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COMPUTER PROGRAM
FOR ANALYSIS OF ENERGY UTILIZATION IN POSTAL FACILITIES

VOLUME II
ENGINEERING MANUAL

U.S Post Office Department
Washington, D.C. 20260

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COMPUTER PROGRAM

FOR ANALYSIS OF ENERGY UTILIZATION IN POSTAL FACILITIES

VOLUME II

ENGINEERING MANUAL

Project No. 67138

CONSTRUCTION RESEARCH DIVISION

Prepared by

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General American Transportation Corporation
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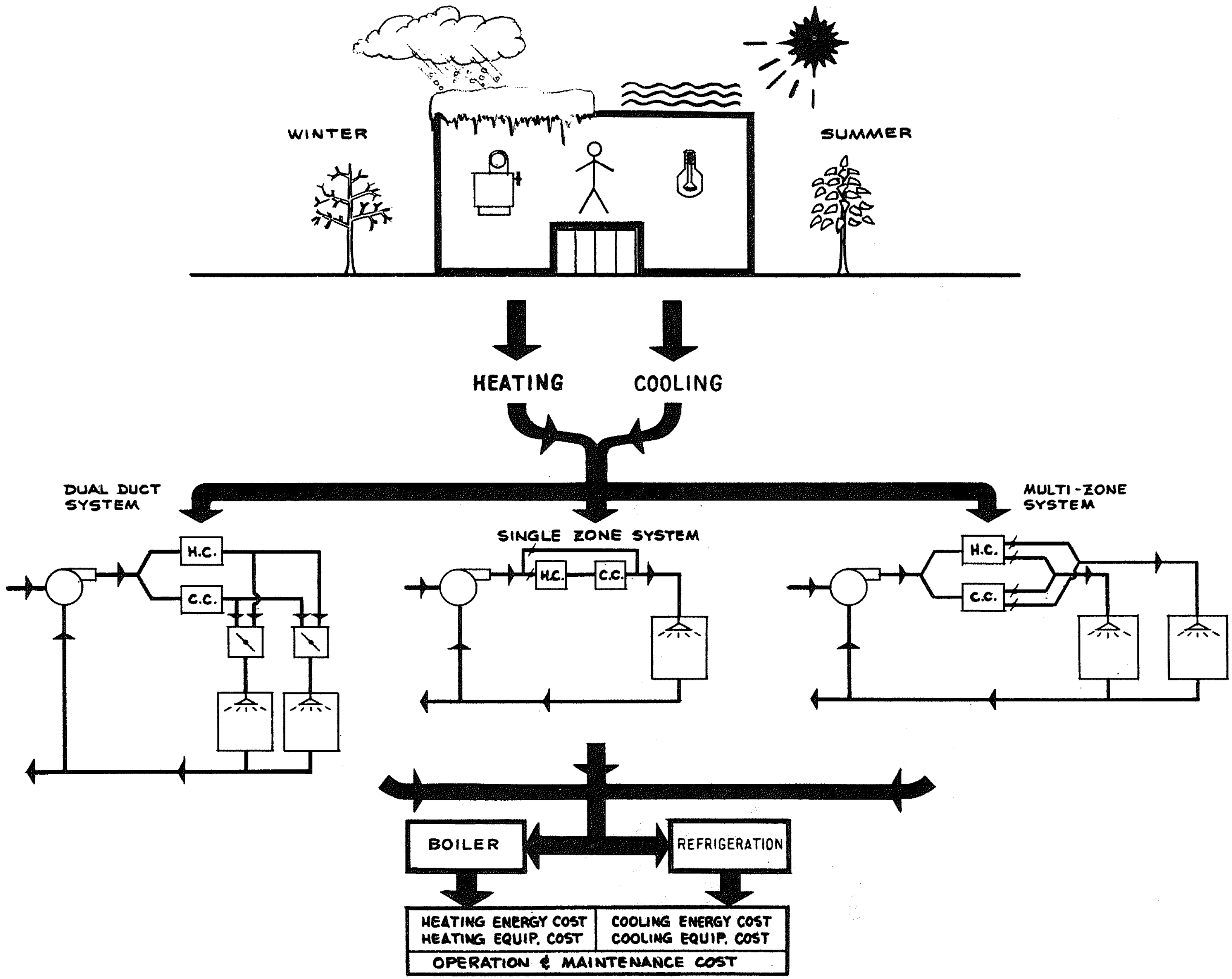
The Post Office Department can not assume any responsibility for application of these manuals or this program beyond the control of its engineers. Users that apply the program to their buildings or facilities do so without recourse to the Post Office Department.

COMPUTER PROGRAM FOR ANALYSIS OF ENERGY UTILIZATION IN POSTAL FACILITIES



PREFACE

This Engineering Manual was prepared by the General American Research Division (GARD) of the General American Transportation Corporation as a part of the Post Office Department Contract No. RE 49-67 for the development of a "Computer Program for Analysis of Energy Utilization in Postal Facilities". The work was started on June 20, 1967 and will be completed on November 14, 1969. The project was monitored by Mr. James M. Anders of the POD's Bureau of Research and Engineering. The GARD team which worked on the project was headed by Mr. Metin Lokmanhekim, Manager of Thermal Systems and Computer Applications Programs. Other GARD personnel who contributed to the project includes: Messrs. James Y. Shih, Robert H. Henninger, Charles C. Groth, Stephen J. Lis, Ajit L. Kapil, and Fred H. Bloedow.

We take this opportunity to acknowledge the guidance and inspiration received from our Project Monitor, Mr. James M. Anders. We were also very fortunate that the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE) became interested in this problem concurrent with our contract. Our appreciation is extended to the members of their Task Group on Energy Requirements for Heating and Cooling, whose technical efforts contributed to this project, with special thanks to:

Dr. T. Kusuda	National Bureau of Standards of USA
Dr. D. G. Stephenson	National Research Council of Canada
Mr. G. P. Mitalas	National Research Council of Canada
Dr. K. Kimura	National Research Council of Canada

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

/	:	Division
*	:	Multiplication
**	:	Exponentiation

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SECTION 1

INTRODUCTION

The Computer Program for Analysis of Energy Utilization in Postal Facilities was written for the Post Office Department, Washington, D. C., and is able to:

1) simulate the thermal response of a building to all sources of heat gains and losses,

2) account for all non-thermal energy requirements in the facility or on the sites,

3) translate the building operating schedule into total energy demand and consumption and costs, and identify the peak capacity requirements of heating and cooling equipment, and

4) perform an economic analysis that selects the most economical total owning and operating cost equipment and energy source (gas, oil, coal, steam or electricity, or combinations).

This Engineering Manual provides a complete documentation for all sub-programs, subroutines and the algorithmic expressions used to calculate the building thermal characteristics and perform the systems simulation and economic analysis included in the program. An accompanying User's Manual explains how the program is to be used and how the input information is to be prepared.

The total program consists of seven separate computer sub-programs, each operating alone and performing a specific function, but with the output of one becoming the input to another. The seven sub-programs include:

1) LOAD CALCULATION SUB-PROGRAM - calculates the hourly heat losses and heat gains for each space within the building for an entire year.

2) PUNCH SUB-PROGRAM - prepares the punched card input data required for the offline Thermal Loads Plot Sub-program.

3) THERMAL LOADS PLOT SUB-PROGRAM - plots the hourly load profiles for any space for any length of time and enables more compatible grouping of spaces into control zones.

4) LOAD EDITING SUB-PROGRAM - aids the engineer in preparing an editted hourly load tape by summing space loads into fan zone loads, thus giving an hourly load tape which can be input directly to the Systems Simulation Sub-program.

5) SYSTEMS SIMULATION SUB-PROGRAM - simulates the operation of fan systems and part load operation of heating and cooling equipment components, thus enabling an accurate determination of the building's hourly energy consumption.

6) ECONOMICS ANALYSIS SUB-PROGRAM - calculates the annual total owning and operating costs of a building for various combinations of heating and cooling plants.

7) PACKAGED SYSTEMS SIMULATION SUB-PROGRAM - simulates the operation of typical packaged unitary heating/cooling systems used in small Post Office buildings, giving the energy consumption as a function of the part load on the packaged system.

The sequence of using the seven sub-programs depends upon what information the engineer wishes to obtain and if he can initially break the building into fan system control zones rather than just spaces. Figure 1 illustrates the paths of sub-program sequencing that can be taken as a function of the engineer's decisions. As the engineer becomes more adept at breaking a building directly into control zones, the need for space load plots and regrouping of zones will diminish.

Sections 2 through 8 of this Engineering Manual outline, where feasible, the sequence of calculations as they occur in each of the seven sub-programs.

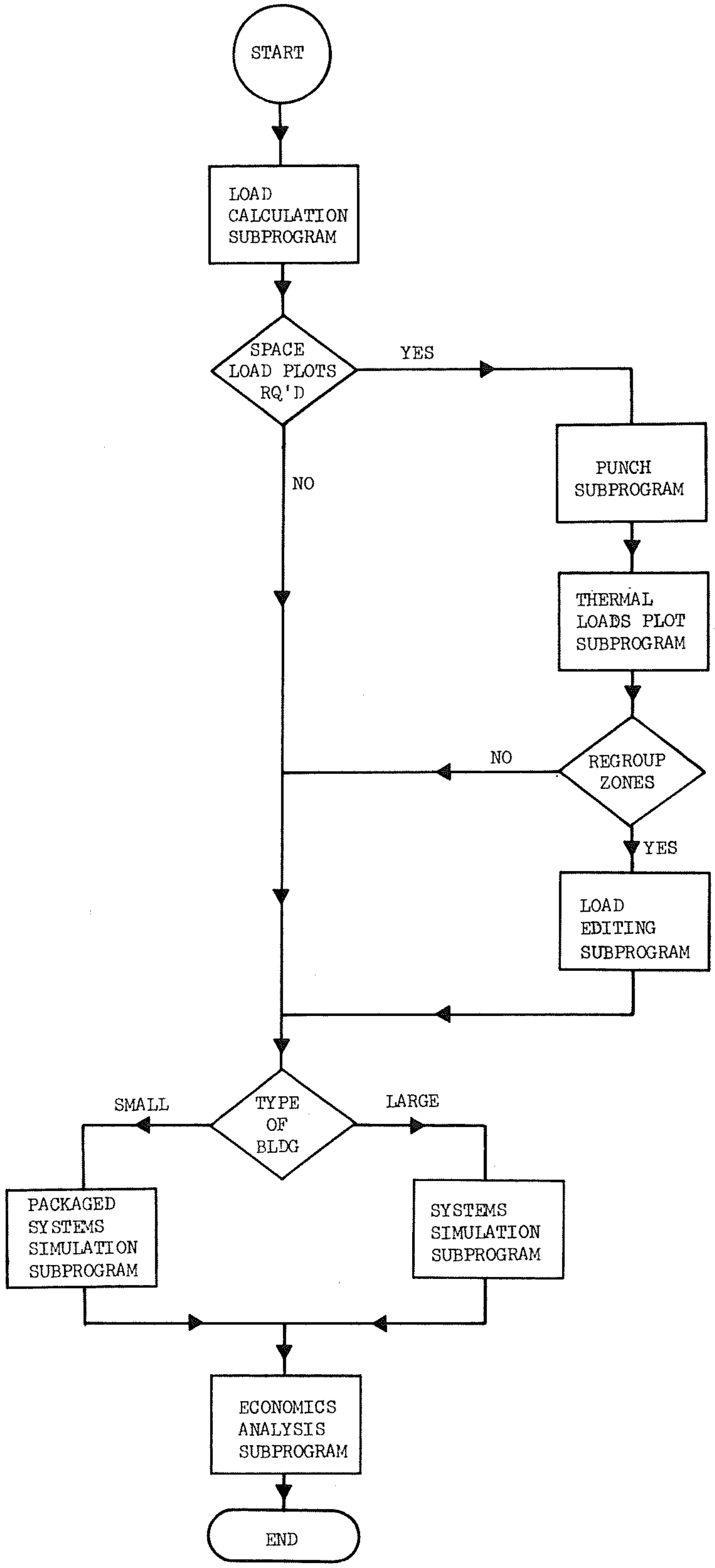

Figure 1 LOGIC FLOW CHART ILLUSTRATING THE SEQUENCE OF USING THE SEVEN SUB-PROGRAMS

SECTION 2

LOAD CALCULATION SUB-PROGRAM*

2.1 Introduction

The Load Calculation Sub-program, a complex of heat transfer, environment and geometry subroutines, computes the hourly thermal loads, both heating and cooling, that are imposed upon each space within the building. The input to the Load Calculation Sub-program reflects building architecture, structure, surroundings, local weather and the position of the sun. The output of the Load Calculation Sub-program includes hourly weather and psychrometric data, sensible and latent loads, plenum return air lighting loads, equipment and lighting power consumption for each space every hour.

A brief description of each subroutine of the Load Calculation Sub-program is given in Table 1 and the interrelationship of these subroutines is illustrated in Figure 2.

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.

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*Most parts of this section were obtained, with the permission of ASHRAE, from "Procedure for Determining Heating and Cooling Loads for Computerized Energy Calculation - Algorithms for Building Heat Transfer Subroutines", by Metin Lokmanhekim, Editor.

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

The Load Calculation Sub-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 understood 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.

2.2 Convolution Principle

The load calculation procedure utilized in this program differs from the conventional method which uses equivalent temperature differences and storage load factors. The present procedure makes extensive use of a convolution technique to account for the thermal storage effect of the building structure. Convolution in this application refers to a transformation or "turning inside out" of the equations used in load calculation.

TABLE 1

LOAD CALCULATION SUB-PROGRAM SUBROUTINES

Name of the Subroutine		Function
APOL		Calculates area and orientation of an irregular surface
CCM		Calculates cloud cover modifier
CENTER		Centers the headings of output
DAYMO		Determines the day of month
DST		Determines Daylight Saving Time
FILM		Calculates outside heat transfer film coefficient
HD		Calculates heat gain through slowly responding surfaces (Delayed surfaces)
HL		Calculates sensible and plenum return air heating and cooling load due to a space
HOLDAY		Determines holiday
HQ		Calculates heat gain through quickly responding surfaces (Quick surfaces)
INF		Calculates infiltration air loads due to a space
LEEP		Determines whether the year is a leap-year
NDOW		Determines day of week
PSY	and	Calculates psychrometric data
	PPWVMS	
RECTANG		Calculates vertex coordinates of a rectangular surface
RESFAC	and	Calculates response factors for walls and roofs
	DER FALSE MATRIX SLOPE ZERO	

TABLE 1 (CONT'D)

Name of the Subroutine	Function
RMRSS and RMRG RMRL RMRLP RMRX	Calculates room hourly weighting factors
ROOFS and MSNRY PITCH WOOD	Determines thermal and physical properties of a selected roof construction
SEARCH	Limits shadow pictures to certain times and certain surfaces
SCHED	Determines lighting, people, and equipment schedules
SHADOW and MATCON	Calculates shadow shapes and areas
SHG	Calculates heat gain through windows
SUN1	Calculates daily data on solar radiation
SUN2	Calculates hourly data on solar radiation
SUN3	Calculates solar data which depends on orientation of a surface
TABMAK	Tabulates output
TAR	Calculates glass absorption and transmission factors
WALLS and BRICK CONCR PINE STUCO	Determines thermal and physical properties of a selected wall construction
WEATHER	Decodes weather tape

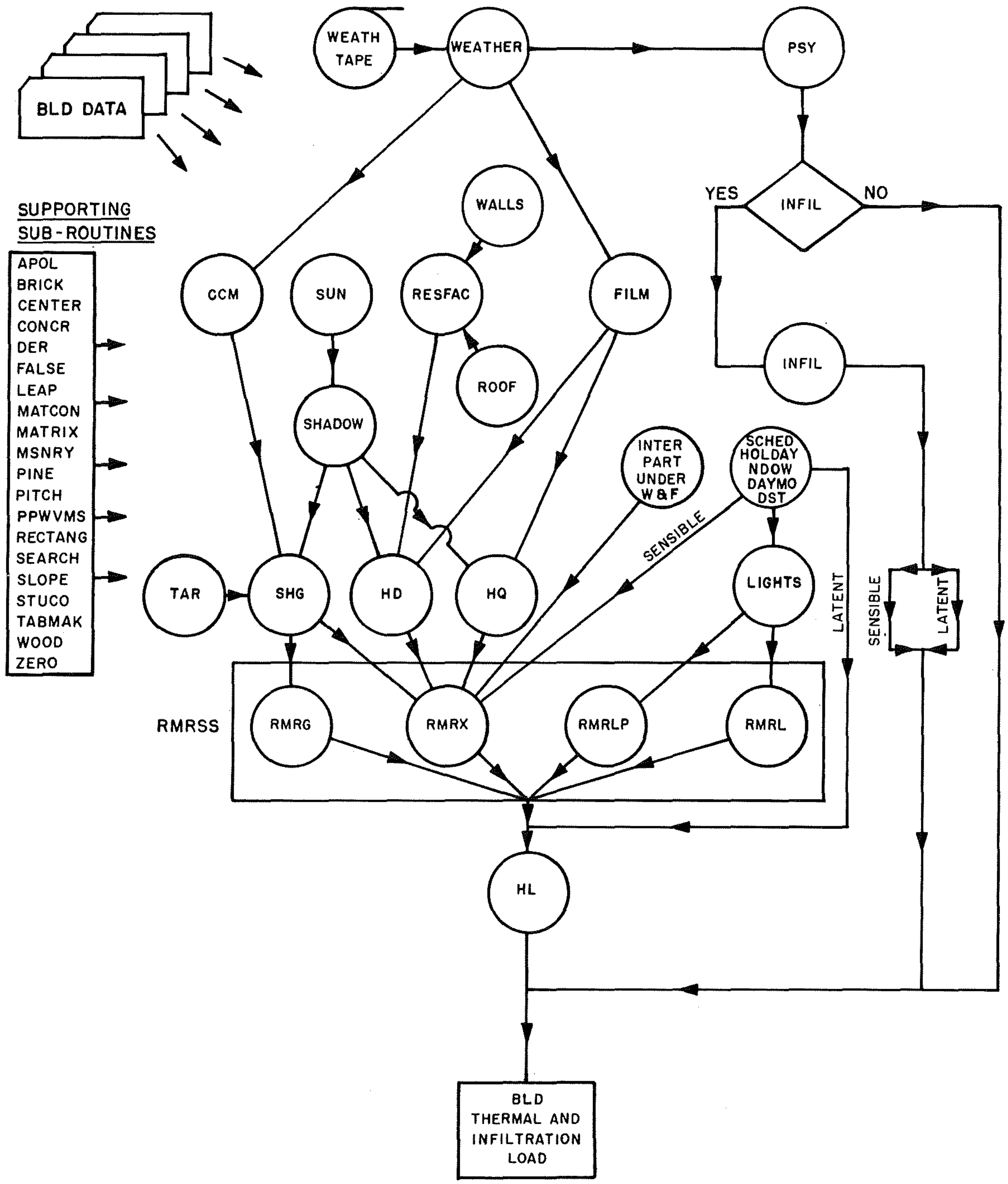


Figure 2 INTERRELATIONSHIP OF LOAD CALCULATION SUB-PROGRAM SUBROUTINES

A time-dependent variable, for example, air temperature, T, is usually expressed as T(t) to mean that T is a function of time, t. Another way of expressing the time-dependent variable is by a set of numbers such as T_1, T_2, T_3 ... T_m to mean that the set consists of a series of numerical values, which are air temperatures at t = 1, 2, ... This set is called the time series and expressed by $\{T\}$. When one time series $\{A\}$ is influenced by another time series $\{B\}$, the relation between these two series may be expressed in a linear form as:

$$A_t = \sum_{j=0}^{m} X_j \, B_{t-j} \quad \text{where } t = 0, 1, 2, \ldots$$

In this example, the value of A at time t is expressed as a linear function of the values of B at t = t, t - 1, t - 2, ... with X_0, X_1 ... X_m being the time-independent coefficients. The above equation is called the "convolution" and X_0, X_1 ... X_m are called the "filter coefficients" in the mathematics equation of "time series analysis", but they may be called the <u>response</u> <u>factors</u> or <u>weighting</u> <u>factors</u> in the load calculation procedure. In the above expression, the time series $\{A\}$ is said to be calculated by "convolving" the time series $\{B\}$ with the response factor $\{X\}$.

The convolution scheme is employed in two different places in the load calculation procedure. First, the transient heat conduction through exterior walls and roofs is calculated by convolving the outside and inside surface temperatures with wall response factors. And, secondly, the space cooling load and heat extraction is calculated by convolving the instantaneous heat gain with its weighting factors.

The value of "m" in the convolution equation depends upon the degree that the time parameter B_{t-m}, or B at "m" hours previous to time t, would influence the value of A_t. If the response of B_{t-m} upon A_t is insignificant, X_m is nearly zero and the values of B beyond (t-m)th hour is of no importance. If the time lag effect does not exist for the relation between two time series, $\{A\}$ and $\{B\}$, the value of "m" will be zero or the response factor X_j will be all zero except for the first term X_0. The simplified steady-state thermal load is calculated on this basis.

2.3 Algorithms of Subroutines

APOL

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

INPUT

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

OUTPUT

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

CALCULATION SEQUENCE

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

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

   $j = 1$ when $i = n$

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

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

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

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

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

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

5. If PROJ << A   AZIM = 0.0

6. If PROJ is appreciable compared to A, use the proper equation given in Table 2 for the calculation of AZIM.

TABLE 2

EQUATIONS FOR THE CALCULATION OF AZIM

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

CCM

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

INPUT

SALT : Solar altitude angle, degrees

TOC : Cloud type index $= \begin{cases} 0 \text{ Stratus} \\ 1 \text{ Cirrus, Cirrostratus} \end{cases}$

TCA : Weather Bureau total cloud amount index

OUTPUT

CCM : Cloud Cover Modifier

CALCULATION SEQUENCE

The values of CCM as a function of SALT, TOC and TCA are given in Table 3, which is derived from Boeing Company Report, "Summary of Solar Radiation Observation D2-90577-1, December 1964".

TABLE 3

CLOUD COVER MODIFIER, CCM

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

The values in Table 3 are curve-fitted and the coefficients calculated.

1. SQ = TCA * TCA

2a. STRATUS CLOUDS, SALT $\leq 45°$

CCM = 0.598 + 0.00026 * TCA + 0.00021 * SQ - 0.00035 * TCA * SQ

2b. STRATUS CLOUDS, SALT $> 45°$

CCM = 0.908 - 0.03214 * TCA + 0.0102 * SQ - 0.00114 * TCA * SQ

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

CCM = 0.849 - 0.01277 * TCA + 0.00360 * SQ - 0.00059 * TCA * SQ

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

$$CCM = 1.010 - 0.01394 * TCA + 0.00553 * SQ - 0.00068 * TCA * SQ$$

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

CENTER

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

INPUT

- Left-justified titles, names, etc.

OUTPUT

- Centered titles, names, etc.

DAYMO

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

INPUT

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

DOY : Day of the year, from start of year

OUTPUT

DOM : Day of the month

MOY : Month of the year

DST

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

INPUT

YEAR	:	Year AD
MOY	:	Month of the year
DOM	:	Day of the month

OUTPUT

DST	:	The Daylight Saving Time indicator $= \begin{cases} 0 & \text{Standard Time period} \\ 1 & \text{Daylight Saving Time period} \end{cases}$
DSTS	:	The day when Daylight Saving Time commences
DSTF	:	The day when Standard Time resumes

CALCULATION SEQUENCE

1. If MOY is less than 4 and greater than 10, DST = 0.

2. If MOY is greater than 4 and less than 10, DST = 1.

3. If MOY = 4 and DOM is less than 24, DST = 0.

4a. If DOM is greater than 23, and
DAY OF THE WEEK = NDOW(JAHR, 4, DOM) is equal to 1, DSTS = DOM.

4b. If DOM is less than DSTS, DST = 0; otherwise, DST = 1.

5. If MOY = 10 and DOM is less than 25, DST = 1.

6a. If DOM is greater than 24, and
DAY OF THE WEEK = NDOW(JAHR, 10, DOM) is equal to 1, DSTF = DOM

6b. If DOM is less than DSTF, DST = 1; otherwise, DST = 0.

FILM

A subroutine which determines the outside surface heat transfer coefficient as a function 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 4.

TABLE 4

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

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

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

GLOSSARY OF SYMBOLS:

X_i	:	i^{th} self response factor, Btu/hr-sq ft-°F
Y_i	:	i^{th} transfer response factor, Btu/hr-sq ft-°F
TO_i	:	Outside wall surface temperature history, (TO_1 is the present outside wall surface temperature), °F
T	:	Constant space temperature, °F
SOLI	:	Total solar radiation intensity, Btu/hr-ft^2
AB	:	Absorptivity of outside surface of wall to radiation in solar spectrum
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 the wall
TCA	:	Total cloud amount index

Heat Balance Equation:

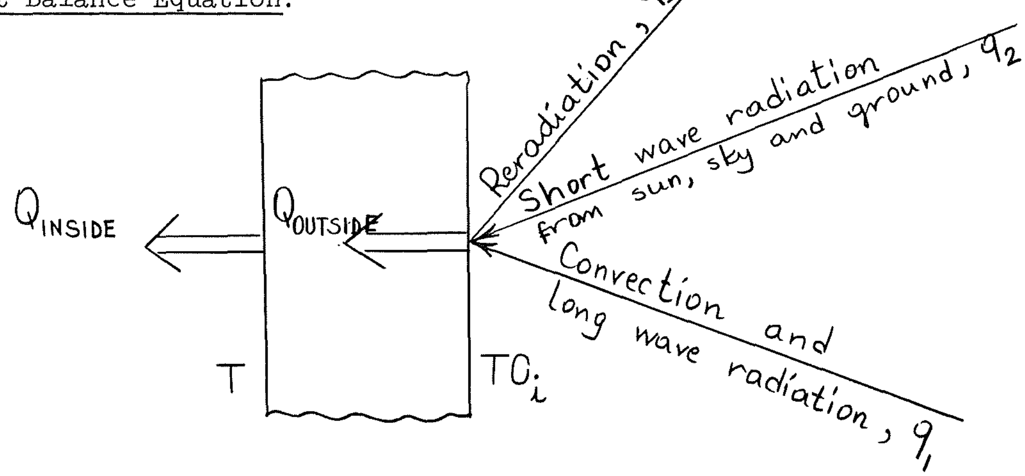


Figure 3 CONCEPTS OF HD SUBROUTINE

Using the diagram given in Figure 3, the heat balance equation of a wall may be constructed as follows:

By the use of response factors:

$$Q_{OUTSIDE} = \sum_{i=1}^{\infty} (TO_i - T)\, X_i \qquad (1)^*$$

$$Q_{INSIDE} = \sum_{i=1}^{\infty} (TO_i - T)\, Y_i \qquad (2)^*$$

Outside Wall Surface Heat Balance:

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

where

$$q_1 = AB * S\emptyset LI \qquad (4)$$

$$q_2 = F\emptyset * (TDB - TO_1) \qquad (5)$$

$$q_3 = 2.0 * A * (10.0 - TCA) \qquad (6)$$

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

$$\sum_{i=1}^{\infty} (TO_i - T)\, X_i = AB * SOLI + FO * (TDB - TO_1) - 2.0 * A * (10.0 - TCA) \qquad (7)$$

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

Rearranging equation 7 as:

$$TO_1 * (X_1 + FO) = X_1 * T + AB * SOLI + FO * TDB - 2.0 * A * (10.0 - TCA) - \sum_{i=2}^{\infty} (TO_i - T)\, X_i \qquad (8)$$

and solving equation 8 for TO_1 gives:

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

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

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

HL

A subroutine which combines different types of sensible and plenum return air heating and/or cooling loads due to a space after multiplying them by the proper weighting factors (i.e., with RMRG, RMRX, RMRL and RMRLP).

INPUT

- Different types of sensible and plenum return air heating and/or cooling loads, Btu/hr

- Weighting factors

OUTPUT

- Hourly sensible heating and/or cooling load due to a space at time t, Btu/hr

CALCULATION SEQUENCE

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

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

HOLDAY

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

INPUT

MOY	:	Month of the year
DOM	:	Day of the month
DOW	:	Day of the week

OUTPUT

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

CALCULATION SEQUENCE

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

   If MOY = 1 and DOM = 1

   MOY = 12, DOM = 31, and DOW = 6

   MOY = 1, DOM = 2, and DOW = 2

   MOY = 2, and DOM = 22

   MOY = 2, DOM = 21, and DOW = 6

   MOY = 2, DOM = 23, and DOW = 2

   MOY = 5, and DOM = 30

   MOY = 5, DOM = 29, and DOW = 6

   MOY = 5, DOM = 31, and DOW = 2

   MOY = 7 and DOM = 4

   MOY = 7, DOM = 3, and DOW = 6

   MOY = 7, DOM = 5, and DOW = 2

   MOY = 12 and DOM = 25

   MOY = 12, DOM = 24, and DOW = 6

   MOY = 12, DOM = 26, and DOW = 2

   MOY = 9, DOM is less than 7 and DOW = 2

   MOY = 1, DOM is greater than 23, and DOW = 5

2. Otherwise, set HOL equal to 0.

HQ

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

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

$$Q_{OUTSIDE} = Q_{INSIDE} = U * (TO_1 - T) \tag{1}$$

where U is the overall heat transfer coefficient.

