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NECAP 4.1 - NASA'S ENERGY-COST ANALYSIS PROGRAM ENGINEERING MANUAL

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This version of NASA'S Energy-Cost Analysis Program (NECAP) is for internal NASA use.

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Section 1

INTRODUCTION

This manual is one in a set of NECAP manuals referenced below that describes the computer program NECAP - NASA's Energy Cost Analysis Program. The program is a versatile building design and energy analysis tool which has embodied within it, state-of-the-art techniques for performing thermal load calculations and energy use predictions. With the program, comparisons of building designs and operational alternatives for new or existing buildings can be made.

The major feature of the program is the "response factor" technique for calculating the heat transfer through the building surfaces which accounts for the building's mass. The program expands the response factor technique into a "space response factor" to account for internal building temperature swings; this is extremely important in determining true building loads and energy consumption when internal temperatures are allowed to swing.

The algorithms for the thermal loads portion of NECAP comes from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., (ASHRAE) manual, Procedure for Determining Heating and Cooling Loads for Computerized Energy Calculation. The original NECAP was published in 1975 and was supported by two manuals entitled NECAP - NASA's Energy Cost Analysis Program, NASA CR-2590 Part I User's Manual and NASA CR-2590 Part II Engineering Manual. Since that time, NASA has used NECAP for building heating and cooling design loads and energy analysis. The program has been used as a reference for the development of several other computerized programs.

This version of NECAP, called NECAP-4.1, contains the following modifications and improvements:

- A NECAP input data processor (NIPP) module was developed which greatly simplifies and reduces the user input task. The original fixed format data field suitable for punching onto computer cards has been eliminated in favor of a free format data field suitable for use with computer terminals.
- Provide built in default values for most input data.
- The Response Factor module was made an integral part of the Thermal Load Analysis and System modules.
- The Variable Temperature module and System and Equipment Simulation module were brought together into one module to allow dynamic simulation and interaction (feedback) between the space, its distribution system, and the heating and cooling plant equipment. In the previous version of NECAP, the hourly space temperatures and system heating/cooling loads were calculated using given heating/cooling capacities. Because of varying plant equipment capacity due to ambient conditions, scheduling, distribution system control options, etc., "loads-not-met" resulted in the old program. "Loads-not-met" were not accounted for in space temperature drift above or below the allowed temperature range.

- Modify the thermostat and ventilation schedule input.
- Improve fan on/off code.
- Addition of process loads.
- Modify the weather tape system.
- Use system component part load performance curves.
- Default CFM, chiller size, and boiler size data.
- Provide an executive summary for energy.
- Print out a temperature frequency chart.
- Add more flexibility to print out.
- Change the glass shade coefficient.
- Correct air infiltration coefficients, fan efficiencies, and floor panel heating algorithms.

The new program is documented in the following manuals:

TM 83238, Users Manual - Describes examples and output forms.

TM 83239, Input Manual - Details the input requirements.

TM 83240, Engineering Manual - Provides the algorithms for the program.

TM 83241, Fast Input Manual and Example - Gives a fast method of input.

TM 83242, Engineering Flow Charts - Provides flow charts that supplements the Engineering Manual.

CR- 165802, Operations Manual - Gives the specific operating instruction for Langley Research Center's computer system operation.

Program modifications were directed specifically at program improvements and not at a complete rework of the program structure. We wish to acknowledge the contributions made by the project's contractor, GARD, Inc. of Niles, IL, for the various changes and documentation in the program performed under contract NASW-3307. The program's maintenance contractor, Computer Sciences Corporation, of Hampton, Virginia also assisted in program updates and documentation.

The program is run on NASA, Langley Research Center's large computer system. Users should be cautioned that program implementation can be time consuming and costly. Although computer run costs are much lower than the original response factor programs, they are still a magnitude greater that the simple "bin method" type energy calculation. With this in mind, judgment should be exercised to assure that needs are compatible with the investment. Operational assistance in running the program cannot be provided by NASA.

There are limited means to update the material. Comments on the program are welcomed, although the Government accepts no obligation even if the suggestions are used. Send comments to:

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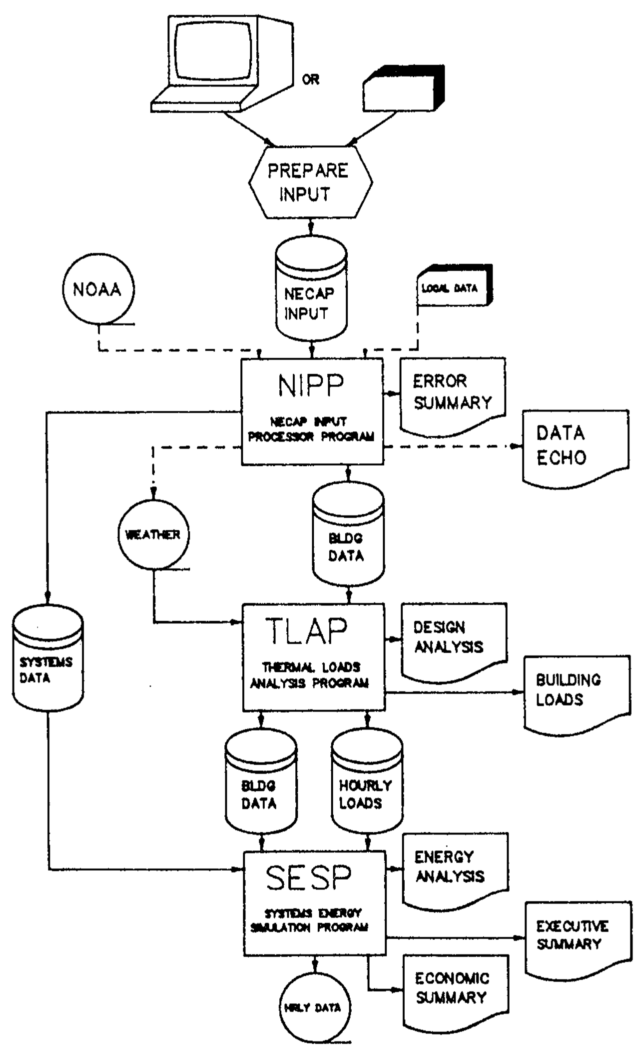
NECAP-4.1 is made up of the following program modules:



SECTION 2

NECAP INPUT PROCESSOR

2.1 OBJECTIVE AND DESCRIPTION

The NECAP Input Processor (NIPP) prepares the data used by NECAP's TLAP and SESP programs. NIPP decodes the L cards (TLAP) and S cards (SESP), provides defaults, counts the items contained in the data, sorts the data into the proper order and generates the rigidly formatted data files used by TLAP and SESP. NIPP also performs simple data checks and provides error flags where necessary. More detailed checking is done by routines DATVER and SYSCHK.

During verification, two types of errors are flagged - warnings and critical errors. Execution of the program will terminate on critical errors - which should be corrected before proceding to TLAP or SESP. Warning errors are not vital to program execution, but may alter the results.

2.2 ALGORITHMS OF SUBROUTINES

DEFAL

This subroutine writes the necessary default variables for cards that are not included in the input deck. If the card index is greater than the maximum (LNOMAX), then the program will terminate abnormally through the subrotuine ITERM.

INPUT:
- INN - Card index number of missing card
- IPROG - Program index (1=TLAP, 2=SESP)
- NUGF - Number of underground surfaces

OUTPUT:
- ICODE - Type of analysis desired
- LSTUD - Length of study requested

DIAG

This subroutine writes diagnostic message output for the input processor. The messages are dependent upon the number and type of errors detected during processing. If errors of sufficient severity have occurred, then this subroutine will terminate the program with an abnormal termination message.

INPUT:
- NCARD - Number of cards processed
- NPROG - Program index (1=TLAP, 2=SESP)

LABEL

This subroutine decodes a card label until it encounters a label terminator (equals) or a character that it does not recognize. If the end of a record is encountered while decoding a label, then a new record will be read in and decoding will continue on the new record.

INPUT:

JA - Position of the last character processed
ISLASH - Multiple card indicator (1=multiple card)
NEXT - Position of the next character to be processed (JA+1)

OUTPUT:

IRET - Return action index (1=proceed to decode variable list, 2=error condition, 3=multiple card without a new label)

RESCH

This subroutine will write 24 variables that range in value from 0.0 to 1.0 onto a 72 character output field. Each output number is limited to a field of 3 characters.

INPUT:

A(24) - The variable array to be printed

OUTPUT:

N(72) - Coded output array

SIMIL

This subroutine copies values for variables from one card to another as directed by the similar card index. This index is found as the first decoded variable for the cards L11, L12, L13, and L17. The variables which have been defaulted are the ones to be copied.

INPUT AND OUTPUT THROUGH COMMON BLOCKS

OUTPUT:

IERR1 - Card error flag
IERR2 - Diagnostic output character

STORE

This subroutine stores the decoded variable, label numbers, and card parameters in arrays. The label parameters and number of decoded variables are stored in five arrays as functions of the card number in the deck.

ARRAY	STORED VARIABLE
I1	LNO, Card Index Number
I2	LRNO, Repetition Number
I3	LSNO, Surface Index
I4	NO, Number of Decoded Variables
I5	IPROG, Program Index

The variables are stored in another array titled "OADS" and are a function of card deck number and position within the variable list. STORE also adds in default values, keeps track of repeated cards, checks dimensional limits, and raises error plags - if necessary.

INPUT AND OUTPUT THROUGH COMMON BLOCKS.

IBITT

This subroutine flags cards containing defaulted variables.

SURF

This subroutine writes the decoded surface variables into the NECAP compatible loads input file (NO=7). The output is a series of card images.

INPUT:

INUMB	-	The card index numbers of TLAP data cards in increasing order.
LCARD	-	The number of decoded variables.
INN	-	Card index
NSS	-	Number of shading surfaces.
IC	-	Current card index.

OUTPUT:

K1	-	Number of surfaces

TERM

This subroutine will terminate execution of the input pre-processor as directed by the calling program. This subroutine is called when a severe error, which would normally end program execution, is encountered.

INPUT:

NCARD	-	Number of the last card read.

VARI

This subroutine decodes the variable list until it encounters a card terminator (semi-colon or slash) or a character that it does not recognize. If the end of a record is encountered in this subroutine, then a continuation flag is set and control is passed to the main program which will read a new record. The continuation flag will return control to this subprogram when ready to continue variable decoding. Unknown characters will cause the subroutine to stop decoding, set an error flag, and return to the main program which will process a new record.

INPUT:

JA	-	Position of the last character processed.

OUTPUT:

IRET	-	Return action index.

PACKIT

This subroutine uses the CDC utility ENCODE to pack data into an array.

INPUT:

AB	-	Input record

A, B, C, and D are input as variables consisting of ten characters and are output as variables (of type A10) of 40 characters. PACKIT uses CDC sized words and CDC's ENCODE and DECODE statements.

WCARD

This subroutine sorts the decoded cards by loads and systems types and by card index numbers. It rearranges the card deck such that the lowest index numbered card is processed first. If a decoding error has occurred for a particular card, as evidenced by the value of IERR1 for that card, then the card will not be included in the rearranged decks.

INPUT AND OUTPUT VARIABLES THROUGH COMMON BLOCKS

IBIT

This function calculates the value of the default flags (ON=1). Since a flag is either on or off, they are conveniently stored as bits in the array "IDEF."

INPUT:
- I - Card deck number
- J - Variable number on the card (J=56 is the card default index)

IHOY

This function, given the month, TMON, and day, computes the hour of the year. The number of hours in each month is the variable NOHIE, which is not corrected for leap year.

