \), 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 \( U \times A \) for all internal heat transfer surfaces in each space. For each space \( I = 1 \) to \( NS \),

\[
JLIM = NIHTS(I) \text{ (number of surfaces)}
\]

8. Initialize run parameters for each space \( I = 1 \) to \( NS \).

\[
\begin{align*}
\text{SMH}(I) & = 1.0 \times 10^{10} \quad \text{space maximum heating} \\
\text{SMC}(I) & = -1.0 \times 10^{10} \quad \text{space maximum cooling} \\
\text{SLT}(I) & = 1.0 \times 10^{10} \quad \text{space lowest temperature} \\
\text{SHT}(I) & = -1.0 \times 10^{10} \quad \text{space highest temperature} \\
\text{ESHT}(I) & = 0.0 \quad \text{heat extraction difference} \\
\text{ETEMP}(I,J) & = 0.0 \quad \text{space temperature deviation}
\end{align*}
\]

where \( J = 1 \) to \( NSRF(I) \)

9. Initialize run parameters for building.

\[
\begin{align*}
\text{TCOOL} & = 0.0 \quad \text{total building cooling consumption} \\
\text{THEAT} & = 0.0 \quad \text{total building heating consumption}
\end{align*}
\]

10. Begin hourly analysis, perform following for each day \( JDAY = ISTRT \) to \( IEND \) incrementing 24 hours each time.

   a) Check condition of boiler. If

   \[
   \begin{cases}
   \text{IBE} > JDAY \\
   \text{IBS} < JDAY \\
   \text{IBC} = 1
   \end{cases}
   \]

   boiler should be off, therefore set \( \text{IBOF} = 0 \). Otherwise, set \( \text{IBOF} = 1 \).

   b) Check condition of chiller. If

   \[
   \begin{cases}
   \text{ICS} < JDAY \\
   \text{ICE} > JDAY
   \end{cases}
   \]

   chiller should be ON, therefore set \( \text{ICOF} = 1 \). Otherwise, set \( \text{ICOF} = 0 \).

   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, °F
   LA - wet-bulb temperature, °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 Jl = 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 Jl = 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 the 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).

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• Fan is operating; therefore perform the following:

\[ J_1 = IVS(I) \]

\[ UCFM = CFM(I) \]

\[ CFM_1 = 1.08 \times CFM(I) \]

\[ CFM_2 = 1.08 \times CFM(I) \times (TSPAC(I) - \text{ETEMP}(J_1,I) - TSPAC(J_1) + HRLDL(J_1)) \]

\[ \text{o) Calculate temperature difference between outside dry-bulb and constant space temperature assumed in basic load calculation.} \]

\[ \text{TOMCS} = LA - TSPAC(I) \]

If \( |\text{TOMCS}| < 0.1 \), set \( \text{TOMCS} = 1.0E35 \)

\[ p) \text{Define various terms to be used in equations later.} \]

\[ \text{SUM}_3 = UQT + UGWT \]

\[ \text{SUM}_4 = \text{SUM}_1 + \text{PIHT} + \text{HRLDS} + \text{CFM}_2 \]

\[ \text{SUM}_5 = -\text{SRF}(I,I) + \text{SUM}_3 + \text{SIHTC}(I) + \text{QSINF}/\text{TOMCS} + \text{CFM}_1 \]

\[ q) \text{Set space thermostat type and check for no thermostat, i.e., floating space temperature. Also set thermostat schedule that applies.} \]

\[ IJUMP = ISTT(I) \]

If \( IJUMP = 0 \), skip to calculation (10u).

\[ \text{JUMP} = IVTSD(IJUMP,IDT,ITIME) \]

\[ r) \text{Set the high and low thermostat limits deviations and space heating and cooling capacity.} \]

\[ TL = VTSD2(IJUMP,IDT,ITIME) - TSPAC(I) \]

\[ TH = VTSD1(IJUMP,IDT,ITIME) - TSPAC(I) \]

\[ \text{HEAT} = -\text{HCAP}(I) \times IBOF \]

\[ \text{COOL} = \text{CCAP}(I) \times ICOF \]

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s) Analysis for a Type 1 thermostat (linear or proportional control) (see Table 4.1).

- Calculate slope of thermostat function line.
  \[ D = \frac{(\text{HEAT} + \text{COOL})}{(\text{TH} - \text{TL})} \]

- Calculate intercept of thermostat function line.
  \[ C = -(\text{HEAT} + D \times \text{TL}) \]

- Calculate space temperature deviation from TSPAC(I) that exists at end of hour.
  \[ \text{TEMPS} = \frac{(\text{SUM4} - C)}{(\text{SUM5} + D)} \]

- Calculate heat extracted from or supplied to space during hour.
  \[ \text{HE} = \text{TEMPS} \times D + C \]

- Check if more heat is required than the space has capacity for.
  If \( \text{TEMPS} < \text{TL} \), set
  \[ \text{HE} = -\text{HEAT} \]
  \[ \text{TEMPS} = \frac{(\text{SUM4} + \text{HEAT})}{\text{SUM5}} \]

- Check if more cooling is required than the space has capacity for.
  If \( \text{TEMPS} > \text{TH} \), set
  \[ \text{HE} = \text{COOL} \]
  \[ \text{TEMPS} = \frac{(\text{SUM4} - \text{COOL})}{\text{SUM5}} \]

- 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**

<table>
<thead>
<tr>
<th>TYPE</th>
<th>DESCRIPTION</th>
<th>ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LINEAR OR PROPORTIONAL CONTROL</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><img src="chart1.png" alt="Diagram" /></td>
</tr>
<tr>
<td>2</td>
<td>HI-LOW OR ON-OFF CONTROL</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><img src="chart2.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

*Lo Limit*: °F Below Setpoint

*Hi Limit*: °F Above Setpoint
• Calculate space temperature deviation from 
  TSPAC(I) that exists at end of hour.
  \[ \text{TEMPS} = \frac{\text{SUM4}}{\text{SUM5}} \]
• Initialize heat extraction rate.
  \[ \text{HE} = 0.0 \]
• Check if lower thermostat temperature limit is 
  exceeded and if so, reset TEMPS and HE.
  If TEMPS < TL, set
  \[ \text{TEMPS} = \text{TL} \]
  \[ \text{HE} = \text{SUM4} - \text{TEMPS} \times \text{SUM5} \]
• Check if space heating capacity has been 
  exceeded and if so, reset TEMPS and HE.
  If |HE| > HEAT, set
  \[ \text{TEMPS} = \frac{\text{SUM4} + \text{HEAT}}{\text{SUM5}} \]
  \[ \text{HE} = -\text{HEAT} \]
• Check if high thermostat temperature limit is 
  exceeded and if so, reset TEMPS and HE.
  If TEMPS > TH, set
  \[ \text{TEMPS} = \text{TH} \]
  \[ \text{HE} = \text{SUM4} - \text{TEMPS} \times \text{SUM5} \]
• Check if space cooling capacity has been 
  exceeded and if so, reset TEMPS and HE.
  If |HE| > COOL, set
  \[ \text{TEMPS} = \frac{\text{SUM4} - \text{COOL}}{\text{SUM5}} \]
  \[ \text{HE} = \text{COOL} \]
• 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, °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

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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 = TCOOL + HE * MULT(I)
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.


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 subscripted. 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 ("x" numbers) are assigned via variable SPACN<sub>k,j</sub>. Each zone "j" of system "k" has a corresponding "i". Thus one doubly-subscripted variable (SPACN<sub>k,j</sub>) is used to identify the particular "x" variable location of a given zone on a given system.

![Figure 5.1 System Simulation Program Numbering Organization with Example](image1)

![Figure 5.2 System-Zone Matrix Using Doubly-Subscripted Variables (k,j)](image2)
<table>
<thead>
<tr>
<th>NAME</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYSIM</td>
<td>Main routine</td>
</tr>
<tr>
<td>HTCON</td>
<td>Heat conservation</td>
</tr>
<tr>
<td>TDATA</td>
<td>Reads off header data from LOAD tape</td>
</tr>
<tr>
<td>CDATA</td>
<td>Reads card input</td>
</tr>
<tr>
<td>FSIZE</td>
<td>Fan sizing</td>
</tr>
<tr>
<td>MZDD</td>
<td>Multi-zone and dual duct fan system simulation</td>
</tr>
<tr>
<td>SZRHT</td>
<td>Single-zone/sub-zone reheat fan system</td>
</tr>
<tr>
<td>FHTG2</td>
<td>Floor panel heating systems</td>
</tr>
<tr>
<td>FCOIL</td>
<td>Fancoil unit simulation (2- and 4-pipe)</td>
</tr>
<tr>
<td>INDUC</td>
<td>Induction unit fan system simulation (2- and 4-pipe)</td>
</tr>
<tr>
<td>VARVL</td>
<td>Variable volume fan system simulation</td>
</tr>
<tr>
<td>RHFS2</td>
<td>Simulation of: Single-zone fan system w/face and bypass dampers,</td>
</tr>
<tr>
<td></td>
<td>Unit ventilator,</td>
</tr>
<tr>
<td></td>
<td>Unit heater,</td>
</tr>
<tr>
<td></td>
<td>Constant volume reheat fan system.</td>
</tr>
<tr>
<td>FANOF</td>
<td>Load handler when fan system is off</td>
</tr>
<tr>
<td>ZL03</td>
<td>Zone load organizer: calculates reheating and recooling loads</td>
</tr>
<tr>
<td>BRAD2</td>
<td>Baseboard radiation simulation</td>
</tr>
<tr>
<td>AHU</td>
<td>Air Handling Unit simulation</td>
</tr>
<tr>
<td>MXAIR</td>
<td>Mixed air calculation</td>
</tr>
<tr>
<td>ECONO</td>
<td>Economizer cycle simulation</td>
</tr>
<tr>
<td>CCOIL</td>
<td>Cooling coil simulation</td>
</tr>
<tr>
<td>TRSET</td>
<td>Linear interpolation routine</td>
</tr>
<tr>
<td>PTLD</td>
<td>Part load fan power calculation</td>
</tr>
<tr>
<td>TEMP</td>
<td>Temperature calculation</td>
</tr>
<tr>
<td>PSYCH</td>
<td>Psychrometrics</td>
</tr>
<tr>
<td>PSY1</td>
<td>Psychrometrics</td>
</tr>
<tr>
<td>PSY2</td>
<td>Psychrometrics</td>
</tr>
<tr>
<td>PPWVM</td>
<td>Psychrometrics</td>
</tr>
</tbody>
</table>

5-3
<table>
<thead>
<tr>
<th>NAME</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALOG1</td>
<td>Base 10 logarithms</td>
</tr>
<tr>
<td>HUM1</td>
<td>Humidity ratio calculation</td>
</tr>
<tr>
<td>DENSY</td>
<td>Air density calculation</td>
</tr>
<tr>
<td>ERROR</td>
<td>Prints error messages</td>
</tr>
<tr>
<td>MAX</td>
<td>Maximum value calculation</td>
</tr>
<tr>
<td>H2OZN</td>
<td>Zone moisture change and requirement calculation</td>
</tr>
<tr>
<td>WZNEW</td>
<td>Humidity ratio calculation</td>
</tr>
<tr>
<td>EQUIP</td>
<td>Boilers, chillers and on-site generation systems</td>
</tr>
<tr>
<td>STTUR</td>
<td>Steam turbine</td>
</tr>
<tr>
<td>CENT</td>
<td>Centrifugal water chiller</td>
</tr>
<tr>
<td>RECIP</td>
<td>Reciprocating water chiller</td>
</tr>
<tr>
<td>ABSOR</td>
<td>Steam absorption water chiller</td>
</tr>
<tr>
<td>SNOWM</td>
<td>Snow melting</td>
</tr>
<tr>
<td>ENGYC</td>
<td>Energy consumption output table</td>
</tr>
</tbody>
</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>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I HOUR</td>
<td>Hour number, hour of year</td>
</tr>
<tr>
<td>IMOY</td>
<td>Month of year</td>
</tr>
<tr>
<td>IDOM</td>
<td>Day of month</td>
</tr>
<tr>
<td>NDOW</td>
<td>Day of the week</td>
</tr>
<tr>
<td>IHOD</td>
<td>Hour of the day</td>
</tr>
<tr>
<td>ISUN</td>
<td>Sun index which indicates whether or not the sun is up (0 = sun up; 1 = sun not up)</td>
</tr>
<tr>
<td>TOA</td>
<td>Outside air dry-bulb temperature (°F)</td>
</tr>
<tr>
<td>TWB</td>
<td>Outside air wet-bulb temperature (°F)</td>
</tr>
<tr>
<td>VEL</td>
<td>Wind velocity (knots)</td>
</tr>
<tr>
<td>WOA</td>
<td>Outside air humidity ratio (lb water/lb dry air)</td>
</tr>
<tr>
<td>PATM</td>
<td>Barometric pressure (inches of mercury)</td>
</tr>
<tr>
<td>DOA</td>
<td>Outside air density (lbm/ft³)</td>
</tr>
<tr>
<td>HOA</td>
<td>Enthalpy of outside air (Btu/lb dry air)</td>
</tr>
<tr>
<td>JSC</td>
<td>Day type (i.e., weekday, Saturday, Sunday, Holiday, Xmas)</td>
</tr>
<tr>
<td>CCM</td>
<td>Cloud cover modifier</td>
</tr>
</tbody>
</table>

For each zone, the following variables appear on the input tape:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS</td>
<td>Space number</td>
</tr>
<tr>
<td>QS</td>
<td>Zone sensible load (Btu/hr)</td>
</tr>
<tr>
<td>QL</td>
<td>Zone latent load (Btu/hr)</td>
</tr>
<tr>
<td>QLITE</td>
<td>Zone lighting load picked up by return air (Btu/hr)</td>
</tr>
<tr>
<td>SLPOW</td>
<td>Zone internal lighting and machinery power consumption (KW)</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>QSINF</td>
<td>Zone sensible infiltration load (Btu/hr)</td>
</tr>
<tr>
<td>QLINF</td>
<td>Zone latent infiltration load (Btu/hr)</td>
</tr>
<tr>
<td>STEMP</td>
<td>Zone temperature (°F) (calculated in Variable Temperature Program)</td>
</tr>
<tr>
<td>UCFM</td>
<td>Air flow if zone is a ceiling plenum (ft³/min) (calculated in Variable Temperature Program)</td>
</tr>
<tr>
<td>PROGRAM VARIABLE</td>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------</td>
</tr>
<tr>
<td><strong>Input Recap</strong></td>
<td>Recapitulation of input card data</td>
</tr>
</tbody>
</table>

**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 $i$ (°F)
<table>
<thead>
<tr>
<th>PROGRAM VARIABLE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loads Not Met</td>
<td></td>
</tr>
<tr>
<td>QCLNM&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Monthly accumulation of cooling loads not met, zone i (MBTU)</td>
</tr>
<tr>
<td>QCPNM&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Peak cooling load not met, zone i (MBH)</td>
</tr>
<tr>
<td>IHCNM&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Number of hours in month cooling load not met, zone i</td>
</tr>
<tr>
<td>QHLNM&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Monthly accumulations of heating loads not met, zone i (MBTU)</td>
</tr>
<tr>
<td>QHPNM&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Peak heating load not met, zone i (MBH)</td>
</tr>
<tr>
<td>IHHNM&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Number of hours in month heating load not met, zone i</td>
</tr>
<tr>
<td>QRCNM</td>
<td>Monthly accumulation of central cooling system loads not met due to undersized equipment (MBTU)</td>
</tr>
<tr>
<td>QR6NM</td>
<td>Peak central cooling system load not met (MBH)</td>
</tr>
<tr>
<td>IHRNM</td>
<td>Number of hours in month central cooling system load not met</td>
</tr>
<tr>
<td>QBCNM</td>
<td>Monthly accumulations of boiler loads not met due to undersized equipment (MBTU)</td>
</tr>
<tr>
<td>QRPNM</td>
<td>Peak boiler load not met (MBH)</td>
</tr>
<tr>
<td>IHBNM</td>
<td>Number of hours in month boiler load not met</td>
</tr>
</tbody>
</table>

**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>
<thead>
<tr>
<th>PROGRAM VARIABLE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>NUMC</td>
<td>Number of chillers</td>
</tr>
<tr>
<td>SIC</td>
<td>Size of chillers (tons)</td>
</tr>
<tr>
<td>NUMB</td>
<td>Number of boilers</td>
</tr>
<tr>
<td>SZB</td>
<td>Size of boilers (MBH)</td>
</tr>
<tr>
<td>NUMT</td>
<td>Number of steam turbines</td>
</tr>
<tr>
<td>SZT</td>
<td>Size of steam turbines (HP)</td>
</tr>
<tr>
<td>M4</td>
<td>Number of on-site generation engines</td>
</tr>
<tr>
<td>SZE</td>
<td>Size of on-site generation engines (KW)</td>
</tr>
<tr>
<td>CAPH</td>
<td>Total heating capacity (MBH)</td>
</tr>
<tr>
<td>CAPC</td>
<td>Total cooling capacity (tons)</td>
</tr>
<tr>
<td>CFMCT</td>
<td>Cooling tower air flows (CFM)</td>
</tr>
<tr>
<td>HPCTF</td>
<td>Horsepower of cooling tower fan motor (HP)</td>
</tr>
<tr>
<td>HPBLA</td>
<td>Horsepower of boiler auxiliaries (HP)</td>
</tr>
<tr>
<td>GPMCL</td>
<td>Chilled water flow (gpm)</td>
</tr>
<tr>
<td>HPCLP</td>
<td>Chilled water pump horsepower (HP)</td>
</tr>
<tr>
<td>GPMCN</td>
<td>Condenser water flow (gpm)</td>
</tr>
<tr>
<td>HPCNP</td>
<td>Condenser water pump horsepower (HP)</td>
</tr>
<tr>
<td>GPMBL</td>
<td>Boiler water flow (gpm)</td>
</tr>
<tr>
<td>HPBLP</td>
<td>Boiler water pump horsepower (HP)</td>
</tr>
<tr>
<td>PROGRAM VARIABLE</td>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>ENGY</td>
<td>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.</td>
</tr>
</tbody>
</table>