The heat balance equation of the outside wall surface becomes:

$$U * (TO_1 - T) = AB * SOLI + FO * (TDB - TO_1) - 2.0 * A * (10.0 - TCA) \tag{2}$$

Solving this equation for TO_1 gives:

$$TO_1 = \frac{U * T + AB * SOLI + FO * TDB - 2.0 * A * (10.0\text{-}TCA)}{U + FO} \tag{3}$$

Now that TO_1 is known, equation 1 may be used to compute Q_{INSIDE} directly.

INF

A subroutine which calculates sensible and latent components of the outside air load which infiltrates through openings of unpressurized loading dock areas.

INPUT

DBT	:	Outside air dry-bulb temperature, °F
HUMRAT	:	Outside air humidity ratio, lbs water/lb dry air
DENS	:	Outside air density, lbs dry air/cu ft
VOL	:	Outside air specific volume, cu ft
TS	:	Space temperature, °F

OUTPUT

QSINF : Sensible infiltration load, Btu/hr

QLINF : Latent infiltration load, Btu/hr

CALCULATION SEQUENCE

1. If DBT is less than 50°F,

$$SHR = \text{SPACE HUMIDITY RATIO} = \frac{53.2 + 0.245 * (DBT - 50.0)}{7000.0}$$

2. If DBT is greater than 50°F,

$$SHR = \text{SPACE HUMIDITY RATIO} = HUMRAT$$

3. $$QSINF = 14.4 * DENS * \frac{VOL}{60.0} * (DBT - TS)$$

$$QLINF = 63300.0 * DENS * \frac{VOL}{60.0} * (HUMRAT - SHR)$$

LEEP

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

INPUT

YEAR : Year AD

OUTPUT

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

NDOW

A subroutine which determines the day of the week.

INPUT

YEAR : Year AD

MOY : Month of the year

DOM : Day of the month

OUTPUT

WKDAY : 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 LOM(1) = 31, LOM(2) = 59, LOM(3) = 90, LOM(4) = 120

   LOM(5) = 151, LOM(6) = 181, LOM(7) = 212, LOM(8) = 243

   LOM(9) = 273, LOM(10)= 304, LOM(11)= 334, LOM(12)= 365

2. Let N = Integer part of YR/4

   ND = N - 485

   IY = 2, IADD = 2

   If ND = 0, go to (4).

   If ND is less than 0, ND = -ND and IADD = -2.

3. Repeat the following steps for ND times

   IY = IY - IADD

   If IY is greater than 7, IY = IY -7.

   If IY is equal to 0, IY = 7.

   If IY is less than 0, IY = IY + 7.

4. Let MD = YR - N * 4

   If MD is equal to 0, IWK = IY

   1, IWK = IY + 2

   2, IWK = IY + 3

   3, IWK = IY + 4

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

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

   If MOY is equal to j, let TDAY = LOM(j) - 31 + DAY - 1.

6. If MD is dqual to 0 and MOY is greater than 2, TDAY = TDAY + 1.

7. NTX = Integer part of TDAY/7

   NDX = TDAY = 7 * NTX + IWK

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

8. Let WKDAY = NDX.

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 sub-function.

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

   PPWV = PPWVMS(DPT)

   Go to step 3.

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

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

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

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

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

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

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

2. Let A(1) = -7.90298
   A(2) = 5.02808
   A(3) = -1.3816 E-7
   A(4) = 11.344
   A(5) = 8.1328 E-3
   A(6) = -3.49149

   B(1) = -9.09718
   B(2) = -3.56654
   B(3) = 0.876793
   B(4) = 0.0060273

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

   If T is less than 273.16, go to 4.

   Otherwise

   z = 373.16/T
   P1 = A(1) * (z-1)
   P2 = A(2) * Log10 (z)
   P3 = A(3) * (10 ** (A(4) * (1-1/z))-1)
   P4 = A(5) * (10 ** (A(6) * (z-1))-1)

   Go to 5.

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

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

RECTANG

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

RESFAC
and
DER, FALSE, MATRIX, SLOPE, ZERO

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

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

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

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

INPUT

N	:	Number of layers to be considered for the analysis of the particular wall or roof where i = 1, 2, ..., N
K_i	:	Thermal conductivity of each layer, Btu/hr-ft-°F If the layer has no thermal mass, $K_i = 0$. where i = 1, 2, ..., N
ρ_i	:	Density of each layer, lb/cu ft If the layer has no thermal mass, $\rho_i = 0$ where i = 1, 2, ..., N
C_i	:	Specific heat of each layer, Btu/lb-°F If the layer has no thermal mass, $C_i = 0$ where i = 1, 2, ..., N
L_i	:	Thickness of each layer, ft If the layer has no thermal mass, $L_i = 0$ where i = 1, 2, ..., N
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, ..., N
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 material.

OUTPUT

X_i, Y_i, Z_i : Response factors series for j = 1, 2, ...M where the value of M, number of the factors in the series, depends upon the type of wall, roof or overhang floor construction

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

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

Definitions of X, Y and Z Response Factors

Consider the wall in Figure 4 and assume that the heat flow rate into side A is Q_A, and the heat flow rate out of side B is Q_B.

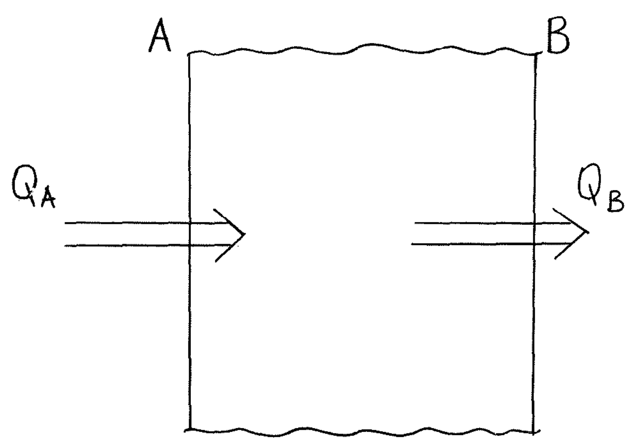


Figure 4 A WALL

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

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

Therefore:

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

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

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

These definitions are shown schematically in Figure 5.

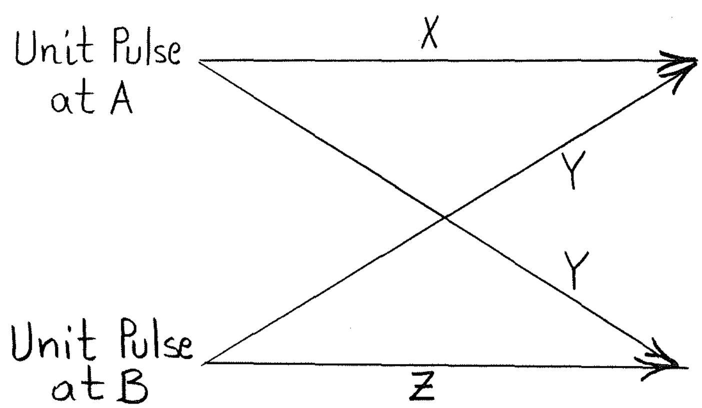


Figure 5 MEANING OF X, Y AND Z

Because of space temperatures assumed to be constant, the Z response factors are not used in the computer program. A typical example is shown in Table 5.

TABLE 5

A TYPICAL EXAMPLE

RESPONSE FACTORS FOR A BRICK VENEER WALL

LAYER NO.	L(I) ft	K(I) Btu per (hr)(ft)(F)	ρ(I) lb per cu ft	C(I) Btu per (lb)(F)	RES(I) (hr)(sq ft)(F) per Btu	DESCRIPTION OF LAYERS
1	0.333	0.770	125.00	0.220	0.00	4" Face Brick
2	0.065	0.066	37.00	0.600	0.00	25/32" Sheathing, (wood)
3	0.000	0.000	0.00	0.000	0.84	Air Space
4	0.250	0.025	5.70	0.300	0.00	3" Insulation Board
5	0.031	0.240	78.00	0.260	0.00	3/8"Gypsum Board
6	0.042	0.270	90.00	0.200	0.00	1/2"Plaster Board
7	0.000	0.000	0.00	0.000	0.68	Air (inside surface)

Thermal Conductance, U = 0.076, Btu per (hr)(sq ft)(F)

Time increment, DT = 1, hr

RESPONSE FACTORS

J	X	Y	Z
0	5.1814	0.0000	0.8620
1	-3.2105	0.0008	-0.4607
2	-0.7363	0.0064	-0.1830
3	-0.4245	0.0126	-0.0783
4	-0.2636	0.0140	-0.0345
5	-0.1676	0.0121	-0.0156
6	-0.1075	0.0093	-0.0072
7	-0.0692	0.0067	-0.0034
8	-0.0447	0.0046	-0.0017
9	-0.0289	0.0031	-0.0009
10	-0.0187	0.0021	-0.0005
11	-0.0121	0.0014	-0.0002
12	-0.0078	0.0009	-0.0001
13	-0.0051	0.0006	-0.0001
14	-0.0033	0.0004	-0.0001
15	-0.0021	0.0002	-0.0000
16	-0.0014	0.0002	-0.0000
17	-0.0009	0.0001	-0.0000
18	-0.0006	0.0001	-0.0000
19	-0.0004	0.0000	-0.0000
20	-0.0002	0.0000	-0.0000
21	-0.0002	0.0000	-0.0000
22	-0.0001	0.0000	-0.0000
23	-0.0001	0.0000	-0.0000
24	-0.0000	0.0000	-0.0000

COMMON RATIO = 0.64775

IT SHOULD BE NOTED THAT:

1- THE VALUE OF THERMAL CONDUCTANCE U, FOR OUTSIDE WALLS AND ROOFS IS DIFFERENT FROM THE NORMAL VALUE OF U IN THE LITERATURE BECAUSE IT DOES NOT INCLUDE THE RESISTANCE AT THE OUTSIDE SURFACE.

2- IF THE RESPONSE FACTORS OF ONE OF TWO SIMILAR CONSTRUCTIONS OF A SOMEWHAT DIFFERENT THERMAL CONDUCTANCE ARE KNOWN, THE UNKNOWN RESPONSE FACTORS OF THE OTHER CONSTRUCTION CAN BE CALCULATED BY MULTIPLYING THE KNOWN RESPONSE FACTORS BY THE RATIO OF THERMAL CONDUCTANCES OF THE CONSTRUCTIONS.

RMRSS

and

RMRG, RMRX, RMRL, RMRLP

The different weighting factors, RMRG, RMRX, RMRL, RMRLP, are combined in the RMRSS subroutine. The description of these weighting factors follows.

RMRG

The weighting factors relating room cooling load to the solar heat gain through glass depend on where the solar energy is absorbed. If the window is shaded by an inside blind or curtain, most of the solar energy is absorbed by the shade and is transferred to the room by convection and long-wave radiation in about the same proportions as the heat gain through walls and roof. Thus the heat gain through windows with inside shading devices can be combined with the wall and roof heat gain and converted to cooling load using the RMRX factors. The heat gain through windows without inside shading devices is almost all radiation and should be converted to cooling load, using the factors given in Table 6.

TABLE 6

RMRG FACTORS

j	0	1	2	3	4	5	6	7	8
$RMRG_j$	.40	.20	.12	.09	.06	.04	.03	.02	.01

RMRX

The ASHRAE Handbook of Fundamentals indicates that 60 percent of the heat gain through walls and roofs is radiated from the inside surface and the other 40 percent being transferred to the room air by convection. The radiant energy has no immediate effect on the room cooling load: It is absorbed by the floor, partitions and furniture and the heat is transferred from these surfaces to the room air only when they are at a higher temperature than the room air. The heat storage effect is taken into account by spreading the radiant portion of the heat gain over a period of several hours. For a structure of medium weight, the radiation is spread over 4 hours. Thus the cooling load in the first hour is 40 percent plus 1/4 of 60 percent, and for each of the next 3 hours, it is 1/4 of 60 percent, i.e.,

$$RMRX_0 = 0.40 + \frac{0.60}{4} = 0.55$$

$$RMRX_j = \frac{0.60}{4} = 0.15 \quad \text{for } j = 1, 2, 3$$

The rate at which the radiant energy is transferred to the room air is not really constant, but decreases as the surfaces cool to room air temperature. The values given in Table 7 are used in the computer program.

TABLE 7

RMRX FACTORS

j	0	1	2	3	4	5	6	7
$RMRX_j$	0.60	0.15	0.09	0.06	0.04	0.03	0.02	0.01

RMRL AND RMRLP

The weighting factors relating room cooling load to the power supplied to the lights may be expressed by:

$$RMRL_0 = 1 - A * EXP(-B * \Delta)$$

and for $j \geq 1$

$$RMRL_j = A * (1 - EXP(-B * \Delta)) * EXP(-j * B * \Delta)$$

where Δ is the interval between the times when cooling load is calculated and usually equals 1 hour.

A and B are constants that depend on the heat storage capacity of the building, the type of light fixture and the air circulation within the room. The values of A and B, for some common situations, are given in Table 8.

If the ventilating air is exhausted through the space above the ceiling, it removes some of the heat from the lights before it enters the room. This heat is a load on the air conditioning plant if the air is recirculated, even though it is not part of the cooling load of the room. In this case, the factors for cooling load of room are:

$$RMRL_0 = D * (1 - A * EXP(-B * \Delta))$$

and for $j \geq 1$

$$RMRL_j = D * A * (1-EXP(-B * \Delta)) * EXP(-j * B * \Delta)$$

The factors for the heat pickup by the air while passing through the space above the ceiling are:

$$RMRLP_0 = (1 - D) * (1 - C * EXP(-B * \Delta))$$

and for $j \geq 1$

$$RMRLP_j = (1 - D) * C * (1 - EXP(-B * \Delta)) * EXP(-j * B * \Delta)$$

Table 8 gives values of A, B, C and D for fluorescent fixtures recessed into a suspended ceiling and with approximately 1 room air-change per hour being exhausted through the plenum.

TABLE 8

VALUES OF COEFFICIENTS A, B, C, AND D FOR FLUORESCENT FIXTURES

Building Type	Recessed Fixtures Unventilated Plenum		Recessed Fixtures Ventilated Plenum			
	A	B(hr^{-1})	A	B(hr^{-1})	C	D
Light (50 lb/sq ft floor area)	0.77	0.23	0.74	0.30	0.57	0.85
Medium (100 lb/sq ft floor area)	0.75	0.13	0.72	0.15		
Heavy (150 lb/sq ft floor area)	0.74	0.08	0.70	0.10		

ROOFS

A subroutine for selecting a standard ASHRAE roof from computer storage which meets but does not exceed a specified overall heat transfer coefficient (UMAX). The subroutine facilitates the selection of a realistic roof composition and its thermal properties when the user specifies the type of roof construction, the insulation thickness, and the desired design season conditions. The subroutine gives the number of layers and the thickness, thermal conductivity, density, specific heat, and thermal resistance of each layer, which are required by the response factor subroutine.

INPUT

IR : Roof construction index;

IR = 1 Flat masonry roof with built-up roofing

IR = 2 Wood or metal flat roof

IR = 3 Pitched roof

(If IR > 3, the subroutine makes IR = 3.)

UMAX : Maximum overall heat transfer coefficient desired (including outside film coefficient), Btu/hr-ft^2-°F

TINS : Thickness of insulation desired, inches

KOLD : Design season condition index
KOLD = 1 Winter conditions (15 mph wind)
KOLD = 2 Summer conditions (7-1/2 mph wind)

OUTPUT

LAYER : Number of layers of the selected ASHRAE roof

$THKNS_i$: Thickness of layer, ft, where i = 1, ..., LAYER

$CTVTY_i$: Thermal conductivity of each layer, Btu/hr-ft-°F, where i = 1, ..., LAYER

$DNSTY_i$: Density of each layer, lb/ft^3 where i = 1, ..., LAYER

OUTPUT (CONT'D)

$SPCHT_i$: Specific heat of each layer, Btu/lb-°F where i = 1, ..., LAYER

RES_i : Thermal resistance of each layer, hr-ft^2-°F/Btu where i = 1, ..., LAYER

CALCULATION SEQUENCE

1. If KOLD = 1, RO = 0.17 hr-ft^2-°F/Btu for winter conditions

   If KOLD = 2, RO = 0.25 hr-ft^2-°F/Btu for summer conditions

2. If IR = 1, call MSNRY.

   If IR = 2, call WOOD.

   If IR = 3, call PITCH.

   These supporting subroutines scan the stored roof constructions to determine the largest overall heat transfer coefficient which does not exceed UMAX. Each subroutine returns the indices K1, L1, M1 corresponding to type of deck, form and ceiling, respectively, for the selected roof.

3. Compute and/or extract from memory for each layer:

   THKNS, CTVTY, DNSTY, SPCHT, and RES

   Note: For each layer that makes up the composite for the deck, form, and ceiling, the layers are ordered from outside to inside, including air spaces and insulation.

SEARCH

A subroutine which changes the controlling index of SHADOW subroutine for pictorial output for desired hour and surface.

SCHED

A subroutine which assigns the proper lighting, people and equipment schedules to spaces.

SHADOW and MATCON

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

Development of the digital computer has now made shading amenable to rational solution. In the program, a newly-developed technique* is utilized. This technique attacks the general problem and treats complicated shapes with as much ease as it deals with simpler configurations. The basis of the technique is the representation of all architectural forms as a series of plane polygons. Even curved surfaces can be so represented with great accuracy. For example, a sphere may be approximated by the 20 sides of a regular icosohedron. This approximation gives a maximum error of only 3% in the shadow area cast by the sphere.

The output of the computer program is a pictorial display of the shadows and the surface upon which they are cast. Shadow areas are also printed as floating point numbers. Where shadows are cast by perforated structures, e.g., trees, the pictorial output shows the shadow as a mottled pattern.

*Developed by Metin Lokmanhekim and Charles C. Groth and presented at the Second International Conference on System Sciences, in Honolulu, Hawaii, January, 1969.

Coordinate Transformation

Designate the polygons which cast shadows as shading polygons (SP) and those upon which shadows are cast as receiving polygons (RP). The vertex coordinates of each RP, and its relevant SP's, are transformed from a base coordinate system, xyz, to a new coordinate system, x'y'z', with origin O attached to the plane of the RP. The first three vertices V_1, V_2, and V_3, of the RP being examined are used to define this new coordinate system. The x' axis passes through V_2 and V_3, while the y' axis passes through V_1. In order that the z' axis point outward from the surface, angle $V_1V_2V_3$ must be convex and the vertices must be numbered counterclockwise. The equation of transformation is written in matrix form as

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

where:

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

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

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

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

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

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

$$x'_s = \begin{pmatrix} \mathrm{Sin}\,\beta \;.\; \mathrm{Cos}\,\alpha \\ \mathrm{Sin}\,\alpha \\ \mathrm{Cos}\,\beta \;.\; \mathrm{Cos}\,\alpha \end{pmatrix}$$

Clipping Transformation

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

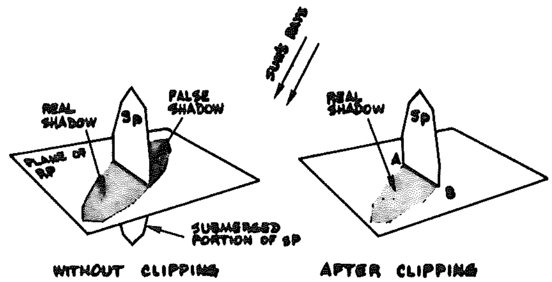


Figure 6 CLIPPING

Projection Transformation

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

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

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

Enclosure Test

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

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

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

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

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

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

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

Display Matrix and Typical Problem

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

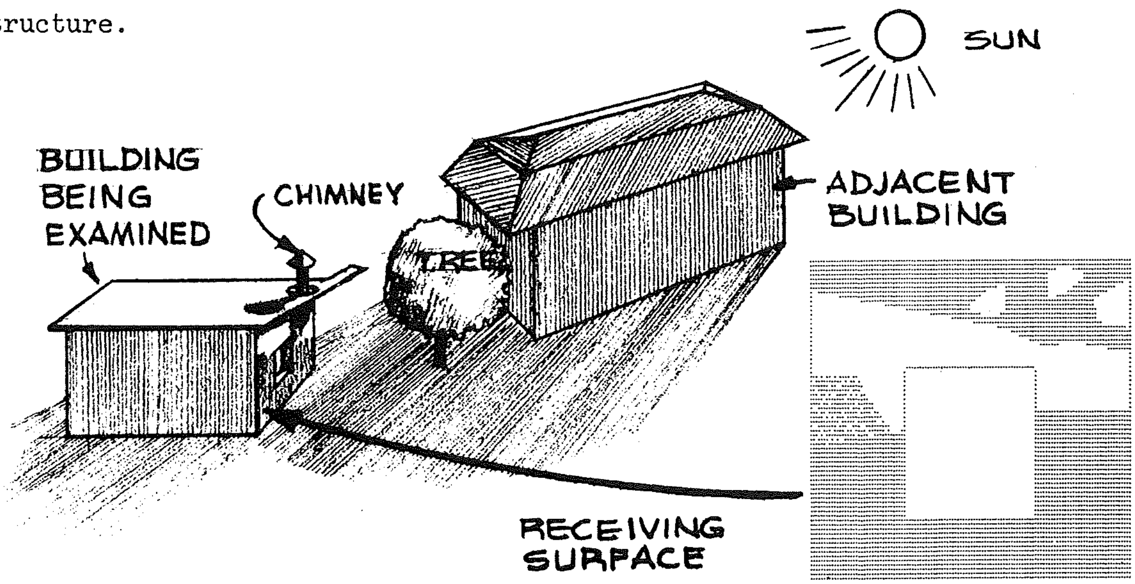


Figure 7 THE COMPUTER OUTPUT OF A TYPICAL PROBLEM

SHG

A subroutine which calculates solar heat gain through windows.

INPUT

IDN	:	Intensity of direct normal solar radiation, Btu/hr-sq ft
BS	:	Sky brightness, Btu/hr-sq ft
BG	:	Ground brightness, Btu/hr-sq ft
$\text{Cos}(\eta)$	:	Cosine of the angle of incidence of direct solar radiation
FWS	:	Form factor between the window and the sky*
FWG	:	Form factor between the window and the ground*
RO, RA, RI	:	Thermal resistances at outside surface, air space, and inside surface, sq ft-hr-°F/Btu
SLA	:	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
T_η, T_d	:	Transmission factors of direct and diffuse radiation for windows
$A_{\eta,\text{outer}}$, $A_{\eta,\text{inner}}$	:	Absorption factors of direct solar radiation through outer and inner window pane
$A_{d,\text{outer}}$, $A_{d,\text{inner}}$	:	Absorption factors of diffuse radiation through outer and inner window pane

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

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

OUTPUT

SHG : Solar 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.

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

$$NO = RO/(RO + RA + RI)$$

2. Let

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

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

3. Calculate solar heat gain through glass.

If $SC = 0$, $SHG = D + d$.

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

SUN
(SUN1 + SUN2 + SUN3)

These subroutines determine the solar position of the sun and calculate the intensities of different components of solar radiation incident on the outer surfaces of the building. Because a part of the calculation depends upon the day of the year, part of the calculation depends upon the time of the day, and part of the calculation depends upon surface orientation, the SUN subroutine is divided into SUN1, SUN2 and SUN3.

Figure 8 illustrates the different angles which are used in the SUN1, SUN2 and SUN3 subroutines.

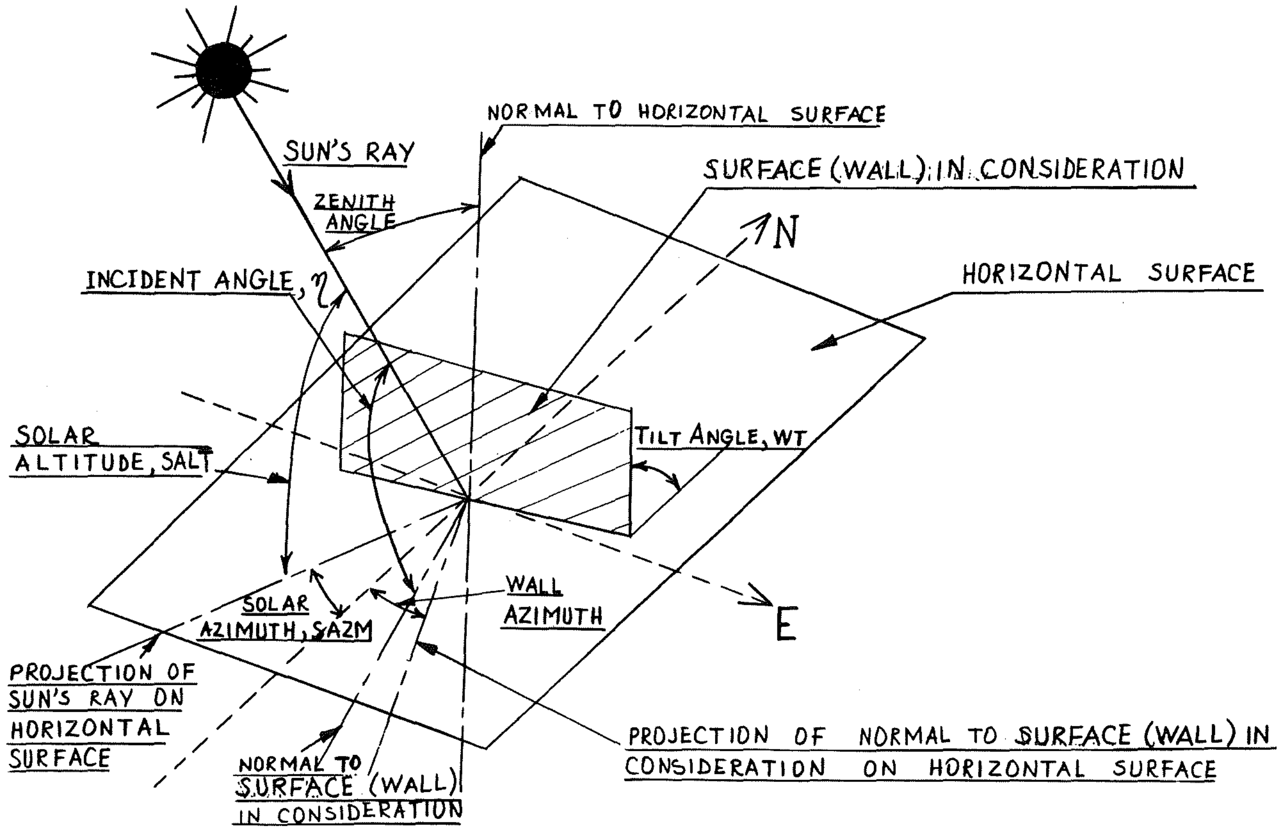


Figure 8 DEFINITION OF ANGLES

INPUT

L	:	Latitude, degrees, $\left\{ \begin{matrix} + \text{ North} \\ - \text{ South} \end{matrix} \right\}$
ℓ	:	Longitude, degrees, $\left\{ \begin{matrix} + \text{ West} \\ - \text{ East} \end{matrix} \right\}$
TZN	:	Time zone number (hours behind Greenwich Mean Time), (see Figure 9 and Table 9)
d	:	Date, days (from start of year), (1-366)
t	:	Time, hours (after midnight), (1-24)
DST	:	Daylight Saving Time indicator = $\left\{ \begin{matrix} 0 \text{ Standard Time period} \\ 1 \text{ Daylight Saving Time period} \end{matrix} \right.$

INPUT (CONT'D)

ρ_g	:	Ground reflectivity
CCM	:	Cloud cover modifier
CN	:	Clearness number*
WA	:	Surface azimuth angle, degrees (from South), $\left\{ \begin{array}{l} + \text{ if West of South} \\ - \text{ if East of South} \end{array} \right\}$
WT	:	Surface tilt angle, degrees (from horizontal)

OUTPUT

SRT and SSt	:	Sunrise and sunset time, hours (after midnight)
COS(Z) COS(W) COS(S)	:	Direction cosines of direct solar beam
α β γ	:	Direction cosines of normal to surface (Reference axes: Vertical, Horizontal to West, Horizontal to South)
COS(η)	:	Cosine of angle of incidence, η
SALT	:	Solar altitude, degrees
SAZM	:	Solar azimuth, degrees
BS	:	Sky brightness (= diffuse sky radiation on horizontal surface), Btu/hr-sq ft
BG	:	Ground brightness (= diffuse ground reflected radiation), Btu/hr-sq ft
IDN	:	Intensity of direct normal solar radiation, Btu/hr-sq ft

*Depending upon type of industry in the locality, use Clearness Number between 0.7 and 0.9. Otherwise, use the Clearness Numbers of non-industrial atmosphere which is given in Figure 10.