INPUT:
- TMON - Month of the year (Real)
- DAY - Day of the month (Real)

OUTPUT:
- IHOY - Hour of the year (Integer)

WCOMS

This subroutine writes the decoded SESP variables into a NECAP compatible systems input file (NO.=8). The output is a series of card images. The subroutine takes the rearranged cards from "WCARD" and compares the card indices, one by one, with a counter. If the card index is greater than the counter, then the program knows that a particular card is not included in the input deck. This will cause the default characteristics to take effect. If the card index equals the counter then the program reformats the variables and writes them. If the card index is less than the counter, then an error has occurred in "WCARD." This subroutine will write a defaulted title if none are decoded from the input deck. If the associated TLAP input has a title, then that one will be used.

INPUT AND OUTPUT VARIABLES THROUGH COMMON BLOCKS.

WLOAD

This subroutine writes the decoded TLAP varialbes into a NECAP compatible loads input file (NO.=7). The output is a series of card images. The subroutine takes the rearranged cards from "WCARD" and compares the card indices, one by one, with a counter. If the card index is greater than the counter, then the program knows that a particular card in not included in the input deck and will cause the default characteristics to take effect.

If the card index equals the counter, then the program reformats the variables and writes them out. If the card index is less than the counter, then an error has occurred in the subroutine "WCARD." This subroutine will write defaulted titles if fewer than five are decoded from the input deck.

INPUT AND OUTPUT VARIABLES THROUGH COMMON BLOCKS

WHEN

This subroutine calculates the month and day of the study when it is not included in the input deck.

OUTPUT:

A - Month of the year
B - Day of the week

CALCULATION SEQUENCE

1. If printing desired, write COMMON BLOCKS.
2. If default list desired as output, write LIST.
3. Make variable initializations to zero.
4. If printing desired, write NUMBER OF CARDS.
5. Set continuation flag to zero.
6. If printing desired, write CONTINUATION FLAG.
7. Read new record.
8. If end of file been encountered, go to 33.
9. If diagnostics are to be printed as encountered, write NUMBER OF CARDS and echo input records.
10. If the card continues, go to 22.
11. Variable initializations to zero.
12. If printing desired, write MULTIPLE CARD FLAG.
13. Further variable initialization to zero.
14. If printing desired, write CARD STATISTICS.
15. Call LABEL to decode card label.
16. If printing desired, write CARD STATISTICS.
17. If IRET = 2, go to 4.
18. If IRET > 2, go to 22.
19. If printing desired, write POSITION OF POINTER in record.
20. If pointer has not reached end of record, go to 22.
21. Set continuation flag to unity, go to 6.
22. If printing desired, write card statistics.
23. Call VARI to decode variable list.
24. If printing of common block desired, go to 1.
25. If IRET = 2, go to 4.
26. If IRET = 3, go to 6.

CALCULATION SEQUENCE (cont'd.)

27. If IRET = 4, go to 2.

28. If printing desired, write CARD STATISTICS.

29. Call STORE to store decoded variables.

30. If printing desired, write CARD STATISTICS, ERRORS, and VARIABLE VALUES.

31. If it is multiple card, to to 12.

32. Go to 4.

33. If printing desired, write NUMBER OF CARDS.

34. Call WCARD to sort the decoded cards.

35. END

DATAV: TLAP DATA CHECKING

OBJECTIVE AND DESCRIPTION

The Thermal Loads data verification routine checks the input for the TLAP program by scanning for syntax errors, input values, and number of cards. The program will issue information as to the severity of errors encountered.

ALGORITHMS OF SUBROUTINES

BLANK

This subroutine checks to make sure that the remainder of the data card is blank up to the limit of IBOP.

CARD1

This subroutine reads and writes eighty character format.

CARD2, CARD3, CARD4, CARD5, CARD6, CARD7, CARD8 and CARD9

These subroutines read and write data according to the format in each.

DECID

This subroutine picks off a character at a time from ICARD and returns JSET (type of character) as a token, and ICAR as the character.

DIMEN

This subroutine echos input data.

FORM

This subroutine checks F-format fields. If an error is found, the error message is printed out along with the card image.

GTACK

This subroutine inputs and checks each data card according to specified format and controls the appearance of the data on the output page.

MSSGB

This subroutine prints a severe error message and provides a heading for severe errors if the error is the first one.

ROUND

This subroutine checks formats for CARD L11 or CARD L12 or CARD L13.

SRORN

This subroutine determines the orientation of the outward normal for a surface, given the building azimuth and the surface azimuth.

XTRCT

This subroutine computes the area, tilt, and azimuth for surfaces which are described by the longer method.

CALCULATION SEQUENCE

1. Initialize variables for dimension puncher.
2. Set up output report heading.
3. Call Blank-check cards L1-L5 for remaining blanks on card.

   For Remaining Cards:

4. Call GTACK - check card.
5. If there are fatal errors, go to 9.
6. If there are other errors, call MSSGB to print error message.
7. Call DIMEN to echo input data.
8. END
9. Call MSSGB to print severe error message.
10. Go to 7.

SYSCHK: SESP DATA CHECKING

OBJECTIVE AND DESCRIPTION

SYSCHK is a data verification for the input to SESP. The program reads the data in the same formats as the SESP program. It also checks the data for dimensional correctness. If any errors are found, they are written. After the occurrence of ten errors the system is aborted to prevent SESP execution.

ALGORITHMS OF SUBROUTINES

INTERR

This subroutine prints out errors for SESP input and will increment error counter each time it is called.

INPUT:
- MIN - Minimum acceptable integer value
- MAX - Maximum acceptable integer value

OUTPUT:
- NOPE - Error counter

REALER

This subroutine prints out errors for SESP input and will increment error counter each time it is called.