**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**
DEFINATION OF VARIABLES IN COMMON

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPRT1</td>
<td>Optional print flag-1</td>
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</tr>
<tr>
<td>IPRT2</td>
<td>Optional print flag-2</td>
<td></td>
</tr>
<tr>
<td>IPRT3</td>
<td>Optional print flag-3</td>
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</tr>
<tr>
<td>KO</td>
<td>Line printer unit number</td>
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</tr>
<tr>
<td>IC</td>
<td>Card reader unit number</td>
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</tr>
<tr>
<td>IT</td>
<td>Input tape unit number</td>
<td></td>
</tr>
<tr>
<td>IBOIL</td>
<td>Boiler on/off flag (1=on; 0=off)</td>
<td></td>
</tr>
<tr>
<td>ICHIL</td>
<td>Chiller on/off flag (1=on; 0=off)</td>
<td></td>
</tr>
<tr>
<td>IFAN</td>
<td>Fan system shut-off flag (0=fans run continuously, 1=fans may be shut off)</td>
<td>2=fans and baseboard radiators may be shut off)</td>
</tr>
<tr>
<td>QSj</td>
<td>Zone sensible load (Btu/hr)</td>
<td></td>
</tr>
<tr>
<td>QLj</td>
<td>Zone latent load (Btu/hr)</td>
<td></td>
</tr>
<tr>
<td>QLITEk</td>
<td>Light heat into ceiling plenum above zone (Btu/hr)</td>
<td></td>
</tr>
<tr>
<td>SLPOWj</td>
<td>Space light and power (KW)</td>
<td></td>
</tr>
<tr>
<td>QSINFk</td>
<td>Zone sensible loss due to infiltration (Btu/hr)</td>
<td></td>
</tr>
<tr>
<td>QLINFk</td>
<td>Zone latent loss due to infiltration (Btu/hr)</td>
<td></td>
</tr>
<tr>
<td>STEMPk</td>
<td>Space temperature at a given hour (°F)</td>
<td></td>
</tr>
<tr>
<td>UCFMk</td>
<td>Air flow through zone if it is a plenum space (ft³/min)</td>
<td></td>
</tr>
<tr>
<td>TSPk</td>
<td>Zone set point temperature (°F)</td>
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</tr>
<tr>
<td>VOLk</td>
<td>Zone volume (ft³)</td>
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</tr>
<tr>
<td>TOA</td>
<td>Outside air dry-bulb temperature (°F)</td>
<td></td>
</tr>
<tr>
<td>WOA</td>
<td>Outside air humidity ratio (lbm-H₂O/1bm-dry air)</td>
<td></td>
</tr>
<tr>
<td>HOA</td>
<td>Outside air enthalpy (Btu/lbm)</td>
<td></td>
</tr>
<tr>
<td>DOA</td>
<td>Outside air density (lbm/ft³)</td>
<td></td>
</tr>
<tr>
<td>PATM</td>
<td>Barometric pressure (in.Hg.)</td>
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</tr>
<tr>
<td>TCO</td>
<td>Changeover temperature (°F)</td>
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</tr>
<tr>
<td>KBLDG</td>
<td>Heat conservation building flag</td>
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</tr>
<tr>
<td>KMAX</td>
<td>Number of energy distribution systems</td>
<td></td>
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<tr>
<td>IZNMX</td>
<td>Number of zones to be studied</td>
<td></td>
</tr>
<tr>
<td>MSTRT</td>
<td>Month in which study begins</td>
<td></td>
</tr>
<tr>
<td>NDAYS</td>
<td>Length of study (days)</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>------------------------</td>
<td></td>
</tr>
<tr>
<td>MEND</td>
<td>Last month of study</td>
<td></td>
</tr>
<tr>
<td>IMAX&lt;sub&gt;m&lt;/sub&gt;</td>
<td>Number of hours in month m (m = 1,12)</td>
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</tr>
<tr>
<td>KFAN&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Energy distribution system index</td>
<td></td>
</tr>
<tr>
<td>JMAX&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Number of zones on system k</td>
<td></td>
</tr>
<tr>
<td>CFMAX&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Design supply air of system k (ft³/min)</td>
<td></td>
</tr>
<tr>
<td>CFMEX&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Exhaust air, system k (ft³/min)</td>
<td></td>
</tr>
<tr>
<td>ALFAM&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Minimum fraction outside air, system k</td>
<td></td>
</tr>
<tr>
<td>OACFM</td>
<td>Minimum ventilation air, system k (ft³/min)</td>
<td></td>
</tr>
<tr>
<td>RHSP&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Relative humidity set point, system k (% R.H.)</td>
<td></td>
</tr>
<tr>
<td>WSP&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Humidity ratio set point, system k (lbm-H₂O/1bm-dry air)</td>
<td></td>
</tr>
<tr>
<td>DAVE&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Average air density, system k (lbm/ft³)</td>
<td></td>
</tr>
<tr>
<td>WRA&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Return air humidity ratio, system k (lbm-H₂O/1bm-dry air)</td>
<td></td>
</tr>
<tr>
<td>DRA&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Return air density, system k (lbm/ft³)</td>
<td></td>
</tr>
<tr>
<td>PWGAL&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Process water volume, system k (gals)</td>
<td></td>
</tr>
<tr>
<td>FMASS&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Supply air mass, system k (lbm-air/hr)</td>
<td></td>
</tr>
<tr>
<td>FMASR&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Return air mass, system k (lbm-air/hr)</td>
<td></td>
</tr>
<tr>
<td>FMASX&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Exhaust air mass, system k (lbm-air/hr)</td>
<td></td>
</tr>
<tr>
<td>TFNPS&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Total supply fan pressure, system k (inches)</td>
<td></td>
</tr>
<tr>
<td>TFNPR&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Total return fan pressure, system k (inches)</td>
<td></td>
</tr>
<tr>
<td>TFNPE&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Total exhaust fan pressure, system k (inches)</td>
<td></td>
</tr>
<tr>
<td>FBHPS&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Supply fan brake horsepower, system k (bhp)</td>
<td></td>
</tr>
<tr>
<td>FBHPR&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Return fan brake horsepower, system k (bhp)</td>
<td></td>
</tr>
<tr>
<td>FBHPE&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Exhaust fan brake horsepower, system k (bhp)</td>
<td></td>
</tr>
<tr>
<td>DTFNS&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Air temperature rise across supply fan, system k, at full load (°F)</td>
<td></td>
</tr>
<tr>
<td>DTFNR&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Air temperature rise across return fan, system k, at full load (°F)</td>
<td></td>
</tr>
<tr>
<td>MXAO&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Mixed air option, system k</td>
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<tr>
<td>IVVRH&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Variable volume reheat option, system k</td>
<td></td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
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</tr>
<tr>
<td>ICZN&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Zone in which humidistat is located, system k, (a &quot;j&quot; number)</td>
<td></td>
</tr>
<tr>
<td>ITMPC&lt;sub&gt;k,1&lt;/sub&gt;</td>
<td>Air temperature control mode, system k</td>
<td></td>
</tr>
<tr>
<td>ITMPC&lt;sub&gt;k,2&lt;/sub&gt;</td>
<td>Air temperature control mode, system k</td>
<td></td>
</tr>
<tr>
<td>NVFC&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Type of fan damper control, system k</td>
<td></td>
</tr>
<tr>
<td>VVMIN&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Minimum air flow through variable volume boxes, system k</td>
<td></td>
</tr>
<tr>
<td>TCOFC&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Two-pipe induction unit fan system changeover temperature or floor panel heating system hot water shut-off temperature, system k (°F)</td>
<td></td>
</tr>
<tr>
<td>TFX1&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Fixed hot deck or AHU discharge temperature, system k (°F)</td>
<td></td>
</tr>
<tr>
<td>TFX2&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Fixed cold deck temperature, system k (°F)</td>
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</tr>
<tr>
<td>RIPA&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Ratio of induced to primary air, system k</td>
<td></td>
</tr>
<tr>
<td>CFM&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Supply air flow rate, zone i (constant) (cu ft/min)</td>
<td></td>
</tr>
<tr>
<td>CFMS&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Supply air flow rate, zone i (variable) (cu ft/min)</td>
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</tr>
<tr>
<td>CFMR&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Return air flow rate, zone i (cu ft/min)</td>
<td></td>
</tr>
<tr>
<td>CFMX&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Exhaust air flow rate, zone i (cu ft/min)</td>
<td></td>
</tr>
<tr>
<td>ZMASS&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Supply air mass flow, zone i (constant) (lbm-air/hr)</td>
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<tr>
<td>ZMAS&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Supply air mass flow, zone i (variable) (lbm-air/hr)</td>
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<td>ZMASR&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Return air mass flow, zone i (lbm-air/hr)</td>
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</tr>
<tr>
<td>ZMASX&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Exhaust air mass flow, zone i (lbm-air/hr)</td>
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</tr>
<tr>
<td>QSI&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Sensible heating load, zone i (Btu/hr)</td>
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</tr>
<tr>
<td>TS&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Supply air temperature, zone i (°F)</td>
<td></td>
</tr>
<tr>
<td>WZ&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Calculated humidity ratio, zone i (lbm-H&lt;sub&gt;2&lt;/sub&gt;O/lbm-dry air)</td>
<td></td>
</tr>
<tr>
<td>WREQD&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Required humidity ratio, zone i (lbm-H&lt;sub&gt;2&lt;/sub&gt;O/lbm-dry air)</td>
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<tr>
<td>ALFBR&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Active length baseboard radiation, zone i (lin ft)</td>
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</tr>
<tr>
<td>CBTU&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Baseboard radiation heat output per linear foot at standard conditions, zone i (Btu/hr-lin ft)</td>
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</tr>
<tr>
<td>QCLNM&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Monthly accumulation of cooling loads not met, (zone i) * MULT&lt;sub&gt;i&lt;/sub&gt; (Btu)</td>
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</tr>
<tr>
<td>QCPNM&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Monthly peak cooling load not met, zone i (Btu/hr)</td>
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<tr>
<td>IHCNM&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Number of hours cooling load not met, zone i (hrs)</td>
<td></td>
</tr>
<tr>
<td>QHLNM&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Monthly accumulation of heating loads not met, (zone i) * MULT&lt;sub&gt;i&lt;/sub&gt; (Btu)</td>
<td></td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>-----------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>QHPNM&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Monthly peak heating load not met, zone i (Btu/hr)</td>
<td></td>
</tr>
<tr>
<td>IHHNM&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Number of hours heating load not met, zone i (hrs)</td>
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</tr>
<tr>
<td>IPLEN&lt;sub&gt;i&lt;/sub&gt;</td>
<td>LOAD program space number of plenum above zone i</td>
<td></td>
</tr>
<tr>
<td>SPACN&lt;sub&gt;k,j&lt;/sub&gt;</td>
<td>Number of space as per LOAD program, applied to system k, zone j</td>
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</tr>
<tr>
<td>MULT&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Multiplication factor, zone i</td>
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</tr>
<tr>
<td>I</td>
<td>Variable subscript i</td>
<td></td>
</tr>
<tr>
<td>TOALO&lt;sub&gt;n&lt;/sub&gt;</td>
<td>Low outside air temperature at which system temperature is THI&lt;sub&gt;n&lt;/sub&gt;, reset schedule n (°F)</td>
<td></td>
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<tr>
<td>TOAHI&lt;sub&gt;n&lt;/sub&gt;</td>
<td>High outside air temperature at which system temperature is TLO&lt;sub&gt;n&lt;/sub&gt;, reset schedule n (°F)</td>
<td></td>
</tr>
<tr>
<td>TLO&lt;sub&gt;n&lt;/sub&gt;</td>
<td>Low system fluid temperature, reset schedule n (°F)</td>
<td></td>
</tr>
<tr>
<td>THI&lt;sub&gt;n&lt;/sub&gt;</td>
<td>High system fluid temperature, reset schedule n (°F)</td>
<td></td>
</tr>
<tr>
<td>ISET&lt;sub&gt;k,m&lt;/sub&gt;</td>
<td>Reset temperature schedule index, system k, reset item m (an &quot;n&quot; number) (&quot;m&quot; is defined in Table 6.4, User Manual)</td>
<td></td>
</tr>
<tr>
<td>TFBHP</td>
<td>Total fan brake horsepower (bhp)</td>
<td></td>
</tr>
<tr>
<td>EFF</td>
<td>Pump and fan motor efficiency</td>
<td></td>
</tr>
<tr>
<td>PLOC&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Location of floor heating panels, system k</td>
<td></td>
</tr>
<tr>
<td>PAREA&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Floor area covered by heating panels, system k (ft&lt;sup&gt;2&lt;/sup&gt;)</td>
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<tr>
<td>PERIM&lt;sub&gt;k&lt;/sub&gt;</td>
<td>Exposed perimeter of floor, system k (lin.ft)</td>
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</tr>
<tr>
<td>KFLCV</td>
<td>Type of floor covering (1=bare concrete; 2=tile; 3=carpeting)</td>
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<tr>
<td>CINSL</td>
<td>Floor insulation conductance (Btu/hr-sq-ft-°F)</td>
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<tr>
<td>DINSL</td>
<td>Floor insulation thickness (ft)</td>
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<tr>
<td>TLCHL</td>
<td>Chilled water set point temperature (°F)</td>
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<tr>
<td>TPS</td>
<td>Steam turbine entering steam temperature (°F)</td>
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</tr>
<tr>
<td>PPS</td>
<td>Steam turbine entering steam pressure (psig)</td>
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<tr>
<td>TESTM</td>
<td>Boiler supply and absorption chiller entering steam temperature (°F)</td>
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<tr>
<td>PESTM</td>
<td>Boiler supply and absorption chiller entering steam pressure (psig)</td>
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<tr>
<td>SZT</td>
<td>Steam turbine size (hp)</td>
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</tr>
<tr>
<td>NUMT</td>
<td>Number of steam turbines</td>
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</tr>
<tr>
<td>------</td>
<td>--------------------------</td>
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</tr>
<tr>
<td>RPM</td>
<td>Steam turbine speed (rpm)</td>
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<tr>
<td>SZE</td>
<td>Engine/Generator set size (KW)</td>
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<tr>
<td>FFLMN</td>
<td>Minimum part load cut-off for chillers</td>
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</tr>
<tr>
<td>KREHT</td>
<td>Source of reheat coil energy</td>
<td></td>
</tr>
<tr>
<td>HVDF</td>
<td>Heating value of diesel fuel (Btu/gal)</td>
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</tr>
<tr>
<td>HVHO</td>
<td>Heating value of heating oil (Btu/gal)</td>
<td></td>
</tr>
<tr>
<td>CFMBN</td>
<td>Building total minimum outside air (cu ft/min)</td>
<td></td>
</tr>
<tr>
<td>CFMBX</td>
<td>Building total design load supply air (cu ft/min)</td>
<td></td>
</tr>
<tr>
<td>CFMBE</td>
<td>Building total exhaust air (cu ft/min)</td>
<td></td>
</tr>
<tr>
<td>PWBIL</td>
<td>Building peak base power load (KW)</td>
<td></td>
</tr>
<tr>
<td>PWOL</td>
<td>Power of external lighting (KW)</td>
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</tr>
<tr>
<td>TLCNM</td>
<td>Maximum allowable condenser water temperature (°F)</td>
<td></td>
</tr>
<tr>
<td>TLCMN</td>
<td>Well or city water design return water temperature (°F)</td>
<td></td>
</tr>
<tr>
<td>TCWIN</td>
<td>City water supply temperature (°F)</td>
<td></td>
</tr>
<tr>
<td>TWWIN</td>
<td>Well water supply temperature (°F)</td>
<td></td>
</tr>
<tr>
<td>TECMNN</td>
<td>Cooling tower water low limit temperature (°F)</td>
<td></td>
</tr>
<tr>
<td>HDCLP</td>
<td>Total chilled water pump head (ft)</td>
<td></td>
</tr>
<tr>
<td>HDCNP</td>
<td>Total condenser water pump head (ft)</td>
<td></td>
</tr>
<tr>
<td>HDBLP</td>
<td>Total boiler water pump head (ft)</td>
<td></td>
</tr>
<tr>
<td>HDWWP</td>
<td>Total well water pump head (ft)</td>
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</tr>
<tr>
<td>GPMCL</td>
<td>Chilled water flow rate (gpm)</td>
<td></td>
</tr>
<tr>
<td>GPMCNCN</td>
<td>Condenser water flow rate (gpm)</td>
<td></td>
</tr>
<tr>
<td>GPMBL</td>
<td>Boiler water flow rate (gpm)</td>
<td></td>
</tr>
<tr>
<td>GPMNW</td>
<td>Well water flow rate (gpm)</td>
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</tr>
<tr>
<td>HPCLP</td>
<td>Chilled water pump power (bhp)</td>
<td></td>
</tr>
<tr>
<td>HPCNP</td>
<td>Condenser water pump power (bhp)</td>
<td></td>
</tr>
<tr>
<td>Code</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>--------</td>
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</tr>
<tr>
<td>HPBLP</td>
<td>Boiler water pump power (bhp)</td>
<td></td>
</tr>
<tr>
<td>HPWWP</td>
<td>Well water pump power (bhp)</td>
<td></td>
</tr>
<tr>
<td>HPCTF</td>
<td>Cooling tower fan power (bhp)</td>
<td></td>
</tr>
<tr>
<td>HPBLA</td>
<td>Boiler accessory power (bhp)</td>
<td></td>
</tr>
<tr>
<td>CFMCT</td>
<td>Cooling tower air flow (cu ft/min)</td>
<td></td>
</tr>
<tr>
<td>IHSRT</td>
<td>Hour of year at which simulation may begin</td>
<td></td>
</tr>
<tr>
<td>IHSIP</td>
<td>Hour of year at which simulation may end</td>
<td></td>
</tr>
<tr>
<td>NCASE</td>
<td>Number of cases to be run</td>
<td></td>
</tr>
<tr>
<td>NRSET</td>
<td>Number of reset schedules to be read</td>
<td></td>
</tr>
<tr>
<td>KHCST</td>
<td>Heat conservation system flag</td>
<td></td>
</tr>
<tr>
<td>NUMB</td>
<td>Number of boilers</td>
<td></td>
</tr>
<tr>
<td>SZB</td>
<td>Size of each boiler (MBH)</td>
<td></td>
</tr>
<tr>
<td>BON</td>
<td>Hour of seasonal boiler start-up (hour of year)</td>
<td></td>
</tr>
<tr>
<td>BOFF</td>
<td>Hour of seasonal boiler shut-down (hour of year)</td>
<td></td>
</tr>
<tr>
<td>NUMC</td>
<td>Number of chillers</td>
<td></td>
</tr>
<tr>
<td>SZC</td>
<td>Size of each chiller (tons)</td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>Hour of seasonal chiller start-up (hour of year)</td>
<td></td>
</tr>
<tr>
<td>COFF</td>
<td>Hour of seasonal chiller shut-down (hour of year)</td>
<td></td>
</tr>
<tr>
<td>KSNOW</td>
<td>Type of snow melting system</td>
<td></td>
</tr>
<tr>
<td>QSNOW</td>
<td>Snow melting system design load (Btu/hr)</td>
<td></td>
</tr>
<tr>
<td>SAREA</td>
<td>Snow melting slab area (sq ft)</td>
<td></td>
</tr>
<tr>
<td>ASYS_{nc}</td>
<td>System identification number, run nc</td>
<td></td>
</tr>
<tr>
<td>ABLDG_{nc}</td>
<td>Heat conservation flag (1=no; 2=yes), run nc</td>
<td></td>
</tr>
<tr>
<td>AM1_{nc}</td>
<td>Type of chiller, run nc</td>
<td></td>
</tr>
<tr>
<td>AM2_{nc}</td>
<td>Source of chiller energy, run nc</td>
<td></td>
</tr>
<tr>
<td>AM3_{nc}</td>
<td>Source of general heating energy, run nc</td>
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</tr>
<tr>
<td>AREHT_{nc}</td>
<td>Source of reheat coil energy, run nc</td>
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</table>