OUTPUT (CONT'D)

I : Intensity of total solar radiation incident on surface, Btu/hr-sq ft

$I_{d,sky}$: Intensity of sky diffuse radiation incident on surface, Btu/hr-sq ft

$I_{d,ground}$: Intensity of ground diffuse radiation incident on surface, Btu/hr-sq ft

TABLE 9

TIME ZONE NUMBERS IN U.S. FOR STANDARD TIME

TIME ZONE	TZ NO.
Atlantic	4
Eastern	5
Central	6
Mountain	7
Pacific	8

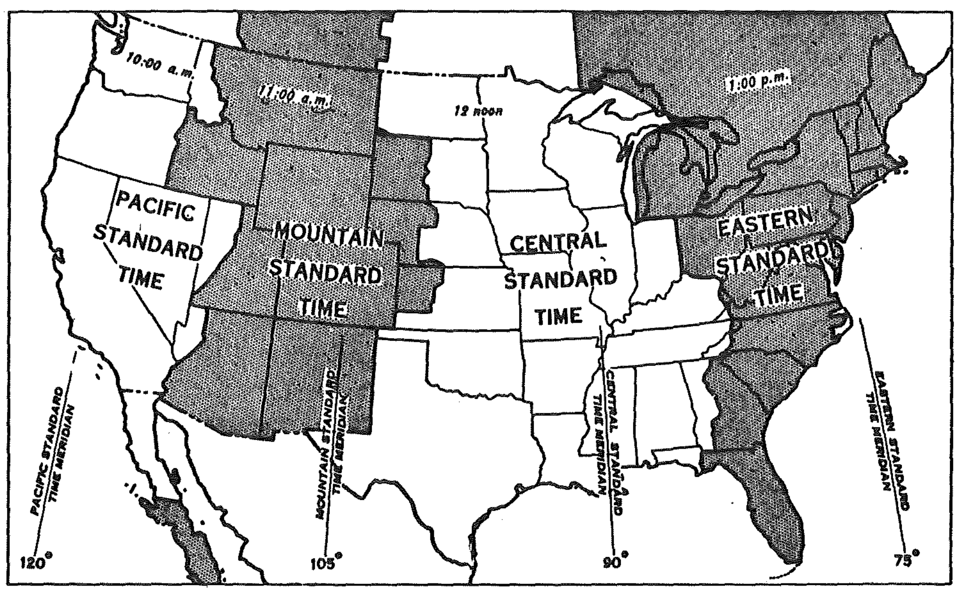


Figure 9 TIME ZONES IN THE UNITED STATES

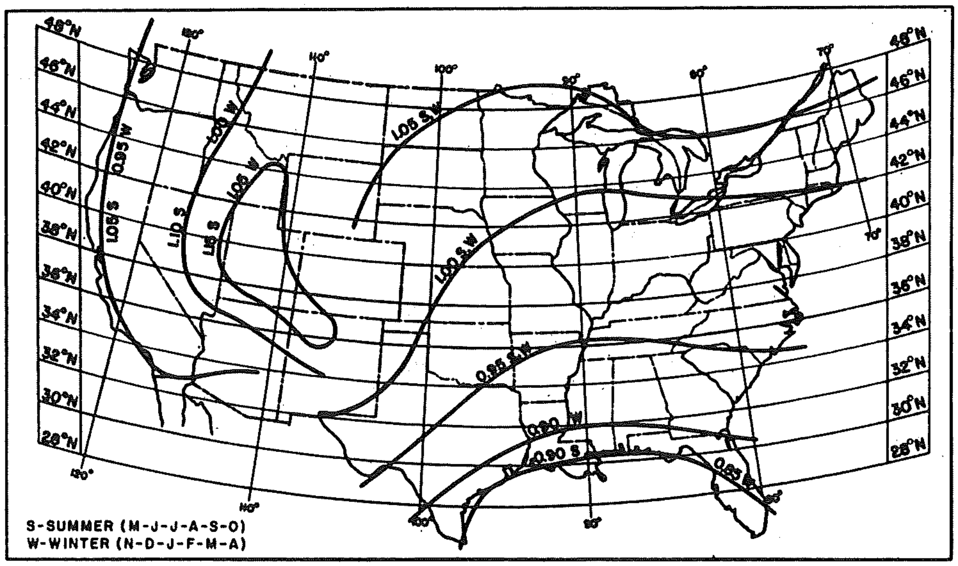


Figure 10 CLEARNESS NUMBERS OF NON-INDUSTRIAL ATMOSPHERE IN UNITED STATES

The data for declination angle, δ, equation of time, ET, and constants A, B and C, which are used in the calculation of direct and diffuse components of solar radiation are given in Table 10.

TABLE 10

DATA FOR CALCULATION OF δ, ET, IDN AND BS

Date	δ Degrees	ET Hours	A Btu per (hr)(sq ft)	B Air Mass^{-1}	C
Jan 21	-20.0	-.190	390	0.142	0.058
Feb 21	-10.8	-.230	385	0.144	0.060
Mar 21	0.0	-.123	376	0.156	0.071
Apr 21	41.6	+.020	360	0.180	0.097
May 21	20.0	+.060	350	0.196	0.121
June 21	23.45	-.025	345	0.205	0.134
July 21	20.6	-.103	344	0.207	0.136
Aug 21	12.3	-.051	351	0.201	0.122
Sept 21	0.0	+.113	365	0.177	0.092
Oct 21	-10.5	+.255	378	0.160	0.073
Nov 21	-19.8	+.235	387	0.149	0.063
Dec 21	-23.45	+.033	391	0.142	0.057

With these data, the Fourier Series Equation coefficients may be calculated. Thus the values of δ, ET, A, B and C as a function of the day of the year, d, are obtained from the following Fourier Series Equation, using the proper coefficients, which are given in Table 11.

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

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

TABLE 11

FOURIER SERIES EQUATION COEFFICIENTS

	A_0	A_1	A_2	A_3	B_1	B_2	B_3
δ	.302	-22.93	-.229	-.243	3.851	.002	-.055
ET	0.000	.007	-.05	-.0015	-.122	-.156	-.005
A	368.44	24.52	-1.14	-1.09	.58	-.18	.28
B	.1717	-.0344	.0032	.0024	-.0043	.0000	-.0008
C	.0905	-.0410	.0073	.0015	-.0034	.0004	-.0006

CALCULATION SEQUENCE

1. Calculate : Declination, δ, degrees
   Equation of time, ET, hours
   Constants, A, B and C

2. Calculate hour angle for sunrise and sunset, h', radians
   $h' = Cos^{-1}(-Tan(L) * Tan(\delta))$

   $Y = h' * (12/\pi)$

   Sunrise time, SRT, hour

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

Sunset time, SST, hour

SST = 24-SRT

3. Calculate hour angle, h, degrees

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

4. Check if $|h| > |h'|$.

If yes, make I = 0 and skip following steps.

If no, go to next step.

5. Calculate direction cosines of direct solar beam.

$$Cos(Z) = Sin(L) * Sin(\delta) \_ Cos(L) * Cos(\delta) * Cos(h)$$

$$Cos(W) = Cos(\delta) * Sin(h)$$

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

If $Cos(h) > (Tan(\delta)/Tan(L)$, Cos(S) is positive; otherwise is negative.

6. Calculate solar altitude and solar azimuth.

$$SALT = Sin^{-1} (Cos(Z))$$

If $Cos(S) > 0$, $SAZM = Sin^{-1} (Cos(W)/Cos(SALT))$.

If $Cos(S) < 0$, $SAZM = 180-Sin^{-1}(Cos(W)/Cos(SALT))$

7. Calculate intensity of direct normal solar radiation.

$$IDN = A * CN * EXP(-B/Cos(Z)) * CCM$$

8. Calculate sky brightness.

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

9. Calculate ground brightness.

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

10. Calculate direction cosines of normal to surface (wall).

$$\alpha = Cos(WT)$$

$$\beta = Sin(WA) * Sin(WT)$$

$$\gamma = Cos(WA * Sin(WT)$$

11. Calculate cosine of angle of incidence, η

$$\text{Cos}(\eta) = \alpha * \text{Cos}(Z) + \beta * \text{Cos}(W) + \gamma * \text{Cos}(S)$$

12. Calculate intensity of direct solar radiation incident on surface (wall), ID.

$$ID = IDN * \text{Cos}(\eta) \quad \text{if } \text{Cos}(\eta) > 0; \text{ otherwise } ID = 0.$$

13. Calculate intensity of sky diffuse radiation incident on surface (wall).

$$I_{d,sky} = BS * ((1 + \alpha)/2)$$

14. Calculate intensity of ground diffuse radiation incident on surface (wall).

$$I_{d,ground} = BG * ((1 - \alpha)/2)$$

15. Calculate intensity of total solar radiation incident on surface (wall).

$$I = (ID + I_{d,sky} + I_{d,ground})$$

TABMAK

A subroutine which tabulates the outputs of the computer program.

TAR

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

INPUT

N	:	Number of panes (1 or 2)
$\text{Cos}(\eta)$	:	Cosine of angle of incidence, η
$k*\ell$	:	Extinction coefficient $[\text{inches}^{-1}]$ * thickness [inches]

Note: In some cases, glass manufacturers give the value of transmission at Normal incidence. In this case, using the curve given in Figure 11, it is possible to obtain the value of $k*\ell$. The data for the curve are taken from National Research Council of Canada Report No. 7104.

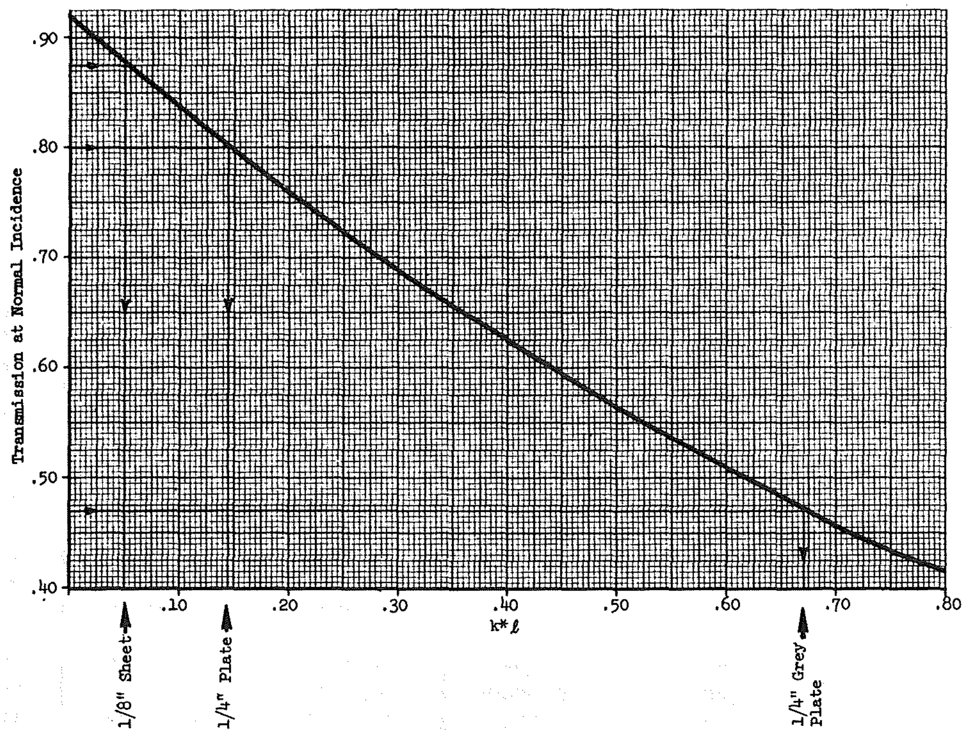


Figure 11 $k^*\ell$ VS TRANSMISSION AT NORMAL INCIDENCE FOR SINGLE SHEET GLASS

OUTPUT

$$\left.\begin{matrix} T_\eta \\ T_d \end{matrix}\right\} \quad : \quad \text{Transmission factors}$$

$$\left.\begin{matrix} A_{\eta,\text{outer}} \\ A_{d,\text{outer}} \\ A_{\eta,\text{inner}} \\ A_{d,\text{inner}} \end{matrix}\right\} \quad : \quad \text{Absorption factors}$$

where η indicates direct solar radiation beam at an incident angle η; subscript d indicates diffuse radiation.

The data for the polynomial coefficients a_j and t_j are given in Table 12. These coefficients are curve-fitted and the equation forms used in the subroutine.

TABLE 12 POLYNOMIAL COEFFICIENTS FOR USE IN CALCULATION OF TRANSMITTANCE AND ABSORPTANCE OF GLASS

$k^*\ell$	j	Single Glazing a_j	Single Glazing t_j	Double Glazing $a_{j,outer}$	Double Glazing $a_{j,inner}$	Double Glazing t_j
0.05 1/8" Sheet	0	0.01154	-0.00885	0.01407	0.00228	-0.00401
	1	0.77674	2.71235	1.06226	0.34559	0.74050
	2	-3.94657	-0.62062	-5.59131	-1.19908	7.20350
	3	8.57881	-7.07329	12.15034	2.22366	-20.11763
	4	-8.38135	9.75995	-11.78092	-2.05287	19.68824
	5	3.01188	-3.89922	4.20070	0.72376	-6.74585
0.10	0	0.01636	-0.01114	0.01819	0.00123	-0.00438
	1	1.40783	2.39371	1.86277	0.29788	0.57818
	2	-6.79030	0.42978	-9.24831	-0.92256	7.42065
	3	14.37378	-8.98262	19.49443	1.58171	-20.26848
	4	-13.83357	11.51798	-18.56094	-1.40040	19.79706
	5	4.92439	-4.52064	6.53940	0.48316	-6.79619
0.15 1/4" Reg. Plate	0	0.01837	-0.01200	0.01905	0.00067	-0.00428
	1	1.92497	2.13036	2.47900	0.26017	0.45797
	2	-8.89134	1.13833	-11.74266	-0.72713	7.41367
	3	18.40197	-10.07925	24.14037	1.14950	-19.92004
	4	-17.48648	12.44161	-22.64299	-0.97138	19.40969
	5	6.17544	-4.83285	7.89954	0.32705	-6.66603
0.20	0	0.01902	-0.01218	0.01862	0.00035	-0.00401
	1	2.35417	1.90950	2.96400	0.22974	0.36698
	2	-10.47151	1.61391	-13.48701	-0.58381	7.27324
	3	21.24322	-10.64872	27.13020	0.84626	-19.29364
	4	-19.95978	12.83698	-25.11877	-0.67666	18.75408
	5	6.99964	-4.95199	8.68895	0.22102	-6.43968
0.40	0	0.01712	-0.01056	0.01423	-0.00009	-0.00279
	1	3.50839	1.29711	4.14384	0.15049	0.16468
	2	-13.86390	2.28615	-16.66709	-0.27590	6.17715
	3	26.34330	-10.37132	31.30484	0.25618	-15.84811
	4	-23.84846	11.95884	-27.81955	-0.12919	15.28302
	5	8.17372	-4.54880	9.36959	0.02859	-5.23666
0.60	0	0.01406	-0.00835	0.01056	-0.00016	-0.00192
	1	4.15958	0.92766	4.71447	0.10579	0.08180
	2	-15.06279	2.15721	-17.33454	-0.15035	4.94753
	3	27.18492	-8.71429	30.91781	0.06487	-12.43481
	4	-23.88518	9.87152	-26.63898	0.02759	11.92495
	5	8.03650	-3.73328	8.79495	-0.02317	-4.07787
0.80 50% Trans. H.A. Plate	0	0.01153	-0.00646	0.00819	-0.00015	-0.00136
	1	4.55946	0.68256	5.01768	0.07717	0.04419
	2	-15.43294	1.82499	-17.21228	-0.09059	3.87529
	3	26.70568	-6.95325	29.46388	0.00050	-9.59069
	4	-22.87993	7.80647	-24.76915	0.06711	9.16022
	5	7.57795	-2.94454	8.05040	-0.03394	-3.12776
1.00	0	0.00962	-0.00496	0.00670	-0.00012	-0.00098
	1	4.81911	0.51043	5.18781	0.05746	0.02576
	2	-15.47137	1.47607	-16.84820	-0.05878	3.00400
	3	25.86516	-5.41985	27.90292	-0.01855	-7.33834
	4	-21.69106	6.05546	-22.99619	0.06837	6.98747
	5	7.08714	-2.28162	7.38140	-0.03191	-2.38328

CALCULATION SEQUENCE

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

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

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

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

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

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

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

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

WALLS

A subroutine for selecting a standard ASHRAE wall from computer storage which meets but does not exceed a specified overall heat transfer coefficient (UMAX). The subroutine facilitates the selection of a realistic wall composition and its thermal properties when the user specifies the construction of the outside layer, the insulation thickness, and the desired design season conditions. The subroutine gives the number of layers and the thickness, thermal conductivity, density, specific heat, and thermal resistance of each layer which are required by the response factor subroutine.

INPUT

IS : Outside layer index

IS = 1 Stucco
IS = 2 Brick or rough plaster
IS = 3 Concrete
IS = 4 Clear Pine
(If IS > 4, the subroutine makes IS = 4.)

INPUT (CONT'D)

UMAX : Maximum overall heat transfer coefficient desired (including outside film coefficient), Btu/hr-ft^2-°F

TINS : Thickness of insulation desired, inches

KOLD : Design season condition index

KOLD = 1 Winter conditions (15 mph winds)
KOLD = 2 Summer conditions (7-1/2 mph winds)

OUTPUT

LAYER : Number of layers of the selected ASHRAE wall

$THKNS_i$: Thickness of layer, ft where i = 1, ..., LAYER

$CTVTY_i$: Thermal conductivity of each layer, Btu/hr-ft-°F where i = 1, ..., LAYER

$DNSTY_i$: Density of each layer, lb/ft^3 where i = 1, ..., LAYER

$SPCHT_i$: Specific heat of each layer, Btu/lb-°F where i = 1, ..., LAYER

RES_i : Thermal resistance of each layer, hr-ft^2-°F/Btu where i = 1, ..., LAYER

CALCULATION SEQUENCE

1. If KOLD = 1, RO = 0.17 hr-ft^2-°F/Btu for winter conditions.

   If KOLD = 2, RO = 0.25 hr-ft^2-°F/Btu for summer conditions.

2. If IS = 1, call STUCO.

   If IS = 2, call BRICK.

   If IS = 3, call CONCR.

   If IS = 4, call PINE.

   These supporting subroutines scan the stored wall constructions to determine the largest overall heat transfer coefficient which does not exceed UMAX. Each subroutine returns the indices K1, L1, M1 corresponding to exterior construction, type of sheathing, and interior finish, respectively, for the selected wall.

3. Compute and/or extract from memory for each layer:

LAYER, THKNS, CTVTY, DNSTY, SPCHT, RES

For each layer that makes up the composition of the exterior wall, sheathing, air space, and interior finish, the layers are ordered from outside to inside, including air spaces and insulation.

WEATHER

The weather subroutine obtains the hourly values of the data listed below, together with Station Number, Year, Month, Day and Hour (Standard Time) from "1440 Magnetic Tapes" of the National Weather Record Center, which are required by the hourly load calculation procedure.

DBT	:	Dry-bulb temperature, °F
DPT or WBT	:	Dew point or wet-bulb temperature, °F
TCA	:	Total cloud amount index
TOC	:	Cloud type index
V	:	Wind velocity, knots
PATM	:	Atmospheric pressure, in. Hg

The hourly values of the data listed above can be obtained either in punch card or magnetic tape form from the National Weather Record Center, NWRC, Asheville, N.C. Detailed information on these data may be found in:

(1) Reference Manual WBAN Hourly Surface Observations 144, April, 1966

(2) Reference Manual WBAN Solar Radiation-Hourly 280, April 1967

(3) Tape Reference Manual, Airways Surface Observations, TDF 14.

SECTION 3

PUNCH SUB-PROGRAM

The Punch Sub-program prepares the punched card input required for the Thermal Loads Plot Sub-program. This sub-program reads through the output tape which was generated by the Load Calculation Sub-program and punches the deck of cards required for plotting the hourly space loads indicated by the engineer. See Figure 12 for a flow chart of the Punch Sub-program operations. No detailed description is given here of the calculations taking place within the sub-program, since the only functions being performed are those of input and output.

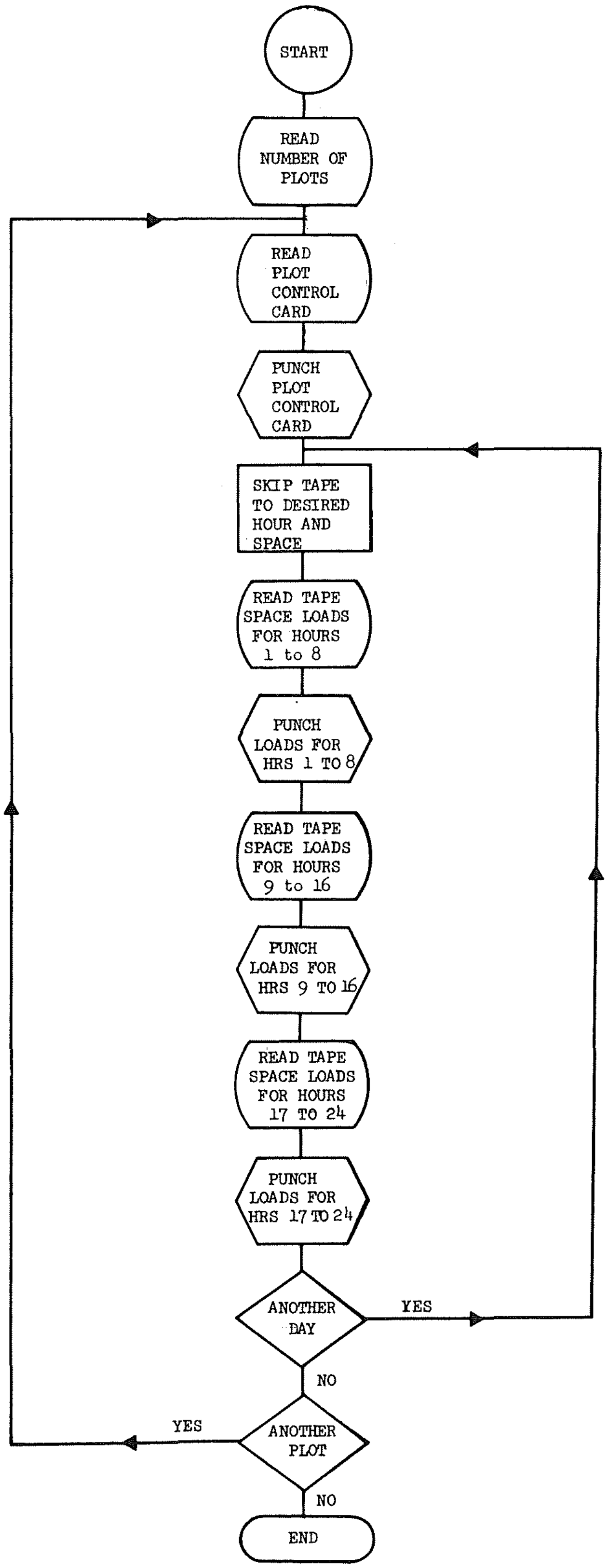


Figure 12 LOGIC FLOW CHART OF PUNCH SUB-PROGRAM

SECTION 4

THERMAL LOADS PLOT SUB-PROGRAM

The Thermal Loads Plot Sub-program is an offline plotting program which takes the card input prepared by the Punch Sub-program and plots these data for either a day, week, month or year as indicated by the engineer for each space and length of time desired. A logic flow chart of the Thermal Loads Plot Sub-program is shown in Figure 13. No detailed calculations are outlined here, since the program is basically only performing input and output functions.

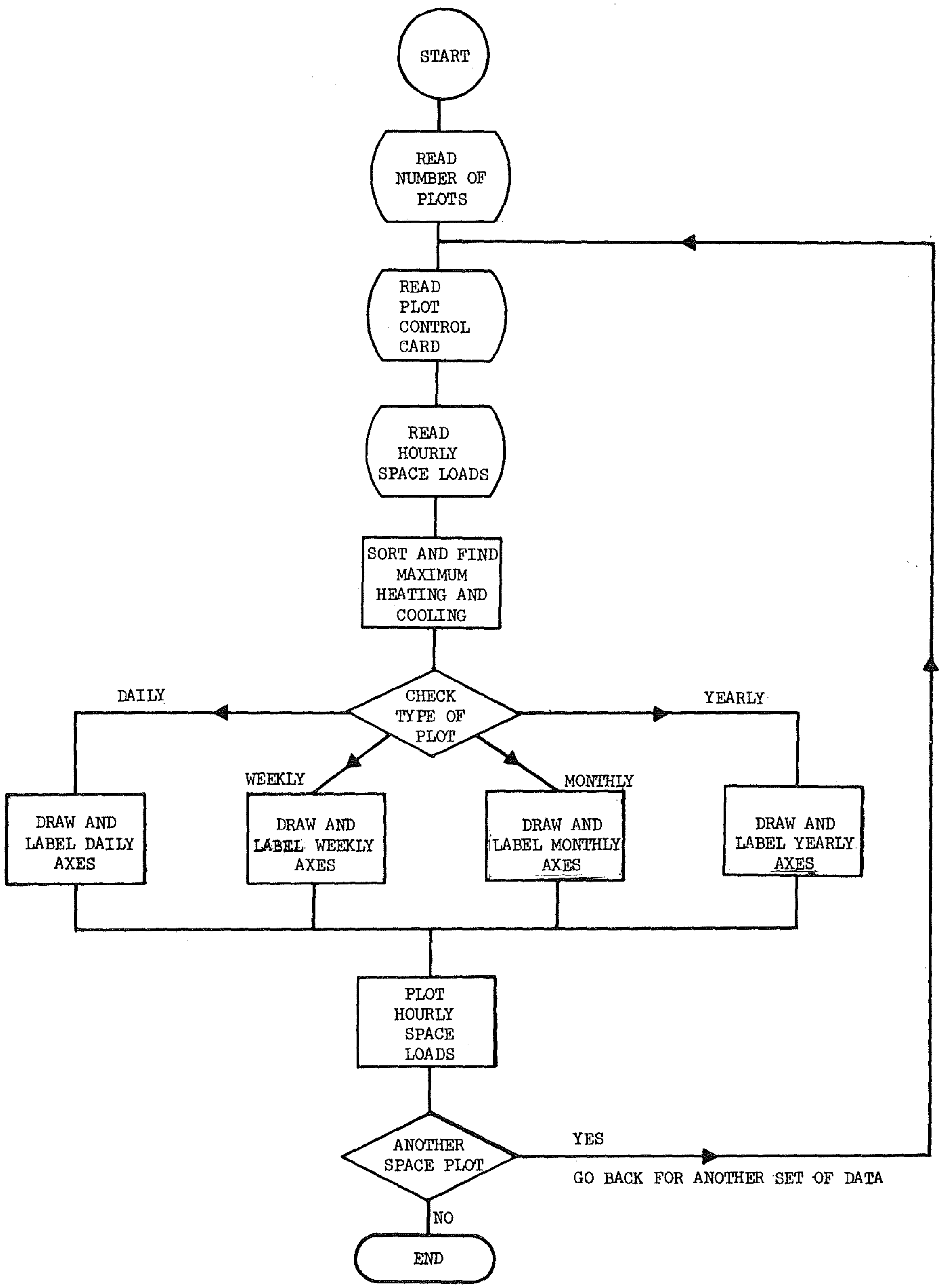


Figure 13 LOGIC FLOW CHART OF THERMAL LOADS PLOT SUB-PROGRAM

SECTION 5

LOAD EDITING SUB-PROGRAM

If, after the running of the Load Calculation Sub-program and the Thermal Loads Plot Sub-program, the engineer decides that the initial breakdown of the building was not satisfactory and therefore he wishes to regroup and/or re-order the spaces or zones, the Load Editing Sub-program can be used to accomplish this task. The sole purpose of this sub-program is to re-assemble the information on the Load Calculation Sub-program output tape according to the grouping and/or ordering sequence chosen by the engineer.