INPUT:
- AMN - Minimum acceptable real value
- AMX - Maximum acceptable real value

OUTPUT:
- NOPE - Error counter

SECTION 3

THERMAL LOAD ANALYSIS PROGRAM

3.1 OBJECTIVE AND DESCRIPTION

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

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

2. Solar gains through windows.

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

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

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

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

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

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

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

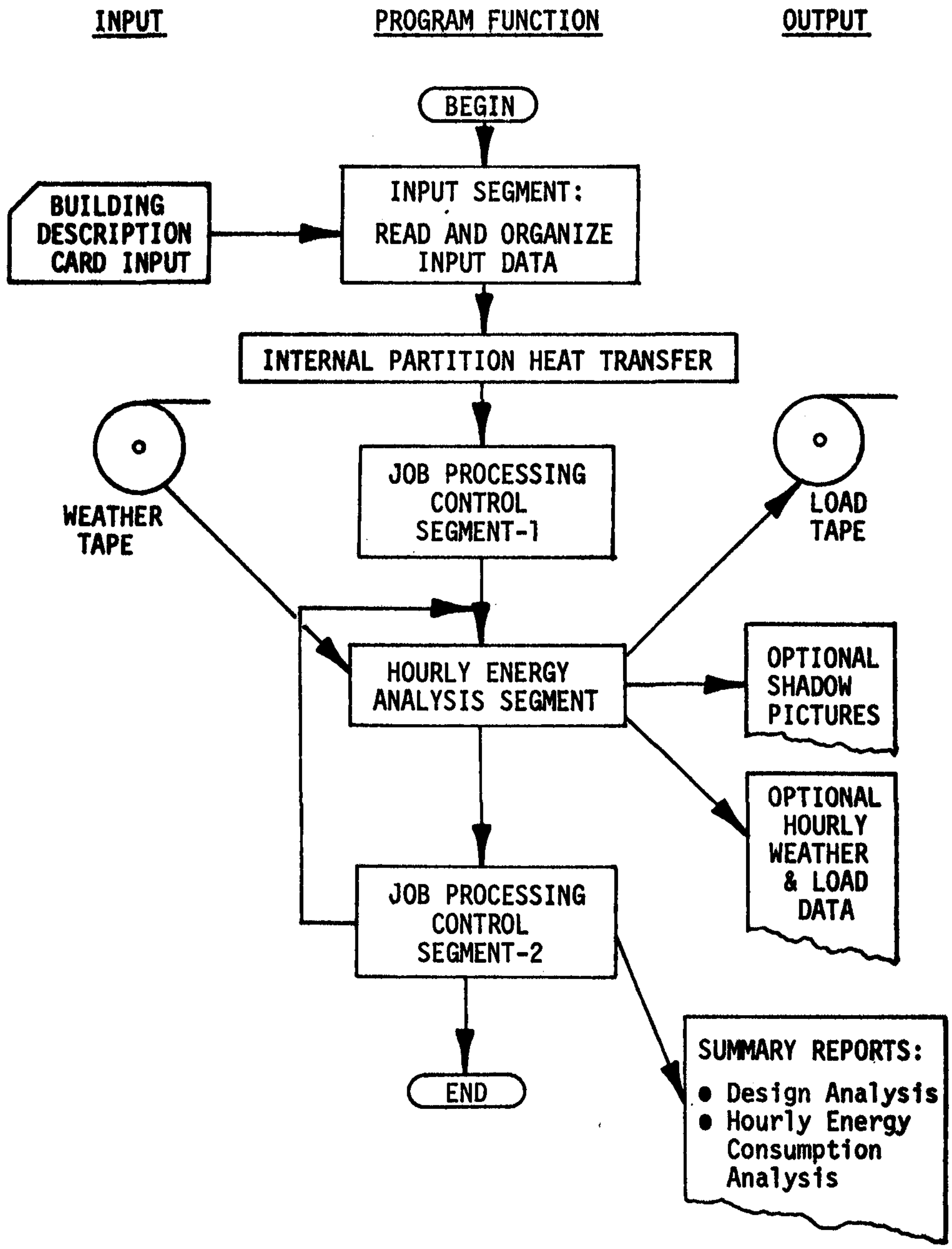


Figure 3.1 THERMAL LOAD ANALYSIS PROGRAM MACRO-FLOW DIAGRAM

TABLE 3.1

THERMAL LOAD ANALYSIS PROGRAM SUBROUTINES

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

TABLE 3.1 (CONT'D)

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

TABLE 3.1a

DEFINITION OF TLAP VARIABLES IN COMMON

/COMQMX/

BCOOLT	- Present hour summation of space cooling loads (BTU/HR)
BHEATT	- Present hour summation of space heating loads (BTU/HR)
DENS	- Ambient air density (LBM/FT^3)
DBT	- Ambient dry bulb temperature (^{o}F)
HLATP	- Space latent load due to people (BTU/HR)
HRLDS	- Present hour space sensible load (BTU/HR)
HUMRAT	- Ambient air humidity ratio $\left(\frac{\text{LBM-H2O}}{\text{LBM-DRY AIR}}\right)$
ITIME	- Hour of day (0-23)
QLEQ	- Space latent load due to equipment (BTU/HR)
QLINF	- Space latent load due to infiltration (BTU/HR)
QSINF	- Space sensible load due to infiltration (BTU/HR)
TOTAL	- Present hour total space load (BTU/HR)
WBT	- Ambient wet bulb temperature (^{o}F)

/NODIM/

BAZ	- Building azimuth angle (RADIANS)
CC	- Cloud cover modifier
CFMSF	- Ventilation air rate (CFM)
CNS	- Summer clearness number
CNW	- Winter clearness number
COSBAZ	- Cosine of building azimuth angle
COSLAT	- Cosine of latitude
DENSUM	- Summer outside air density (LBM/FT^3)
DENWIN	- Winter outside air density (LBM/FT^3)
DTC	- Space cold air supply temperature (^{o}F)
DTH	- Space hot air supply temperature (^{o}F)