5-17
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>AM6\textsubscript{nc}</td>
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<tr>
<td>AM7\textsubscript{nc}</td>
<td>Type of supplemental heat, run nc</td>
</tr>
<tr>
<td>AM4\textsubscript{nc}</td>
<td>Number of engine/generator sets, run nc</td>
</tr>
<tr>
<td>AM5\textsubscript{nc}</td>
<td>Type of engine/generator set, run nc</td>
</tr>
<tr>
<td>QRCNM</td>
<td>Monthly accumulation of chiller loads not met due to undersizing (MBTU)</td>
</tr>
<tr>
<td>QRPNM</td>
<td>Monthly peak chiller load not met (MBH)</td>
</tr>
<tr>
<td>IHRNM</td>
<td>Number of hours chiller load not met</td>
</tr>
<tr>
<td>QBCNM</td>
<td>Monthly accumulation of boiler loads not met due to undersizing (Btu)</td>
</tr>
<tr>
<td>QBPNM</td>
<td>Monthly peak boiler load not met (Btu)</td>
</tr>
<tr>
<td>IHBNM</td>
<td>Number of hours boiler load not met</td>
</tr>
</tbody>
</table>

5-18
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)
\( \text{DTFNS}_k \): Temperature rise across supply fan, system \( k \)

\( \text{DTFNR}_k \): Temperature rise across return fan, system \( k \)

\( \text{ZMAS}_i \): Supply air mass flow to zone \( i \) at design load (lbm/hr)

\( \text{ZMASX}_i \): Exhaust air mass flow from zone \( i \) (lbm/hr)

\( \text{ZMASR}_i \): Return air mass flow from zone \( i \) at design load (lbm/hr)

\( \text{FMASS}_k \): Total supply air mass flow of system \( k \) at design conditions (lbm/hr)

\( \text{FMASX}_k \): Total exhaust air mass flow of system \( k \) (lbm/hr)

\( \text{FMASR}_k \): Total return air mass flow of system \( k \) at design conditions (lbm/hr)

\( \text{CFMBE} \): \( \sum_{k=1}^{k_{max}} \text{CFMEX}_k \)

\( \text{CFMBX} \): \( \sum_{k=1}^{k_{max}} \text{CFMAX}_k \)

\( \text{CFMBN} \): \( \sum_{k=1}^{k_{max}} \text{CFMIN}_k \)

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

\( \text{CAPH} = \text{SZB} \times \text{NUMB} \)

\( \text{CAPC} = \text{SZC} \times \text{NUMC} \)

\( \text{SZT} = \text{SZC} \)

\( \text{NUMT} = \text{NUMC} \)

6.2 Steam turbines (to drive centrifugal chillers).

If \( M1=5 \), determine number of steam turbines required.

\( \text{NUMT} = \text{NUMC} \)

5-20
Determine size of steam turbines required, if used, assuming 1 HP per ton of cooling.

\[ \text{SZT} = \text{SZC} \]

6.3 Compute total heating capacity required.

If \( M_1 = 4 \) (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

\[ \text{CAPH}_1 = \text{CAPC} \times 20.0 \times 33.472/34.5 \]

If \( \text{CAPH} < \text{CAPH}_1 \),

\[ \text{CAPH} = \text{CAPH}_1 \]

\[ \text{SZB} = \frac{\text{CAPH}}{\text{NUMB}} \]

6.4 Size all pump water flows.

Chilled water flow rate (gpm)

\[ \text{GPMCL} = 2.4 \times \text{CAPC} \]

Condenser water flow rate (gpm)

If \( M_1 \neq 4 \), \( \text{GPMCN} = 3.0 \times \text{CAPC} \)

If \( M_1 = 4 \) (steam absorption chiller),

\[ \text{GPMCN} = 3.5 \times \text{CAPC} \]

Boiler water flow rate (gpm)

\[ \text{GPMBL} = \frac{\text{CAPH} \times 1000.0}{500.0 \times 20.0} \]

6.5 Size pump motors assuming a pump efficiency of 60%.

Chilled water pump horsepower

\[ \text{HPCLP} = \frac{\text{GPMCL} \times \text{HDCLP}}{(3962.0 \times 0.6 \times \text{EFF})} \]

Condenser water pump horsepower

\[ \text{HPCNP} = \frac{\text{GPMCN} \times \text{HDCNP}}{(3962.0 \times 0.6 \times \text{EFF})} \]
Boiler water pump horsepower

\[ HPBLP = GPMBL \times HDBLP/(3962.0 \times 0.6 \times EFF) \]

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

\[ HPBLA = CAPH \times 1000.0/(33472.0 \times 20.0) \]

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

\[ CFMCT = 300.0 \times CAPC \]

For steam absorption system, use 350 cfm per ton of cooling; therefore

\[ CFMCT = 350.0 \times CAPC \]

Cooling tower fan horsepower requirement assuming 1.0 inch water total pressure

\[ HPCTF = CFMCT \times 1.0/(6346.0 \times EFF) \]

6.8 Sum heating and cooling equipment brake horsepower demand.

\[ HPHEQ = HPBLA + HPBLP \text{ where } HPHEQ \text{ has units of horsepower} \]

\[ HPCEQ = HPCTF + HPCLP + HPCNP \text{ where } HPCEQ \text{ has units of horsepower} \]

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).

\[ BKWDM = PWBIL + PWOL + (TFBHP + HPCEQ + HPHEQ) \times 0.7457 \]

5-22
Calculate number and size of on-site generation units.

If \( M4 \neq 0 \), set

\[
NUME = M4
\]

where \( NUME \) is number of engines.

Size of engines is then

\[
SZE = \frac{BKWDM}{NUME}
\]

If \( SZE > 500 \text{ KW} \), increase the number of engines until \( SZE \leq 500 \text{ KW} \).

Finally, set \( M4 = NUME \).

If \( M4 = 0 \), set

\[
NUME = 2
\]

where \( NUME \) is number of engines

Size of engines is then

\[
SZE = \frac{BKWDM}{NUME}
\]

If \( SZE > 500 \text{ KW} \), increase \( NUME \) until \( SZE \leq 500 \text{ KW} \).

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 (°F)
- **TWB**: Outside air wet-bulb temperature (°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/ft³)
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.

ISₚ : Space number
QSₚ : Zone sensible load (Btu/hr)
QLₚ : Zone latent load (Btu/hr)
QLITEₚ : Zone lighting load picked up by return air (Btu/hr)
SLPOWₚ : Zone internal lighting and machinery power consumption (KW)
QSINFₚ : Zone sensible infiltration load (Btu/hr)
QLINFₚ : Zone latent infiltration load (Btu/hr)
STEMPₚ : Zone temperature (°F)

Initialize total net fan brake horsepower (TNFBP).

TNFBP = TFBHP

8. Call energy distribution systems.

Check type of fan system.

If KFANₖ = 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

5-24
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.

\[
QHBC = \sum_{k=1}^{k_{max}} QFPC_k
\]
\[
QHBRH = \sum_{k=1}^{k_{max}} QFPH_k + QFPPh_k + TQB_k + \frac{-WATER_k}{1000.0}
\]
\[
QHBRH = \sum_{k=1}^{k_{max}} QFPRH_k
\]
\[
PWILM = \sum_{k=1}^{k_{max}} PWL_k
\]
\[
H2O = \sum_{k=1}^{k_{max}} WATER_k
\]

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°F 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,
\[ ELDEM = PWILM + PWEL + (TNFBP + HPCLP + HPCNP + HDCTF * KCTF) \times 0.7457 \]
If heating equipment only is ON,
\[ ELDEM = PWILM + PWEL + (TNFBP + HPHEQ) \times 0.7457 \]
If heating and cooling equipment are ON,
\[ ELDEM = PWILM + PWEL + (TNFBP + HPCLP + HPCNP + HDCTF * KCTF + HPHEQ) \times 0.7457 \]

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.
\[ SNOW = 0.1 \times SNOWF(ID)/24.0 \]
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

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)
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**

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

<table>
<thead>
<tr>
<th>FAC</th>
<th>Name of facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>CITY</td>
<td>Name of city in which facility is located</td>
</tr>
<tr>
<td>ENGR</td>
<td>Name of user</td>
</tr>
<tr>
<td>PROJ</td>
<td>Project number</td>
</tr>
<tr>
<td>DATE</td>
<td>Date of computer run</td>
</tr>
<tr>
<td>MSTRT</td>
<td>First month on LOAD tape</td>
</tr>
<tr>
<td>MEND</td>
<td>Last month on LOAD tape</td>
</tr>
<tr>
<td>IMAX_m</td>
<td>Number of hours in month m</td>
</tr>
<tr>
<td>spacn_{k,j}</td>
<td>Variable relating load program zone numbering with system simulation zone numbering</td>
</tr>
<tr>
<td>MULT_i</td>
<td>Zone duplication factor</td>
</tr>
<tr>
<td>IZNMX</td>
<td>Number of fan zones in building</td>
</tr>
<tr>
<td>VOL_{k,l}</td>
<td>Volume of load program, zone l, fan system k (cu ft)</td>
</tr>
<tr>
<td>QS_{k,l}</td>
<td>Hourly zone sensible load, zone l (Btu/hr)</td>
</tr>
<tr>
<td>QL_{k,l}</td>
<td>Hourly zone latent load, zone l (Btu/hr)</td>
</tr>
<tr>
<td>QLITE_{k,l}</td>
<td>Hourly zone lighting load picked up by return air, zone l (Btu/hr)</td>
</tr>
<tr>
<td>SLPOW_{k,l}</td>
<td>Hourly zone internal lighting and machinery power consumption, zone l (KW)</td>
</tr>
<tr>
<td>KMAX</td>
<td>Total number of fan systems within the building</td>
</tr>
</tbody>
</table>

5-30
INPUT (CONT'D)

KFAN_k : Type of energy distribution system, system k
TSP_k : Set point temperature, zone i (°F)
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)

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FBHPR<sub>k</sub> : Return fan brake horsepower required for fan system k (bhp)

FBHPE<sub>k</sub> : Exhaust fan brake horsepower required for fan system k (bhp)

CFMEX<sub>k</sub> : \[ \sum_{j=1,j_{\text{max}}} CFM_{X_{j}} \text{ (cfm)} \]

WSP<sub>k</sub> : Humidity ratio set point for system k (lbm-H<sub>2</sub>O/lbm-dry air)

CFMBX : \[ \sum_{k=1,k_{\text{max}}} CFMAX_{k} \text{ (cfm)} \]

CFMBN : \[ \sum_{k=1,k_{\text{max}}} CFMIN_{k} \text{ (cfm)} \]

CFMBE : \[ \sum_{k=1,k_{\text{max}}} CFMEX_{k} \text{ (cfm)} \]

PWBIL : Maximum hourly building internal lighting and machinery power consumption (KW)

DTFNS<sub>k</sub> : Temperature rise across supply fan at full load, system k (°F)

DTFNR<sub>k</sub> : Temperature rise across return fan at full load, system k (°F)

**CALCULATION SEQUENCE**

1. **Segment One.** Read through the load input tape and find the following quantities:
   
   - QSZCM<sub>i</sub>: Maximum zone sensible cooling load for each zone, i
   - QSZHM<sub>i</sub>: 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.
   
   \[ TDC = TSP_{k} - \frac{(TPAC_{k} + TIAC \times ARIPA_{k})}{(1 + ARIPA_{k})} \]
CALCULATION SEQUENCE (CONT'D)

\[ TDH = TSP_k - \left( \frac{TPA_k + TIAH * ARIPA_k}{1 + ARIPA_k} \right) \]

where

- **TDC**: terminal unit cooling design temperature difference (°F)
- **TDH**: terminal unit heating design temperature difference (°F)
- **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°F
- **TIAH**: design dry-bulb temperature of induced air after passing through coil, heating mode = 120°F
- **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

<table>
<thead>
<tr>
<th>SYSTEM TYPE (kf)</th>
<th>SYMBOL</th>
<th>PRIMARY AIR COOLING DESIGN (°F)</th>
<th>PRIMARY AIR HEATING DESIGN (°F)</th>
<th>INDUCED AIR HEATING (°F)</th>
<th>INDUCED AIR COOLING (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SZFB</td>
<td>55.</td>
<td>120.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>MZS</td>
<td>55.</td>
<td>120.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>DDS</td>
<td>55.</td>
<td>120.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>SZRH</td>
<td>52.</td>
<td>95.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>UVT</td>
<td>55.</td>
<td>120.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>UHT</td>
<td>55.</td>
<td>120.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>FPH</td>
<td>0.</td>
<td>0.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>2PFC</td>
<td>55.</td>
<td>110.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>4PFC</td>
<td>55.</td>
<td>110.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>2PIU</td>
<td>53.</td>
<td>53.</td>
<td>120.</td>
<td>62.</td>
</tr>
<tr>
<td>11</td>
<td>4PIU</td>
<td>53.</td>
<td>53.</td>
<td>120.</td>
<td>62.</td>
</tr>
<tr>
<td>12</td>
<td>VAVS</td>
<td>55.</td>
<td>120.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>RHFS</td>
<td>55.</td>
<td>120.</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
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 \[ \left| \frac{QSZHM_i}{TDH} \right| < \left| \frac{QSZCM_i}{TDC} \right|, \]

\[ CFM_i = \frac{QSZHM_i}{(0.245*0.075*60.*TDH)(1.+ARIPA_k)} \]

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

\[ CFMAX_k = \sum_{j=1,j_{max}} CFM_i \]
\[ CFMEX_k = \sum_{j=1,j_{max}} CFMX_i \]

2.5 Average system temperature - \( TAVE_k \)

\[ TAVE_k = \frac{\sum_{j=1,j_{max}} (CFM_i * TSP * MULT_i)}{\sum_{j=1,j_{max}} (CFM_i * MULT_i)} \]

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 \( \lambda \) for each \( i \); a relationship defined by the variable \( SPACN_{k,j} \).
If CFMEX\(_k\) < OACFM\(_k\) < CFMAX\(_k\),

\[
ALFAM\(_k\) = \frac{OACFM\(_k\)}{CFMAX\(_k\)}
\]

If CFMEX\(_k\) > OACFM\(_k\) < CFMAX\(_k\),

\[
OACFM\(_k\) = CFMEX\(_k\)
\]

\[
ALFAM\(_k\) = \frac{CFMEX\(_k\)}{CFMAX\(_k\)}
\]

2.7 Calculate fan power.

Supply Fan:

\[
FBHPS\(_k\) = \frac{CFMAX\(_k\) \cdot TFNPS\(_k\)}{6346 \cdot \text{EFF}}
\]

Return Fan:

\[
FBHPR\(_k\) = \frac{(CFMAX\(_k\) - CFMEX\(_k\)) \cdot TFNPR\(_k\)}{6346 \cdot \text{EFF}}
\]

Exhaust Fan:

\[
FBHPE\(_k\) = \frac{CFMEX\(_k\) - TFNPE\(_k\)}{6346 \cdot \text{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 \cdot 0.4014)}{(0.245 \cdot 0.075 \cdot 60.0)}
\]

Return Fan:

\[
DTFNR\(_k\) = \frac{(TFNPR\(_k\) \cdot 0.4014)}{(0.245 \cdot 0.075 \cdot 60.0)}
\]

2.10 Calculate mass flows

Zones:

\[
ZMASS_i = CFM_i \cdot 0.075 \cdot 60.0
\]

\[
ZMASX_i = CFMX_i \cdot 0.075 \cdot 60.0
\]
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


3.1 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
\lambda
MULT_i
CFM_i
CFMX_i
TSP_\lambda
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$_2$O/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.

If boiler on, call subroutine BRAD2 to calculate baseboard radiation heat ($Q_{B_j}$) and to adjust $QSI_i$ for $QB_j$.

Sum baseboard radiation heat,

$$TQB = \sum_{j=1}^{j_{max}} QB_j$$

If boiler off, continue.