SECTION 6

SYSTEMS SIMULATION SUB-PROGRAM

The hourly space loads calculated by the Load Calculation Sub-program are not necessarily the heating and/or cooling loads that are transferred through the fan systems and back to the heating and cooling plants. Due to outside air requirements and the limitations imposed by various component control schedules, the building's hourly heating and/or cooling requirement can be different from the summation of the hourly heating and/or cooling space loads. The Systems Simulation Sub-program is required, therefore, to perform two functions. First, translate the hourly space loads, including the ventilation air requirements, by means of the individual performance characteristics of each fan system, into the actual hourly thermal requirements imposed upon the heating and cooling plants, and second, convert these hourly thermal requirements into energy requirements based upon the part-load characteristics of the heating and cooling plant equipment.

The System Simulation Sub-program is actually made up of 15 smaller programs or subroutines. (See Table 13 for a description of these subroutines.) Subroutine SYSIM directs the flow of logic through the sub-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 sized using the peak hourly heating and cooling zone loads. Next, the central heating and cooling plant components are sized based upon the peak building heating and cooling loads. Then, an hour-by-hour analysis of the building's heating/cooling systems is performed. Each heating/cooling 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 calculation, 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 done repeatedly for every hour of each month, thus establishing the monthly energy requirements for the building equipment combination in question. An annual summary of the energy 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. Figures 14 to 16 depict schematically the workings of the SYSIM, EQUIP and HTCON subroutines and Figure 17 illustrates the interrelationship of all 15 subroutines.

A detailed description of the Systems Simulation Sub-program subroutines follows.

TABLE 13

SYSTEM SIMULATION SUB-PROGRAM SUBROUTINES
AND THEIR FUNCTION

NAME OF THE SUBROUTINE	FUNCTION
SYSIM	Controls the operation of the entire Systems Simulation Sub-program by executing the subroutines in their proper order.
FSIZE	Sizes the air flow quantities for each fan zone.
HTCON	Simulates the operation of the heat conservation system.
SZMZD	Simulates the operation of single zone, multizone and dual-duct fan systems.
SZRHT	Simulates the operation of single zone/reheat fan system.
UVENT	Simulates the operation of unit ventilator and unit heater systems.
FHEAT	Simulates the operation of floor panel heating systems.
PSYCH	Calculates the psychrometric properties of moist air.
EQUIP	Simulates the operation of heating and cooling central systems and on-site generation systems.
RECIP	Simulates the operation of reciprocating water chillers.
CENT	Simulates the operation of hermetic centrifugal water chillers.
ABSOR	Simulates the operation of steam absorption water chillers.
STTUR	Simulates the operation of steam turbines.
SNOW	Simulates the operation of snow-melting systems.
ENGYC	Prints out annual energy consumption summary in a form similar to POD Form No. 2215.

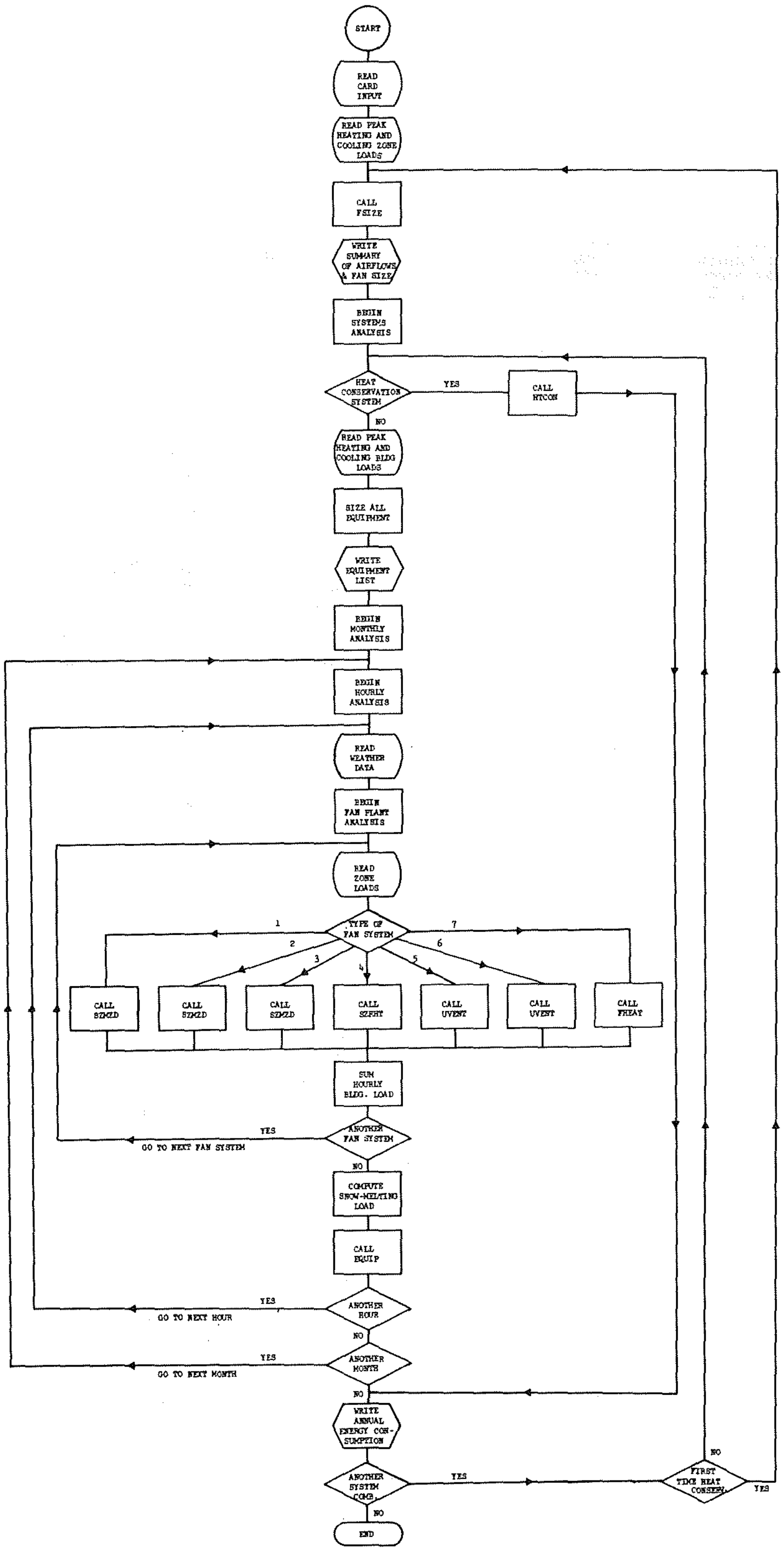


Figure 14 LOGIC FLOW CHART OF SYSTEMS SIMULATION SUB-PROGRAM (SYSIM SUBROUTINE)

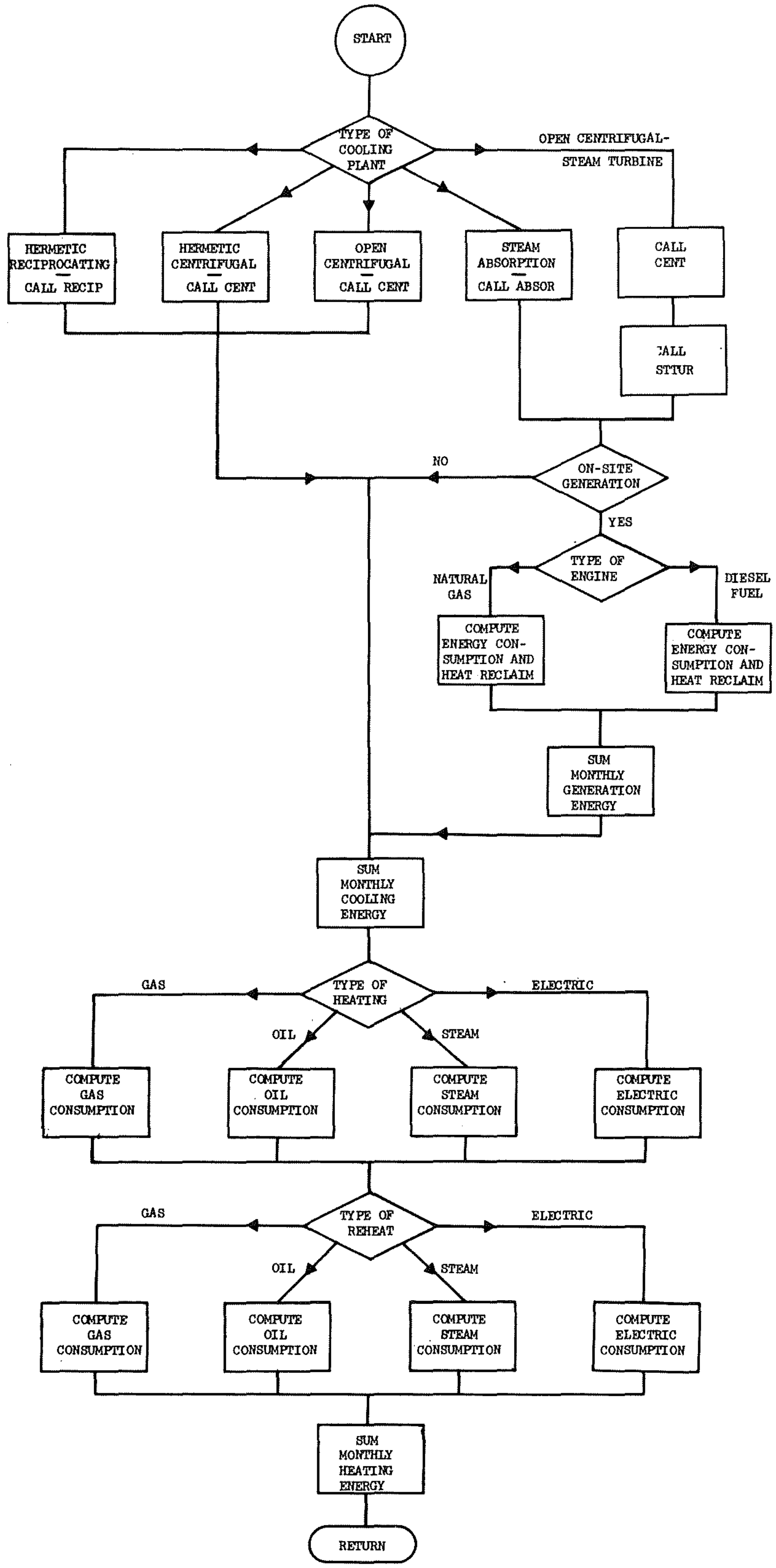


Figure 15 LOGIC FLOW CHART OF EQUIP SUBROUTINE

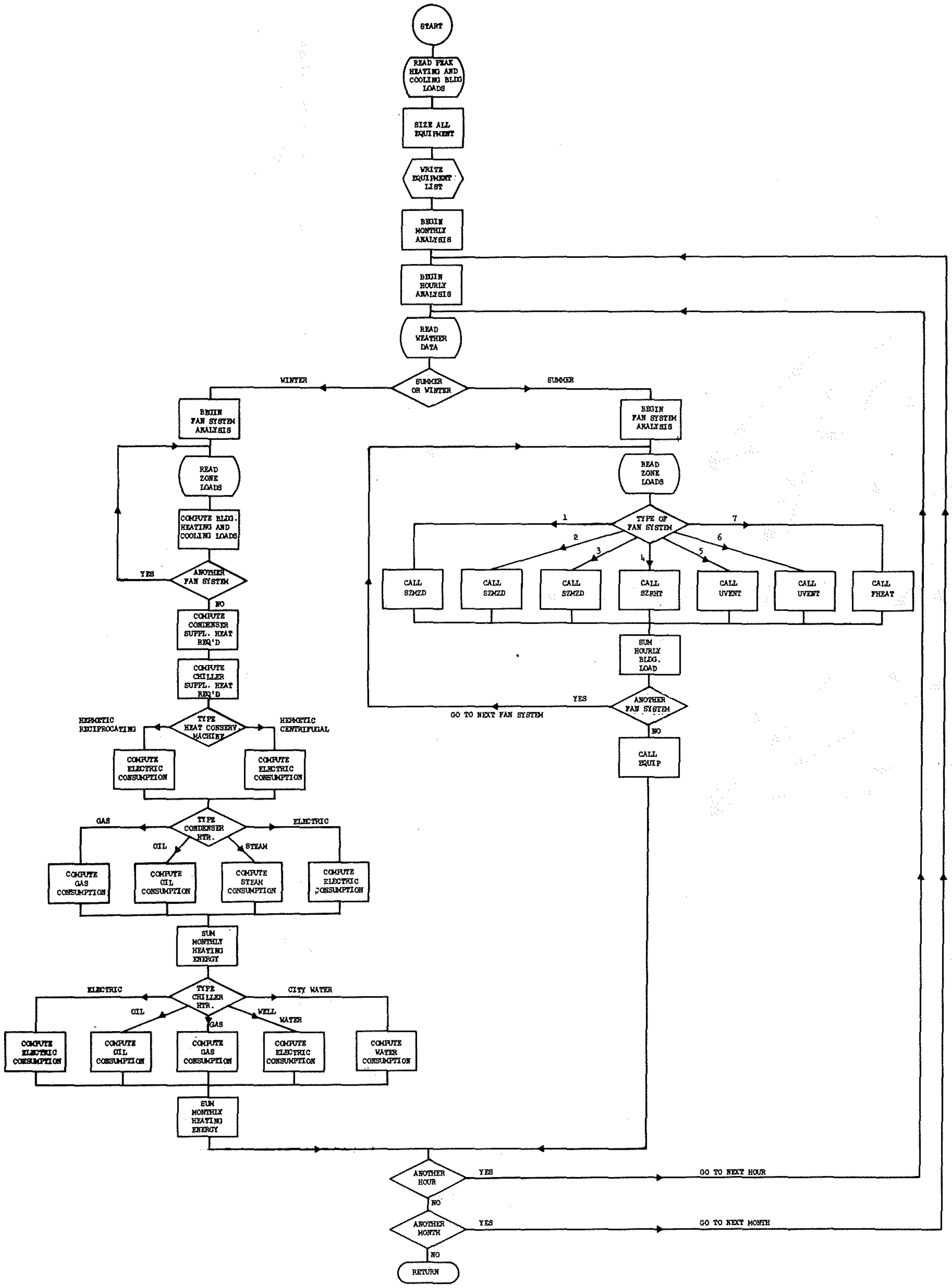
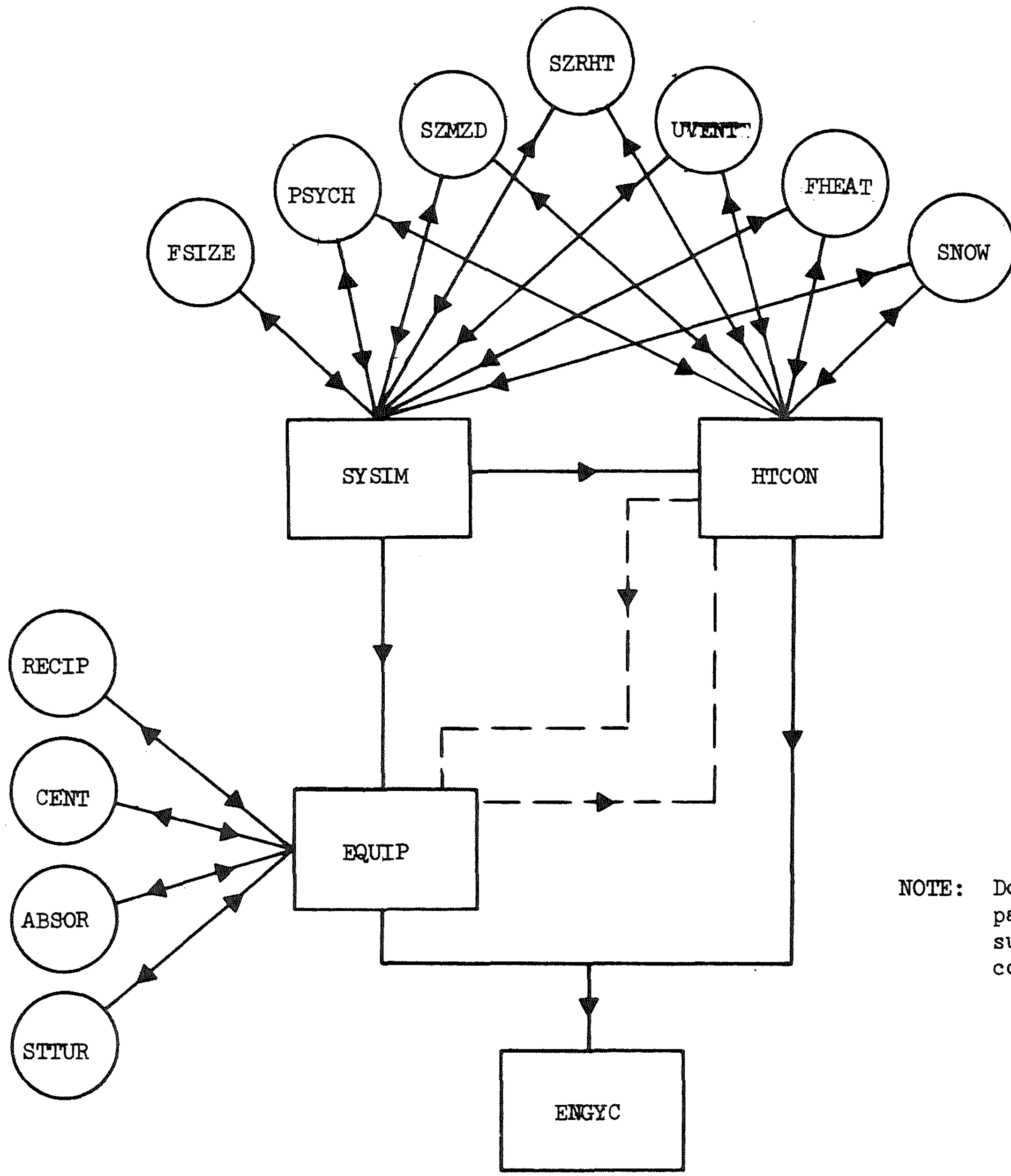


Figure 16 LOGIC FLOW CHART OF HTCON SUBROUTINE



NOTE: Dotted line indicates path of logic taken for summer operation of heat conservation machines.

Figure 17 INTERRELATIONSHIP OF SYSTEMS SIMULATION SUB-PROGRAM SUBROUTINES

SYSIM

A subroutine which calls in proper sequence the various subroutines necessary for simulation of the building's heating and cooling systems and for determination of the building's annual energy consumption. In particular, this subroutine reads input data, sizes all conventional and on-site generation system components and performs an hour-by-hour analysis of the building's energy needs.

INPUT

CARD INPUT VARIABLES:

TCO	:	Building changeover temperature, °F
TLCHL	:	Chilled water set point temperature, °F
TECMN	:	Low limit cooling tower water temperature, °F
TLCNM	:	Maximum condenser water temperature, °F
HVDF	:	Heating value of diesel fuel, Btu/gal
HVHO	:	Heating value of heating oil, Btu/gal
TCLMN	:	Returning supplementary water temperature, °F
TCWIN	:	Temperature of city water, °F
TWWIN	:	Temperature of well water, °F
PESTM	:	Pressure of low pressure steam, °F
TESTM	:	Temperature of low pressure steam, °F
PPS	:	Pressure of high pressure steam, psig
TPS	:	Temperature of high pressure steam, °F
EFF	:	Fan and pump motor efficiency, decimal
RPM	:	Speed of steam turbine, rpm
HDCLP	:	Head of chilled water pump, feet
HDCNP	:	Head of condenser water pump, feet
HDBLP	:	Head of boiler water pump, feet

CARD INPUT VARIABLES: (CONT'D)

HDWWP	:	Head of well water pump, feet
PWØL	:	Power of external lights, KW
NUMB	:	Number of boilers
FFLMN	:	Minimum part load cutoff point for chillers, decimal
KSNOW	:	Type of snow-melting system
QSNOW	:	Design load of snow-melting system, Btu/hr
SAREA	:	Total snow-melting slab area, sq ft
KFLCV	:	Type of floor covering used with floor panel heating system
CINSL	:	Floor insulation conductance, Btu/hr-sq ft-°F
DINSL	:	Floor insulation thickness, feet
KMAX	:	Number of fan systems in building
NCASE	:	Number of cases to be run
KHCST	:	Is one of cases a conventional building?
IHRMC	:	Peak cooling hour number
TOAC	:	Outside air temperature for peak cooling hour, °F
WOAC	:	Outside air humidity ratio for peak cooling hour, lb water/lb dry air
PATMC	:	Barometric pressure for peak cooling hour, inches of mercury
QSBCM	:	Building sensible load for peak cooling hour, Btu/hr
QLBCM	:	Building latent load for peak cooling hour, Btu/hr
QLITC	:	Building lighting load picked up by return air for peak cooling hour, Btu/hr
IHRMH	:	Peak heating hour number
TOAH	:	Outside air temperature for peak heating hour, Btu/hr

CARD INPUT VARIABLES: (CONT'D)

WOAH	:	Outside air humidity ratio for peak heating hour, Btu/hr
PATMH	:	Barometric pressure for peak heating hour, inches of mercury
QSBHM	:	Building sensible load for peak heating hour, Btu/hr
KFAN(K)	:	Type of fan system
JMAX(K)	:	Number of zones on fan system No. K
TSP(K)	:	Set point temperature of fan system No. K, °F
FPRES(K)	:	Total pressure of fan system No. K, inches water
PLOC(K)	:	Location of floor panel heating system No. K
PAREA(K)	:	Floor area available for heating panels for system No. K, sq ft
PERIM(K)	:	Exposed perimeter of floor for system No. K, feet
CFMX(K,J)	:	Auxiliary exhaust air quantity for fan system No. K, and zone No. J
ISYS	:	System combination number
KBLDG	:	Type of building system
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
SNOW(ID)	:	Snow-fall for day No. ID, inches

TAPE INPUT VARIABLES:

FAC	:	Name of facility
CITY	:	Name of city in which facility is located
ENGR	:	Name of engineer
PROJ	:	Project number
DATE	:	Date of computer run
MSTRT	:	Month at which analysis is to start
NDAYS	:	Number of days for which analysis is to run
IMAX(M)	:	Number of hours in month No. M
IZNMX	:	Number of fan zones in building
VOL(K,J)	:	Volume of zone No. J of fan system No. K, cu ft

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

IHOUR	:	Hour number
ISUN	:	Sun index which indicates whether or not the sun is up
TOA	:	Outside air dry-bulb temperature, °F
VEL	:	Wind velocity, knots
WOA	:	Outside air humidity ratio, lb water/lb dry air
PATM	:	Barometric pressure, inches of mercury
HOA	:	Enthalpy of outside air, Btu/lb dry air
DOA	:	Density of outside air, lb dry air/cu ft

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

IS	:	Space number
QS(J)	:	Zone sensible load, Btu/hr
QL(J)	:	Zone latent load, Btu/hr
QLITE(J)	:	Zone lighting load picked up by return air, Btu/hr
SLPOW(J)	:	Zone internal lighting and machinery power consumption, KW

OUTPUT

NUMC	:	Number of chillers
SZC	:	Size of chillers, tons
NUMB	:	Number of boilers
SZB	:	Size of boilers, MBH
NUMT	:	Number of steam turbines
SZT	:	Size of steam turbines, HP
M4	:	Number of on-site generation engines
SZE	:	Size of on-site generation engines, KW
CAPH	:	Total heating capacity, MBH
CAPC	:	Total cooling capacity, tons
CFMCT	:	Cooling tower air flows, cfm
HPCTF	:	Horsepower of cooling tower fan motor, HP
HPBLA	:	Horsepower of boiler auxiliaries, HP
GPMCL	:	Chilled water flow, gpm
HPCLP	:	Chilled water pump horsepower, HP
GPMCN	:	Condenser water flow, gpm
HPCNP	:	Condenser water pump horsepower, HP
GPMBL	:	Boiler water flow, gpm
HPBLP	:	Boiler water pump horsepower, HP

ENGY : Monthly energy consumptions and demands.
A 12 x 2 x 17 matrix with indices defined as indicated below.

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 demand
2 is Maximum monthly cooling demand
3 is Electric, internal lights and motors
4 is Electric, external lights
5 is Electric heat
6 is Electric cool
7 is Gas heat
8 is Gas cool
9 is Gas generation
10 is Steam heat
11 is Steam cool
12 is Oil heat
13 is Oil cool
14 is Diesel fuel generation
15 is Minimum monthly heating demand
16 is Minimum monthly cooling demand
17 is City water.

CALCULATION SEQUENCE

1. Read all card input information.

2. Call FSIZE to calculate the following quantities:

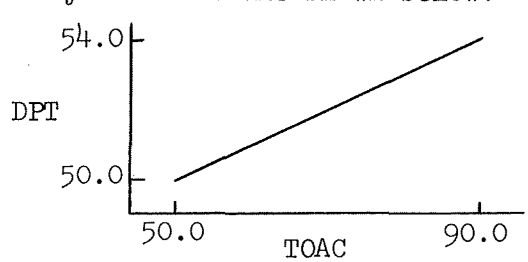
CFM(K,J)	:	Supply air quantity required for zone No. J of fan system No. K, cfm
CFMAX(K)	:	Total air supplied by fan system No. K, cfm
CFMIN(K)	:	Minimum outside air required for fan system No. K, cfm
ALFAM(K)	:	Percent of minimum outside air required for fan system No. K, decimal
FBHP(K)	:	Fan brake horsepower required for fan system No. K, HP
TFBHP	:	Summation of FBHP(K) for K = 1 to KMAX
CFMBN	:	Summation of CFMIN(K) for K = 1 to KMAX
CFMBE	:	Summation of CFMEX(K) for K = 1 to KMAX
PWILM	:	Maximum hourly power demand for internal lights and motors

3. For each building system, perform calculations 4 through 32.

4. Check type of system

   If conventional or on-site generation, go to calculation 5.
   If heat conservation, call HTCON and then go to calculation 31.

5. Calculate humidity ratio of air leaving cooling coil at peak cooling hour.
   Since no provision is made in the fan system analysis to simulate coil performance, the dehumidifying effect of the cooling coil is accounted for by the schedule shown below.



where DPT is the dew point temperature of the air leaving the cooling coil, °F, and TOAC is peak cooling hour outside air temperature. This schedule can be translated into the following equation with the help of a psychrometric chart:

$$WRA = (53.2 + 0.245 * (TOAC - 50.0))/7000.0$$

where WRA is the humidity ratio of the air leaving the cooling coil, lb water/lb dry air.

6. Compute the peak cooling hour outside air load assuming that all fan systems are taking in minimum outside air and that the entire building is maintained at 75°F.

   Sensible outside air load, Btu/hr

   $$QSOA = 14.4 * DOAC * CFMBN * (TOAC - 75.0)$$

   Latent outside air load, Btu/hr

   $$QLOA = 63300.0 * DOAC * CFMBN * (WOAC - WRA)$$

7. Compute the peak cooling hour lighting load (Btu/hr) picked up by return air.

   $$QLITM = QLITC * (CFMBX - CFMBN)/(CFMBX - CFMBE)$$

8. Determine total cooling capacity required.

   $$CAPC = 1.0 * (QSBCM + QLBCM + QSOA + QLOA + QLITM)/12000.0$$

   where CAPAC has units of tons.

9. Calculate number of chillers required.

   Set NUMC = 2 (number of chillers)

   Calculate size of chillers.

   $$SZC = CAPC/NUMC$$

   If necessary, increase NUMC until SZC < 2000.0.

10. Determine number of steam turbines required, if used.

   $$NUMT = NUMC$$

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

   $$SZT = SZC$$

12. Compute total heating capacity required.

If M1 = 4 (steam absorption chiller), go to calculation 12.2; otherwise, go to calculation 12.1.

12.1 Heating capacity required based upon peak heating hour

Sensible outside air load, Btu/hr

QSOA = 1.08 * CFMBN * (TOAH - 75.0)

Total heating capacity†

CAPH = -1.0 * (QSBHM + QSOA + QSNOW)/1000.0

where CAPH has units of MBH.

Go to calculation 13.

12.2 Heating capacity required is larger of peak heating or peak cooling hour requirement.

12.2.1 Heating capacity based upon peak cooling hour assuming 20 lbs steam per ton of cooling.

CAPH1 = CAPC * 20.0 * 33.472/34.5

where CAPH1 has units of MBH.