DEFINITION OF TLAP VARIABLES IN COMMON (CONT'D)

FPRES	- Estimated total fan pressure (IN OF H2O)
FTCA	- Total cloud amount index
IDAY	- Day of month
IDOY	- Day of year
IER	- Error indicator
IGNOR	- Program operation flag
IOUTA	- I/O reference to hourly date tape (output - "A" tape)
IOUTP	- I/O reference to data tape (output - "I" tape)
IXMAS	- Length of special schedule at end of year
JAHR	- Weather year for study
JC	- Christmas period indicator
JEND	- Study ending hour of year (1-8784)
JMONTH	- Starting month of study (1-12)
JSC	- Type of day of the week (1-9)
JSTART	- Study beginning hour of year (1-8784)
JSTAT	- Weather station number
JUMP	- Program operation flag
KAGIT	- I/O reference to printer
KODE	- Program operation flag
LCODE	- Type of study processing flag
LEAP	- Leap year indicator
LENGTH	- Length of study (HOURS)
LUNFWT	- I/O reference to weather input tape
MONTH	- Month of year (1-12)
NDB	- Number of delayed surfaces for building
NLOOKD	- Number of shadow pictorials for delayed surfaces
NLOOKQ	- Number of shadow pictorials for quick surfaces

DEFINITION OF TLAP. VARIABLES IN COMMON (CONT'D)

NLOOKW	- Number of shadow pictorials for windows
NQB	- Number of quick surfaces for building
NRF	- Number of different types of delayed surfaces
NS	- Number of spaces in building
NSP	- Number of shading surfaces
NTZ	- Time zone
NWB	- Number of windows for building
PATM	- Atmospheric Pressure (LBF/IN^2)
RANGS	- Summer daily dry bulb temperature range
RANGW	- Winter daily dry bulb temperature range
SINBAZ	- Sine of building azimuth angle
SINLAT	- Sine of latitude
STALON	- Longitude
TANLAT	- Tangent of latitude
TDB	- Estimated initial wall and roof outside surface temperature (^oR)
TDBS	- Summer maximum dry bulb temperature (^oF)
TDBW	- Winter minimum dry bulb temperature (^oF)
TDPS	- Summer dew point temperature (^oF)
TDPSUM	- Design day summer dew point temperature (^oF)
TDPW	- Winter Dew Point Temperature (^oF)
TDPWIN	- Design day winter dew point temperature (^oF)
TMIN	- Design day minimum summer dry bulb temperature (^oF)
VELS	- Desgin day summer wind speed (KNOTS)
VELW	- Design day winter wind speed (KNOTS)
WINDS	- Design day summer wind speed (MPH)
WINDW	- Design day winter wind speed (MPH)

DEFINITION OF TLAP VARIABLES IN COMMON (CONT'D)

/TLP1/

- $BODER_K$ - Border between shade fins and glass, window K (IN)
- $FFIHTS_K$ - Indices of space's internal surfaces, count K
- FID_K - Indices of space's delayed surfaces, count K
- $FIDD_K$ - Indices of shading surfaces deleted from delayed surface, count K
- $FIDQ_K$ - Indices of shading surfaces deleted from quick surface, count K
- $FIDW_K$ - Indices of shading surfaces deleted from window, count K
- $FIHTS_K$ - Heat transfer coefficient, internal surface K
- FIQ_K - Indices of space's quick surfaces, count K
- $FIUF_K$ - Indices of space's underground surfaces, count K
- FIW_K - Indices of space's windows, count K
- $IHTS_{K,M}$ - Indices of space's internal surfaces, surface K, Space M
- $ILITE_K$ - Light fixture type, space K
- $ISPC1_K$ - Index of space connected to one side of internal surface, surface K
- $ISPC2_K$ - Index of space connected to other side of internal surface, surface K
- $NIHTS_K$ - Number of internal surfaces, space K
- $SETBK_K$ - Window setback, window K (IN)
- SXN_K - Response factor variable, delayed surface type K
- SXR_K - Response factor variable, delayed surface type K
- SYN_K - Response factor variable, delayed surface type K
- SYR_K - Response factor variable, delayed surface type K
- WOR_K - Weight of floor, space K (LB/FT^2)

/TLP2/

- $CFMD_K$ - Infiltration, delayed surface K (CFM)
- $CFMQ_K$ - Infiltration, quick surface K (CFM)
- $CFMW_K$ - Infiltration, window K (CFM)

$HRLDL_K$ - Present hour plenum return air load, space K (BTU/HR)

$H1_K$ - Previous hour window solar load, space K (BTU/HR)

$H2_K$ - Previous hour total transmission and internal load, space K (BTU/HR)

$H3_K$ - Previous hour plenum return air load, space K (BTU/HR)

$H2P_{10,K}$ - Previous hour components of sensible load, space K (BTU/HR)

$ICALD_K$ - Calculation flag, delayed surface K

$ICALQ_K$ - Calculation flag, quick surface K

$ICALW_K$ - Calculation flag, window K

$QSTORC_K$ - Conductive heat gain, window K ($BTU/HR-FT^2$)

$QSTORD_K$ - Space heat gain from delayed surfaces, surface K ($BTU/HR-FT^2$)

$QSTORQ_K$ - Space heat gain from quick surfaces, surface K ($BTU/HR-FT^2$)

$QSTORR_K$ - Radiant heat gain, window K ($BTU/HR-FT^2$)

QUF_K - Total underground surface heat transfer, space K (BTU/HR)

$SHADD_{24,K}$-Hourly % of area that is shaded, delayed surface K

$SHADQ_{24,K}$-Hourly % of area that is shaded, quick surface K

$SHADW_{24,K}$-Hourly % of area that is shaded, window K

$SSHMAX_K$ - Maximum sensible heating load, space K (BTU/HR)