4. Calculate base power (KW); includes internal power, lights receptacles, equipment, misc.

$$BPKW = \sum_{j=1}^{j_{max}} SLPOW_j \times MULT_j$$

5. System and zone mass flows remain constant.

$$FMAS_k = \sum_{j=1}^{j_{max}} ZMASS_i \times MULT_i$$

$$FMR_k = \sum_{j=1}^{j_{max}} ZMASR_i \times MULT_i$$

6. Calculate return air temperature ($T_{RA_k}$).

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,

$$DTL2_i = 0.$$

$$QLITI = QLITE\lambda + QS_p\lambda + QLITE_p\lambda + QSINF_p\lambda$$

If VARIABLE TEMPERATURE tape is used,

$$DTL2_i = STEMP_p\lambda - TSP\lambda$$

$$QLITI = QLITE\lambda$$

**There is a corresponding $\lambda$ for each $i$; a relationship defined by the variable $SPACN_{k,j}$. Hence, $i$ and $\lambda$ 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,

\[ DTL_2 = 0. \]

\[ QLITI = QLITE_j \]

\[ DTL_1 = QLITI/(0.245 \times ZMAS_j) \]

\[ TRA_k = \sum_{j=1,j_{\text{max}}}^k (TSP_j + DTL_1 + DTL_2) \times ZMAS_j \times \text{MULT}_j \]

\[ \sum_{j=1,j_{\text{max}}}^k ZMAS_j \times \text{MULT}_j + DTFNR_k \]

where \( DTL_2 \) - difference between zone and plenum temperatures as calculated by VARIABLE TEMPERATURE program.

\( QLITI \) - thermal load of plenum \( pl \) above zone \( j \) as calculated by LOAD program.

\( pl \) - LOAD program space number of plenum above zone \( j \).

7. Calculate required supply air temperature of each zone.

\[ TS_1 = TSP_1 - QSI/(0.245 \times ZMASS_1) \]

8. Calculate zone humidification requirements.

Using subroutine H2OZN, calculate total moisture requirements including set point recovery load (H2OAD_1) and moisture changes in current hour due to environmental and room effects (H2OAD_1).

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.

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Call subroutine TEMP to calculate hot and cold deck leaving air temperatures (THC and TCC).

10. Calculate desired economizer approach temperature entering supply fan.

\[ \text{EAT} = \text{TCC} - \text{DTFNS}_k \]

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 \( \text{TMA} < \text{EAT} \),

\[ \text{QPHC} = 0.245 \times \text{FMASS}_k \times (\text{TMA} - \text{EAT}) \]

\[ \text{TMABF} = \text{EAT} \]

If \( \text{TMA} \geq \text{EAT} \),

\[ \text{QPHC} = 0. \]

\[ \text{TMABF} = \text{TMA} \]

(\( \text{TMABF} = \text{temperature of mixed air before fan (°F)} \))

If boiler off,

\[ \text{QPHC} = 0. \]

\[ \text{TMABF} = \text{TMA} \]

13. Calculate mixed air temperature after supply fan.

\[ \text{TMAAF} = \text{TMABF} + \text{DTFNS}_k \]
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.

\[ PCTC_i = \frac{(THC - TS_i)}{(THC - TCC)} \]

If \( PCTC_i \leq 0.0 \), heating load not met.

\[ PCTC_i = 0. \]

\[ QLN_{i} = 0.245 * ZMASS_{i} * (THC - TS_{i}) \]  \( (QLNM_{i} = \text{load not met}) \)

Update as required the following variables:

\[ QHLNM_{i} - \]

\[ QHPNM_{i} - \]

\[ IHNM_{i} - \]

\[ TS_{i} = THC \]

IF \( PCTC > 1.0 \), cooling load not met.

\[ QLN_{i} = 0.245 * ZMASS_{i} * (TCC - TS_{i}) \]

Update as required the following variables:

\[ QCLNM_{i} - \]

\[ QCPNM_{i} - \]

\[ IHCNM_{i} - \]

\[ TS_{i} = TCC. \]

16. Sum cold and hot deck mass flows.

\[ CMASS = \sum_{j=1,j_{max}} ZMASS_{i} * PCTC_{i} \]

\[ HMASS = MASS_{k} - CMASS \]
17. Calculate heating coil load.

\[ Q_{HC} = H_{MASS} \times 0.245 \times (T_{MAAF} - THC) \]

\[ W_{HC} = W_{MA} \]

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).

\[ C_{MESS} = Z_{MASS_{icz}} \times PCTC_{icz} \]

\[ H_{MESS} = Z_{MASS_{icz}} \times (1. - PCTC_{icz}) \]

\[ W_{ZRD} = W_{icz} - H20R_{icz}/Z_{MASS_{icz}} \]

\[ WHRQD = (Z_{MASS_{icz}} \times W_{ZRD} - WCC \times C_{MESS})/H_{MESS} \]

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 HUMI 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.

\[ WATER = H_{MASS} \times (WHC - WMA) \]

20. Calculate zone humidity ratio.

Using function WZNEW, calculate the humidity ratio of each zone (WZ).
21. Calculate return air humidity ratio and density.

\[
WRA_k = \frac{\sum_{j=1}^{j_{\text{max}}} WZ_j \cdot ZMASR_j \cdot \text{MULT}_j}{\sum_{j=1}^{j_{\text{max}}} ZMASR_j \cdot \text{MULT}_j}
\]

\[
DRA_k = \frac{\text{PATM}}{(0.745 \cdot (\text{TRA}_k + 460.) \cdot (1.0 + 7000.0 \cdot WRA_k / 4360.)}
\]


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-H2O/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.

If boiler on, call subroutine BRAD2 to calculate baseboard radiation heat \( QB_j \) and to adjust \( QSI_i \) for \( QB_j \).

\[
TQB = \sum_{j=1}^{j_{\text{max}}} QB_j
\]

If boiler off, continue.

4. Calculate required supply air temperature to each zone,
\[
TS_i = TSP - QSI_i / (0.245 \times ZMASH_i)
\]

5. Calculate AHU discharge temperature.
\[
TLVG = TS_i \quad \text{(equals supply air temperature of air to central zone which in "j" sequence is assumed to be No. 1)}
\]

6. Calculate fraction of primary air required.
\[
BETA_i = (TS_i - TRPRI) / (TLVG - TRPRI)
\]

If \( BETA_i \leq 0.5 \), reheat coil required.
\[
QZRHC_i = 0.245 \times ZMASS_i \times (0.5 \times (TRPRI + TLVG) - TS_i)
\]

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:

\[
\begin{align*}
QCLNM_i & - \\
QCPNM_i & - \\
IHCNM_i & - \\
TS_i & = TLVG
\end{align*}
\]

**NOTE:** There is a corresponding \( i \) for each \( j \); a relationship defined by the variable \( SPACN_{k,j} \). Hence, \( i \) and \( j \) are defined by system number \( (k) \) and zone number \( (j) \). See Para. 5.1 for zone labeling organization.

5-45
If BETA \(< 1.0\), continue.

7. Calculate zone mass flows.
   \[ ZMAS_1 = ZMASS_1 \times BETA_1 \]
   \[ ZMASR_1 = ZMAS_1 - ZMASX_1 \]
   If ZMASR < 0.0,
   \[ ZMASR = 0. \]

8. Calculate system mass flows.
   \[ FMAS = \sum_{j=1}^{j_{max}} ZMAS_j \times MULT_j \]
   \[ FMAR = \sum_{j=1}^{j_{max}} ZMASR_j \times MULT_j \]

9. Calculate percent of full load.
   \[ PCTSA = \frac{FMAS}{FMASS_k} \]
   \[ PCTRA = \frac{FMAR}{FMASR_k} \]

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,
    \[ DTL2_i = 0. \]
    \[ QLITI = QLITE_i + QS_{p_j} + QLITE_{p_j} + QSINF_{p_j} \]
    If VARIABLE TEMPERATURE tape is used,
    \[ DTL2_i = STEMP_{p_j} - TSP_j \]
    \[ QLITI = QLITE_i \]
    If ceiling plenum is not calculated as a separate zone,
    \[ DTL2_i = 0. \]
    \[ QLITI = QLITE_i \]
$\text{DTL}_i = \frac{\text{QLITI}}{0.245 \text{ ZMASR}_i}$

$\text{TRA}_k = \sum_{j=1,j_{\text{max}}} \frac{(\text{TSP}_j + \text{DTL}_1 + \text{DTL}_2)_j \text{ ZMASR}_i \text{ MULT}_j}{\sum_{j=1,j_{\text{max}}} \text{ ZMASR}_i \text{ MULT}_j}$

$+ \text{ DTFNR}_k \text{ PTLD(NVFC}_k, \text{ PCTRA})$

where

- $\text{DTL}_2$ - difference between zone and plenum temperatures as calculated by VARIABLE TEMPERATURE program.
- $\text{QLITI}$ - thermal load of plenum $p\ell$ above zone $\ell$ as calculated by LOAD program.
- $p\ell$ - LOAD program space number of plenum above zone $\ell$.

11. Calculate desired economizer approach temperature (EAT).

\[ \text{EAT} = \text{TLVG} - \text{DTFNS}_k \text{ PTLD(NVFC}_k, \text{ PCTSA}) \]

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 ($\text{QHC}$ and $\text{QCC}$), the effect of fan heat, and the addition of steam ($\text{WATER}$) by a humidifier on the discharge side of the unit.

Go to 14.
13.2 If boiler off and heating required at AHU,

\[ TLVG = TMA + DTFNS_k \times PTLD(NVFC_k, PCTSA) \]

Go to 13.4.

13.3 If chiller off and cooling required at AHU,

\[ TLVG = TMA + DTFNS_k \times PTLD(NVFC_k, PCTSA) \]

Go to 13.4.

13.4 If \( TLVG - TLVG_2 < 0.001 \),

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 \( TLVG - TLVG_2 > 0.001 \),

\[ TLVG = TLVG_2 = TLVG. \]

Go to Step 2.


\[ PCTSA = SMCFM/CFMAX_i \]

\[ TNFBP = TNFBP + (PTLD(NVFC_k, PCTSA) - 1.0) \times FBHPS_k \]

\[ + (PTLD(NVFC_k, PCTRA) - 1.0) \times FBHPR_k \]

15. Calculate base power (KW); includes internal power, lights receptacles, equipment, misc.

\[ BPKW = \sum_{j=1}^{j_{max}} SLPOW_j \times MULT_j \]

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.
\[ \text{WRA}_k = \frac{\sum_{j=1}^{\text{imax}} w_{z_i} \times \text{ZMASR}_i \times \text{MULT}_i}{\sum_{j=1}^{\text{imax}} \text{ZMASR}_i \times \text{MULT}_i} \]

\[ \text{DRA}_k = \frac{\text{PATM}}{(0.754 \times (\text{TRA}_k + 460.)(1.0 + 7000.0 \times \text{WRA}_k/4360.)} \]
A subroutine for simulating the system performance of the floor panel heating system.

**INPUT**

- **TOA**: Dry-bulb temperature of outside air, °F
- **K**: Fan system number
- **JMAXK**: Number of zones on fan system No. K
- **QS**: Hourly sensible load for zone No. l Btu/hr
- **QL**: Hourly latent load for zone No. l Btu/hr
- **QLITE**: Hourly lighting load picked up by return air in zone No. l Btu/hr.
- **SLPOW**: Hourly zone internal lighting and machinery power consumption, KW, for zone No. l
- **TCO**: Building changeover temperature, °F
- **PERIM**: Exposed perimeter of floor for distribution system No. k, ft.
- **PAREA**: Floor area available for heating panels, system k sq. ft.
- **PLOC**: Location of floor heating panel for system No. k
- **CINS**: Floor insulation conductance, Btu/hr-sq.ft.-°F
- **DINS**: Floor insulation thickness, ft.
- **TSP**: Set point temperature of zone No. l, °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

5-50
CALCULATION SEQUENCE*

1. Read load input tape for zones required and calculate:

\[ BPKW = \sum_{j=1}^{JMAXK} \frac{SLPON_{ij}}{MULT_{ij}} \]
\[ QSI_{ij} = QS_{ij} + QLITE_{ij} \]
\[ QSSUM = \sum_{j} QSI_{ij} \]

for all zones on this system requiring heating.

2. If \( TOA > TOAC_{ij} \), 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, \( QPAN \).

\[ QPAN = \frac{QSSUM}{PAREA_{ij}} \]

Calculate set point temperature of system

\[ TSP_{ij} = TSP_{ij} \]

where \( TSP_{ij} \) is the set point of the first zone.

Initially, set \( TPAN = 76.0 \)

\[ QCALC = 0.15 \times \left( \frac{TPAN + 460.0}{100.0} \right) \]

** 4.0 - 0.15 \((TSP_{ij} + 460.0)/100.0) **

** 4.0 + 0.32 \times (TPAN - TSP_{ij}) ** 1.31

If \((QPAN - QCALC)\) is greater than \((0.01 \times QPAN)\), calculate a new \( TPAN \)

\[ TPAN = TPAN + 0.5 \times (QPAN - QCALC) \]

and repeat above calculation. If necessary, repeat again until \( QCALC \) is within \((0.01 \times QPAN)\).

*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

\[ TSUR = TPAN + QPAN \times 0.05 \]

2.2.2.3 If KFLCV = 3, carpeting, therefore

\[ TSUR = TPAN + QPAN \times 1.4 \]

2.2.3 If TSUR as calculated above is greater than 85.0°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 DINS = 0.0, then only perimeter insulation, therefore

\[ C3 = 1.32 + 0.25 \times CINSL \]

2.2.4.3 If CINSL > 0.0 and DINS > 0.0, then

\[ C3 = 0.932 + 0.523 \times CINSL - 0.479 \times CINSL^2 + 0.271 \times DINS + 0.046 \times DINS^2 + 0.786 \times CINSL \times DINS - 0.72 \times DINS \times CINSL^2 - 0.182 \times CINSL \times DINS^2 + 0.24 \times (DINS \times CINSL)^2 \]

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2.2.5 Calculate downward and edgewise heat loss, QLOSS.

2.2.5.1 If $PLOC_k = 1$, then

$$QLOSS = \frac{PERIM_k \cdot C3 \cdot (TPAN - TOA)}{PAREA_k}$$

2.2.5.2 If $PLOC (K) = 2$, then

$$QLOSS = 0.15 \times \frac{((TPAN + 460.0)/100.0)^4 - 0.15 \times (TSPJ1 + 460.0)/100.0)^4}{100.0} + 0.021 \times (TPAN - TSPJ1)^{1.25}$$

2.2.6 Calculate heating requirement of system.

$$QFPH = 1.0 \times (Q PAN + QLOSS) \times PAREA_k$$

$$QFPC = 0.0$$

$$QFPRH = 0.0$$

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) \( QC = \sum_{j=1}^{j_{\text{max}}} QC_j \) **

\( QH \) : Heating load (BTU/HR) \( QH = \sum_{j=1}^{j_{\text{max}}} QH_j \) **

\( TQB \) : 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 \( \ell \) for each \( i \), a relationship defined by the variable \( \text{SPACN}_{k,j} \). Hence, \( i \) and \( \ell \) 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.

\[ BPKW = \sum_{j=1, j_{max}} SLPOW_i \times MULT_i \]

Calculation sequence 4 through 12 is repeated for each fancoil zone on system k.

4. Calculate sensible thermal load.

\[ QSI_i = QS_i + QLITE_i \]

5. Baseboard radiation.

If boiler is on, call subroutine BRAD2 to calculate baseboard radiation heat \( QB_j \) and adjust QSI.

Sum baseboard radiation heat.

\[ TQB = \sum_{j=1, j_{max}} QB_j \]

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.

\[ ZMAS = CFM_i \times DMA \times 60.0 \]

where DMA = mixed air density (LBM/FT^3)

8. Calculate required supply air temperature.

\[ TSA_i = TSP_i - QSI_i/(0.245 \times ZMAS_i) \]

**NOTE: There is a corresponding i for each i, a relationship defined by the variable SPACN_k, j. Hence, i and \( \lambda \) 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.

\[ Q_{FAN} = CFM_{i} \left( \frac{TFNPS_{k}}{0.4014} \right) \]

\[ TMA = TMA + \frac{Q_{FAN}}{(0.245 \times ZMAS_{i})} \]

10. Zone humidity calculations.

Using subroutine H2OZN, calculate total moisture requirements including set point recovery load (H2O\text{RD} \_i) and moisture changes in current hour due to environmental and room effects (H2O\text{AD} \_i).

11. Calculate fancoil performance and distribute thermal loads.

11.1 Two-Pipe Fancoil System

11.1.1 Heating Mode (IPW = -1)

If TMA \(_i\) < TSA, heating required.

If boiler on, call subroutine ZLJJ3 to calculate QH and distribute unmet load, if any.

If boiler off, heating load not met,

\[ Q_{LN_{i}} = ZMAS_{i} \times 0.245 \times (TMA - TSA) \]

Update as required:

\[ Q_{HLM_{i}} : \text{Sum of all heating loads not met, zone } i \]

\[ Q_{HPN_{i}} : \text{Peak heating load not met, zone } i \]

\[ I_{HHNM_{i}} : \text{Hours heating load not met, zone } i \]

If TMA > TSA, cooling load not met.

Call subroutine CCOIL to calculate cooling load not met.

Update as required the following variables:

\[ Q_{CLNM_{i}} : \text{Sum of all cooling loads not met, zone } i \]

\[ Q_{CPNM_{i}} : \text{Peak cooling load not met, zone } i \]

\[ I_{HCM_{i}} : \text{Hours cooling load not met, zone } i \]
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 temperature of the hydronic system (see 13.).

11.1.3 Cooling Mode (IPW = +1)

If TMA < TSA, cooling required.

If chiller on, call subroutine ZL03 to calculate QC, 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 < TSA, heating required.