12.2.2 Heating capacity based upon peak heating hour.

Sensible outside air load, Btu/hr

QSOA = 1.08 * CFMBN * (TOAH - 75.0)

Total heating capacity†

CAPH2 = -1.0 * (QSBHM + QSOA + QSNOW)/1000.0

where CAPH2 has units of MBH.

12.2.3 If CAPH1 $\geq$ CAPH2, set

CAPH = CAPH1

If CAPH2 > CAPH1, set

CAPH = CAPH2

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†For further clarification of QSNOW, see note in HTCON subroutine, calculation sequence 5.

13. Compute size of boilers.

$$SZB = CAPH/NUMB$$

where SZB has units of MBH.

14. Size all pump water flows.

14.1 Chilled water flow rate, gpm

$$GPMCL = 2.4 * CAPC$$

14.2 Condenser water flow rate, gpm

If $M1 \neq 4$, $GPMCN = 3.0 * CAPC$

If $M1 = 4$ (steam absorption chiller), $GPMCN = 3.5 * CAPC$.

14.3 Boiler water flow rate, gpm

$$GPMBL = CAPH * 1000.0/(500.0 * 20.0)$$

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

15.1 Chilled water pump horsepower

$$HPCLP = GPMCL * HDCLP/(3962.0 * 0.6 * EFF)$$

15.2 Condenser water pump horsepower

$$HPCNP = GPMCN * HDCNP/(3962.0 * 0.6 * EFF)$$

15.3 Boiler water pump horsepower

$$HPBLP = GPMBL * HDBLP/(3962.0 * 0.6 * EFF)$$

16. Horsepower requirement for motors running boiler auxiliary equipment such as fans, blowers, pumps, etc. should be computed. From American Standard catalog for packaged boilers ranging in size from 20 to 750 HP, the auxiliary horsepower requirement was approximately 1/20 of the total boiler horsepower capacity; therefore,

$$HPBLA = CAPH * 1000.0/(33472.0 * 20.0)$$

17. Size cooling tower fan.

17.1 Cooling tower air flow requirement

For all chillers except steam absorption, use 300 cfm per ton of cooling; therefore,

$$CFMCT = 300.0 * CAPC$$

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

$$CFMCT = 350.0 * CAPC$$

17.2 Cooling tower fan horsepower requirement assuming 1.0 inch water total pressure

$$HPCTF = CFMCT * 1.0/(6346.0 * EFF)$$

18. Compute heating and cooling equipment electrical power demand.

When heating equipment is operating

$HPHEQ = HPBLA + HPBLP$ where HPHEQ has units of horsepower

$PWHEQ = HPHEQ * 0.7457$ where PWHEQ has units of KW

When cooling equipment is operating

$HPCEQ = HPCTF + HPCLP + HPCNP$ where HPCEQ has units of horsepower

$PWCEQ = HPCEQ * 0.7457$ where PWCEQ has unit of KW

19. Size on-site generation plants.

19.1 Calculate maximum building electrical demand assuming all possible electrical equipment operating.

$$BKWDM = PWBIL + PWOL + (TFBHP + HPCEQ + HPHEQ) * 0.7457$$

where BKWDM has units of KW.

19.2 Calculate number and size of on-site generation units.

19.2.1 If $M4 \neq 0$, set

$NUME = M4$ where NUME is number of engines.

Size of engines is then

$$SZE = BKWDM/NUME$$

If SZE > 500 KW, increase the number of engines until SZE $\leq$ 500 KW.

Finally, set M4 = NUME

19.2.2 If M4 = 0, set

NUME = 2 where NUME is number of engines.

Size of engines is then

SZE = BKWDM/NUME

If SZE > 500 KW, increase NUME until SZE $\leq$ 500 KW.

Finally, set M4 = NUME.

20. Begin hourly energy consumption analysis repeating calculations 21 through 30 for every hour of the analysis.

21. Read hourly weather data which includes:

IHOUR	:	Hour number
ISUN	:	Sun index
TOA	:	Dry-bulb temperature, °F
VEL	:	Wind velocity, knots
WOA	:	Humidity ratio, lb/lb
PATM	:	Barometric pressure, inches of mercury
HOA	:	Enthalpy, Btu/lb
DOA	:	Density, cu ft/lb

22. Calculate outside air wet-bulb temperature

22.1 If HOA > 11.758

TWB = 30.9185 - 39.682 * ALOG(HOA)
+ 20.584 * ALOG(HOA) ** 2.0
- 1.758 * ALOG(HOA) ** 3.0

22.2 If HOA $\leq$ 11.758

TWB = 0.604 + 3.4841 * ALOG(HOA) + 1.3601 * ALOG(HOA) ** 2.0 + 0.9731 * ALOG(HOA) ** 3.0

23. Calculate wind velocity in units of mph.

VWIND = 1.151 * VEL

24. Determine if cooling tower fan is operating.

24.1 If TOA < TCO, cooling tower fan is OFF; set KCTF = 0.

24.2 If TOA $\geq$ TCO, entering condenser water temperature is

TECON = TWB + 7.0

24.2.1 If TECON $\geq$ 85.0, cooling tower fan is ON; set KCTF = 1.

24.2.2 If TECON < 85.0

24.2.2.1 If TECON > (TECMN + 10.0) and from previous hour KCTF = 0, cooling tower fan is OFF, set KCTF = 0. Otherwise, cooling tower fan is ON; set KCTF = 1.

24.2.2.2 If TECON $\leq$ (TECMN + 10.0), cooling tower fan is OFF; set KCTF = 0.

25. Begin fan system analysis repeating the following for each fan system within the building.

25.1 Check type of fan system.

If KFAN(K) = 1, call SZMZD

= 2, call SZMZD

= 3, call SZMZD

= 4, call SZRHT

= 5, call UVENT

= 6, call UVENT

= 7, call FHEAT

Each of the above subroutines calculates the quantities:

QFPC	fan system cooling requirement, Btu/hr
QFPH	fan system heating requirements, Btu/hr
QFPRH	fan system reheat requirement, Btu/hr
PWL	power consumption of internal lights and motors in zones being served by the fan plant, KW.

25.2 Keep running total of building's hourly cooling, heating and reheat loads and zone power consumption.

QHBC = QHBC + QFPC

QHBH = QHBH + QFPH

QHBRH = QHBRH + QFPRH

PWILM = PWILM + PWL

26. Determine hourly electrical demand of the building (ELDEM) for on-site generation, if used.

26.1 If ISUN = 0, exterior lights are OFF; therefore, set

PWEL = 0.0

26.1.1 If TOA $\geq$ TCO, cooling equipment is ON; therefore,

ELDEM = PWILM + PWEL + (TFBHP + HPCLP + HPCNP + HDCTF * KCTF) * 0.7457

26.1.2 If TOA < TCO, heating equipment is ON; therfore,

ELDEM = PWILM + PWEL + (TFBHP + HPHEQ) * 0.7457

26.2 If ISUN = 1, exterior lights are ON; therefore, set

PWEL = PWOL

26.2.1 If TOA $\geq$ TCO, cooling equipment is ON; therefore,

ELDEM = PWILM + PWEL + (TFBHP + HPCLP + HPCNP + HPCTF * KCTF) * 0.7457

26.2.2 If TOA < TCO, heating equipment is ON; therefore,

$$ELDEM = PWILM + PWEL + (TFBHP + HPHEQ) * 0.7457$$

27. Check type of snow-melting system.

27.1 If KSNOW = 0, no snow-melting system. Go to calculation 28.

27.2 If KSNOW = 1 or 2, snow-melting considered.

27.2.1 Calculate amount of snowfall for the hour, assuming that 1/24 of the day's total fell during the hour.

$$SNOW = 0.1 * SNOWF(ID)/24.0$$

where SNOW has units of equivalent inches of water, SNOWF(ID) has units of inches of snow and ID is the day number of the year, calculated as follows:

$$ID = 1 + IHOUR/24$$

27.2.2 Call SNOWM subroutine which calculates QTOT, the snow-melting load.

27.2.3 Add QTOT to heating requirement of building.

27.2.3.1 If KSNOW = 1, liquid type snow-melting system; therefore,

$$QHBH = QHBH - QTOT$$

27.2.3.2 If KSNOW = 2, electric type snow-melting system; therefore,

$$ELEH = ELEH + QTOT/3413.0$$

28. Calculate hourly energy consumption.

Call EQUIP which calculates the following:

GASC
GASH
GASG
OILC
OILH
STMC
STMH
ELEC
ELEH
FUEL

See page 126 for explanation of these variables.

29. 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,2,9) 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)	See page 142 for explanation of ENGY matrix.

30. Keep a record of maximum hourly energy demands by checking, at the end of each hour's calculation, and updating the following energy demand quantities.

ENGY (M,1,1) ENGY (M,1,2) ENGY (M,1,3) ENGY (M,1,4) ENGY (M,1,5) ENGY (M,1,6) ENGY (M,1,7) ENGY (M,1,8) ENGY (M,1,9) ENGY (M,1,10) ENGY (M,1,11) ENGY (M,1,15) ENGY (M,1,16)	See page 142 for explanation of these quantities.

END OF HOURLY ANALYSIS FOR ENTIRE YEAR

31. Write out summary of equipment sizes. See page 67 for list of the items printed out.

32. Call ENGYC to write out annual summary of building monthly energy consumption and demands.

33. Check to see if there is another case to be run.

    If YES, go to calculation 4 and start over again.

    If NO, PROGRAM FINISHED.

HTCON

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

COMMON INPUT VARIABLES:

TCO	:	Building changeover temperature, °F
TLCHL	:	Chilled water set point temperature, °F
TLCNM	:	Maximum condenser water temperature, °F
HVDF	:	Heating value of diesel fuel, Btu/gal
HVHO	:	Heating value of heating oil, Btu/gal
TCLMN	:	Returning supplementary water temperature, °F
TCWIN	:	Temperature of city water, °F
TWWIN	:	Temperature of well water, °F
EFF	:	Fan and pump motor efficiency, decimal
HDCLP	:	Head of chilled water pump, feet
HDCNP	:	Head of condenser water pump, feet
HDBLP	:	Head of boiler water pump, feet
HDWWP	:	Head of well water pump, feet
FFLMN	:	Minimum part load cutoff point for chillers, decimal

INPUT (CONT'D)

PWOL	:	Power of external lights, KW
NUMB	:	Number of boilers
KSNOW	:	Type of snow-melting system
QSNOW	:	Design load of snow-melting system, Btu/hr
SAREA	:	Total snow-melting slab area, sq ft
KFLCV	:	Type of floor covering used with floor panel heating system
CINSL	:	Floor insulation conductance, Btu/hr-sq ft-°F
DINSL	:	Floor insulation thickness, feet
KMAX	:	Number of fan systems in building
KFAN(K)	:	Type of fan system
JMAX(K)	:	Number of zones on fan system No. K
TSP(K)	:	Set point temperature of fan system No. K, °F
FPRES(K)	:	Total pressure of fan system No. K, inches of water
PLOC(K)	:	Location of floor panel heating system No. K
PAREA(K)	:	Floor area available for heating panels for system No. K, sq ft
PERIM(K)	:	Exposed perimeter of floor for system No. K, feet
CFMX(K,J)	:	Auxiliary exhaust air quantity for fan system No. K, and zone No. J
IHRMC	:	Peak cooling hour number
TOAC	:	Outside air temperature for peak cooling hour, °F
WOAC	:	Outside air humidity ratio for peak cooling hour, lb water/lb dry air
PATMC	:	Barometric pressure for peak cooling hour, inches of mercury
QSBCM	:	Building sensible load for peak cooling hour, Btu/hr

QLBCM : Building latent load for peak cooling hour, Btu/hr

QLITC : Building lighting load picked up by return air for peak cooling hour, Btu/hr

IHRMH : Peak heating hour number

TOAH : Outside air temperature for peak heating hour, Btu/hr

WOAH : Outside air humidity ratio for peak heating hour, Btu/hr

PATMH : Barometric pressure for peak heating hour, inches of mercury

QSBHM : Building sensible load for peak heating hour, Btu/hr

KBLDG : Type of building system

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

SNOW(ID) : Snowfall for day No. ID, inches

TAPE INPUT VARIABLES:

FAC : Name of facility

CITY : Name of city in which facility is located

ENGR : Name of engineer

PROJ : Project number

DATE : Date of computer run

MSTRT : Month at which analysis is to start

INPUT (CONT'D)

NDAYS	:	Number of days for which analysis is to run
IMAX(M)	:	Number of hours in month No. M
IZNMX	:	Number of fan zones in building
VOL(K,J)	:	Volume of zone No. J of fan system No. K, cu ft

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

IHOUR	:	Hour number
ISUN	:	Sun index which indicates whether or not sun is "up"
TOA	:	Outside air dry-bulb temperature, °F
VEL	:	Wind velocity, knots
WOA	:	Outside air humidity ratio, lb water/lb dry air
PATM	:	Barometric pressure, inches of mercury
HOA	:	Enthalpy of outside air, Btu/lb dry air
DOA	:	Density of outside air, lb dry air/cu ft

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

IS	:	Space number
QS(J)	:	Zone sensible load, Btu/hr
QL(J)	:	Zone latent load, Btu/hr
QLITE(J)	:	Zone lighting load picked up by return air, Btu/hr
SLPOW(J)	:	Zone internal lighting and machinery power consumption, KW

OUTPUT

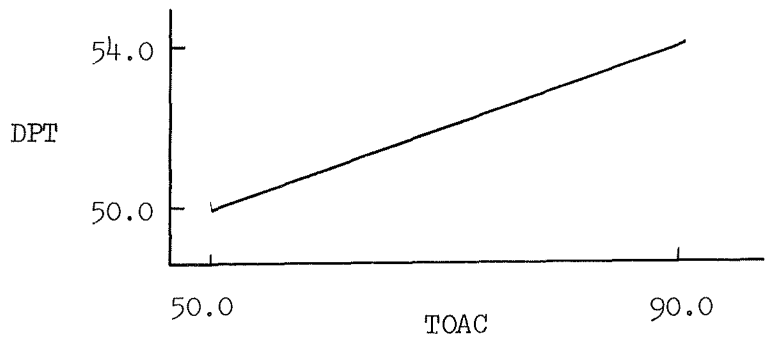
NUMHC	:	Number of heat conservation machines
SZHC	:	Size of heat conservation machines, tons
NUMC	:	Number of auxiliary chillers
SZC	:	Size of auxiliary chillers, tons

OUTPUT (CONT'D)

NUMB	:	Number of boilers
SZB	:	Size of boilers, MBH
CAPH	:	Total heating capacity, MBH
CAPC	:	Total cooling capacity, tons
SZSCL	:	Size of supplementary heating unit in chilled water circuit, MBH

CALCULATION SEQUENCE

1. Calculate the humidity ratio of air leaving cooling coil at peak cooling hour. Since no provision is made in the fan system analysis to simulate coil performance, the dehumidifying effect of the cooling coil is accounted for by the schedule shown below.



where DPT is the dew point temperature of the air leaving the cooling coil, °F; TOAC is peak cooling hour outside air temperature. This schedule can be translated into the following equation with the help of a psychrometric chart:

$$WRA = (53.2 + 0.245 * (TOAC - 50.0))/7000.0$$

where WRA is the humidity ratio of the air leaving the cooling coil, lb water/lb dry air.

2. Compute the peak cooling hour outside air load assuming that all fan systems are taking in minimum outside air and that the entire building is maintained at 75°F.

Sensible outside air load, Btu/hr

$$QSOA = 14.4 * DOAC * CFMBN * (TOAC - 75.0)$$

Latent outside air load, Btu/hr

$$QLOA = 63300.0 * DOAC * CFMBN * (WOAC - WRA)$$

3. Compute the peak cooling hour lighting load picked up by return air, Btu/hr

$$QLITM = QLITC * (CFMBX - CFMBN)/(CFMBX - CFMBE)$$

4. Calculate the total cooling capacity required.

$$QCR = 1.0 * (QSBCM + QLBCM + QSOA + QLOA + QLITM)$$

where QCR has unit of Btu/hr.

5. Calculate the total heating capacity required assuming no minimum outside air load at peak heating hour.

$$QHR = 1.0 * (QSBHM + QSNOW)$$

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 <u>1967 ASHRAE Guide and Data Book</u>, Systems and Equipment Volume, Chapter 27, Table 2.

6. Compare peak cooling requirement to the peak heating requirement expressed as equivalent cooling and size heat conservation machines based upon the smaller of the two. Assume 1.3 heat rejection ratio between condenser and evaporator, and a 0.5 ratio of winter cooling capacity to summer cooling capacity.

If $QCR \geq |QHR/(1.3 * 0.5)|$ go to calculation 6.2.

If $QCR < |QHR/(1.3 * 0.5)|$ go to calculation 6.1.

6.1 Size heat conservation machine based upon peak cooling load.

6.1.1 Compute total cooling capacity required.

$$CAPC = QCR/12000.0$$

where CAPC has units of tons.

6.1.2 Set NUMHC = 2 (number of heat conservation machines).

SZHC = CAPC * 1.3 * 0.5/NUMHC

where SZHC is the heat rejected at the condenser expressed in tons during winter operation of heat conservation machines.

If necessary, increase NUMHC until SZHC< 600.0.

6.1.3 Compute total heating capacity required.

CAPH = -QHR/1000.0

where CAPH has units of MBH.

6.1.4 Compute size of boilers required in condenser water circuit.

SZB = (-QHR - SZHC * NUMHC * 12000.0)/1000.0

where SZB has units of MBH.

6.1.5 Compute size of supplementary heat element required in chilled water circuit.

SZSCL = CAPH/1.3

where SZSCL has units of MBH.

Go to calculation 7.

6.2 Size heat conservation machine based upon peak heating load.

6.2.1 Compute the total heating capacity required.

CAPH = -QHR/1000.0

where CAPH has units of MBH.

6.2.2 Set NUMHC = 2 (number of heat conservation machines).

SZHC = CAPH/(12.0 * NUMHC)

where SZHC is the heat rejected at the condenser expressed in tons during winter operation of heat conservation machines.

If necessary, increase NUMHC until SZHC < 600.0.

6.2.3 Compute amount of cooling available from heat conservation machines during summer operation, Btu/hr.

QCA = (SZHC * NUMHC) * 12000.0/(1.3 * 0.5)

6.2.4 Compute amount of cooling which must be provided by auxiliary chillers, Btu/hr.

QDIF1 = QCR - QCA

6.2.5 Compute size of auxiliary chillers.
Set NUMC = 1 (number of auxiliary chillers).

SZC = QDIF1/(12000.0 * NUMC)

where SZC has units of tons.

If necessary, increase NUMC until SZC < 2000.0.

6.2.6 Compute total cooling capacity.

CAPC = QCA/12000.0 + NUMC * SZC

where CAPC has units of tons.

6.2.7 Compute size of supplementary heating element in chilled water circuit, MBH.

SZSCL = CAPH/1.3

7. Size all pump water flows.

7.1 Chilled water flow rate, gpm

GPMCL = 2.4 * CAPC

7.2 Condenser water flow rate, gpm

GPMCN = 3.0 * CAPC

7.3 Boiler water flow rate, gpm

GPMBL = CAPH * 1000.0/(500.0 * 20.0)

7.4 Well water flow rate, if used, gpm

GPMWW = SZSCL * 1000.0/(60.0 * 8.3 * 1.0 * (TWWIN - TCLMN))

8. Size all pump motors assuming pump efficiency of 60%.

8.1 Chilled water pump horsepower

HPCLP = GPMCL * HDCLP/(3962.0 * 0.6 * EFF)

8.2 Condenser water pump horsepower

HPCNP = GPMCN * HDCNP/(3962.0 * 0.6 * EFF)

8.3 Boiler water pump horsepower

HPBLP = GPMBL * HDBLP/(3962.0 * 0.6 * EFF)

8.4 Well water pump horsepower

HPWWP = GPMWW * HDWWP/(3962.0 * 0.6 * EFF)

9. Calculate the horsepower requirement for motors running boiler auxiliary equipment such as fans, blowers, pumps, etc. From American Standard Catalog for packaged boilers ranging in size from 20 to 750 horsepower, the auxiliary horsepower requirement was approximately 1/20 of the total boiler horsepower capacity, therefore,

HPBLA = CAPH * 1000.0/(33472.0 * 20.0)

10. Size cooling tower fan.

10.1 Cooling tower air flow requirement, cfm

CFMCT = 300.0 * CAPC

10.2 Cooling tower fan horsepower requirement assuming 1.0 inches of water total pressure.

HPCTF = CFMCT * 1.0/(6346.0 * EFF)

11. Begin hourly energy consumption analysis repeating calculations 12 through 20 for every hour of the year.

12. Read hourly weather data which includes:

IHOUR	:	Hour number
ISUN	:	Sun index
TOA	:	Dry-bulb temperature, °F
VEL	:	Wind velocity, knots

WOA	:	Humidity ratio, lb/lb
PATM	:	Barometric pressure, inches of mercury
HOA	:	Enthalpy, Btu/lb
DOA	:	Density, cu ft/lb

13. Calculate outside air wet-bulb temperature.

    13.1 If HOA > 11.758

    TWB = 30.9185 - 39.682 * ALOG (HOA) + 20.584 * ALOG (HOA) ** 2.0 - 1.758 * ALOG (HOA) ** 3.0

    13.2 If HOA ≤ 11.758

    TWB = 0.604 + 3.4841 * ALOG (HOA) + 1.3601 * ALOG (HOA) ** 2.0 + 0.9731 * ALOG (HOA) ** 3.0

14. Calculate wind velocity in units of mph.

    VWIND = 1.151 * VEL

15. Determine if external lights are ON.

    15.1 If ISUN = 1, set PWEL = 0.0.

    15.2 If ISUN = 1, set PWEL = PWOL.

16. Check outside air temperature to determine if summer or winter operation.

    If TOA ≥ TCO, summer operation; therefore go to calculation 17.

    If TOA < TCO, winter operation; therefore go to calculation 18.

17. Summer operation of heat conservation machines

    17.1 Begin fan system analysis repeating the following calculations for each fan system within the building.

17.1.1 Check type of fan system.

If KFAN(K) = 1, call SZMZD

= 2, call SZMZD

= 3, call SZMZD

= 4, call SZRHT

= 5, call UVENT

= 6, call UVENT

= 7, call FHEAT

All of the above subroutines calculate the quantities.

QFPC Fan system cooling requirement, Btu/hr

QFPH Fan system heating requirement, Btu/hr

QFPRH Fan system reheat requirement, Btu/hr

PWL Power consumption of internal lights and motors in zones being served by the fan system, KW

17.1.2 Keep running total of building cooling, heating and reheat loads.

QHBC = QHBC + QFPC

QHBH = QHBH + QFPH

QHBRH = QHBRH + QFPRH

17.2 Calculate hourly energy consumption. Call EQUIP which calculates the following:

GASC
GASH
GASG
OILC
OILH
STMC
STMH
ELEC
ELEH
FUEL

See subroutines ENGYC for explanation of these variables.

17.3 Go to calculation 19.

18. Winter operation of heat conservation machines

18.1 Begin fan system analysis repeating calculation 18.1.1 through 18.1.6 for each fan system K.

18.1.1 Read zone loads from input tape and form the following summations:

$$\left.\begin{aligned} QSUMC &= \sum(+QS(J)) \\ QSUMH &= \sum(-QS(J)) \end{aligned}\right\} \text{ for } J = 1 \text{ to } JMAX(K)$$

18.1.2 Calculate supply air temperature required for each zone, °F.

$$TS(J) = TSP(K) - QS(J)/(1.08 * CFM(K,J))$$

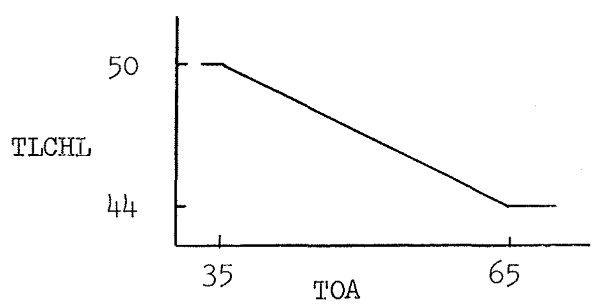
18.1.3 Form the summation

$$SUMCT = \sum(CFM(K,J) * TS(J)) \quad \text{for } J = 1 \text{ to } JMAX(K)$$

18.1.4 Calculate required leaving-condenser water temperature assuming schedule below which is a function of the hourly heating requirement of the building.

$$TLCON = TLCNM - 22.5 * (1.0 - QSUMH/QSBHM)$$

18.1.5 Calculate leaving-chilled water temperature assuming the schedule shown below.



This schedule can be expressed in equation form as

$$TLCHL = 44.0 + (65.0 - TOA)/5.0$$

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.

18.1.6 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,

$$\text{GAMA(K)} = \frac{\sum(\text{BETA(J)} + \text{CFM(K,J)})}{\text{CFMAX(K)}}$$

$$\text{for J} = 1 \text{ to JMAX(K)}$$

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

$$\text{TS(J)} = \text{TCD} * \text{BETA(J)} + \text{THD}(1 - \text{BETA(J)})$$

where TS(J) 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

$$\text{BETA(J)} = \frac{\text{THD} - \text{TS(J)}}{\text{THD} - \text{TCD}}$$

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

$$\text{THD} = \text{TLCON} - 5.0 * (1 - \text{GAMA(K)})$$

The temperature of air leaving the cooling coil (TCD) is then

$$TCD = TLCHL + 5.0 * GAMA(K)$$

Substituting the equation for BETA(J), THD and TCD into the equation for GAMA(K) results in

$$GAMA(K) = \frac{CFMAX(K) * (TLCON - 5.0) - SUMCT}{CFMAX(K) * (TLCON - TLCHL - 10.0)}$$

where

$$SUMCT = \sum(CFM(K,J) * TS(J)) \quad \text{for } J = 1 \text{ to } JMAX(K)$$

18.2 Calculate the quantity

$$SUMGX = \sum(GAMA(K) * CFMAX(K)) \quad \text{for } K = 1 \text{ to } KMAX$$

18.3 Calculate fraction of total air circulated within building that is passing through cooling coils.

$$GAMAB = SUMGX/CFMBX$$

18.4 Determine a weighted average return air temperature for the building.

$$TPLB = 75.0 + QLITB/(1.08 * (CFMBX - CFMEX))$$

18.5 Determine a weighted average cooling coil leaving air temperature for building.

$$TCDB = TLCHL + 5.0 * GAMAB$$

18.6 Calculate a weighted average heating coil leaving air temperature for the building.

$$THDB = TLCON - 5.0 * (1.0 - GAMAB)$$

18.7 Determine the amount of outside air required to create a cooling load that will produce the required heating at the condenser.

A heat balance about the building's heating coils, cooling coils and outside air-return air damper systems yields the following three equations:

$$QHBC = 1.08 * CFMBX * GAMAB * (TMA - TCDB)$$

$$QHBH = 1.08 * CFMBX * (1.0 - GAMAB) * (THDB - TMA)$$

$$TMAB = TPLB * (1.- ALFA) + TOA * ALFA$$

where

QHBC is hourly building cooling load

QHBH is hourly building heating load

TMAB is mixed air temperature

ALFA is fraction of outside air mixing with return air

Since the heat rejection ratio at the condenser of a heat conservation machine is approximately 1.3 times the cooling load, find the fraction of outside air, ALFA, required, such that

QHBH = 1.3 QHBC

Substituting the equations for QHBC, QHBH and TMAB into the above equation yields

```
ALFA = TPLB/(TPLB - TOA) - (THDB * (1.0 - GAMAB)
       + 1.3 * GAMAB * TCDB)/((TPLB - TOA)
       * (1.0 + 0.3 * GAMAB))
```

If ALFA > 1.0, the heating requirement can be obtained with 100% outside air; therefore, reset ALFA = 1.0.

If $0.0 \leq$ ALFA ≤ 1.0, the heating requirement can be obtained with no need for supplementary heat.

If ALFA < 0.0, supplementary heat is required; therefore, reset ALFA = 0.0.