$STCMAX_K$ - Maximum total cooling load, space K (BTU/HR)

$SUMA_K$ - Present hour window solar load, space K (BTU/HR)

$SUMB_K$ - Present hour sensible load, space K (BTU/HR)

$SUMBP_{10,K}$-Present hour sensible load components, space K (BTU/HR)

$SUMC_K$ - Present hour lighting load, space K (BTU/HR)

/TLP12A/

$CFMEX_K$ - Exhaust air, space K (CFM)

$CODINF_K$ - Infiltration rate, Space K

$FLORA_K$ - Floor area, space K (FT^2)

$HASSL_K$ - People activity level, space K (BTU/HR)

$HTNZ_K$ - Height from neutral zone, space K (FT)

$ID_{K,M}$ - Indices of delayed surfaces, count K, space M

$IPICK_K$ - Type of infiltration analysis, space K

$IPLEN_K$ - Plenum indicator, space K

$IQ_{K,M}$ - Indices of quick surfaces, count K, space M

$ISKIP_K$ - Space summation indicator, space K

$IUF_{K,M}$ - Indices of underground surfaces, count K, space M

$IW_{K,M}$ - Indices of windows, count K, space M

$IWOE_K$ - Electric schedule index, space K

$IWOL_K$ - Light schedule index, space K

$IWOP_K$ - People schedule index, space K

$MULT_K$ - Number of additional identical spaces, space K

ND_K - Number of delayed surfaces, space K

$NFOLK_K$ - Number of people, space K

NQ_K - Number of quick surfaces, space K

NUF_K - Number of underground surfaces, space K

NW_K - Number of windows, space K

$PLITE_K$ - Total lighting load, space K (KW)

$PWEKW_K$ - Total electric equipment load, space K (KW)

QEQ_K - Total equipment load, space K (KW)

$QEQLAT_K$ - Latent equipment load, space K (BTU/HR)

$QIHTS_K$ - Internal surface heat transfer, space K

$RATRG_K$ - Window solar load weighing factor, space K

$RATRIS_K$ - Space lighting load weighing factor, space K

$RATRPS_K$ - Return plenum lighting load weighing factor, space K

$RATRX_K$ - Space sensible load weighing factor, space K

$RMRGC_K$ - Window solar load weighing factor, space K

$RMRG1_K$ - Window solar load weighing factor, space K

$RMRISC_K$ - Space lighting load weighing factor, space K

$RMRIS1_K$ - Space lighting load weighing factor, space K

$RMRPSC_K$ - Return plenum lighting load weighing factor, space K

$RMRPS1_K$ - Return plenum lighting load weighing factor, space K

$RMRXC_K$ - Space sensible load weighing factor, space K

$RMRX1_K$ - Space sensible load weighing factor, space K

$TROOM_K$ - Set point temperature, space K (^oF)

$TSPAC_K$ - Set point temperature, space K (^oR)

VOL_K - Volume, space K (FT^3)

/TLP12B/

ABD_K - Outside absorptivity, delayed surface K

AD_K - Area, delayed surface K (FT^2)

$CINFD_K$ - Infiltration flow coefficient, delayed surface K

$IDD_{K,M}$ - Indices of shading surfaces deleted, count K, delayed surface M

IRF_K - Type of surface index, delayed surface K

ISD_K - Exterior surface roughness index, delayed surface K

NDD_K - Number of shading surfaces deleted, delayed surface K

NVD_K - Number of vertices, delayed surface K

NXD_K - Number of X divisions, delayed surface K

NYD_K - Number of Y divisions, delayed surface K

$QN_{3,K}$ - Response factor variable, delayed surface K

$QR_{3,K}$ - Response factor variable, delayed surface K

$ROGD_K$ - Reflectivity of ground, delayed surface K

$SUMN_{3,K}$ - Response factor variable, delayed surface K

$SUMR_{3,K}$ - Response factor variable, delayed surface K

$TD_{100,K,3}$ - Outside surface temperature history, delayed surface K

WAD_K - Surface azimuth angle, delayed surface K (radians)

WTD_K - Surface tilt angle, delayed surface K (radians)

$XVD_{K,M}$ - Vertices' X coordinates, vertex K, delayed surface K (FT)

$YVD_{K,M}$ - Vertices' Y coordinates, vertex K, delayed surface K (FT)

$ZVD_{K,M}$ - Vertices' Z coordinates, vertex K, delayed surface K (FT)

/TLP12C/

ABQ_K - Outside absorptivity, quick surface K

AQ_K - Area, quick surface K (FT^2)

$CINFQ_K$ - Infiltration flow coefficient, quick surface K

$IDQ_{K,M}$ - Indices of shading surfaces deleted, count K, quick surface M

ISQ_K - Exterior surface roughness index, quick surface K

NDQ_K - Number of shading surfaces deleted, quick surface K

NVQ_K - Number of vertices, quick surface K

NXQ_K - Number of X divisions, quick surface K

NYQ_K - Number of Y divisions, quick surface K

$QPERIM_K$ - Perimeter, quick surface K (FT)

$ROGQ_K$ - Reflectivity of ground, quick surface K

UQ_K - Heat transfer coefficient, quick surface K ($BTU/HR\text{-}FT^2\text{-}^oF$)

WAQ_K - Surface azimuth angle, quick surface K (radians)

WTQ_K - Surface tilt angle, quick surface K (radians)

$XVQ_{K,M}$ - Vertices' X coordinates, vertex K, quick surface M (FT)

$YVQ_{K,M}$ - Vertices' Y coordinates, vertex K, quick surface M (FT)

$ZVQ_{K,M}$ - Vertices' Z coordinates, vertex K, quick surface M (FT)