If boiler on, call subroutine ZL03 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 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 ZL03 to calculate QC, 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:

\[ QCLNM_i : \text{Sum of all cooling loads not met, zone } i. \]
\[ QC\text{PNM}_i : \text{Peak cooling load not met, zone } i. \]
\[ IH\text{CNM}_i : \text{Hours cooling load not met, zone } i. \]

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

\[ QCO = PWGAL_k \times 8.3 \times (THW - TLCHL) \]

where

\[ PWGAL_k : \text{Water volume of two-pipe system (GALS)} \]
\[ TLCHL : \text{Chilled water temperature (°F)} \]

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) \( (QCC = \sum_{j=1}^{j_{\text{max}}} QC_j) \) 

QHC : Heating load at AHU (Btu/hr) \( (QHC = \sum_{j=1}^{j_{\text{max}}} QH_j) \) 

QTRHC : Heating load at induction unit (Btu/hr) \( (QTRHC = \sum_{j=1}^{j_{\text{max}}} QRHC_j) \) 

TQB : Baseboard heating load (Btu/hr)

WATER : Steam humidification supplied at air handling unit (lbs-H\(_2\)O/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:

![Diagram](image)

Figure 5.3 TWO-PIPE INDUCTION UNIT AIR AND WATER SCHEDULING

NOTE: TOAH[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 TFIX[1]).

3. Calculate fraction of primary to total air (ALFIU)

\[
ALFIU = \frac{1.0}{1.0 + RIPA_k}
\]

4. Calculate base power (KW); includes internal power, lights, receptacles, equipment, miscellaneous.

\[
BPKW = \sum_{j=1}^{j_{max}} SLP \cdot \text{MULT}_i
\]

5. Identify sensible thermal load of each zone on this system.

\[
QSI_i = QS \cdot \lambda
\]

**NOTE:** There is a corresponding \( \lambda \) for each \( i \), a relationship defined by the variable \( \text{SPACN}_k,j \). Hence, \( i \) and \( \lambda \) are defined by system number (\( k \)) and zone number of system (\( j \)). See Table 5.1 for zone labeling organization.

If boiler on, call subroutine BRAD2 to calculate baseboard radiation heat \((QB_j)\) and adjust \(QSI_j\) for \(QB_j\).

Sum baseboard radiation heat.

\[ TQB = \sum_{j=1}^{j_{\text{max}}} QB_j \]

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,

\[ DTL2_i = 0.0 \]
\[ QLITI = QLITE_i + QS_p + QLITE_p + QSINF_p \]

If VARIABLE TEMPERATURE tape is used,

\[ DTL2_i = STEMP_p - TSP_p \]
\[ QLITI = QLITE_i \]

If ceiling plenum is not calculated as a separate zone,

\[ DTL2_i = 0.0 \]
\[ QLITI = QLITE_i \]

\[ DTL_i = QLITI / (0.245 \times ZMASR_i) \]

\[ TRA_k = \left[ \left( \sum_{j=1}^{j_{\text{max}}} (TSP_j + DTL_i + DTL2_i) \times ZMASR_i \times MULT_i \right) + DTFNR_k \right] \]

\[ \left( \sum_{j=1}^{j_{\text{max}}} ZMASR_i \times MULT_i \right) \]

where \( DTL2_i \) -- Difference between zone and plenum temperatures as calculated by VARIABLE TEMPERATURE program.

\( QLITI \) -- Thermal load of plenum \( p\) above zone \( l \) as calculated by LOAD program.
8. Zone humidity calculations.

Using subroutine H20ZN, calculate total moisture requirements including set point recovery load (H2ORD,) and moisture changes in current hour due to environmental and room effects (H2OAD.).

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.

\[ Q_{SIU_i} = Q_{SI_i} + Z_{MASS_i} * 0.245 * (TLVG - TSP) \]

\[ Z_{MAS_i} = Z_{MASS_i} * RIPA \]

13. Induction unit simulation.

13.1 Two-pipe induction unit.

13.1.1 Hot water mode (IPW = -1).

If \( Q_{SIU_i} \leq 0.0 \),

If boiler on,

\[ TLC_i = -Q_{SIU_i} / (Z_{MAS_i} * 0.245) + TSP \]

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.

\[ QLN_{i} = Q_{SIU_i} \]

Update as required the following variables:

\[ QHLNM_i, QHPNM_i, IHHNM_i \]

If \( Q_{SIU_i} > 0.0 \), cooling load not met.

\[ QLN_{i} = Q_{SIU_i} \]

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 $Q_{SIU_1} > 0.0$, cooling required.

If chiller on,

$$TLC_1 = -\frac{Q_{SIU_1}}{(ZMAS_1 * 0.245)} + TSP_2$$

Call subroutine ZL03 to calculate cooling load and distribute an unmet load, if any.

If chiller off, cooling load not met.

$$QLN_{NM_1} = Q_{SIU_1}$$

Update as required the following variables:

$$Q_{CLNM_1} -$$
$$Q_{CPNM_1} -$$
$$I_{HCMN_1} -$$

If $Q_{SIU_1} < 0.0$, heating load not met.

$$QLN_{NM_1} = Q_{SIU_1}$$

Update as required the following variables:

$$Q_{HLMN_1} -$$
$$Q_{HPNM_1} -$$
$$I_{HHNM_1} -$$

13.2 Four-pipe induction unit.

If $Q_{SIU_1} < 0.0$, heating required.

If boiler on,

$$TLC_1 = -\frac{Q_{SIU_1}}{(ZMAS_1 * 0.245)} + TSP_2$$

Call subroutine ZL03 to calculate induction unit heating load and distribute an unmet load, if any.

If boiler off, heating load not met.

$$QLN_{NM_1} = Q_{SIU_1}$$

Update as required the following variables:

$$Q_{HLMN_1} -$$
$$Q_{HPNM_1} -$$
$$I_{HHNM_1} -$$
If QSIU_i > 0.0, cooling required,

If chiller on,

\[ TLC_i = -\frac{QSIU_i}{(ZMAS_i \times 0.245)} + TSP \]

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:

\[ QCLNM_i, QCPNM_i, IHNCNM_i \]

14. Calculate thermal properties (temperature and humidity ratio) of air leaving the induction unit.

\[ TTLVG_i = \frac{(TLVG \times ZMASS_i + TLC \times ZMAS_i)}{(ZMASS_i + ZMAS_i)} \]

\[ WTLVG_i = \frac{(WSUP \times ZMASS_i + WCLVG \times ZMAS_i)}{(ZMASS_i + ZMAS_i)} \]

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.

\[ WRA_k = \frac{\sum_{j=1}^{m_{max}} WZ_i \times ZMASR_i \times \text{MULT}_i}{\sum_{j=1}^{m_{max}} ZMASR_i \times \text{MULT}_i} \]

\[ DRA_k = \frac{PATM}{(0.754 \times (TRA_k + 460.0) \times (1.0 + 7000.0 \times WRA_k/4360.0))} \]

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

\[ QCO = PWGAL_k \times 8.3 \times (THW - TLCHL) \]

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\textsubscript{2}O/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.

\[ QSI_i = QS \] **


If boiler on, call subroutine BRAD2 to calculate baseboard radiation heat \( (QB_j) \) and to adjust \( QSI_i \) for \( QB_j \).

\[ TQB = \sum_{j=1,j_{max}} QB_j \]

If boiler off, continue.

5. Calculate air mass flow and temperature to each zone,

\[ ZMAS_i = \frac{QSI_i}{0.245 \times (TSP_j - TLVG)} \]

If \( ZMAS_i > ZMASS_i \)

\[ ZMAS_i = ZMASS_i \]

If \( ZMAS_i < ZMASS_i \times VVMIN_k \)

\[ ZMAS_i = ZMASS_i \times VVMIN_k \]

\[ ZMASR_i = ZMAS_i - ZMASX_i \]

If \( ZMASR_i < 0.0 \),

\[ ZMASR_i = 0. \]

\[ TSi = TSP_j - \frac{QSI_i}{0.245 \times ZMAS_i} \]

6. Calculate system mass flows.

\[ FMAS_k = \sum_{j=1,j_{max}} ZMAS_i \times MULT_i \]

\[ FMR_k = \sum_{j=1,j_{max}} ZMASR_i \times MULT_i \]

7. Calculate supply and return air full load flows.

\[ PCTSA = \frac{FMAS_k}{FMAS_k} \]

\[ PCTRA = \frac{FMR_k}{FMR_k} \]

** There is a corresponding \( i \) for each \( i \); a relationship defined by the variable SPACN. Hence, \( i \) and \( j \) 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,

\[
\begin{align*}
DLT2 &= 0. \\
QLITI &= QLITJ + QS_{pl} + QLITJ_{pl} + QSINF_{pl} \\
& \quad + DTL2_{i} + DTL_{i} + DTL2_{i} \cdot ZMASR_{i} \cdot MULT_{i}
\end{align*}
\]

If VARIABLE TEMPERATURE tape is used,

\[
\begin{align*}
DLT2 &= STEM_{pl} - TSP_{pl} \\
QLITI &= QLITJ
\end{align*}
\]

If ceiling plenum is not calculated as a separate zone,

\[
\begin{align*}
DLT2 &= 0. \\
QLITI &= QLITJ \quad \text{if ceiling plenum is not calculated as a separate zone},
\end{align*}
\]

\[
\begin{align*}
DTL_{i} &= QLITJ/(0.245 \cdot ZMASR_{i}) \\
TRA &= \sum_{j=1,j_{max}^{1}}^{j_{max}} (TSP_{j} + DTL_{i} + DTL2_{i}) \cdot ZMASR_{i} \cdot MULT_{i} \\
& \quad + DTFNR_{k} \cdot PTLD(NVFC_{k}, PCTRA)
\end{align*}
\]

where

\[
\begin{align*}
DLT2_{i} &= \text{difference between zone and plenum temperatures as calculated by VARIABLE TEMPERATURE program.} \\
QLITI &= \text{thermal load of plenum } pl \text{ above zone } \lambda \text{ as calculated by LOAD program.} \\
pl &= \text{LOAD program space number of plenum above zone } \lambda.
\end{align*}
\]

9. Zone humidity calculations.

Using subroutine H20ZN, 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°F
   \[ TLVG = 125°F \]
   \[ EAT = TLVG - DTFNS_k \]
   If EAT < 40°F
   \[ EAT = 40°F \]
   \[ TLVG = EAT + DTFNS_k \]

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 (temperature, 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,
       \[ TLVG = TMA + DTFNS_k \times PTLD(NVFC_k, PCTSA) \]
       Go to 12.4.
   12.3 If chiller off and cooling required at AHU,
       \[ TLVG = TMA + DTFNS_k \times PTLD(NVFC_k, PCTSA) \]
       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.

$\text{PCTSA} = \frac{\text{SMCFM}}{\text{CFMAX}}_k$

$\text{TNFBP} = \text{TNFBP} + (\text{PTLD}(\text{NVFC}_k, \text{PCTSA}) - 1.0) \times \text{FBHPS}_k$  

$+ (\text{PTLD}(\text{NVFC}_k, \text{PCTRA}) - 1.0) \times \text{FBHPR}_k$

14. Calculate base power (KW); includes internal power, lights receptacles, equipment, misc.

$\text{BPKW} = \sum_{j=1}^{\text{jmax}} \text{SLPOW}_{j} \times \text{MULT}_{j}$

15. Terminal unit performance.

$\text{QT}_{i} = \text{ZMAS}_{i} \times 0.245 \times (\text{TLVG} - \text{TS}_{i})$

If no reheat coils,

If $\text{QT}_{i} < 0.0$, heating load not met.

$\text{QLNM}_{i} = \text{QT}_{i}$

Update as required the following variables:

$\text{QHLM}_{i}$

$\text{QHPNM}_{i}$

$I\text{HHNM}_{i}$

5-71
\[ T_{S_i} = TLVG \]
\[ WTLVG = WSUP \] (\( WSUP = \) supply air humidity ratio. \( WSUP = \) 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 ZLO3 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 QT₁ = 0.0,

\[ WTLVG = WSUP \]

If QT₁ > 0.0, cooling load not met.

Call subroutine CCOIL to calculate cooling load not met (QLNM₁).

Update as required the following variables:

- QCLNM₁ -
- QCPNM₁ -
- IHCNM₁ -
- TS₁ = TLVG
- WTLVG₁ = WSUP

Go to 13.

16. Calculate zone humidity ratio.

Using function WZNEW, calculate the humidity ratio of each zone (WZ₁).

17. Calculate return air humidity ratio and density.

\[
WRA_k = \frac{\sum_{j=1, \text{jmax}} WZ_j \times ZMASR_j \times \text{MULT}_j}{\sum_{j=1, \text{jmax}} ZMASR_j \times \text{MULT}_j}
\]

\[
DRA_k = \frac{\text{PATM}}{(0.754 \times (T_R A_k + 460.) \times (1.0 + 7000.0 \times WRA_k/4360.)}
\]

5-73
RHFS2

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-H₂O/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.

   \[ Q_{SI_i} = Q_{SI_k} \]

5-74

If boiler on, call subroutine BRAD2 to calculate baseboard radiation heat (QB\textsubscript{j}) and to adjust QSI\textsubscript{i} for QB\textsubscript{j}.

Sum baseboard radiation heat,

\[
TQB = \sum_{j=1, j_{max}}^{QB_j}
\]

If boiler off, continue.

4. Calculate required zone supply air temperatures.

\[
T_{S_{i}} = T_{SP_{k}} - Q_{SI_{i}} / (0.245 - Z_{MASS_{i}})
\]

5. Calculate base power (Kw); includes internal power, lights receptacles, equipment, misc.

\[
BPKW = \sum_{j=1, j_{max}}^{SLPOW_{j} \cdot MULT_{i}}
\]

6. Calculate return air temperature, TR\textsubscript{A\textsubscript{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,

\[
DTL_{2i} = 0.
\]

\[
QLITI = QLTE_{A} + QS_{PL} + QLTE_{PL} + QSINF_{PL} **
\]

If VARIABLE TEMPERATURE tape is used,

\[
DTL_{2i} = STEMP_{PL} - TSP_{PL}
\]

\[
QLITI = QLTE_{PL}
\]

If ceiling plenum is not calculated as a separate zone,

\[
DTL_{2i} = 0
\]

\[
QLITI = QLTE_{PL}
\]

**NOTE: There is a corresponding \( \lambda \) for each \( i \); a relationship defined by the variable SPACN\textsubscript{i}. Hence, \( i \) and \( \lambda \) are defined by system number (k) and zone number (j). See Para. 5.1 for zone labeling organization.
DTL\_i = QL\_ITI/(0.245 \* ZMASR\_i)\\

\[ TRA_k = \left[ \sum_{j=1,j_{\max}} \frac{(TSP + DTL\_i + DTL2\_i) \* ZMASR\_i \* MULT\_i}{\sum_{j=1,j_{\max}} ZMASR\_i \* MULT\_i} \right] + DTFNR\_k \]

where \( DTL2\_i \) - difference between zone and plenum temperatures as calculated by VARIABLE TEMPERATURE program.

QL\_ITI - thermal load of plenum \( px \) above zone \( x \) as calculated by LOAD program.

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,

\( TLVG = TS\_i \) (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 \( 125.0^\circ \text{F} \)

\( TLVG = 125.0^\circ \text{F} \)

\( EAT = TLVG - DTFNS\_k \)

If EAT \( 40.0^\circ \text{F} \)

\( EAT = 40.0^\circ \text{F} \)

\( TLVG = EAT + DTFNS\_k \)

5-76
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 \((Q_{T1})\) and distribute loads not met.

12.1 Single-zone fan system and constant volume reheat fan systems.

\[
Q_{T1} = ZMASS_1 \times 0.245 \times (TLVG_1 - TS_1)
\]

If \(Q_{T1} < 0.0\),

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.

\[
QLNM_1 = Q_{T1}
\]

Update as required the following variables:

- \(QHLNM_1\)
- \(QHPNM_1\)
- \(IHHNM_1\)
- \(TS_1 = TLVG\)

\[
WTLVG_1 = WSUP \quad (WSUP = \text{supply air humidity ratio. It is calculated in subroutine AHU.})
\]

If \(Q_{T1} = 0.0\),

\[
WTLVG_1 = WSUP
\]

Go to 13.

If \(Q_{T1} > 0.0\), cooling load not met.

Call subroutine CCOIL to calculate cooling load not met \((QLNM_1)\).

Update as required the following variables:

- \(QCLNM_1\)
- \(QCPNM_1\)
- \(IHCNM_1\)
- \(TS_1 = TLVG\)
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.

\[ QLN_{i1} = QT_i \]

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.

\[ QLN_{i1} = QT_i \]

Update as required the following variables:

\[ QCLNM_{i1}, QCPNM_{i1}, IHCNM_{i1} \]

\[ TS_i = TLVG \]

\[ WTLVG_i = WSUP \]

Go to 13.

13. Calculate zone humidity ratio.

Using function \( WZ{NEW} \), calculate the humidity ratio of each zone (\( WZ_i \)).

14. Calculate return air humidity ratio and density.
\[
WRA_k = \frac{\sum_{j=1, j_{\text{max}}} WZ_j \times ZMASR_j \times MULT_j}{\sum_{j=1, j_{\text{max}}} ZMASR_j \times MULT_j}
\]

\[
DRA_k = \frac{\text{PATM}}{(0.754 \times (\text{TRA}_k + 460.)(1.0 + 7000.0 \times WRA_k / 4360.)}
\]
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.

\[
\text{If } \sum_{j=1, j_{max}} |QS_i| \neq 0, \text{ return.}
\]

**NOTE:** There is a corresponding relationship for each i; a relationship defined by the variable SPACN_k,j. Hence, i and j are defined by system number (k) and zone number (j). See Para. 5.1 for zone labeling organization.
If $\sum_{j=1, j_{\text{max}}} |Q_{S,j}| = 0$, **

CONTINUE.

2. Fan system turned off, distribute loads not met.

2.1 Initialize general variables.

\[ QCC = 0. \]
\[ QHC = 0. \]
\[ \text{WATER} = 0. \]
\[ QTRHC = 0. \]
\[ QPHC = 0. \]
\[ TQB = 0. \]

2.2 Zone load distribution.

2.2.1 Sum base power requirements.

\[ \text{BPKW} = \sum_{j=1, j_{\text{max}}} \text{SLPOW}_j \ast \text{MULT}_j \]

2.2.2 Sum baseboard radiation heat.

\[ \text{QLNM}_j = Q_{S} + Q_{\text{LITE}} \]

If boiler on, call subroutine BRAD2 to calculate baseboard radiation heat ($Q_{B_j}$) and adjust $\text{QLNM}_j$.