18.8 Calculate actual building mixed air temperature, °F.

```
TMAB = TOA * ALFA + TPLB * (1.0 - ALFA)
```

18.9 Calculate actual building heating load, Btu/hr.

```
QHBH = 1.08 * CFMBX * (1.0 - GAMAB) * (TMAB - THDB)
```

18.10 Calculate any snow-melting load, if applicable, Btu/hr.

18.10.1 If KSNOW = 0, no snow-melting system.
Go to calculation 18.11.

18.10.2 If KSNOW = 1 or 2, snow-melting is to be considered.

18.10.2.1 Calculate amount of snowfall for the hour assuming that 1/24 of the day's total fell during the hour.

$$SNOW = 0.1 * SNOWF(ID)/24.0$$

where SNOW has units of equivalent inches of water, SNOWF(ID) has units of inches of snow and ID is the day number of the year calculated as follows:

$$ID = 1 + IHOUR/24$$

18.10.2.2 Call SNOWM subroutine which calculates QTOT, the snow-melting load.

18.10.2.3 Add QTOT to the heating requirement of the building.

If KSNOW = 1, liquid type snow-melting system; therefore,

$$QHBH = QHBH - QTOT$$

If KSNOW = 2, electric type snow-melting system; therefore.

$$ELEH = QTOT/3413.0$$

18.11 Calculate actual building cooling load, Btu/hr.

$$QHBC = 1.08 * CFMBX * GAMAB * (TMAB - TCDB)$$

18.12 Calculate energy required to produce the building heating and cooling required.

18.12.1 If $|QHBH| > |SZHC * NUMHC * 12000.0|$, supplementary heat in condenser water line is required.

18.12.1.1 Calculate condenser water supplementary heat requirement, Btu/hr.

$$QSHCN = QHBH + CAPHC$$

where

$$CAPHC = SZHC * NUMHC * 12000.0$$

and QHBH is (-).

18.12.1.2 If $|QHBC| \geq |CAPHC/1.3|$, then no supplementary heating is required in chilled water line; therefore, set

$$QSHCL = 0.0$$

If $|QHBC| < |CAPHC/1.3|$, then calculate supplementary heat required in chilled water line, Btu/hr.

$$QSHCL = -(CAPHC/1.3 - QHBC)$$

18.12.1.3 Heat conservation machines are operating at 100% capacity, therefore

$$FFL = 1.0$$

18.12.1.4 Calculate energy consumption required by heat conservation machines.

For SZHC < 200 tons

$$POWER = QEVAP * (0.3371 + 0.01223 * TECON - 0.00974 * TLCHL) * (0.868 + 0.0133 * FFL * 16.0)$$

For SZHC $\geq$ 200 tons

$$POWER = QEVAP * (1.74 - 1.0234 * FFL + 0.3707 * FFL * FFL - 0.010025 * TDIF + 0.000175 * TDIF * TDIF)$$

where

$$QEVAP = QHBC/12000.0$$

$$TECON = TLCON + 16.0$$

$$TDIF = TECON - TLCHL$$

18.12.1.5 Update monthly electric heat energy consumption totals.

$$ELEH = ELEH + POWER$$

Go to calculation 18.13.

18.12.2 If $|QHBH| \leq |SZHC * NUMHC * 12000.0|$, then heat conservation machines are operating at part load.

18.12.2.1 Calculate chilled water supplementary heat requirement.

For $|QHBH| > |1.3 * QHBC|$, then

$$QSHCL = QHBH/1.3 + QHBC$$

For $|QHBH| \leq |1.3 * QHBC|$, then

$$QSHCL = 0.0$$

18.12.2.2 Calculate the number of heat conservation machines operating.

Estimated number operating is

$$ENHCM = -QHBH/(1.3 (12000.0 * 0.9 * SZHC)$$

Round ENHCM up to next whole number and set equal to NHCON.

18.12.2.3 Calculate fraction of full load on each machine operating.

$$FFL = QEVAP/(NHCON * SZHC/1.3)$$

where $QEVAP = QHBC/12000.0 + QDIF2$

$$QDIF2 = (-QHBH/1.3 - QHBC)/12000.0$$

18.12.2.4 Calculate energy consumption of heat conservation machines operating.

For SZHC < 200 tons

$$POWER = QEVAP * (0.3371 + 0.01223 * TECON - 0.00974 * TLCHL) * (0.868 + 0.0133 * FFL * 16.0)$$

For SZHC $\geq$ 200 tons

POWER = QEVAP * (1.74 - 1.0234 * FFL + 0.3707 * FFL * FFL - 0.010025 * TDIF + 0.000175 * TDIF * TDIF)

18.12.2.5 Calculate condenser heat available based upon evaporator load and work done.

QWORK = 0.2844 * POWER

QCOND = QEVAP + QWORK

18.12.2.6 Compare actual condenser heat available, QCOND, to that required, QHBH.

ERROR = 0.5 * (-QHBH/12000.0 - QCOND)

If |ERROR| > |0.005 * SZHC|, set QDIF2 = QDIF2 + ERROR and return to calculation 18.12.2.3 and repeat procedure until

|ERROR| $\leq$ |0.005 * SZHC|

18.12.2.7 Check to see if FFL is below FFLMN.

If FFL $\geq$ FFLMN, then go to calculation 18.13.

If FFL < FFLMN, heat conservation machine not allowed to operate; therefore, set

QSHCL = 0.0

QHBH = 0.0

QHBC = 0.0

QHBRH = 0.0

Go to calculation 18.13.

18.13 Convert condenser supplementary heat requirement into energy requirements.

If M3 = 1, gas heating; therefore

GASH = GASH - QSHCN/80000.0

If M3 = 2, oil heating; therefore

OILH = OILH - QSHCN/(0.8 * HVHO)

If M3 = 3, steam heating; therefore

STMH = STMH - QSHCN/(HESTM - HLSTM)

If M3 = 4, electric heating; therefore

ELEH = ELEH - QSHCN/3413.0

18.14 Convert chilled water supplementary heat requirement into energy requirements.

If M7 = 1, gas heating source; therefore

GASH = GASH - QSHCL/80000.0

If M7 = 2, oil heating source; therefore

OILH = OILH - QSHCL/(0.8 * HVHO)

If M7 = 3, electric heating source; therefore

ELEH = ELEH - QSHCL/3413.0

If M7 = 4, well water heating source; therefore

ELEH = ELEH + HPWWP * 0.7457

If M7 = 5, city water heating source; therefore

GALCW = -QSHCL/(8.3 * (TCWIN - TCLMN))

19. Update the running totals of the following monthly energy consumption variables.

ENGY (M,2,3)
ENGY (M,2,4)
ENGY (M,2,5)
ENGY (M,2,6)
ENGY (M,2,7)
ENGY (M,2,10)
ENGY (M,2,12)
ENGY (M,2,15)
ENGY (M,2,16)
ENGY (M,2,17)

See subroutine ENGY for an explanation of these quantities.

20. Keep a record of maximum hourly energy demands by checking and updating if necessary the following monthly demand variables.

ENGY (M,1,1)	
ENGY (M,1,2)	
ENGY (M,1,3)	
ENGY (M,1,4)	
ENGY (M,1,5)	See subroutine ENGY for explanation
ENGY (M,1,6)	of these quantities.
ENGY (M,1,7)	
ENGY (M,1,10)	
ENGY (M,1,12)	
ENGY (M,1,15)	
ENGY (M,1,16)	
ENGY (M,1,17)	

END OF HOURLY ANALYSIS

21. Return command to SYSIM.

FSIZE

A subroutine for sizing the air flow quantities required for each fan zone within the building.

INPUT

FAC	:	Name of facility
CITY	:	Name of city in which facility is located
ENGR	:	Name of engineer
PROJ	:	Project number
DATE	:	Date of computer run
MSTRT	:	Month at which analysis is to start
MEND	:	Month at which analysis is to end
NDAYS	:	Number of days for which analysis is to run
IMAX(M)	:	Number of hours in month No. M
IZNMX	:	Number of fan zones in building
VOL(K,J)	:	Volume of zone No. J of fan system No. K, cu ft
QS(J)	:	Hourly zone sensible load, Btu/hr
QL(J)	:	Hourly zone latent load, Btu/hr
QLITE(J)	:	Hourly zone lighting load picked up by return air, Btu/hr
SLPOW(J)	:	Hourly zone internal lighting and machinery power consumption, KW
KMAX	:	Total number of fan systems within the building
KFAN(K)	:	Type of fan system
TSP(K)	:	Set point temperature of fan system No. K, °F
JMAX(K)	:	Number of zones on fan system No. K
FPRES(K)	:	Total pressure of fan system No. K
EFF	:	Efficiency of fan and pump motors, decimal

INPUT (CONT'D)

KBLDG	:	Type of building system
CFMX(K,J)	:	Auxiliary exhaust air quantity for zone No. J of fan system No. K, cfm

OUTPUT

CFM(K,J)	:	Supply air quantity required for zone No. J of fan system No. K, cfm
CFMAX(K)	:	Total air supplied by fan system No. K, cfm
CFMIN(K)	:	Minimum outside air required for fan system No. K, cfm
ALPCT(K)	:	Percent of minimum outside air required for fan system No. K, percent
FBHP(K)	:	Fan brake horsepower required for fan system No. K, HP
CFMEX(K)	:	Summation of CFMX(K,J) for fan system No. K, J = 1 to JMAX(K), cfm
CFMBX	:	Summation of CFMAX(K) for K = 1 to KMAX, cfm
CFMBN	:	Summation of CFMIN(K) for K = 1 to KMAX, cfm
CFMBE	:	Summation of CFMEX(K) for K = 1 to KMAX, cfm
PWBIL	:	Maximum hourly building internal lighting and machinery power consumption, KW

CALCULATION SEQUENCE

1. Read through the load input tape and find the following quantities:

QTZCM(IZ)	Maximum zone cooling load (total) for each zone, IZ
QSZHM(IZ)	Maximum zone heating load (sensible) for each zone, IZ
PWBIL	Maximum hourly building internal lighting and machinery power consumption

2. Calculate the air flow quantity required for each zone repeating calculation 2 for each zone within the building.

2.1 For a building system of the conventional or on-site generation type:

2.1.1 If type of fan system is either a single zone, multi-zone, dual duct, unit ventilator, or unit heater, then

CFM(K,J) = QTZCM(IZ)/(1.08 * 23.0)

or

CFM(K,J) = -QSZHM(IZ)/(1.08 * 60.0)

whichever is greater.
Go to calculation 2.3.

2.1.2 If type of fan system is a single zone/reheat, then

CFM(K,J) = QTZCM(IZ)/(1.08 * 23.0)

or

CFM(K,J) = -QSZHM(IZ)/(1.08 * 30.0)

whichever is greater.
Go to calculation 2.3.

2.2 For a building system of the heat conservation type, then

CFM(K,J) = QTZCM(IZ)/(1.08 * 23.0)

or

CFM(K,J) = -QSZHM(IZ)/(1.08 * 30.0)

whichever is greater.
Go to calculation 2.3.

2.3 If CFM(K,J) is less than the CFMX(K,J), then reset

CFM(K,J) = CFMX(K,J)

3. For each fan system, K, within the building:

3.1 Calculate the minimum outside air requirement, CFMIN(K).

3.1.1 For each fan zone, J, the minimum outside air requirement is

CFMOA = VOL(K,J)/60.0

or

CFMOA = CFM(K,J)/10.0

whichever is greater.

If CFMOA is greater than CFM(K,J), reset

CFM(K,J) = CFMOA

3.1.2 Sum together all CFMOA to obtain CFMIN(K).

$$\text{CFMIN(K)} = \sum \text{CFMOA for J = 1 to JMAX(K)}$$

3.2 Sum together the zone air flows to get the fan system air capacity.

$$\text{CFMAX(K)} = \sum \text{CFM(K,J) for J = 1 to JMAX(K)}$$

3.3 Calculate minimum outside air requirement expressed in percent of total fan air capacity.

ALPCT(K) = CFMIN(K) * 100.0/CFMAX(K)

3.4 Sum together the zone auxiliary exhaust air quantities to obtain the quantity CFMEX(K).

$$\text{CFMEX(K)} = \sum \text{CFMX(K,J) for J = 1 to JMAX(K)}$$

3.5 Calculate the fan motor size, FBHP(K).

FAHP = CFMAX(K) * FPRES(K)/6346.0

FBHP(K) = FAHP/EFF

4. Calculate the following building summations:

4.1 $\text{CFMBX} = \sum \text{CFMAX(K) for K = 1 to KMAX}$

4.2 $\text{CFMBN} = \sum \text{CFMIN(K) for K = 1 to KMAX}$

4.3 $\text{CFMBE} = \sum \text{CFMEX(K) for K = 1 to KMAX}$

4.4 $\text{TFBHP} = \sum \text{FBHP(K) for K = 1 to KMAX}$

5. Write out for permanent record the following quantities.

5.1 For each fan system, write out

K
KFAN(K)
FBHP(K)
JMAX(K)
TSP(K)
CFMAX(K)
CFMIN(K)
CFMEX(K)
ALPCT(K)

5.2 For each fan zone, write out

K
J
CFM(K,J)
CFMX(K,J)

SZMZD

A subroutine for simulating the system performance of the single zone, multi-zone and dual duct fan systems. Schematics of each system are shown in Figures 18 to 20. Inherent in the analysis are the assumptions that the heating and cooling coils react ideally; that is, they provide exactly the heating and cooling required. Further, it is also assumed that the ducts are adiabatic and the outside air/return air dampers are controlled based upon the enthalpy and temperature comparison outlined later.

INPUT

TCO	:	Building changeover temperature, °F
TOA	:	Dry-bulb temperature of outside air, °F
WOA	:	Humidity ratio of outside air, lb water/lb dry air
PATM	:	Barometric pressure, inches mercury
HOA	:	Enthalpy of outside air, Btu/lb
DOA	:	Density of outside air, lb dry air/cu ft
K	:	Fan system number
JMAXK	:	Number of zones on fan system No. K
M4	:	Number of on-site generation engines
QS(J)	:	Hourly sensible load for zone No. J, Btu/hr
QL(J)	:	Hourly latent load for zone No. J, Btu/hr
QLITE(J)	:	Hourly lighting load picked up by return air in zone No. J, Btu/hr
SLPOW(J)	:	Hourly zone internal lighting and machinery power consumption, KW
TSP(K)	:	Set point temperature of fan system No. K, °F
CFMAX(K)	:	Total air flow circulated by fan system No. K, cfm
CFM(K,J)	:	Air flow supply to zone No. J of fan system No. K, cfm
CFMEX(K)	:	Auxiliary exhaust air flow for fan system No. K, cfm
ALFAM(K)	:	Amount of minimum outside air for fan system No. K, decimal

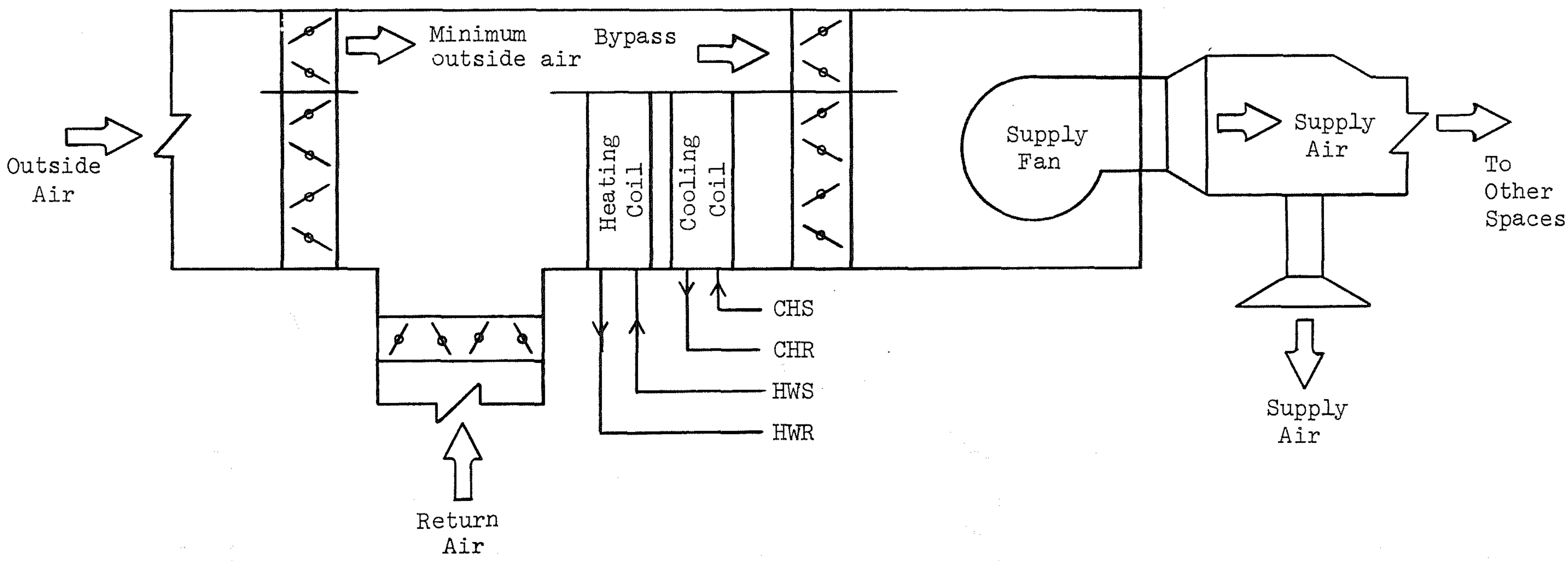


Figure 18 SINGLE ZONE FAN SYSTEM

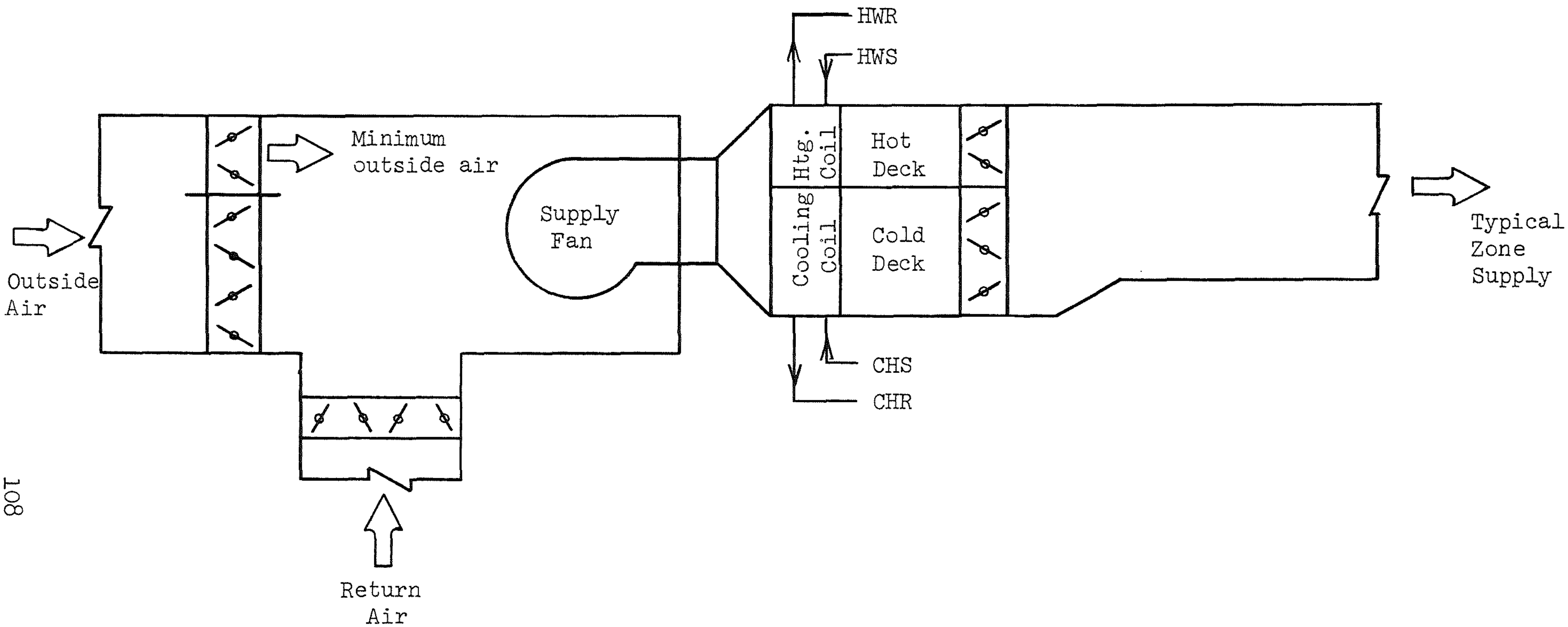


Figure 19 MULTI-ZONE FAN SYSTEM

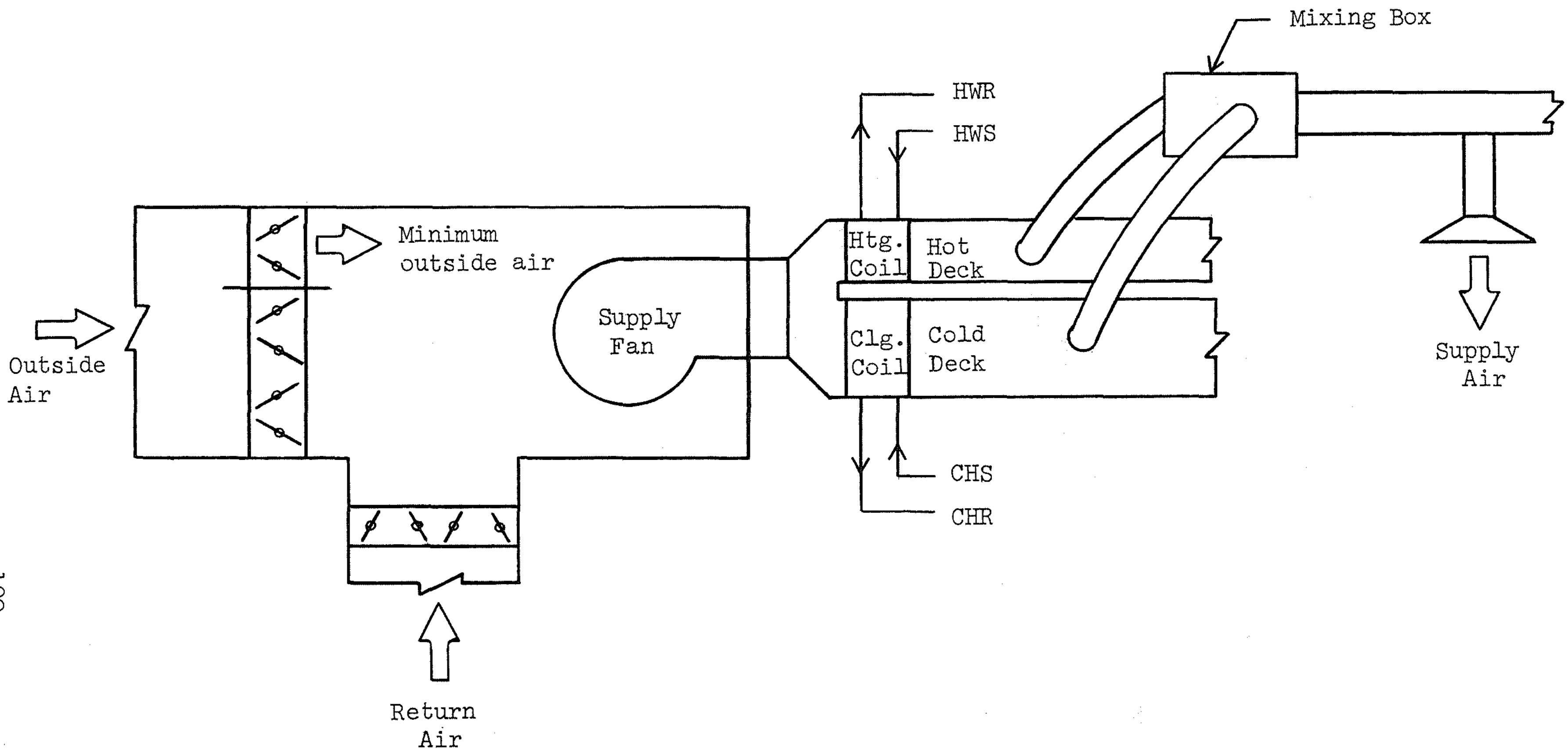


Figure 20 DUAL-DUCT FAN SYSTEM

OUTPUT

QFPC	:	Hourly fan system cooling requirement, Btu/hr
QFPH	:	Hourly fan system heating requirement, Btu/hr
QFPRH	:	Hourly fan system reheat requirement, Btu/hr
PWL	:	Total internal lights and machinery power consumption for zones served by fan system under consideration, KW

CALCULATION SEQUENCE

1. Read from load tape the zone loads for zones J = 1 to JMAXK and calculate the following quantities:

   1.1 QSUMC = $\sum$(QS(J) + QL(J)) for all zones requiring cooling

   1.2 QSUMH = $\sum$QS(J) for all zones requiring heating

   1.3 QSLIT = $\sum$QLITE(J) for J = 1 to JMAXK

   1.4 PWL = $\sum$SLPOW(J) for J = 1 to JMAXK

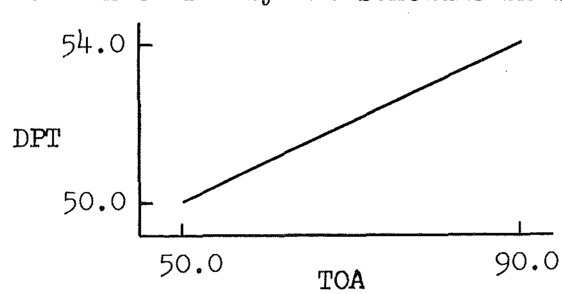
2. Calculate the quantity of fan heat being added to supply air

   QSFAN = 0.4014 * CFMAX(K) * FPRES(K)

3. Calculate return air temperature

   TRA = TSP(K) + QSLIT/(1.08 * CFMAX(K))

4. Calculate humidity ratio of air leaving cooling coil. Since no provision is made in the fan system analysis to simulate coil performance, the dehumidifying effect of the cooling coil is accounted for by the schedule shown below:



where DPT is the dew point temperature of the air leaving the cooling coil, °F. This schedule can be translated into the following equation with the help of a psychrometric chart:

$$WRA = (53.2 + 0.245 * (TOA - 50.0))/7000.0$$

where WRA is the humidity ratio of the air leaving the cooling coil, lb water/lb dry air.

5. Call PSYCH subroutine to calculate

   HRA   Enthalpy of return air, Btu/lb dry air

   DRA   Density of return air, lb/cu ft dry air

6. Calculate the supply air temperature of zones requiring the highest and lowest temperature supply air.

$$TS(J) = TSP(K) - QS(J)/(1.08 * CFM(K,J))$$

where TS(J) is the supply air temperature required for zone No. J.

Set $TSMAX = TS(J)_{MAX}$

$TSMIN = TS(J)_{MIN}$

7. Determine the fraction of outside air (ALFA) mixing with return air as outlined below.

   If the building system under consideration is an on-site generation type, then set ALFA = ALFAM(K); otherwise continue as outlined below.

   7.1 When TOA $\geq$ TCO, and

   7.1.1 If HOA > HRA, then

   ALFA = ALFAM(K)

   7.1.2 If HOA $\leq$ HRA, and

   7.1.2.1 If TOA $\geq$ TSMAX, and

   7.1.2.1.1 If TOA $\geq$ TRA, then

   ALFA = ALFAM(K)

   7.1.2.1.2 If TOA < TRA, then

   ALFA = 1.0

7.1.2.2 If TOA < TSMAX, then

ALFA = (TRA - TSMAX)/(TRA - TOA)

7.2 When TOA < TCO, and

7.2.1 If TOA ≥ TSMIN, then

ALFA = 1.0

7.2.2 If TOA < TSMIN, then

ALFA = (TRA - TSMIN)/(TRA - TOA)

8. Calculate the sensible outside air load.

QSOA = 14.4 * DOA * ALFA * CFMAX(K) * (TOA - TPS(K))

9. Calculate the latent outside air load.

QLOA = 63000.0 * DOA * ALFA * CFMAX(K) * (WOA - WRA)

10. Determine the hourly fan system cooling requirement and heating requirement.

10.1 If TOA ≥ TCO, then

QFPC = QSUMC + QSOA + QLOA + QSLIT * CFMAX(K)

+ (1.0 - ALFA)/(CFMAX(K) - CFMEX(K))

QFPH = 0.0

10.2 If TOA < TCO, then

QFPH = QSUMH + QSOA + QSLIT * CFMAX(K)

* (1.0 - ALFA)/(CFMAX(K) - CFMEX(K))

QFPC = 0.0

11. Determine hourly fan system reheat requirement

QFPRH = 0.0

since none of the fan systems considered have reheat coils.

SZRHT

A subroutine for simulating the system performance of a single zone fan system that has subzones requiring reheat. See Figure 21 for a schematic of this type of fan system. Primary air is supplied to an interior zone which requires cooling the year around. During the winter and intermediate seasons, the primary air is colder than that required for the subzones. Subzone mixing boxes therefore modulate open and induce return air to mix with the primary air. A maximum of 50% induced air can mix with primary air. If further reheat of primary air is necessary, the reheat coil is activated. The simulation assumes that all ducts are adiabatic and that outside air-return air dampers are controlled based upon enthalpy and temperature comparisons as outlined later.