/TLP12D/

AW_K - Area, window K (FT^2)

$CINFW_K$ - Infiltration flow coefficient, window K

$FFWG_K$ - Form factor between window and ground, window K

$FFWS_K$ - Form factor between window and sky, window K

$IDW_{K,M}$ - Indices of shading surfaces deleted, count K, window M

$IGLASW_K$ - Type of glass, window K

NAW_K - Number of setback shadings added, window K (0 or 3)

NDW_K - Number of shading surfaces deleted, window K

NPW_K - Number of panes of glass, window K

$NVAW_{3,K}$ - Number of vertices for each of 3 setback shadings, window K (0 or 4)

NVW_K - Number of vertices, window K

NXW_K - Number of X divisions, window K

NYW_K - Number of Y divisions, window K

$ROGW_K$ - Reflectivity of ground, window K

$SHACO_K$ - ASHRAE shading coefficient, window K

WAW_K - Surface azimuth angle, window K (radians)

$WPERIM_K$ - Perimeter, window K (FT^2)

WTW_K - Surface tilt angle, window K (radians)

$XAW_{4,3,K}$ - 3 setback shadings' vertices, X coordinates, window K (FT)

$XVW_{K,M}$ - Vertices' X coordinates, vertex K, window M (FT)

$YAW_{4,3,K}$ - 3 setback shadings' vertices, Y coordinates, window K (FT)

$YVW_{K,M}$ - Vertices' Y coordinates, vertex K, Window M (FT)

$ZAW_{4,3,K}$ - 3 setback shadings' vertices, Z coordinates, window K (FT)

$ZVW_{K,M}$ - Vertices' Z coordinates, vertex K, window M (FT)

/TLP12E/

FUF_K - Heat transfer coefficient, underground surface K

$ILOOKD_K$ - Hours of the day for shadow pictorials of delayed surfaces, count K

$ILOOKQ_K$ - Hours of the day for shadow pictorials of quick surfaces, count K

$ILOOKW_K$ - Hours of the day for shadow pictorials of windows, count K

IR_K - Number of response factors for each outside surface type K

$JLOOKD_K$ - Delayed surface indices requesting shadow pictorials, count K

$JLOOKQ_K$ - Quick surface indices requesting shadow pictorials, count K

$JLOOKW_K$ - Window indices requesting shadow pictorials, count K

$MLOOKD_K$ - Months of the year for shadow pictorials of delayed surfaces, count K

$MLOOKQ_K$ - Months of the year for shadow pictorials of quick surfaces, count K

$MLOOKW_K$ - Months of the year for shadow pictorials of windows, count K

$NVSP_K$ - Number of vertices, shading surface K

PSP_K - Transmittance, shading surface K

$RATOS_K$ - Response factor common ratio for each outside surface type K

$RX_{100,K}$ - X response factors for outside surface type K

$RY_{100,K}$ - Y response factors for outside surface type K

$XSP_{K,M}$ - Vertices' X coordinates, count K, shading surface M

$YSP_{K,M}$ - Vertices' Y coordinates, count K, shading surface M

$ZSP_{K,M}$ - Vertices' Z coordinates, count K, shading surface M

/TLPXTR/

$FUTURE_{14}$ - Design day ground temperatures and weather station name

$IDEN1_{35}$ - Facility name

$IDEN2_{35}$ - Facility location

$IDEN3_{35}$ - Engineer's name

$IDEN4_{15}$ - Project number

$IDEN5_{15}$ - Date of run

$IWTH_{11,24}$ - Weather data for 24 hours

$KPRINT_8$ - Print code for hourly space thermal and infiltration loads

$MONTHS_{12}$ - 3-letter name for each month

$NOHIEM_{12}$ - Number of hours in each month

$SCHD_{15,9,24}$ - People, lighting, and equipment schedule codes per hour of day per day of week

$TDBSUM_{24}$ - Hourly summer dry bulb temperatures (^{o}F)

$TGRND_{12}$ - Monthly ground temperatures (^{o}F)

$TWBSUM_{24}$ - Hourly summer wet bulb temperatures (^{o}F)

$TWBWIN_{24}$ - Hourly winter wet bulb temperatures (^{o}F)