If boiler off, CONTINUE.

2.2.3 Distribute sensible load not met ($\text{QLNM}_j$).

If $\text{QLNM}_j < 0.0$, heating load not met.

Update the following variables as required:

\[ \text{QHLNM}_j \]
\[ \text{QHPNM}_j \]
\[ \text{IHHNM}_j \]

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$_k$

100 = 1.
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**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IQ</td>
<td>Coil type index (1 = heating; 2 = cooling).</td>
</tr>
<tr>
<td>AMULT</td>
<td>Zone multiplication factor.</td>
</tr>
<tr>
<td>TLC</td>
<td>Desired leaving coil temperature (°F).</td>
</tr>
<tr>
<td>TEC</td>
<td>Entering coil temperature (°F).</td>
</tr>
<tr>
<td>WEC</td>
<td>Entering coil humidity ratio (lbm-H₂O/lbm-dry air).</td>
</tr>
<tr>
<td>TLMCMX</td>
<td>Maximum allowable leaving coil temperature (°F).</td>
</tr>
<tr>
<td>TLMCMN</td>
<td>Minimum allowable leaving coil temperature (°F).</td>
</tr>
</tbody>
</table>

Variables in COMMON. See Table 5.4 for definitions.

**OUTPUT**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>WLVG</td>
<td>Leaving humidity ratio (lbm-H₂O/lbm-dry air).</td>
</tr>
<tr>
<td>QTRHC</td>
<td>System reheat load (Btu/hr).</td>
</tr>
<tr>
<td>QTRCC</td>
<td>System recooling load (Btu/hr).</td>
</tr>
</tbody>
</table>

Also, some variables in COMMON.

**Calculation Sequence**

1. Heating supplied.

   If TLC > TLMCMX,

   TDIF = TLMCMX - TLC
   TLC = TLMCMX
   QTDIF = ZMASᵢ * 0.245 * (TDIF - TLC)
QLNM\_i = QTDIF

Update as required the following variables:

\[ \text{QHLNM}_i \]
\[ \text{QHPNM}_i \]
\[ \text{IHHNM}_i \]

QT = \( ZMAS_i \times 0.245 \times (\text{TEC} - \text{TLC}) \)

\[ \text{QTRHC} = \text{QTRHC} + QT \times \text{AMULT} \]

\[ \text{WLVG} = \text{WEC} \]

If TLC \( \leq \) TLCMX,

\[ \text{QT} = ZMAS_i \times 0.245 \times (\text{TEC} - \text{TLC}) \]

\[ \text{QTRHC} = \text{QTRHC} + QT \times \text{AMULT} \]

\[ \text{WLVG} = \text{WEC} \]

2. Cooling supplied.

If TLC \( < \) TLMCM,

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 TLMCM.

\[ \text{TLC} = \text{TLMCM} \]

\[ \text{QTDIF} = QCTLC - QT \]

\[ \text{QLNM}_i = \text{QTDIF} \]

Update the following variables as required:

\[ \text{QCLNM}_i \]
\[ \text{QCPNM}_i \]
\[ \text{IHCNM}_i \]

\[ \text{QTRCC} = \text{QTRCC} + QT \times \text{AMULT} \]
If TLC \geq TLCMN,

Call subroutine CCOIL to calculate cooling load QT

\[ Q_{TRCC} = Q_{TRCC} + QT \times AMULT \]
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 (°F)
- **CBTU**: Heat output of baseboard radiation at standard conditions (215°F avg. water temp., 65°F entering air temp.) (Btu/hr-lin.ft.)
- **ALFBR**: Active length baseboard radiation (lin.ft.)
- **TOA**: Dry-bulb temperature outside air (°F)
- **THWHI**: °F
- **THWLO**: °F
- **TOAH**: °F
- **TOALO**: °F

**OUTPUT**

- **QB**: Heat given off by baseboard radiation (Btu/hr)

**CALCULATION SEQUENCE**

1. Baseboard heating off.
   
   If \( \text{TOA} > \text{TOAH} \),
   
   \( \text{QB} = 0. \)

2. Baseboard heating on.
   
   If \( \text{TOA} \leq \text{TOAH} \),
   
   \( \text{TAIR} = \text{TSP} - 10. \)

Figure 5.4 Graphic illustration of baseboard hot water temperature reset as function of outside air temperature

5-87
Calculate THW using function TRSET.

\[ QB = - \left( \frac{\text{THW} - \text{TAIR}}{215. - 65.} \right)^{1.4} \times (\text{CBTU} \times \text{ALFBR}) \]

3. Adjust QS.

\[ QS = QS - QB \]
AHU

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-H2O/lbm-dry air).

TMA : Inlet dry bulb temperature (°F).

WMA : Inlet humidity ratio (lbm-H2O/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).
WLYG : Humidity ratio entering humidifier section (lbm-H₂O/lbm-dry air).
DLVG : Air density entering humidifier section (lbm/ft³).
WSUP : Humidity ratio after humidifier section (lbm-H₂O/lbm).
WATER : Water added to air by humidifier (lbm-H₂O/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
   WLYG = WMA
   SHR = 1.0
   GO TO 3.
   If TMA = TLC,
   QHC = 0.0
   QCC = 0.0
   WLYG = WMA
   SHR = 1.0
   GO TO 3.
   If TMA > TLC,
   Call subroutine CCOIL to calculate WLYG, QCC, and SHR.
   QHC = 0.0
   GO TO 3.

5-90
2. Draw-through unit with bypass around cooling coil.

TLC = TLVG - DTFAN * PTLD * (NVPC, PCTLD)

If TMA < TLC,

\[ QHC = MFAN \times 0.245 \times (TMA - TLC) \]
\[ QCC = 0.0 \]
\[ WLVG = WMA \]
\[ SHR = 1.0 \]

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).

\[ QCC = MFAN \times (1.0 - ALFA) \times QCC1 \]

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.)

$$WATER = -MFAN \times (WLVG - WSUP)$$
**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**

<table>
<thead>
<tr>
<th>MXAO</th>
<th>Type of outside air control.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fixed percent outside air.</td>
</tr>
<tr>
<td>2</td>
<td>Enthalpy/temperature type economizer cycle control.</td>
</tr>
<tr>
<td>3</td>
<td>Temperature type economizer cycle control.</td>
</tr>
</tbody>
</table>

**Air Stream #1**

<table>
<thead>
<tr>
<th>TOA</th>
<th>Outside air dry bulb temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOA</td>
<td>Outside air density (lbm/ft³)</td>
</tr>
<tr>
<td>HOA</td>
<td>Outside air enthalpy (Btu/lbm)</td>
</tr>
<tr>
<td>WOA</td>
<td>Outside air humidity ratio (lbm-H₂O/lbm-dry air)</td>
</tr>
</tbody>
</table>

| PATM | Barometric pressure (in. Hg) |

**Air Stream #2**

<table>
<thead>
<tr>
<th>TRA</th>
<th>Return air temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRA</td>
<td>Return air density (lbm/ft³)</td>
</tr>
<tr>
<td>WRA</td>
<td>Return air humidity ratio (lbm-H₂O/lbm-dry air)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EAT</th>
<th>Desired mixed air temperature (economizer approach temperature) (°F)</th>
</tr>
</thead>
</table>

| ALFAM | Minimum fraction of outside air (for MXAO type 1, ALFAM is the fixed portion of outside air). |

**OUTPUT**

<table>
<thead>
<tr>
<th>ALFA</th>
<th>Actual portion of outside air which meets or approaches EAT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMA</td>
<td>Mixed air dry bulb temperature (°F)</td>
</tr>
<tr>
<td>WMA</td>
<td>Mixed air humidity ratio (lbm-H₂O/lbm-dry air)</td>
</tr>
</tbody>
</table>

5-93
OUTPUT (Concluded)

DMA : Mixed air density (lbm/ft³)

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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OA</td>
<td>Outside air dry bulb temperature (°F)</td>
</tr>
<tr>
<td>DOA</td>
<td>Outside air density (lbm/ft$^3$)</td>
</tr>
<tr>
<td>RA</td>
<td>Return air dry bulb temperature (°F)</td>
</tr>
<tr>
<td>DRA</td>
<td>Return air density (lbm/ft$^3$)</td>
</tr>
<tr>
<td>LVG</td>
<td>Desired mixed air dry bulb temperature (°F)</td>
</tr>
<tr>
<td>ALFAM</td>
<td>Minimum fraction of outside air</td>
</tr>
</tbody>
</table>

OUTPUT

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALFA</td>
<td>Portion of outside air yielding mixed temperature closest to desired mixed air temperature</td>
</tr>
</tbody>
</table>

CALCULATION SEQUENCE

1. Select appropriate mode.

   Mode 1. Return air temperature greater than outside air temperature.

   If LVG < OA,

   \[ ALFA = 1.0 \]

   If LVG > OA,

   If LVG < RA,

   \[ ALFA = \frac{(DRA \times (RA - LVG))/(RA \times DRA - OA \times DOA + LVG)}{(DOA - DRA)} \]

   If LVG > 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 \( LVG < OA \),

\[ ALFA = \frac{(DRA \times (RA - LVG))}{(RA \times DRA - OA \times DOA + LVG \times (DOA - DRA))} \]

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\(_2\)O/lb-dry air)
TDBO : Dry bulb temperature of leaving air (°F)

OUTPUT

WO : Humidity ratio of leaving air (lb-H\(_2\)O/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 \( DT < 0.0 \),

\[
QCC = 0.0
\]

\[
SHR = 1.0
\]

\[
WO = WI
\]
If DT > 0.0,

\[ QSC = MASS \times 0.245 \times DT \]

Use subroutine PSY1 to calculate leaving air humidity ratio (WO)
\[ DW = WI - WO \]

If DW < 0.0,
\[ WO = WI \]
\[ QCC = QSC \]
\[ SHR = 1.0 \]

If DW > 0.0,
\[ QLC = MASS \times 1090.0 \times DW \]
\[ QCC = QSC + QLC \]
\[ SHR = QSC/QCC \]

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.
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.](image)

**CALCULATION SEQUENCE**

- If \( TOA \leq TOALO \),
  - \( TRSET = THI \)
- If \( TOA > TOALO \),
  - If \( TOA > TOAHI \),
    - \( TRSET = TLO \)
  - If \( TOA < TOAHI \),
    - \( TRSET = \frac{(THI - (THI - TLO) \times (TOA - TOALO))}{(TOAHI - TOALO)} \)
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 < PC < 1.10

CALCULATION SEQUENCE

1. Variable Speed Motor

\[ PTLD = 0.0015302776 + PC \times (0.0052080574 + PC \times (1.1086242 + PC \times (-0.11635563))) \]
2. Inlet Vane Damper

\[ PTLD = 0.35071223 + PC \times (0.3080535 + PC \times (-0.54137364 + PC \times (0.87198823))) \]

3. Discharge Damper

\[ PTLD = 0.37073425 + PC \times (0.97250253 + PC \times (-0.34240761)) \]

**Figure 5.7** POWER SAVINGS VS AIR QUANTITY REDUCTION FOR THREE COMMON METHODS OF CONTROLLING DUCT STATIC PRESSURES
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 \( \text{TOACO} < \text{TOA} \),

If \( \text{TDBHI} \leq \text{TOA} \),

\( \text{TLVG} = \text{TLALO} \)

\( \text{IPW} = 1 \)

\( \text{TOACO} = \text{TDBLO} \)

If \( \text{TDBHI} > \text{TOA} \),

Calculate \( \text{TLVG} \) using function \( \text{TRSET} \).

\( \text{IPW} = 1 \)

\( \text{TOACO} = \text{TDBLO} \)

If \( \text{TOACO} = \text{TOA} \),

Calculate \( \text{TLVG} \) using function \( \text{TRSET} \).

If \( \text{TOACO} \leq \text{TDBLO} \),

\( \text{TOACO} = \text{TDBLO} + 5.0 \)

\( \text{IPW} = -1 \)

If \( \text{TOACO} > \text{TDBLO} \),

\( \text{TOACO} = \text{TDBLO} \)

\( \text{IPW} = -1 \)

If \( \text{TOACO} > \text{TOA} \),

\( \text{TLVG} = \text{TLALO} \)

\( \text{TOACO} = \text{TDBLO} + 5.0 \)

\( \text{IPW} = -1 \)
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 T\textsubscript{S1} values. Set TLVG equal to largest T\textsubscript{S1}.

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PSYCH

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.

\[ H = 0.24 \times T + W \times (1061.0 + 0.444 \times T) \]

2. Calculate specific volume.

\[ V = 0.754 \times (T + 459.688) \times (1.0 + 7000.0 \times W/4360.0)/PATM \]

3. Calculate specific density.

\[ DEN = 1.0/V \]
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 temperature (°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).

\[
PPWV = PPWVM(WBT) - 0.000367 \times PATM \times (DBT - WBT) / \\
(1.0 + (WBT - 32.0) / 1571.0)
\]

2. \(HUMRAT = 0.622 \times PPWV / (PATM - PPWV)\)

3. \(ENTH = 0.24 \times DBT + (1061.0 + 0.444 \times DBT) \times HUMRAT\)

4. \(DENS = 1.0 / (0.754 \times (DBT + 460.0) \times (1.0 + 7000.0 \times HUMRAT / 4360.0) / PATM)\)
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 (°F)

OUTPUT

PPWVM : partial pressure of water in moisture-saturated air
        (in. Hg)

CALCULATION SEQUENCE

1. Let $A(1) = -7.90298$
   $A(2) = 5.02808$
   $A(3) = -1.3816 \times 10^{-7}$
   $A(4) = 11.344$
   $A(5) = 8.1328 \times 10^{-3}$
   $A(6) = -3.49149$

2. Let $T = (t + 459.688)/1.8$
   If $T$ is less than 273.16, go to 3.
   Otherwise
   
   $z = 373.16/T$
   $P1 = A(1) \times (z-1)$
   $P2 = A(2) \times \log_{10}(z)$
   $P3 = A(3) \times (10^{(A(4) \times (1-1/z))-1})$
   $P4 = A(5) \times (10^{(A(6) \times (z-1))-1})$

   Go to 4.

3. Let $z = 273.16/T$
   $P1 = B(1) \times (x-1)$
   $P2 = B(2) \times \log_{10}(z)$
   $P3 = B(3) \times (1-1/z)$
   $P4 = \log_{10}(B(4))$

4. $PVS = 29.921 \times 10^{(P1 + P2 + P3 + P4)}$
HUMI

A subroutine to calculate the humidity ratio (1b-H₂O/1b-dry air) of air given

T - dry-bulb temperature (°F)
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 (1b-air/cu.ft.) given

T - dry-bulb temperature (°F)
W - humidity ratio (1b-H₂O/1b-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.

\[
\log_{10}(X) = 0.434294481 \times \log_e(X)
\]
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<sub>2</sub>O/lbm-dry air)
QLINF : Latent load due to infiltration from load tape (Btu/hr)
WZON : Current zone humidity ratio (lbm-H<sub>2</sub>O/lbm-dry air)
WOA : Outside air humidity ratio (lbm-H<sub>2</sub>O/lbm-dry air)

**OUTPUT**

H2OAD : Zone water change in current hour (lbm-H<sub>2</sub>O)
H2ORD : Net zone water requirement

**CALCULATION SEQUENCE**

1. Zone load water.
   \[ H20RM = QL/1090.0 \]

2. Infiltration water.
   \[ H20IN = (QLINF/1090.0) \times \frac{(WOA - WZON)}{(WOA - WSP)} \]

3. Set point recovery load.
   \[ H20VL = (WZON - WSP) \times ZMASS \]

4. Summaries.
   \[ H2OAD = H20RM + H20IN \]
   \[ H2ORD = H2OAD + H20VL \]
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 temperature (°F)
- **TLC**: Supply air temperature (°F)
- **WLC**: Supply air humidity ratio (lbm-H$_2$O/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 in current hour (lbm-H$_2$O)
- **WZ**: Current zone humidity ratio (lbm-H$_2$O/lbm-dry air)

**OUTPUT**

- **WZNEW**: New humidity ratio (lbm-H$_2$O/lbm-dry air)

**CALCULATION SEQUENCE**

1. Calculate supply air moisture and net moisture to zone.
   
   Call function DENSY to calculate supply air density (DLVG)
   
   \[ H2OS2 = CFMS \times DLVG \times 60.0 \times (WLC - WZ) \]
   
   \[ DH2O = H2OS2 + H2OAD \]

2. Calculate new humidity ratio.
   
   \[ AIR = CFMS \times 60.0 \]
   
   If \( AIR < VOL \), \( AIR = VOL \)
   
   \[ WZNEW = DH2O/(AIR \times DLVG) + WZ \]
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 (°F)
ELDEM : Hourly electrical demand of the building (KW)
TLCHL : Chilled water set point temperature (°F)
TPS : Temperature of high pressure purchased steam (°F)
PPS : Pressure of high-pressure purchased steam (psig)
TESTM : Temperature of low pressure steam (°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.

\[ QHBC = \frac{QHBC}{12000.0} \]

2. Calculate the enthalpy of entering and leaving steam (for boilers and absorption chillers).
2.1 For entering condition, use

\[
\begin{align*}
   AH &= 1068.0 - 0.485 \times PESTM \\
   BH &= 0.432 + 0.000953 \times PESTM \\
   CH &= 0.000036 - 0.000000496 \times PESTM \\
   HESTM &= AH + BH \times TESTM + CH \times TESTM \times TESTM
\end{align*}
\]

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 \( (1.0 - QHBC/(0.9 \times NUMC \times SZC)) \) 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.

\[
FFL = \frac{QHBC}{NC \times SZC}
\]

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.

\[
FFL = 1.1
\]

\[
QRNM = (QHBC - NC \times SZC \times FFL) \times 12
\]

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 \((1.0 - \frac{QHBC}{0.9 \times NUMC \times SZC})\) 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.

\[
FFL = \frac{QHBC}{NUMC \times SZC + NAC \times SZAC}
\]

If necessary, increase NAC until FFL < 0.9.