INPUT

TCO	:	Building changeover temperature, °F
TOA	:	Dry-bulb temperature of outside air, °F
WOA	:	Humidity ratio of outside air, lb water/lb dry air
PATM	:	Barometric pressure, inches mercury
HOA	:	Enthalpy of outside air, Btu/lb dry air
DOA	:	Density of outside air, lb dry air/cu ft
K	:	Fan system number
JMAXK	:	Number of zones on fan system No. K
M4	:	Number of on-site generation engines
QS(J)	:	Hourly zone sensible load, Btu/hr
QL(J)	:	Hourly zone latent load, Btu/hr
QLITE(J)	:	Hourly zone lighting load picked up by return air, Btu/hr
SLPOW(J)	:	Hourly zone internal lighting and machinery power consumption, KW
TSP(K)	:	Set point temperature of fan system No. K, °F
CFMAX(K)	:	Total air flow circulated by fan system No. K, cfm
CFM(K,J)	:	Air flow supply to zone No. J of fan system No. K, cfm

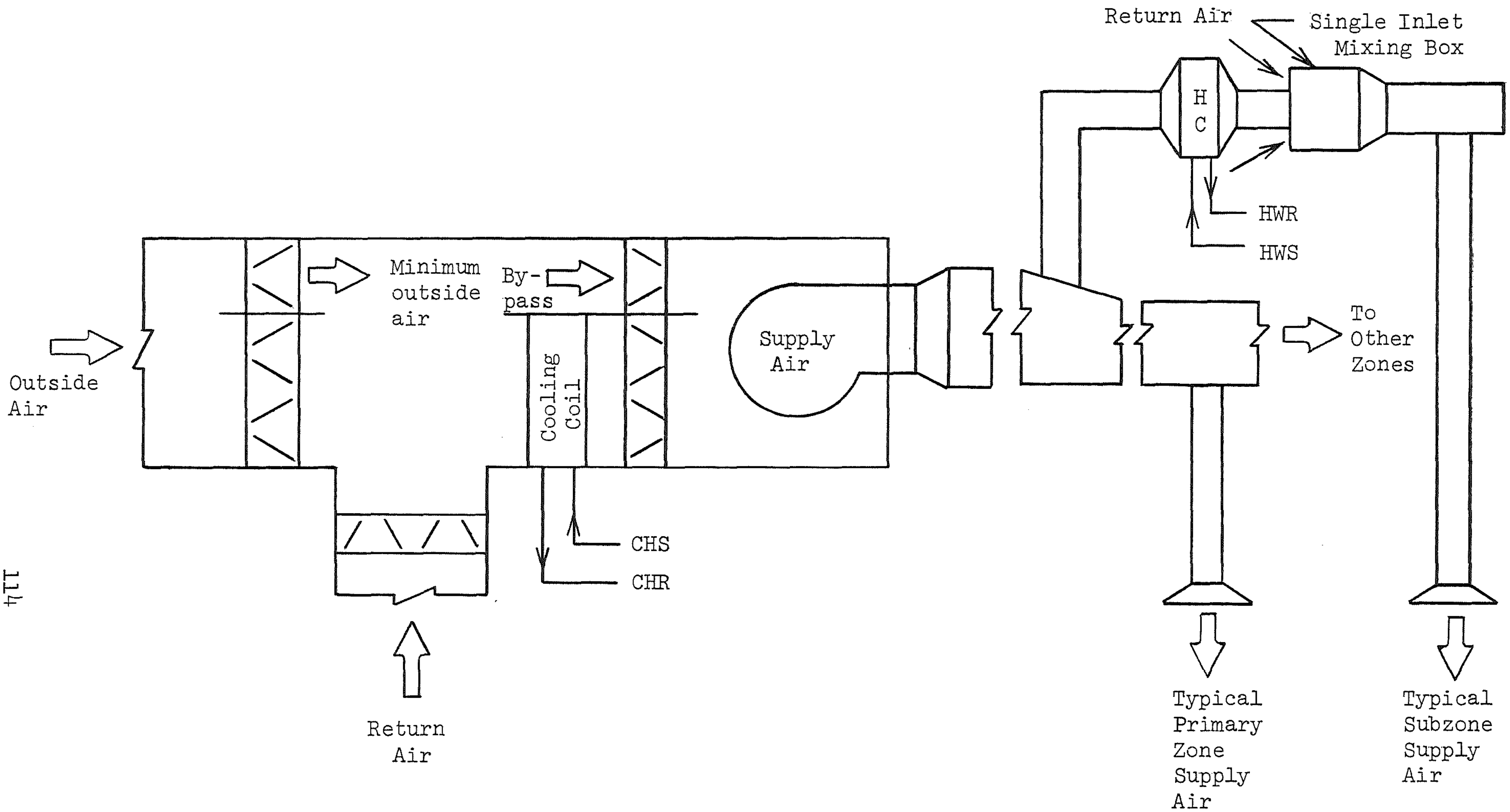


Figure 21 SINGLE ZONE/REHEAT FAN SYSTEM

INPUT (CONT'D)

CFMEX(K) : Auxiliary exhaust air flow for fan system No. K, cfm

ALFAM(K) : Amount of minimum outside air required for fan system No. K, decimal

CFMX(K,J) : Auxiliary exhaust air flow for zone No. J of fan system No. K, cfm

KREHT : Type of reheat coils

OUTPUT

QFPC : Hourly fan system cooling requirement, Btu/hr

QFPH : Hourly fan system heating requirement, Btu/hr

QFPRH : Hourly fan system reheat requirement, Btu/hr

PWL : Total internal lights and machinery power consumption for zones served by fan system under consideration, KW

CALCULATION SEQUENCE

1. Read from the load input tape the zone loads for zones J = 1 to JMAXK and calculate the following quantities.

$$QSUML = \sum QL(J) \quad \text{for } J = 1 \text{ to JMAXK}$$

$$PWL = \sum SLPOW(J) \quad \text{for } J = 1 \text{ to JMAXK}$$

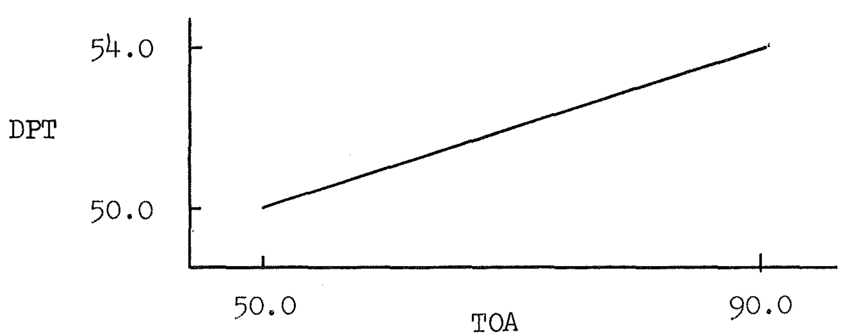
2. Calculate the primary zone return air plenum temperature.

$$TPL(1) = TSP(K) + QLITE(1)/(1.08 * (CFMAX(K) - CFMX(K,J)))$$

Primary zone is always denoted by J = 1.

3. Calculate humidity ratio of air leaving cooling coil.

Since no provision is made in the fan system analysis to simulate coil performance, the dehumidifying effect of the cooling coil is accounted for by the schedule shown below:



where DPT is the dew point temperature of the air leaving the cooling coil, °F. This schedule can be translated into the following equation with the help of a psychrometric chart:

WPL = (53.2 + 0.245 * (TOA - 50.0))/7000.0

where WPL is the humidity ratio of the air leaving the cooling coil and has units of lb water/lb dry air.

4. Call PSYCH to calculate the enthalpy, HPL(1), and density, DPL(1), of the primary zone return air.

5. Calculate the supply air temperature required for primary zone and subzones.

   TS(J) = TSP(K) - QS(J)/(1.08 * CFM(K,J)) for J = 1 to JMAXK

6. Calculate the fraction of outside air (ALFA) mixing with return air as outlined below, where:

TOA	:	Dry-bulb temperature of outside air, °F
TPL(1)	:	Primary zone plenum air temperature, °F
TS(1)	:	Primary zone supply air temperature, °F
HOA	:	Enthalpy of outside air, Btu/lb dry air
HPL(1)	:	Enthalpy of return air, Btu/lb dry air
ALFAM(K)	:	Fraction of minimum outside air required for fan system No.K, decimal

   If building system under consideration is an on-site generation type, then set ALFA = ALFAM(K); otherwise, continue as outlined below.

   6.1 If HOA ≥ HPL(1), then

   ALFA = ALFAM(K)

   6.2 If HOA < HPL(1), and

   6.2.1 If TOA ≥ TS(1), and

   6.2.1.1 If TOA > TPL(1), then

   ALFA = ALFAM(K)

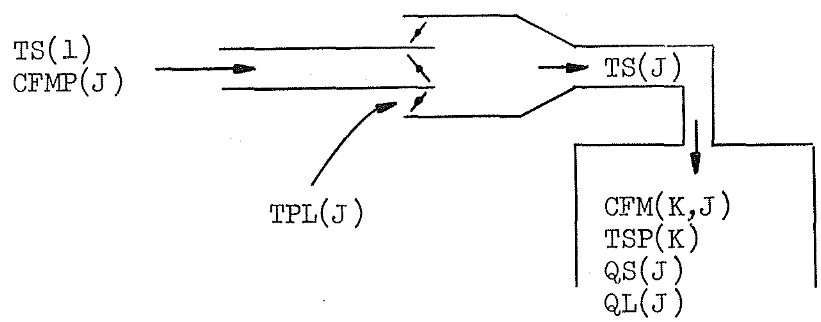
6.2.1.2 If $TOA \leq TPL(1)$, then

$$ALFA = 1.0$$

6.2.2 If $TOA < TS(1)$, then

$$ALFA = (TPL(1) - TS(1)/(TPL(1) - TOA)$$

7. Calculate the percent of primary air used by each subzone. A schematic of the induced air mixing box is shown below.



A heat balance around mixing box gives

$$TS(J) * CFM(K,J) = TS(1) * CFMP(J) + TPL(J) * (CFM(K,J) - CFMP(J))$$

Letting $BETA(J) = CFMP(J)/CFM(K,J)$ and solving for BETA(J)

$$BETA(J) = (TS(J) - TPL(J))/(TS(1) = TPL(J))$$

where

$$0.5 \leq BETA(J) \leq 1.0$$

Calculate BETA(J) for all subzones on fan system under consideration.

8. Calculate the total CFM handled by fan system for the hour in question.

$$CFMT = CFM(K,1) + \sum(BETA(J) * CFM(K,J))$$

$$\text{for } J = 2 \text{ to } JMAXK$$

9. Calculate the reheat requirement when BETA(J) < 0.5.

QFPRH = 1.08 * CFM(K,J) * (0.5 * (TPL(J) + TS(1)) - TS(J))

for only those zones where BETA(J) < 0.5.

10. Calculate sensible load on cooling coil.

QSML = 1.08 * CFMT * (TOA * ALFA + (1.0 - ALFA)
* TPL(1) - TS(1))

11. Calculate latent load on cooling coil.

QLML = 4747.5 * CFMT *ALFA *(WOA - WPL) + QSUML * CFMT
* (1.0 - ALFA)/(CFMT - CFMEX(K))

where QSUML is $\sum$QL(J) for J = 1 to JMAXK.

12. Calculate total fan plant cooling load.

QFPC = QSML + QLML

13. Calculate total fan plant heating load.

QFPH = 0.0

UVENT

A subroutine for simulating the system performance of the unit ventilator or unit heater.

INPUT

TOA	:	Dry-bulb temperature of outside air, °F
DOA	:	Density of outside air, lb dry air/cu ft
K	:	Fan system number
JMAXK	:	Number of zones on fan system No. K
KFANK	:	Type of fan system
QS(J)	:	Hourly sensible load for zone No. J, Btu/hr
QL(J)	:	Hourly latent load for zone No. J, Btu/hr
QLITE(J)	:	Hourly lighting load picked up by return air in zone No. J, Btu/hr
SLPOW(J)	:	Hourly zone internal lighting and machinery power consumption, KW
TCO	:	Building changeover temperature, °F
CFMAX(K)	:	Total air flow circulated by fan system No. K, cfm
ALFAM(K)	:	Amount of minimum outside air for fan system No. K, decimal
TSP(K)	:	Set point temperature of fan system No. K, °F

OUTPUT

QFPC	:	Hourly fan system cooling requirement, Btu/hr
QFPH	:	Hourly fan system heating requirement, Btu/hr
QFPRH	:	Hourly fan system reheat requirement, Btu/hr
PWL	:	Total internal lights and machinery power consumption for zones served by fan system under consideration, KW

CALCULATION SEQUENCE

1. Read the load input tape for required number of zones and calculate the following:

$$PWL = \sum SLPOW(J) \quad \text{for } J = 1 \text{ to } JMAXK$$

$$QSUMH = \sum QS(J) \quad \text{for all zones requiring heating}$$

2. If $TOA \geq TCO$, 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

$$QFPH = 0.0$$

$$QFPC = 0.0$$

$$QFPRH = 0.0$$

2.2 Heating available within building, therefore perform the following calculations:

2.2.1 If KFAN(K) = 5, calculate outside air load and system heating, cooling and reheat loads.

$$QSOA = 14.4 * DOA * CFMAX(K) * ALFAM(K) * (TOA - TSP(K))$$

$$QFPH = QSUMH + QSOA$$

$$QFPC = 0.0$$

$$QFPRH = 0.0$$

2.2.2 If KFAN(K) = 6, calculate system cooling, heating and reheat loads.

$$QSOA = 0.0$$

$$QFPH = QSUMH + QSOA$$

$$QFPC = 0.0$$

$$QFPRH = 0.0$$

FHEAT

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(J)	:	Hourly sensible load for zone No. J, Btu/hr
QL(J)	:	Hourly latent load for zone No. J, Btu/hr
QLITE(J)	:	Hourly lighting load picked up by return air in zone No. J, Btu/hr
SLPOW(J)	:	Hourly zone internal lighting and machinery power consumption, KW
TCO	:	Building changeover temperature, °F
PERIM(K)	:	Exposed perimeter of floor for fan system No. K, ft
PAREA(K)	:	Floor area available for heating panels, sq ft
PLOC(K)	:	Location of floor heating panel for system No. K
CINSL	:	Floor insulation conductance, Btu/hr-sq ft-°F
DINSL	:	Floor insulation thickness, ft
TSP(K)	:	Set point temperature of fan system No. K, °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
PWL	:	Total internal lights and machinery power consumption for zones served by system under consideration, KW

CALCULATION SEQUENCE*

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

   $PWL = \sum SLPOW(J)$ for J = 1 to JMAXK

   $QSSUM = \sum QS(J)$ for all zones requiring heating

2. If TOA $\geq$ TCO, 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

   2.2 Heating available within building, therefore perform the following:

   2.2.1 Calculate panel temperature, TPAN, required for desired heating flux, QPAN.

   QPAN = -QSSUM/PAREA(K)

   Initially, set TPAN = 76.0.

   QCALC = 0.15 * ((TPAN + 460.0)/100.0)

   ** 4.0 - 0.15 ((TSP(K) + 460.0)/100.0)

   ** 4.0 + 0.32 * (TPAN - TSP(K)) ** 1.31

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

   TPAN = TPAN + 0.5 * (QPAN - QCALC)

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

*See 1967 ASHRAE Guide and Data Book, Systems and Equipment Volume, Chapter 58, for derivation of all equations.

2.2.2 Calculate surface temperature of floor required as a function of the type of floor covering.

2.2.2.1 If KFLCV = 1, bare concrete floor, therefore

TSUR = TPAN

2.2.2.2 If KFLCV = 2, tile covering, therefore

TSUR = TPAN + QPAN * 0.05

2.2.2.3 If KFLCV = 3, carpeting, therefore

TSUR = TPAN + QPAN * 1.4

2.2.3 If TSUR as calculated above is greater than 85.0°F, reset

TSUR = 85.0

2.2.4 Calculate the downward and edgewise loss coefficient, C3.

2.2.4.1 If CINSL = 0.0, no insulation, therefore

C3 = 1.8

2.2.4.2 If CINSL > 0.0, and DINSL = 0.0, then only perimeter insulation, therefore

C3 = 1.32 + 0.25 * CINSL

2.2.4.3 If CINSL > 0.0 and DINSL > 0.0, then

```
C3 = 0.932 + 0.523 * CINSL
     - 0.479 * CINSL ** 2.0
     - 0.271 * DINSL + 0.046 * DINSL
     ** 2.0 + 0.786 * CINSL * DINSL
     - 0.72 * DINSL * CINSL ** 2.0
     - 0.182 * CINSL * DINSL ** 2.0
     + 0.24 * (DINSL * CINSL) ** 2.0
```

2.2.5 Calculate downward and edgewise heat loss, QLOSS.

2.2.5.1 If PLOC(K) = 1, then

QLOSS = PERIM(K) * C3 * (TPAN - TOA)/
PAREA(K)

2.2.5.2 If PLOC(K) = 2, then

QLOSS = 0.15 * ((TPAN + 460.0)/100.0)
** 4.0 - 0.15 * (TSP(K) + 460.0)/
100.0) ** 4.0 + 0.021
* (TPAN - TPS(K)) ** 1.25

2.2.6 Calculate heating requirement of system.

QFPH = 1.0 * (QPAN + QLOSS) * PAREA(K)

QFPC = 0.0

QFPRH = 0.0

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

INPUT (CONT'D)

PESTM	:	Pressure of low pressure steam, psig
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, gallons
OILH	:	Hourly oil consumption for heating, gallons
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, gallons

CALCULATION SEQUENCE

1. Convert hourly building cooling load into tons.

   QHBC = QHBC/12000.0

2. Calculate the enthalpy of entering and leaving low pressure steam.

2.1 For entering condition, use

$$AH = 1068.0 - 0.485 * PESTM$$

$$BH = 0.432 + 0.000953 * PESTM$$

$$CH = 0.000036 - 0.000000456 * PESTM$$

$$HESTM = AH + BH * TESTM + CH * TESTM * TESTM$$

where HESTM is enthalpy of entering steam, Btu/lb.

2.2 For leaving condition, assume saturated water, therefore

$$HLSTM = 180.07$$

where HLSTM is enthalpy of leaving steam, Btu/lb.

3. Check the type of building system.

If $M4 = 0$, then conventional system or conventionally-operated heat conservation system.

Go to calculation 4.

If $M4 > 0$, then on-site generation system.

Go to calculation 8.

4. Calculate the number of chillers operating.

4.1 If the quantity (1.0 - QHBC/(0.9 * NUMC * SZC)) is (+), then building system is a conventional system or a conventionally-operated heat conservation system with no auxiliary chillers needed.

Set NC = 1 (number of chillers operating).

Calculate fraction of full load.

$$FFL = QHBC/(NC * SZC)$$

If necessary, increase NC until FFL $\leq$ 0.9.

If NC = 1, and FFL < FFLMN, then no cooling available.

4.2 If the quantity (1.0 - QHBC/(0.9 * NUMC * SZC)) is (-), then building system is a conventionally-operated heat conservation system with auxiliary chillers needed.

Set NAC = 1 (number of auxiliary chillers operating).

Calculate fraction of full load.

FFL = QHBC/(NUMC * SZC + NAC * SZAC)

If necessary, increase NAC until FFL $\leq$ 0.9.

5. Calculate the energy consumption required for cooling.

5.1 If the quantity (1.0 - QHBC/(0.9 * NUMC * SZC)) is (+), proceed as follows:

If M1 = 1, call RECIP, which calculates ELEC.

= 2, call CENT, which calculates ELEC.

= 3, call CENT, which calculates ELEC, then adjust as follows:

ELEC = ELEC/(1.0 + 0.02133 * ELEC/QHBC)

= 4, call ABSOR, which calculates STMC and equivalent heating requirement, QHMC.

= 5, 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

= 2, OILC = QHMC/(0.8 * HVHO)

STMC = 0.0

= 3, STMC = STMC

= 4, ELEC = QHMC/3413.0

STMC = 0.0

5.2 If the quantity (1.0 - QHBC/(0.9 * NUMC * SZC)) is (-), proceed as follows:

If M1 = 1, call RECIP, which calculates PW1.

= 2, call CENT, which calculates PW1.

= 3, call CENT, which calculates PW1, then adjust as follows:

PW1 = PW1/(1.0 + 0.02133 *PW1/(FFL * NUMC * SZC))

If M6 = 1, call RECIP, which calculates PW2.

= 2, call CENT, which calculates PW2.

= 3, call CENT, which calculates PW2, then adjust as follows:

PW2 = PW2/(1.0 + 0.02133 * PW2/(NAC * SZAC * FFL))

Total energy consumption for cooling

ELEC = PW1 + PW2

6. Calculate the energy consumption required for heating.

If M3 = 1, GASH = -QHBH/80000.0

= 2, OILH = -QHBH/(0.8 * HVHO)

= 3, STMH = -QHBH/(HESTM - HLSTM)

= 4, ELEH = -QHBH/3413.0

7. Calculate the energy consumption required for reheat.

If KREHT = 0, no reheat energy available.

= 1, GASH = GASH - QHBRH/80000.0

= 2, OILH = OILH - QHBRH/(0.8 * HVHO)

= 3, STMH = STMH - QHBRH/(HESTM - HLSTM)

= 4, ELEH = ELEH - QHBRH/3413.0

END OF CONVENTIONAL ANALYSIS

8. Calculate the number of on-site generation engines in operation.

Set NE = 1 (number of engines operating).

Calculate fraction of full load.

$$FFLE = ELDEM/(NE * SZE)$$

If necessary, increase NE until FFLE $\leq$ 1.1.

9. Calculate the energy consumption required for operation of engines.

If M5 = 1, FUEL = (8900.0 + 2000.0/FFLE)/HVDF

= 2, GASG = 0.085 + 0.0289/FFLE

10. Calculate the amount of engine heat able to be reclaimed.

If M5 = 1, QEN = (69.2 + 21.2 * FFLE) * ELDEM

= 2, QEN = (60.51 + 16.64/FFLE + 14.0 * FFLE) * ELDEM

11. Compute the number of chillers operating.

Set NC = 1 (number of chillers operating).

Calculate fraction of full load.

$$FFL = QHBC/(NC * SZC)$$

If necessary, increase NC until FFL $<$ 0.9.

If NC = 1, and FFL $<$ FFLMN, then no cooling available.

12. Calculate the energy consumption required for cooling.

If M1 = 1, not applicable.

= 2, not applicable.

= 3, not applicable.

= 4, call ABSOR, which calculates STMC and the equivalent heating requirement, QHMC.

= 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 M3 = 1, GASH = (QHMC - QHBH - QEN)/80000.0

STMC = 0.0

If GASH < 0.0, set GASH = 0.0.

= 2, OILH = (QHMC - QHBH - QNE)/(0.8 * HVHO)

STMC = 0.0

If OILH < 0.0, set OILH = 0.0.

14. Compute energy consumption required for reheat.

If KREHT = 0, not applicable.

= 1, GASH = GASH - QHBRH/80000.0

= 2, not applicable.

= 3, not applicable.

END OF ON-SITE GENERATION ANALYSIS

RECIP

A subroutine for calculating the energy consumption of an electric hermetic reciprocating water chiller as a function of part load.

INPUT

QHBC	:	Hourly building cooling load, tons
TECON	:	Temperature of entering condenser water, °F
TLCHL	:	Temperature of leaving chilled water, °F
FFL	:	Fraction of full load, decimal

OUTPUT

POWER	:	Hourly electrical power consumption, kilowatt hours

CALCULATION SEQUENCE

1. Calculate the power per ton as determined from an equation fit of Carrier catalog data (Model 30HR).

$$\mathrm{POPTN} = (0.3371 + 0.01223 * \mathrm{TECON} - 0.009749 * \mathrm{TLCHL}) * (0.868 + 0.133 * \mathrm{FFL})$$

where POPTN has units of kilowatts per ton.

2. Determine total hourly power consumption.

$$\mathrm{POWER} = \mathrm{POPTN} * \mathrm{QBHC}$$

CENT

A subroutine for calculating the energy consumption of an electric hermetic centrifugal water chiller as a function of part load.

INPUT

QHBC	:	Hourly building cooling load, tons
TECON	:	Temperature of entering condenser water, °F
TLCHL	:	Temperature of leaving chilled water, °F
FFL	:	Fraction of full load, decimal

OUTPUT

POWER	:	Hourly electrical power consumption, kilowatt hours

CALCULATION SEQUENCE

1. Calculate the temperature of leaving condenser water at full load.

   TLCON = TECON + 10.0

2. Calculate the full load power per ton.

   POPTN = 0.049 * ALOG (TLCON/TLCHL) * TLCHL ** 0.8

   (This equation excerpted from personal correspondence from R.S. Arnold of Carrier to J. M. Anders of P.O.D.)

3. Determine the error correction to be applied to above equation to make it conform with Carrier catalog data (Model 19C).

   ERROR = 2.4531 - 0.041229 * TLCON - 0.0273842 * TLCHL
   + 0.000118191 * TLCON * TLCON + 0.00047537
   * TLCHL * TLCON - 0.000197535 * TLCHL * TLCHL

4. Calculate the full load power per ton.

   POPTN = POPTN - ERROR

5. Determine the total hourly part load power consumption.

   POWER = (0.1641/FFL + 0.2543 + 0.73965 * FFL
   - 0.15835 * FFL * FFL) * POPTN * QHBC

ABSOR

A subroutine for calculating the energy consumption of a steam absorption water chiller.

INPUT

QHBC	:	Hourly building cooling load, tons
TECON	:	Temperature of entering condenser water, °F
TLCHL	:	Temperature of leaving chilled water, °F
TDROP	:	Chilled water temperature drop at full load, °F, set equal to 10°F in program
FFL	:	Fraction of full load, decimal
PESTM	:	Pressure of low pressure steam, psig

OUTPUT

STEAM	:	Hourly steam consumption, lbs/hr

CALCULATION SEQUENCE (CARRIER 16HA)

1. Determine the capacity factor which adjusts nominal capacity for operation at conditions other than the standard of 12 psig inlet steam, 85°F entering condenser water and 44°F leaving chilled water.

```
RAT = -2.8246 + 0.06575 * TECON - 0.06011 * PESTM
      + 0.06433 * TLCHL + 0.0011862 * TECON * PESTM
      + 0.00023232 * TECON * TLCHL + 0.00025421 * PESTM
      * TLCHL - 0.0006438 * TECON * TECON - 0.0015887
      * PESTM * PESTM - 0.0006199 * TLCHL * TLCHL
```

2. Find the capacity factor which adjusts for chilled water temperature drop other than 10°F.

```
CMULT = 0.9190 + 0.010333 * TDROP - 0.0002222 * TDROP *TDROP
```

3. Calculate the total capacity factor.

$$RAT = 0.91 * CMULT * RAT$$

where 0.91 is fouling factor.

4. Calculate the full load steam rate, lbs/hr-ton.

$$SRATE = 22.169 + 0.592 * PESTM - 0.0196 * PESTM * PESTM - 6.9384 * RAT$$

5. Determine the part load steam consumption.

$$STEAM = SRATE * (0.0136/FFL + 0.7928 + 0.11843 * FFL + 0.0752 * FFL * FFL) * QHBC$$

STTUR

A subroutine for calculating the energy consumption of a single stage, condensing steam turbine as a function of its power output.