5. Calculate the energy consumption required for cooling.

5.1 If the quantity \((1.0 - \frac{QHBC}{0.9 \times NUMC \times SZC})\) 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:

\[
ELEC = \frac{ELEC}{1.0 + 0.02133 \times ELEC/QHBC}
\]

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

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If \( M2 = 2 \), 
\[
QILC = \frac{QHMC}{(0.8 \times HYHO)}
\]
\[
STMC = 0.0
\]

If \( M2 = 3 \), 
\[
STMC = STMC
\]

If \( M2 = 4 \), 
\[
ELEC = \frac{QHMC}{3413.0}
\]
\[
STMC = 0.0
\]

5.2 If the quantity \((1.0 - \frac{QHBC}{(0.9 \times NUMC \times SZC)})\) 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:

\[
PW1 = \frac{PWL}{(1.0 + 0.02133 \times PW1)}
\]

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:

\[
PW2 = \frac{PW2}{(1.0 + 0.02133 \times NAC \times SZAC \times FFL)}
\]

Total energy consumption for cooling

\[
ELEC = PW1 + PW2
\]

6. Calculate the energy consumption required for heating.

If \( QHBH > NUMB \times SZB \times 1000.0 \), boiler load not met.

\[
QBNM = QHBH + SZB \times NUMB \times 1000.0 \quad (QBNM = \text{boiler load not met})
\]

\[
QHBH = SZB \times NUMB \times (-1000.0)
\]

Update as required the following boiler load not met variables:
If $M3 = 1$, (gas-fired boiler), $GASH = -QHBH/80000.0$

If $M3 = 2$, (oil-fired boiler), $OILH = -QHBH/(0.8 \times HVHO)$

If $M3 = 3$, (purchased steam heat), $STMH = -QHBH/(HESTM - HLSTM)$

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),
    $OILH = OILH - QHBRH/(0.8 \times HVHO)$

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.

$$FFLE = ELDEM/(NE \times SZE)$$

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.
   \[ FFL = \frac{QHBC}{NC \times SZC} \]
   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.
   \[ FFL = 1.1 \]
   \[ QRNM = (QHBC - NC \times SZC \times FFL) \times 12 \]
   \[ QHBC = NC \times SZC \times FFL \]
   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 \(-Q_{HBH} - Q_{EN} + Q_{HMC} > NUMB \cdot SZB \cdot 1000.0\), boiler load not met:

\[ Q_{BNM} = (Q_{HBH} + Q_{EN} - Q_{HMC}) + (NUMB \cdot SZB \cdot 1000.0) \]

\[ Q_{HBH} = NUMB \cdot SZB \cdot (-1000.0) \]

Update as required the following boiler load not met variables:

\[ Q_{BCNM} - \]

\[ Q_{BPNM} - \]

\[ I_{HBNM} - \]

If \(M3 = 1\), \(GASH = (Q_{HMC} - Q_{HBH} - Q_{EN})/80000.0\)

\[ STMC = 0.0 \]

If \(GASH < 0.0\), set \(GASH = 0.0\).

If \(M3 = 2\), \(OILH = (Q_{HMC} - Q_{HBH} - Q_{EN})/(0.8 \cdot HVHO)\)

\[ STMC = 0.0 \]

If \(OILH < 0.0\), set \(OILH = 0.0\).

14. Compute energy consumption required for reheat.

If \(K_{REHT} = 0\), not applicable.

If \(K_{REHT} = 1\), \(GASH = GASH - Q_{HRB}/80000.0\)

If \(K_{REHT} = 2\), not applicable.

If \(K_{REHT} = 3\), not applicable.

END OF ON-SITE POWER GENERATION ANALYSIS.
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)
   
   \[
   \text{POWER} = 1.341 \times \frac{\text{POWER}}{\text{NSTON}}
   \]

2. Determine the enthalpy of entering steam (H1).
   
   \[
   \text{H1} = \text{AH} + \text{BH} \times \text{TPS} + \text{CH} \times \text{TPS} \times \text{TPS}
   \]
   
   where
   - \( \text{AH} = 1068.0 - 0.485 \times \text{PPS} \)
   - \( \text{BH} = 0.432 + 0.000953 \times \text{PPS} \)
   - \( \text{CH} = 0.000036 - 0.000000496 \times \text{PPS} \)

3. Calculate the entropy of steam.
   
   \[
   \text{S} = 2.385 - 0.004398 \times \text{TSAT1} + 0.000008146 \times \text{TSAT1} \times \text{TSAT1}
   
   -0.662 \times 10^{-8} \times (\text{TSAT1}^2) + 2.0 \times \text{CH} \times (\text{TPS} - \text{TSAT1})
   
   + (\text{BH} - 920.0 \times \text{CH}) \times \text{ALOG}((\text{TPS} + 460.0)/(\text{TSAT1} + 460.0))
   \]
where

\[ TSAT_1 = 1.0/(0.0017887 - 0.00011429 \times \text{ ALOG (PPS)}) - 460.0 \]

4. Find the temperature of steam after isentropic expansion and exhausting at 2 psia (condensing turbine).

\[ T_2 = 1.0/(0.0017887 - 0.00011429 \times \text{ ALOG (2.0)}) - 460.0 \]

5. Find the enthalpy of leaving steam.

\[ H_2 = 1.0045 \times T_2 - 32.448 + (T_2 + 460.0) \times (S - 1.0045 \times \text{ ALOG (T_2 + 460.0)} + 6.2264) \]

6. Calculate the theoretical steam rate (lb/HP-hr).

\[ \text{TSR} = 3413.0/(H_1 - H_2) \]

7. Calculate base steam rate.

\[ \text{BSR} = \text{SLOPE} \times \text{TSR} + B \]

where

\[ B_0 = 84.0 - 0.017 \times \text{SZT} + 1.5625 \times ((\text{SZT}/1000.0) \times 2.0) \]
\[ B_1 = -19.7 + 0.001025 \times \text{SZT} \]
\[ B_2 = 1.4 \]

\[ B = B_0 + B_1 \times \text{RPM/1000.0} + B_2 \times ((\text{RPM/1000.0}) \times 2.0) \]
\[ \text{SLOPE} = 5.88 - 0.011865 \times \text{SZT} + 0.1173 \times ((\text{SZT/1000.0}) \times 2.0) \]
\[ S_1 = -1.1 + 0.000533 \times \text{SZT} - 0.0581 \times ((\text{SZT/1000.0}) \times 2.0) \]
\[ S_2 = 0.116 - 0.000057 \times \text{SZT} + 0.00709 \times ((\text{SZT/1000.0}) \times 2.0) \]

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).

\[ \text{HPLSS} = 0.0334 \times ((\text{RPM/1000.0}) \times 2.42) \times ((\text{SZT/1000.0}) \times 1.47) \]
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).

\[ \text{FLSR} = \frac{\text{BSR}}{\text{SC}} \times (\frac{\text{SZT} + \text{HPLSS}}{\text{SZT}}) \]

11. Determine the part load steam rate for one turbine (lb/hr).

\[ \text{STEAM} = \text{FLSR} \times \text{SZT} \times (\frac{\text{PLB} + \text{PLM} \times \text{POWER}}{\text{SZT}}) \]

12. Calculate the total hourly steam consumption (lb/hr).

\[ \text{STEAM} = \text{STEAM} \times \text{NSTON} \]
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.
   
   \[ POPTN = 0.049 \times \text{ALOG} (TLCON/TLCHL) \times TLCHL \times 0.8 \]
   
   (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).
   
   \[ ERROR = 2.4531 - 0.041229 \times TLCON - 0.0273842 \times TLCHL \]
   
   \[ + 0.000118191 \times TLCON \times TLCON + 0.00047537 \]
   
   \[ * TLCHL \times TLCON - 0.000197535 \times TLCHL \times TLCHL \]

4. Calculate the full load power per ton.
   
   \[ POPTN = POPTN - ERROR \]
5. Determine the total hourly part load power consumption.

\[
\text{POWER} = \left(\frac{0.1641}{\text{FFL}} + 0.2543 + 0.73965 \times \text{FFL} - 0.15835 \times \text{FFL} \times \text{FFL}\right) \times \text{POPTN} \times \text{QHBC}
\]
RECIPE

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).

   \[ POPTN = (0.3371 + 0.01223 \times TECON - 0.009749 \times TLCHL) \times (0.868 + 0.133 \times FFL) \]

   where POPTN has units of kilowatts per ton.

2. Determine total hourly power consumption.

   \[ POWER = POPTN \times QBHC \]
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.

\[
RAT = -2.8246 + 0.06575 \times TECON - 0.06011 \times PESTM \\
+ 0.06433 \times TLCHL + 0.0011862 \times TECON \times PESTM \\
+ 0.00023232 \times TECON \times TLCHL + 0.00025421 \times PESTM \times TLCHL \\
- 0.0006199 \times PESTM \times PESTM - 0.0006438 \times TECON \times TECON - 0.0015887 \\
\]

2. Find the capacity factor which adjusts for chilled water temperature drop other than 10°F.

\[
CMULT = 0.9190 + 0.010333 \times TDROP - 0.0002222 \times TDROP \\
\times TDROP
\]
3. Calculate the total capacity factor.

\[ \text{RAT} = 0.91 \times \text{CMULT} \times \text{RAT} \]

where 0.91 is fouling factor.

4. Calculate the full load steam rate (lb/hr-ton).

\[ \text{SRATE} = 22.169 + 0.592 \times \text{PESTM} - 0.0196 \times \text{PESTM} \times \text{PESTM} - 6.9384 \times \text{RAT} \]

5. Determine the part load steam consumption.

\[ \text{STEAM} = \text{SRATE} \times (0.0136/\text{FFL} + 0.7928 + 0.11843 \times \text{FFL} + 0.0752 \times \text{FFL} \times \text{FFL}) \times \text{QHBC} \]

5-130
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)
   \[ VP = (WOA/0.622 \times PATM)/(1.0 + WOA/0.622) \]

2. Sensible heat required to raise temperature of snow from outside air temperature to melting point (Btu/hr-sq ft)
   \[ QSEN = 2.6 \times SNOW \times (33.0 - TOA) \]

3. Latent heat required to melt snow (Btu/hr-sq ft)
   \[ QLAT = 746.0 \times SNOW \]

4. Heat required to evaporate melted snow (Btu/hr-sq ft)
   \[ QEVAP = 1075.0 \times (0.0201 \times VWIND + 0.055) \times (0.185 - VP) \]

5. Heat transferred by convection and radiation (Btu/hr-sq ft)
\[ Q_{\text{CONV}} = 11.4 \times (0.0201 \times V_{\text{WIND}} + 0.055) \times (33.0 - T_{\text{OA}}) \]

6. Determine total heat required (Btu/hr)
\[ Q_{\text{TOT}} = \frac{(S_{\text{AREA}} \times (Q_{\text{SEN}} + Q_{\text{LAT}} + 0.5 \times Q_{\text{EVAP}} + 0.5 \times Q_{\text{CONV}}))}{0.7} \]

where the edge loss factor is 0.3 and the area ratio of snow-free area to slab area is 0.5.
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

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 HTCON as given below.
COMMON INPUT VARIABLES:

See Table 5.4 for definitions of variables in COMMON.

OUTPUT

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NUMHC</td>
<td>Number of heat conservation machines</td>
</tr>
<tr>
<td>SZHC</td>
<td>Size of heat conservation machines, tons</td>
</tr>
<tr>
<td>NUMC</td>
<td>Number of auxiliary chillers (In COMMON)</td>
</tr>
<tr>
<td>SZC</td>
<td>Size of auxiliary chillers, tons (In COMMON)</td>
</tr>
<tr>
<td>NUMB</td>
<td>Number of boilers (In COMMON)</td>
</tr>
<tr>
<td>SZB</td>
<td>Size of boilers, MBH (In COMMON)</td>
</tr>
<tr>
<td>CAPH</td>
<td>Total heating capacity, MBH</td>
</tr>
<tr>
<td>CAPC</td>
<td>Total cooling capacity, tons</td>
</tr>
<tr>
<td>SZSCL</td>
<td>Size of supplementary heating unit in chilled water circuit, MBH</td>
</tr>
<tr>
<td>ENGY</td>
<td>Energy resource peak and consumption matrix (See Table 5.3).</td>
</tr>
</tbody>
</table>

CALCULATION SEQUENCE

1. Calculate cooling capacity required.
   
   \[ QCR = NUMC \times SZC \times 12000 \]
   
   where QCR has unit of Btu/hr.

2. Calculate heating capacity required.
   
   \[ QHR = -1000 \times NUMB \times SZB \]
   
   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 ≥ |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.

\[
CAPC = \frac{QCR}{12000.0}
\]

where CAPC has units of tons.

3.1.2 Set NUMHC = 2 (number of heat conservation machines).

\[
SZHC = CAPC \times 1.3 \times 0.5 / NUMHC
\]

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).

\[
CAPH = SZHC \times NUMHC \times 12000.0 / 1000.
\]

3.1.4 Compute total heating requirements (MBH).

\[
QHR = NUMB \times SZB
\]

3.1.5 Compute size of boilers required in condenser water circuit. This is for supplemental heat.

\[
SZB = \frac{(QHR - CAPH)}{NUMB}
\]

where SZB has units of MBH. Note that the definitions of SZB and NUMB have changed from those at entry to HTC01N. The number value of NUMB does not change.
3.1.6 Compute size of supplementary heat element required in chilled water circuit.

\[ \text{SIZSCL} = \frac{\text{CAPH}}{1.3} \]

where SIZSCL 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.

\[ \text{CAPH} = \frac{-\text{QHR}}{1000.0} \]

where CAPH has units of MBH.

3.2.2 Set NUMHC = 2 (number of heat conservation machines).

\[ \text{SZHC} = \frac{\text{CAPH}}{12.0 \times \text{NUMHC}} \]

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.

\[ \text{QCA} = \frac{(\text{SZHC} \times \text{NUMHC}) \times 12000.0}{(1.3 \times 0.5)} \]

3.2.4 Compute amount of cooling which must be provided by auxiliary chillers, Btu/hr.

\[ \text{QDIF1} = \text{QCR} - \text{QCA} \]

3.2.5 Compute size of auxiliary chillers.

Set NUMC = 1 (number of auxiliary chillers).

\[ \text{SZC} = \frac{\text{QDIF1}}{12000.0 \times \text{NUMC}} \]

where SZC has units of tons. Note that the definitions and number values of SZC and NUMC have changed from those at HTC0N entry.

5-138
3.2.6 Compute total cooling capacity.

\[ \text{CAPC} = \frac{QCA}{12000.0} + \text{NUMC} \times \text{SZC} \]

where CAPC has units of tons.

3.2.7 Compute size of supplementary heating element in chilled water circuit, MBH.

\[ \text{SZSCL} = \frac{\text{CAPH}}{1.3} \]

4. Size all pump water flows.

4.1 Chilled water flow rate, gpm.

\[ \text{GPMCL} = 2.4 \times \text{CAPC} \]

4.2 Condenser water flow rate, gpm.

\[ \text{GPMCN} = 3.0 \times \text{CAPC} \]

4.3 Boiler water flow rate, gpm.

\[ \text{GPMBL} = \frac{\text{CAPH} \times 1000.0}{(500.0 \times 20.0)} \]

4.4 Well water flow rate, if used, gpm.

\[ \text{GPMWW} = \frac{\text{SZSCL} \times 1000.0}{(60.0 \times 8.3 \times 1.0 \times (\text{TWWIN} - \text{TCLMN}))} \]

5. Size all pump motors assuming pump efficiency of 60%.

5.1 Chilled water pump horsepower.

\[ \text{HPCLP} = \frac{\text{GPMCL} \times \text{HDCLP}}{3962.0 \times 0.6 \times \text{EFF}} \]

5.2 Condenser water pump horsepower.

\[ \text{HPCNP} = \frac{\text{GPMCN} \times \text{HDCNP}}{3962.0 \times 0.6 \times \text{EFF}} \]

5.3 Boiler water pump horsepower.

\[ \text{HPBLP} = \frac{\text{GPMBL} \times \text{HDBLP}}{3962.0 \times 0.6 \times \text{EFF}} \]

5.4 Well water pump horsepower.

\[ \text{HPWWP} = \frac{\text{GPMWW} \times \text{HDWWP}}{3962.0 \times 0.6 \times \text{EFF}} \]
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,

\[ \text{HPBLA} = \frac{\text{CAPH} \times 1000.0}{(33472.0 \times 20.0)} \]

7. Size cooling tower fan.

7.1 Cooling tower air flow requirement, cfm.

\[ \text{CFMCT} = 300.0 \times \text{CAPC} \]

7.2 Cooling tower fan horsepower requirement assuming 1.0 inch of water total pressure.

\[ \text{HPCTF} = \frac{\text{CFMCT} \times 1.0}{(6346.0 \times \text{EFF})} \]

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.

\[ \text{VWIND} = 1.151 \times \text{VEL} \]

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 \( \text{TOA} \geq \text{TCO} \), summer operation; therefore, go to calculation 13.

If \( \text{TOA} < \text{TCO} \), winter operation; therefore, go to calculation 14.


13.1 Begin fan system analysis repeating the following calculations for each fan system within the building.

5-140
13.1.1 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

13.1.2 Keep running total of building cooling, heating, and power loads.

QHBC = \sum_{k=1, k_{\text{max}}}^{k} QFPC_k

QHBH = \sum_{k=1, k_{\text{max}}}^{k} QFPH_k + QFPCH_k + TQB_k

QHRBH = \sum_{k=1, k_{\text{max}}}^{k} QFPRH_k

PWL_K = \sum_{k=1, k_{\text{max}}}^{k} PWL_k

13.2 Calculate hourly energy consumption. Call EQUIP, which the following:

GASC

GASH

GASG

OILC

OILH

STMC

STMH

ELEC

ELEH

FUEL 5-141
13.3 Go to calculation 15.


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:

\[ Q_{SUMC} = \sum_{j=1, j_{max}}^{max_k} Q_{S(L)(pos)} \times \text{MULT} \]

\[ Q_{SUMH} = \sum_{j=1, j_{max}}^{max_k} Q_{S(L)(pos)} \times \text{MULT} \]

14.1.2 Calculate supply air temperature required for each zone.

\[ T_{S(I)} = T_{S(L)} - \frac{Q_{S(L)}}{1.08 \times CFM(I)} \]

14.1.3 Form the summation.

\[ SUMC_T = \sum_{j=1, j_{max}}^{max_k} (CFM(I) \times T_{S(I)}) \]

14.1.4 Calculate required leaving-condenser water temperature assuming schedule below which is a function of the hourly heating requirement of the building.

\[ T_{LCON} = T_{LCNM} - 22.5 \times (1.0 - \frac{Q_{SUMH}}{QHR}) \]

14.1.5 Calculate leaving-chilled water temperature assuming the schedule shown below.

```
<table>
<thead>
<tr>
<th>TLCHL</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
</tr>
<tr>
<td>44</td>
</tr>
<tr>
<td>35</td>
</tr>
<tr>
<td>65</td>
</tr>
</tbody>
</table>
```

This schedule can be expressed in equation form as:

\[ TLCHL = 44.0 + \frac{(65.0 - TOA)}{5.0} \]

**NOTE:** There is a corresponding L for each I, a relationship defined by the variable SPACH(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 flowing through the cold duct to zone J.

A heat balance around any fan zone J yields

\[ TS(I) = TCD \times BETA(J) + THD(1 - BETA(J)) \]

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

\[ THD = TLCON - 5.0 \times (1 - GAMA(K)) \]
The temperature of air leaving the cooling coil (TCD) is then

\[ TCD = TLCHL + 5.0 \times GAMA(K) \]

Substituting the equation for BETA(J), THD and TCD into the equation for GAMA(K) results in

\[ GAMA(K) = \frac{CFMAX(K) \times (TLCON - 5.0) - SUMCT}{CFMAX(K) \times (TLCON - TLCHL - 10.0)} \]

where

\[ SUMCT = \sum_{j=1}^{jmax} (CFM(I) \times TS(I) \times MULTI(I)) \]

14.2 Calculate the quantity

\[ SUMGX = (GAMA(K) \times CFMAX(K)) \text{ for } K=1 \text{ to } KMAX \]

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.

\[ TPLB = 75.0 + QL1TB / (1.08 \times (CFMBX - CFMEX)) \]

14.5 Determine a weighted average cooling coil leaving air temperature for building.

\[ TCDB = TLCHL + 5.0 \times GAMAB \]

14.6 Calculate a weighted average heating coil leaving air temperature for the building.

\[ THDB = TLCON - 5.0 \times (1.0 - GAMAB) \]

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:

\[ QHBC = 1.08 \times CFMBX \times GAMAB \times (TMA - TCDB) \]

\[ QHBB = 1.08 \times CFMBX \times (1.0 - GAMAB) \times (THDB - TMA) \]

\[ TMAB = TPLB \times (1.0 - ALFA) + TOA \times ALFA \]

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where

\[ \begin{align*} 
Q_{HBC} & \quad \text{is hourly building cooling load} \\
Q_{HBH} & \quad \text{is hourly building heating load} \\
T_{MAB} & \quad \text{is mixed air temperature} \\
\alpha & \quad \text{is fraction of outside air mixing with return air} 
\end{align*} \]

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, \( \alpha \), required such that

\[ Q_{HBH} = 1.3 \times Q_{HBC} \]

Substituting the equations for \( Q_{HBC} \), \( Q_{HBH} \), and \( T_{MAB} \) into the equation yields

\[ \alpha = \frac{T_{PLB}}{T_{PLB} - T_{OA}} - \frac{T_{THDB} \times (1 - \Gamma_{MAB}) + 1.3 \times \Gamma_{MAB} \times T_{CDB}}{(T_{PLB} - T_{OA}) \times (1 + 0.3 \times \Gamma_{MAB})} \]

If \( \alpha > 1.0 \), the heating requirement can be obtained with 100% outside air; therefore, reset \( \alpha = 1.0 \).

If \( 0.0 \leq \alpha \leq 1.0 \), the heating requirement can be obtained with no need for supplementary heat.

If \( \alpha < 0.0 \), supplementary heat is required; therefore, reset \( \alpha = 0.0 \).

14.8 Calculate actual building mixed air temperature, °F.

\[ T_{MAB} = T_{OA} \times \alpha + T_{PLB} \times (1 - \alpha) \]

14.9 Calculate actual building heating load, Btu/h.

\[ Q_{HBH} = 1.08 \times CF_{MBX} \times (1 - \Gamma_{MAB}) \times (T_{MAB} - T_{THDB}) \]

14.10 Calculate any snow-melting load, if applicable, Btu/h.

14.10.1 If \( K_{SNOW} = 0 \), no snow-melting system.

Go to calculation 14.11.

14.10.2 If \( K_{SNOW} = 1 \) 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.

\[
\text{SNOW} = 0.1 \times \frac{\text{SNOWF(ID)}}{24.0}
\]

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:

\[
\text{ID} = 1 + \frac{\text{I HOUR}}{24}
\]

14.10.2.2 Call SNOWM subroutine which calculates QTOT, the snow-melting load.

14.10.2.3 Add QTOT to the heating requirement of the building.

If KSNOW = 1, liquid-type snow-melting system; therefore,

\[
\text{QHBH} = \text{QHBH} - \text{QTOT}
\]

If KSNOW = 2, electric-type snow melting system; therefore,

\[
\text{ELEH} = \frac{\text{QTOT}}{3413.0}
\]

14.11 Calculate actual building cooling load, Btu/hr.

\[
\text{QHBC} = 1.08 \times \text{CFMBX} \times \text{GAMAB} \times (\text{TMA} - \text{TCDB})
\]

14.12 Calculate energy required to produce the building heating and cooling required.

14.12.1 If |QHBH| > |SZHC \times \text{NUMHC} \times 12000.0|, supplementary heat in condenser water line is required.

14.12.1.1 Calculate condenser water supplementary heat requirement, Btu/hr.

\[
\text{QSHCN} = \text{QHBH} + \text{CAPHC}
\]

where

\[
\text{CAPHC} = \text{SZHC} \times \text{NUMHC} \times 12000.0
\]

and QHBH is negative.
14.12.1.2 If $|QHBC| > |CAPHC/1.3|$, 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:

$$POWER = QEVAP \times (0.3371 + 0.01233 \times (TECON - 0.00974 \times TLCHL) \times (0.868 + 0.0133 \times FFL \times 16.0)$$

For $SZHC \geq 200$ tons:

$$POWER = QEVAP \times (1.74 - 1.0234 \times FFL + 0.3707 \times FFL \times FFL - 0.010025 \times TDIF + 0.000175 \times TDIF \times TDIF)$$

where

$$QEVAP = QHBC/12000.0$$

$$TECON = TLCON + 16.0$$

$$TDIF = TECON - TLCHL$$
14.12.1.5 Update monthly electric heat energy consumption totals.

\[ \text{ELEH} = \text{ELEH} + \text{POWER} \]

Go to calculation 14.13.

14.12.2 If \( |QHBH| < |SZHC \times \text{NUMHC} \times 12000.0| \), then heat conservation machines are operating at part load.

14.12.2.1 Calculate chilled water supplementary heat requirement.

For \( |QHBH| > |1.3 \times QHBC| \), then

\[ QSHCL = \frac{QHBH}{1.3} + QHBC \]

For \( |QHBH| < |1.3 \times QHBC| \), then

\[ QSHCL = 0.0 \]

14.12.2.2 Calculate the number of heat conservation machines operating.

Estimated number operating is

\[ \text{ENHCM} = \frac{-QHBH}{1.3 \times (12000.0 \times 0.9 \times SZHC)} \]

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.

\[ FFL = \frac{QEVAP}{(\text{NHCON} \times SZHC/1.3)} \]

where \( QEVAP = \frac{QHBC}{12000.0} + QDIF2 \)

\[ QDIF2 = \frac{(-QHBH/1.3 - QHBC)}{12000.0} \]
14.12.2.4 Calculate energy consumption of heat conservation machines operating.

For $\text{SZHC} < 200$ tons:

$$\text{POWER} = \text{QEVAP} \times (0.3371 + 0.01223 \times \text{TECON} - 0.00974 \times \text{TLCHL}) \times (0.868 + 0.133 \times \text{FFL} \times 16.0)$$

For $\text{SZHC} \geq 200$ tons:

$$\text{POWER} = \text{QEVAP} \times (1.74 - 1.0234 \times \text{FFL} + 0.3707 \times \text{FFL} \times \text{FFL} - 0.010025 \times \text{TDIF} + 0.000175 \times \text{TDIF} \times \text{TDIF})$$

14.12.2.5 Calculate condenser heat available based upon evaporator load and work done.

$$\text{QWORK} = 0.2844 \times \text{POWER}$$

$$\text{QCOND} = \text{QEVAP} + \text{QWORK}$$

14.12.2.6 Compare actual condenser heat available, $\text{QCOND}$, to that required, $\text{QHBH}$.

$$\text{ERROR} = 0.5 \times (-\frac{\text{QHBH}}{12000.0} - \text{QCOND})$$

If $|\text{ERROR}| > |0.005 \times \text{SZHC}|$, set $\text{QDIF2} = \text{QDIF2} + \text{ERROR}$ and return to calculation 14.12.2.3 and repeat procedure until

$$|\text{ERROR}| \leq |0.005 \times \text{SZHC}|$$

14.12.2.7 Check to see if FFL is below $\text{FFLMN}$. If $\text{FFL} > \text{FFLMN}$, then go to calculation 14.13.
If $\text{FFL} < \text{FFLMN}$, heat conservation machine not allowed to operate; therefore, set

\[
\begin{align*}
\text{QSHCL} &= 0.0 \\
\text{QHBH} &= 0.0 \\
\text{QHBC} &= 0.0 \\
\text{QHBRH} &= 0.0
\end{align*}
\]

Go to calculation 14.13.

14.13 Convert condenser supplementary heat requirement into energy requirements.

If $M3 = 1$, gas heating; therefore

\[
\text{GASH} = \text{GASH} - \frac{\text{QSHCN}}{80000.0}
\]

If $M3 = 2$, oil heating; therefore

\[
\text{OILH} = \text{OILH} - \frac{\text{QSHCN}}{0.8 \times \text{HVHO}}
\]

If $M3 = 3$, steam heating; therefore

\[
\text{STMH} = \text{STMH} - \frac{\text{QSHCN}}{\text{HESTM} - \text{HLSTM}}
\]

If $M3 = 4$, electric heating; therefore

\[
\text{ELEH} = \text{ELEH} - \frac{\text{QSHCN}}{3413.0}
\]

14.14 Convert chilled water supplementary heat requirement into energy requirements.

If $M7 = 1$, gas heating source; therefore

\[
\text{GASH} = \text{GASH} - \frac{\text{QSHCL}}{80000.0}
\]

If $M7 = 2$, oil heating source; therefore

\[
\text{OILH} = \text{OILH} - \frac{\text{QSHCL}}{0.8 \times \text{HVHO}}
\]

If $M7 = 3$, electric heating source; therefore

\[
\text{ELEH} = \text{ELEH} - \frac{\text{QSHCL}}{3413.0}
\]

If $M7 = 4$, well water heating source; therefore

\[
\text{ELEH} = \text{ELEH} + \text{HPWWP} \times 0.7457
\]

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15. Update the running totals of the following monthly energy consumption variables.

\[
\text{GALCW} = -\frac{Q_{\text{SHCL}}}{8.3 \times (T_{\text{CMIN}} - T_{\text{CLW}})}
\]

16. Keep a record of maximum hourly energy demands by checking and updating if necessary the following monthly demand variables.

See subroutine ENGY for an explanation of these quantities.

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 ENGINEERING

BUILDING

HAMPTON, VA

ENGINEER - R. JENSEN
PROJECT NO - NASI-12043
DATE - JULY 10, 1974

Figure 6.1 OWNING AND OPERATING COST ANALYSIS PROGRAM OUTPUT REPORT
**INPUT ASSUMPTIONS**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUILDING LIFE</td>
<td>40.00 YEARS</td>
</tr>
<tr>
<td>ANNUAL INTEREST RATE</td>
<td>12.00 PERCENT</td>
</tr>
<tr>
<td>ESTIMATED LABOR WAGE ANNUAL INCREASE</td>
<td>8.00 PERCENT</td>
</tr>
<tr>
<td>ESTIMATED MATERIAL COST ANNUAL INCREASE</td>
<td>15.00 PERCENT</td>
</tr>
<tr>
<td>ESTIMATED FLOOR SPACE COST ANNUAL INCREASE</td>
<td>10.00 PERCENT</td>
</tr>
<tr>
<td>ESTIMATED ENERGY COST ANNUAL INCREASE</td>
<td>10.00 PERCENT</td>
</tr>
</tbody>
</table>

**Figure 6.2** OWNING AND OPERATING COST ANALYSIS PROGRAM OUTPUT REPORT
ANALYSIS FOR - SYSTEM NO. 1 - MULTI ZONE W/BOARD, CENTRIFUGAL CHILLERS, STEAM HEAT OC-10

********************************************************** ENERGY COST SUMMARY **********************************************************

*  ** Unit Cost **  ** Consumption **  ** Total Cost **  ** Annuity **
*  ** ($)**  ** ($)**  ** ($)**
*  ** ELECTRICITY **
*  ** LIGHTING ** 0.03  52000.  15600.  *
*  ** HEATING-BOILER PUMPS, CONTROLS ** 0.05  57658.  1729.  *
*  ** COOLING-CHILLER, PUMPS, TOWER ** 0.05  205446.  6165.  *
*  ** FANS-SUPPLY, RETURN, EXHAUST ** 0.05  359160.  10774.  *
*  ** STEAM ** 1.50  1142264.  34267.  117425.  *
*  ** HEATING **
*  ** WATER **
*  ** TOWER MAKE-UP ** 0.75  389.  291.  999.  *
*  ** GRAND TOTALS **

GRAND TOTALS 37304.  127629.  *

********************************************************** SYSTEMS AND EQUIPMENT COST **********************************************************

*  ** Initial Cost **  ** Anticipated Life **  ** Salvage Considered **  ** Major Overhaul Period **  ** Labor Material Cost **  ** Annual Maintenance Labor Material Cost **  ** Floor Space **  ** Annuity **
*  ** Chiller, Tower, Pumps, Piping ** 80000.  40  YES  10  800.  200.  16000.  8000.  0000.  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 (ls) through (lah).
s) DESC - system description label
t) ENCAT - number of energy categories

For "ENCAT" number of energy categories, repeat (1u) through (1w).
u) ETYPET - energy type coded as follows:

1 electricity
2 gas
3 oil
4 steam
5 water
6 diesel fuel
v) ECQNS  - annual consumption
w) ENLAB  - energy category label
x) EQCAT  - number of equipment categories

For each of "EQCAT" equipment categories, repeat (ly) through (lah).
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 ENCATH) 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
  \[\text{TOTAL} = UCOST(J) \times ECONS(I)\]
• Total consumption of J energy type
  \[TCONS(J) = \sum ECONS(I)\]
• Total cost of energy type J
  \[TENGY(J) = \sum \text{TOTAL}\]
• Annuity for energy type J
  \[AE(J) = PE \times ((RINT \times 100)/(1.0-1.0/(1.0+RINT \times 100))^{BLGLF})\]

where PE the present value is

\[PE = \sum (TENGY(J) \times ((1.0 + RINE \times 100)/(1.0 + RINT))^{L}) \text{ for } L = 1 \text{ to } BLGLF\]

c) Grand total cost for all energy consumed

\[UA = \sum TENGY(J) \text{ for } J = 1 \text{ to } 6\]
d) Grand total annuity for all energy consumed

\[UE = \sum AE(J) \text{ for } J = 1 \text{ to } 6\]

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

\[PC = \sum [COST(I) \times ((1.0 + RINM)/(1.0 + RINT))^{((J-1) \times LIFE(I))}] \text{ for } J = 1 \text{ to } L\]

where \(L = BLGLF/LIFE(I) + 1\)

If salvage value is considered, adjust the present-value, PC, as follows:

\[PC = PC - COST(I) \times (L-AL)/(1.0+RINT)^{BLGLF}\]
where $AL = BLGLF / LIFE(I)$

b) Present-value of floor space cost

$$PF = \sum [FLR(I) \times ((1.0 + RINF)/(1.0 + RINT))^{J}] \text{ for } J = 1 \text{ to } LF$$

where $LF = BLGLF$

c) Present-value analysis of annual maintenance labor cost

$$PAML = \sum [AML(I) \times ((1.0 + RINL)/(1.0 + RINT))^{J}] \text{ for } J = 1 \text{ to } LF$$

d) Present-value analysis of annual maintenance material cost

$$PAMM = \sum [AMM(I) \times ((1.0 + RINM)/(1.0 + RINT))^{J}] \text{ for } J = 1 \text{ to } LF$$

e) Present-value analysis of major overhaul labor cost

$$POHL = \sum [OHL(I) \times ((1.0 + RINL)/(1.0 + RINT))^{(J \times OHPD(I))}] \text{ for } J = 1 \text{ to } K$$

where $K = BLGLF / OHPD(I)$

f) Present-value analysis of major overhaul material cost

$$POHM = \sum [OHM(I) \times ((1.0 + RINM)/(1.0 + RINT))^{(J \times OHPD(I))}] \text{ for } J = 1 \text{ to } K$$

g) Total present-value of system

$$P(I) = PC + PF + PAML + PAMM + POHL + POHM$$

h) Total owning and operating annuity for equipment $I$

$$A(I) = P(I) \times (RINT/(1.0 - 1.0/(1.0 + RINT ** BLGLF))$$

6. Print total owning and operating annuity for entire system.

$$TOOA = \sum A(I) + UE$$

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.
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"The aeronautical and space activities of the United States shall be conducted so as to contribute ... to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—National Aeronautics and Space Act of 1958

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