INPUT

PPS	:	Pressure of high pressure steam, psig
TPS	:	Temperature of high pressure steam, °F
RPM	:	Speed of steam turbine, rpm
SZT	:	Size of steam turbine, HP, taken as 1 HP/ton
NSTON	:	Number of steam turbines operating; same as number of chillers operating
POWER	:	Total power output required by all turbines, KW

OUTPUT

STEAM	:	Hourly steam consumption, lb/hr

CALCULATION SEQUENCE

1. Find the power output for each turbine, HP.

   POWER = 1.341 * POWER/NSTON

2. Determine the enthalpy of entering steam, H1.

   H1 = AH + BH * TPS + CH * TPS * TPS

   where AH = 1068.0 - 0.485 * PPS

   BH = 0.432 + 0.000953 * PPS

   CH = 0.000036 - 0.000000496 * PPS

3. Calculate the entropy of steam.

   S = 2.385 - 0.004398 * TSAT1 + 0.000008146 * TSAT1 * TSAT1

   -0.662 * E-08 * TSAT1 * * 3.0 + 2.0 * CH * (TPS - TSAT1)

   + (BH - 920.0 * CH) * ALOG ((TPS + 460.0)/(TSAT1 + 460.0)) where

$$TSAT1 = 1.0/(0.0017887 - 0.00011429 * ALOG (PPS)) - 460.0$$

4. Find the temperature of steam after isentropic expansion and exhausting at 2 psia (condensing turbine).

$$T2 = 1.0/(0.0017887 - 0.00011429 * ALOG (2.0)) - 460.0$$

5. Find the enthalpy of leaving steam.

$$H2 = 1.0045 * T2 - 32.448 + (T2 + 460.0) * (S - 1.0045 * ALOG (T2 + 460.0) + 6.2264)$$

6. Calculate the theoretical steam rate, lb/HP-hr

$$TSR = 3413.0/(H1 - H2)$$

7. Calculate base steam rate.

$$BSR = SLOPE * TSR + B$$

where

$$B0 = 84.0 - 0.017 * SZT + 1.5625 * ((SZT/1000.0) * * 2.0)$$

$$B1 = -19.7 + 0.001025 * SZT$$

$$B2 = 1.4$$

$$B = B0 + B1 * RPM/1000.0 + B2 * ((RPM/1000.0) * * 2.0)$$

$$S0 = 3.88 - 0.0011865 * SZT + 0.1173 * ((SZT/1000.0) * * 2.0)$$

$$S1 = -1.1 + 0.000533 * SZT - 0.0581 * ((SZT/1000.0) * * 2.0)$$

$$S2 = 0.116 - 0.000057 * SZT + 0.00709 * ((SZT/1000.0) * * 2.0)$$

$$SLOPE = S0 + S1 * RPM/1000.0 + S2 * ((RPM/1000.0) * * 2.0)$$

The base steam rate calculation was made by equation-fitting the Elliott YR single-stage steam turbine data.

8. Calculate the horsepower loss again determined by equation-fitting the Elliott YR single-stage steam turbine catalog data for condensing turbine (2 psia).

$$HPLSS = 0.0334 * ((RPM/1000.0) * * 2.42) * ((SZT/1000.0) * * 1.47)$$

9. Calculate the superheat correction factor determined by equation-fitting of Elliott YR single-stage steam turbine catalog data.

   See computer listing of STTUR subroutine for equation of SC.

10. Determine the full load steam rate, lb/HP-hr.

   FLSR = (BSR/SC) * ((SZT + HPLSS)/SZT)

11. Determine the part load steam rate for one turbine, lbs/hr.

   STEAM = FLSR * SZT * (PLB + PLM * POWER/SZT)

12. Calculate the total hourly steam consumption, lb/hr.

   STEAM = STEAM * NSTON

SNOW

A subroutine for calculating the heat required to melt snow.

INPUT

TOA	:	Dry-bulb temperature of outside air, °F
WOA	:	Humidity ratio of outside air, lb water/lb dry air
PATM	:	Barometric pressure, inches of mercury
VWIND	:	Wind velocity, mph
SAREA	:	Snow-melting slab area, sq ft
SNOW	:	Inches of snow water equivalent, inches

OUTPUT

QTOT	:	Total hourly heating requirement of snow-melting system, Btu/hr

CALCULATION SEQUENCE*

1. Partial pressure of water vapor in moist air, inches of mercury

   VP = (WOA/0.622 * PATM)/(1.0 + WOA/0.622)

2. Sensible heat required to raise temperature of snow from outside air temperature to melting point, Btu/hr-sq ft

   QSEN = 2.6 * SNOW * (33.0 - TOA)

3. Latent heat required to melt snow, Btu/hr-sq ft

   QLAT = 746.0 * SNOW

4. Heat required to evaporate melted snow, Btu/hr-sq ft

   QEVAP = 1075.0 * (0.0201 * VWIND + 0.055) * (0.185 - VP)

5. Heat transferred by convection and radiation, Btu/hr-sq ft

   QCONV = 11.4 * (0.0201 * VWIND + 0.055) * (33.0 - TOA)

---

*For derivation and justification of equations, see "Design of Snow-Melting Systems", Heating and Ventilating, April, 1952, by William P. Chapman, and 1967 ASHRAE Guide and Data Book, Systems and Equipment Volume, Chapter 67 entitled "Snow Melting".

6. Determine total heat required, Btu/hr.

QTOT = (SAREA * (QSEN + QLAT + 0.5 * QEVAP + 0.5 QCONV))/0.7

where the edge loss factor is 0.3 and the area ratio of snow-free area to slab area is 0.5.

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 * T + W * (1061.0 + 0.444 * T)

2. Calculate specific volume.

   V = 0.754 * (T + 459.688) * (1.0 + 7000.0 * W/4360.0)/PATM

3. Calculate specific density.

   DEN = 1.0/V

ENGYC

A subroutine for printing the monthly energy consumption summary in a format similar to P.O.D. Form 2215.

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 motors
4 Electric, external lights
5 Electric heat
6 Electric cool
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 Minimum monthly heating demand
16 Minimum monthly cooling demand
17 City water

OUTPUT

Tabular summary of monthly energy consumption in format of P.O.D. Form No. 2215. See Figures 75 to 78 in the User's Manual.

SECTION 7

ECONOMICS ANALYSIS SUB-PROGRAM

The Economics Analysis Sub-program determines the annual owning and operating costs of each building equipment combination considered with the Systems Simulation Sub-program or Packaged Systems Simulation Sub-program and enables the P.O.D. engineer to determine which building equipment combination is the most economical for the building in question. Within the sub-program, an account is made of energy cost, installed equipment cost, resale value of equipment at the end of the building's life, maintenance costs, periodic overhaul costs and floor space costs. The annual owning and operating cost is computed based upon the discounted cash flow technique. Figure 22 outlines the workings of the Economics Analysis Sub-program.

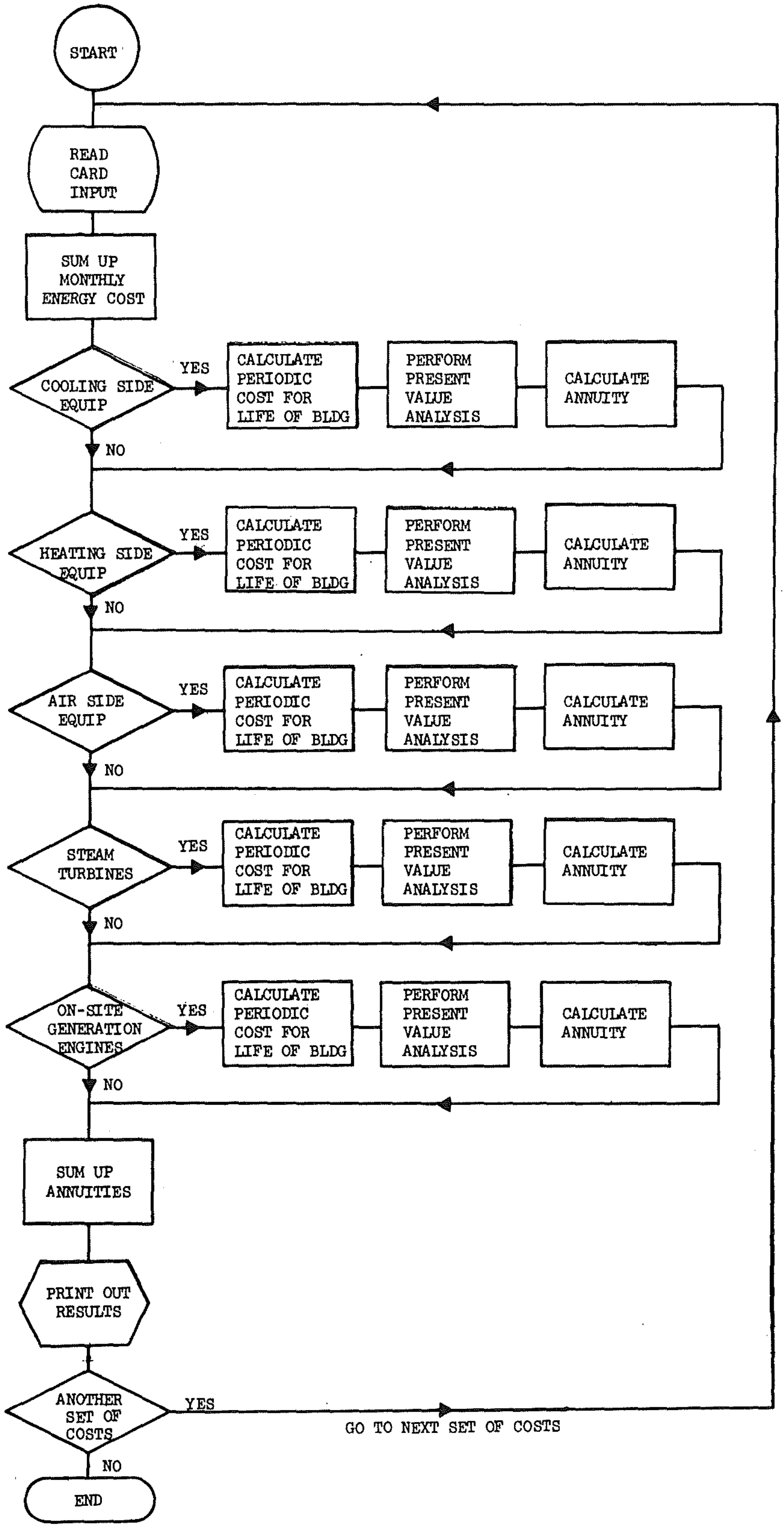


Figure 22 LOGIC FLOW CHART OF ECONOMICS ANALYSIS SUB-PROGRAM

ECON

A sub-program for calculating the total owning and operating costs for the life of the building for every system combination considered.

INPUT

FAC	:	Name of facility
CITY	:	Location of facility
PROJ	:	Project number
DATE	:	Date of program run
ENGR	:	Name of engineer
SYSTM	:	Type of building system
BLGLF	:	Building life, years
RINT	:	Annual interest rate, percent
RINL	:	Estimated annual labor wage increase, percent
RINM	:	Estimated annual maintenance material cost increase, percent
RINF	:	Estimated annual increase of floor space cost, percent
ENGY(I,J)	:	Monthly energy cost matrix, $, where subscripts I and J indicate the following:

I = 1, January
= 2, February
= 3, March
= 4, April
= 5, May
= 6, June
= 7, July
= 8, August
= 9, September
= 10, October
= 11, November
= 12, December

INPUT (CONT'D)

J = 1, Fuel Oil
= 2, Gas
= 3, Electricity
= 4, Purchased Steam
= 5, City Water
= 6, Diesel Fuel

COST(I)	:	Installed cost of equipment, \$, where I identifies the type of equipment as follows:

I = 1, Cooling side equipment
= 2, Heating side equipment
= 3, Air side equipment
= 4, Steam turbines
= 5, On-site engine-generator sets

LIFE(I)	:	Expected life of equipment, years See COST(I) for identification of I.
SV(I)	:	Is resale value to be considered?
OHPD(I)	:	Major overhaul period, years See COST(I) for identification of I.
AML(I)	:	Estimated annual maintenance labor cost, \$ See COST(I) for identification of I.
AMM(I)	:	Estimated annual maintenance material cost, \$ See COST(I) for identification of I.
OHL(I)	:	Estimated major overhaul labor cost, \$ See COST(I) for identification of I.
OHM(I)	:	Estimated major overhaul material cost, \$ See COST(I) for identification of I.
FLR(I)	:	Estimated cost of floor space required by equipment, \$ See COST(I) for identification of I.

OUTPUT

Summary of owning and operating costs for each building system combination considered.

CALCULATION SEQUENCE

1. Read all card input data.

2. Calculate annual energy costs using the monthly energy cost inputs.

$$\text{TENGY(J)} = \sum \text{ENGY(I,J)} \quad \text{for I = 1 to 12}$$

and J is identified as indicated below:

J = 1, Fuel Oil

= 2, Gas

= 3, Electricity

= 4, Purchased Steam

= 5, City Water

= 6, Diesel Fuel

3. Calculate total annual energy cost for building.

$$\text{UA} = \sum \text{TENG(J)} \quad \text{for J = 1 to 6}$$

4. Perform a present-value analysis each of the five types of equipment. Repeat calculations 4.1 through 4.8 for each type of equipment.

4.1 Present-value analysis of installed equipment cost

$$\text{PC} = \sum \Big[\text{COST(I)} * ((1.0 + \text{RINM})/(1.0 + \text{RINT})) ** ((\text{J-1}) * \text{LIFE(I)})\Big] \quad \text{for J = 1 to L}$$

where L = BLGLF/LIFE(I) + 1

If salvage value is considered, adjust the present-value PC as follows:

$$\text{PC} = \text{PC} - \text{COST(I)} * (\text{L} - \text{AL})/((1.0 + \text{RINT}) ** \text{BLGLF})$$

where AL = BLGLF/LIFE(I)

4.2 Present-value analysis of floor space cost

$$\text{PF} = \sum \Big[\text{FLR(I)} * ((1.0 + \text{RINF})/(1.0 + \text{RINT})) ** \text{J}\Big] \quad \text{for J = 1 to LF}$$

where LF = BLGLF

4.3 Present-value analysis of annual maintenance labor cost

$$PAML = \sum\left[AML(I) * ((1.0 + RINL)/(1.0 + RINT)) ** J\right]$$

for J = 1 to LF

4.4 Present-value analysis of annual maintenance material cost

$$PAMM = \sum\left[AMM(I) * ((1.0 + RINM)/(1.0 + RINT)) ** J\right]$$

for J = 1 to LF

4.5 Present-value analysis of major overhaul labor cost

$$POHL = \sum\left[OHL(I) * ((1.0 + RINL)/(1.0 + RINT)) ** (J * OHPD(I))\right] \quad \text{for } J = 1 \text{ to } K$$

where K = BLGLF/OHPD(I)

4.6 Present-value analysis of major overhaul material cost

$$POHM = \sum\left[OHM(I) * ((1.0 + RINM)/(1.0 + RINT)) ** (J * OHPD(I))\right] \quad \text{for } J = 1 \text{ to } K$$

4.7 Total present-value of system

$$P(I) = PC + PF + PAML + PAMM + POHL + POHM$$

4.8 Total owning and operating annuity for equipment I

$$A(I) = P(I) * (RINT/(1.0 - 1.0/(1.0 + RINT ** BLGLF))$$

5. Total owning and operating annuity for entire system

$$ANTYM = A(1) + A(2) + A(3) + A(4) + A(5) + UA$$

6. Write out results for permanent record.

7. Check to see if there is another set of data to be read.

If yes, go back to calculation 1 and start again.

If no, PROGRAM FINISHED.

SECTION 8

PACKAGED SYSTEMS SIMULATION SUB-PROGRAM

Small one- or two-story Post Office buildings usually do not contain the type of fan systems or heating and cooling plants discussed in Section 6. Instead, packaged unitary heating/cooling systems are usually installed within or atop the building. The Packaged Systems Simulation Sub-program was written, therefore, to simulate the operation of the following four types of packaged unitary equipment:

(1) Electric air conditioning (DX coil) with gas heat

(2) Electric air conditioning (DX coil) with oil heat

(3) Reversible cycle heat pump with electric resistance heating

(4) Gas air conditioning with gas heat.

The procedures for analyzing a small Post Office building which contains packaged system(s) are as follows:

(1) Break the building up into spaces so that each space will be served by a single packaged system.

(2) Use the Load Calculation Sub-program to compute the hourly loads for each space within the building.

(3) Since each packaged system serves only one space, there will probably be no need to use the Thermal Loads Plot Sub-program or Load Editing Sub-program. The engineer could, however, run the Thermal Loads Plot Sub-program to establish the load profile of a space or the entire building, if he deemed it necessary.

(4) Prepare the necessary card input and run the Packaged Systems Simulation Sub-program using the output tape of the Load Calculation Sub-program as the input load tape.

A logic flow chart of the calculations performed within the Packaged Systems Simulation Sub-program is shown in Figure 50. A detailed description of the PKGSY Sub-program follows.

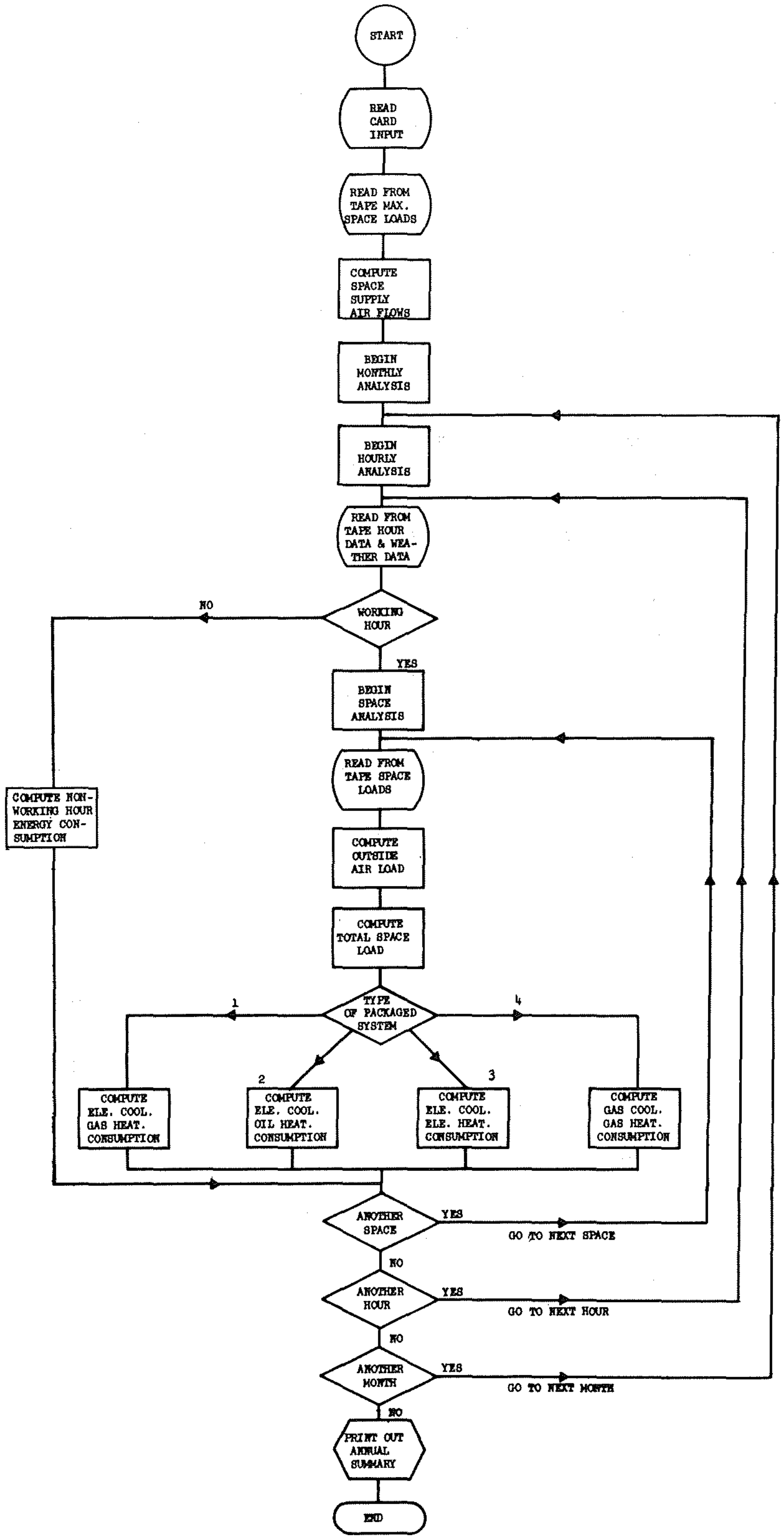


Figure 23 LOGIC FLOW CHART OF PACKAGED SYSTEMS SIMULATION SUB-PROGRAM

PKGSY

A sub-program for simulating the performance of typical packaged heating/cooling units used in small Post Office buildings.

INPUT

CARD INPUT VARIABLES:

FSDW	:	First day on weather tape
SUDST	:	Sunday start-up time of air conditioning system
SUDWH	:	Number of Sunday operating hours of air conditioning system
SADST	:	Saturday start-up time of air conditioning system
SADWH	:	Number of Saturday operating hours of air conditioning system
WKDST	:	Weekday start-up time of air conditioning system
WKDWH	:	Number of weekday operating hours of air conditioning system
CHRST	:	Christmas start-up time of air conditioning system
CHRWH	:	Number of Christmas operating hours of air conditioning system
UKWBX	:	Power of external lights during working hours, KW
UKWBI	:	Power of internal lights and motors during working hours, KW
UKWNX	:	Power of external lights during non-working hours, KW
UKWNI	:	Power of internal lights and motors during non-working hours, KW
HVHO	:	Heating value of heating oil, Btu/gal
JMAX	:	Total number of spaces in building
JM(J)	:	Type of packaged system used for space No. J

INPUT (CONT'D)

TAPE INPUT VARIABLES:

FAC	:	Name of facility
CITY	:	Name of city in which facility is located
ENGR	:	Name of engineer
PROJ	:	Project number
DATE	:	Date of computer run
MSTRT	:	Month at which analysis is to start
NDAYS	:	Number of days for which analysis is to run
IMAX(M)	:	Number of hours in month No. M
ISBMX	:	Number of spaces in building
VOL(K,J)	:	Volume of space No. J of fan system No. K, cu ft

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

I	:	Hour number of year
ISUN	:	Sun index which indicates whether or not the sun is "up"
TOA	:	Outside air dry-bulb temperature, °F
VEL	:	Wind velocity, knots
WOA	:	Outside air humidity ratio, lb water/lb dry air
PATM	:	Barometric pressure, inches of mercury
HOA	:	Enthalpy of outside air, Btu/lb dry air
DOA	:	Density of outside air, lb dry air/cu ft

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

IS	:	Space number
QS(J)	:	Space sensible load, Btu/hr

INPUT (CONT'D)

TAPE INPUT VARIABLES: (CONT'D)

QL(J)	:	Space latent load, Btu/hr
QLITE(J)	:	Space lighting load picked up by return air, Btu/hr
SLPOW(J)	:	Space internal lighting and machinery power consumption, KW

CALCULATION SEQUENCE

1. Read all card input information.

2. Read through load input tape and for each space find the following:

QTZCM(J)	Maximum space cooling load (total), Btu/hr
QSZHM(J)	Maximum space heating load (sensible), Btu/hr
TOAC(J)	Outside air temperature at peak cooling hour, °F
WOAC(J)	Outside air humidity ratio at peak cooling hour, lb/lb
QLITC(J)	Space lighting load picked up by return air during peak cooling hour, Btu/hr
TOAH(J)	Outside air temperature at peak heating hour, °F

3. Calculate supply air requirements, CFMX(J), for each space, J.

   3.1 If QTZCM(J) $>$ QSZHM(J)

   set CFMX(J) = QTZCM(J)/30.0

   3.2 If QTZCM(J) $\leq$ QSZHM(J)

   set CFMX(J) = -QSZHM(J)/30.0

4. Calculate peak cooling load for each space, J.

   QCMAX(J) = (QTZCM(J) + QSOAC + QLOAC + QLIT)/12000.0

   where

   QSOAC = 1.08 * 0.1 * CFMX(J) * (TOAC(J) - 75.0)

   QLOAC = 4747.5 * 0.1 * CFMX(J) * (WOAC(J) - 0.009)

   QLIT = QLITC(J) * 0.9

   and QCMAX(J) has units of tons.

5. Calculate peak heating load for each space, J.

QHMAX(J) = (QSZHM(J) + QSOAH)/1000.0

where

QSOAH = 1.08 * 0.1 * CFMX(J) * (TOAH(J) - 75.0)

and QHMAX(J) has units of MBTU.

6. Write out page 1 of output (title page).

7. Write out page 2 of output, listing

J	Space number
JM(J)	Type of heating/cooling system serving space No. J
CFMX(J)	Space supply air flow rate, cfm
QCMAX(J)	Peak cooling load for system serving space No. J
QHMAX(J)	Peak heating load for system serving space No. J

8. Begin hourly analysis repeating calculation 8.1 through 8.7 for each hour of the month.

8.1 Read from input tape the hourly weather and space load information.

8.2 Check the hour number of the year, I, to determine if hour is a weekday, Saturday, Sunday or Christmas season day.

8.2.1 If a weekday, and the following is true of IHRDY, the hour number of the day

$$WKDST \leq IHRDY \leq (WKDST + WKDWH)$$

then go to calculation 8.4; otherwise go to calculation 8.3.

8.2.2 If a Saturday, and the following is true of IHRDY,

$$SADST \leq IHRDY \leq (SADST + SADWH)$$

then go to calculation 8.4; otherwise go to calculation 8.3.

8.2.3 If a Sunday, and the following is true of IHRDY,

$$SUDST \leq IHRDY \leq (SUDST + SUDWH)$$

then go to calculation 8.4; otherwise go to calculation 8.3.

8.2.4 If a Christmas season hour (between November 15 and December 31), go to calculation 8.4.

8.3 Hour under consideration is a non-working hour. The only energy being consumed within the building is the non-working hour internal and external lighting load and any heating energy, if required.

8.3.1 If TOA $\geq$ 60°F, then no heating required in building. Update the monthly non-working hour internal and external energy consumption totals.

$$UKWXT = UKWXT + UKWNX$$

$$UKWIT = UKWIT + UKWNI$$

Go to next hour's calculation.

8.3.2 If TOA < 60°F, then heating energy is required for non-working hour.

Go to calculation 8.4.

8.4 Hour under consideration is a working hour or a non-working hour with a heating requirement. Perform the following calculations for each space, J.

8.4.1 If heating is required by space J, calculate the total heating load, Q, and corresponding energy consumption.

$$Q = QS(J) + QOA + QLITE(J) * (CFMX(J) - CFM)/CFMX(J)$$

where

$$QOA = 1.08 * CFM * (TOA - 75.0)$$

$$CFM = 0.1 * CFMX(J)$$

8.4.1.1 If JM(J) = 1, calculate gas heating energy and fan energy required.

$$HGAS = Q/75000.0$$

$$FANP = HGAS * 1.1$$

8.4.1.2 If JM(J) = 2, calculate oil heating energy and fan energy required.

$$HOIL = Q/(0.7 * HVHO)$$

$$FANP = HOIL * HVHO * 1.1$$

8.4.1.3 If JM(J) = 3, calculate electric heating energy required.

For TOA > 0.0

$$HKW = Q * (0.1 + 0.58443 ** ((-TOA - 10.0)/24.0)) * 0.001$$

For TOA $\leq$ 0.0

$$HKW = Q * 0.29 * 0.001$$

8.4.1.4 If JM(J) = 4, calculate gas heating energy and fan energy required.

$$HGAS = Q/75000.0$$

$$FANP = HGAS * 1.1$$

8.4.2 If cooling is required by space J, calculate the total cooling load, Q, and corresponding energy consumption.

$$Q = QS(J) + QL(J) + QOA + QLITE(J) * (CFMX(J) - CFM)/CFMX(J)$$

where

a) $CFM = 0.1 * CFMX(J)$ for $TOA \geq 70°F$ or $TOA \leq 40°F$

b) $CFM = CFMX(J)$ for $40 < TOA < 70$ and $TSA < TOA$

where $TSA = 75.0 - QS(J)/(1.08 * CFMX(J))$

8.4.2.1 If JM(J) = 1, 2 or 3, calculate the electric cooling energy required.

CKW = 0.166 * Q * 0.001

8.4.2.2 If JM(J) = 4, calculate the gas cooling energy and fan energy required.

CGAS = Q/25000.0

FANP = CGAS * 1.1

8.5 Update the monthly internal and external power consumption totals.

8.5.1 If hour under consideration is a non-working hour with a heating requirement:

UKWIT = UKWIT + AFANP

8.5.2 If hour under consideration is a working hour:

AKWX = AKWX + UKWBX

AKWI = AKWI + UKWBI + AFANP

8.6 Keep a running total of hourly energy consumption for the month.

AHKW = AHKW + HKW

ACKW = ACKW + CKW

AHGAS = AHGAS + HGAS

ACGAS = ACGAS + CGAS

AHOIL = AHOIL + HOIL

AFANP = AFANP + FANP

8.7 Keep track of the maximum hourly energy demands by checking each at the end of each hour's calculation and updating the following energy demand variables.

DNCB	Minimum building cooling demand
DNHB	Minimum building heating demand
DMCB	Maximum building cooling demand
DMHB	Maximum building heating demand
HKWD	Maximum electric heating demand
CKWD	Maximum electric cooling demand
CGASD	Maximum gas cooling demand
HGASD	Maximum gas heating demand

END OF HOURLY ANALYSIS

9. Call ENGYC to write out annual summary of building monthly energy consumption and demands.

GPO 889-666