NOTES

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

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

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

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

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

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

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

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

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

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

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

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

3.2 THE CONVOLUTION PRINCIPLE

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

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

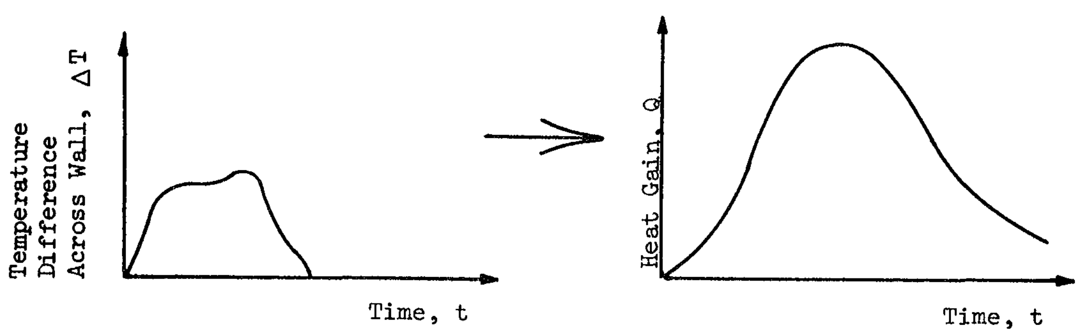


Figure 3.2 DEPENDENCE OF HEAT GAIN SCHEDULE ON TEMPERATURE DIFFERENCE SCHEDULE

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

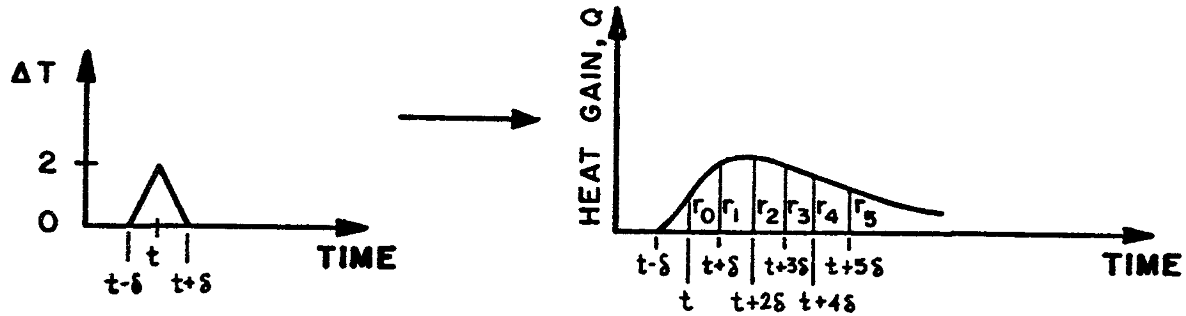
Any arbitrary schedule of ΔT may be squared off to give a schedule of approximate temperature differences, $\Delta T'$, whose values agree with those of ΔT at integral multiples of the time interval, δ. This schedule of approximate temperature differences, $\Delta T'$, may be resolved into a series of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

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

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

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

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



T = OUTSIDE SURFACE TEMPERATURE

T_o = INSIDE AIR TEMPERATURE

$\Delta T = T - T_o$

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

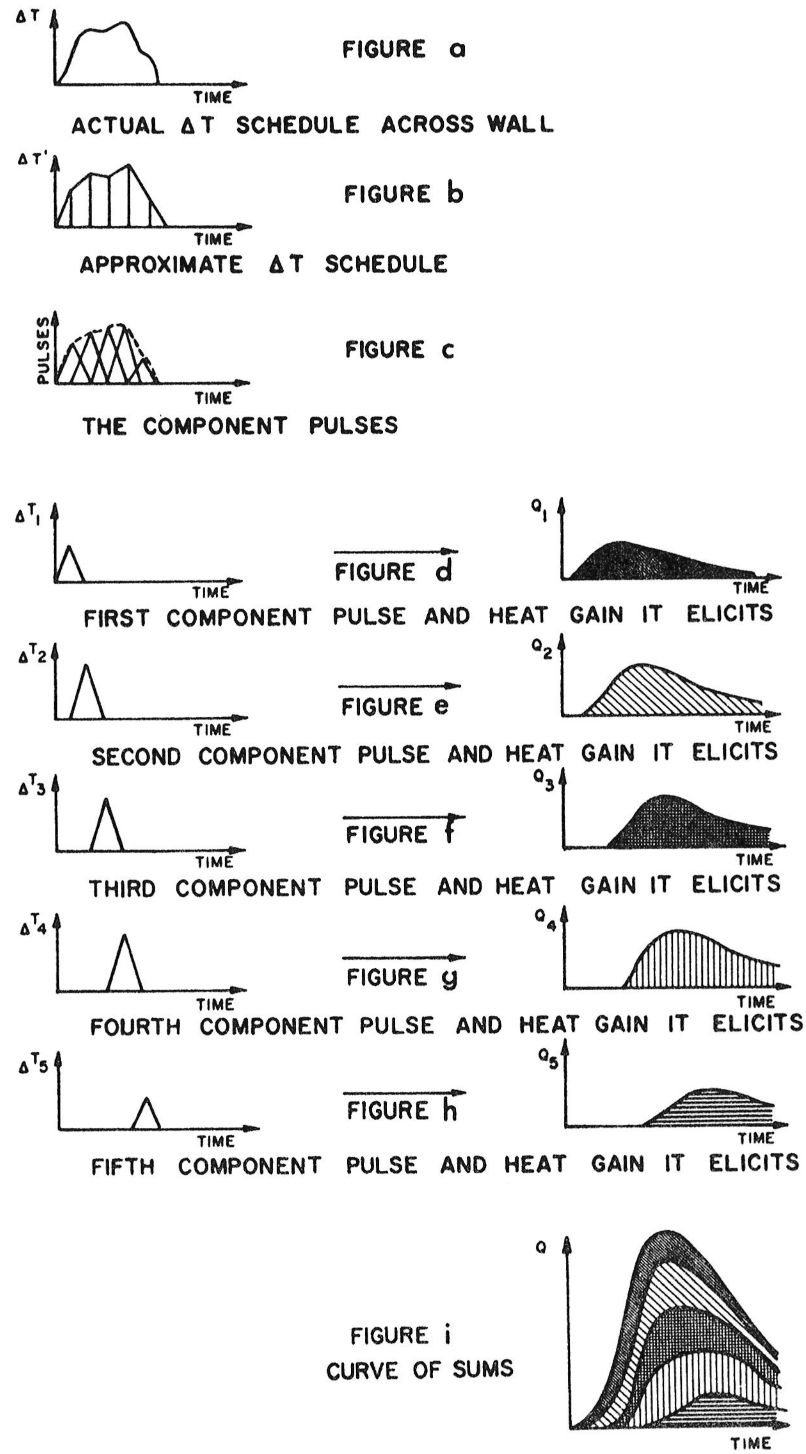


Figure 3.4 THE CONVOLUTION PRINCIPLE

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

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

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

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

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

2. To compute heat gain as already described.

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

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

3.3 MAIN ROUTINES

The THERMAL LOADS ANALYSIS PROGRAM (TLAP) is divided into three segments: TLAP, BUILDING INPUT ROUTINE (INITIAL), and HOURLY ANALYSIS ROUTINE (HLA). The calling sequence of the routines by TLAP are: INITIAL and then HLA. If an hourly analysis and a design analysis are selected in the same run, TLAP will then call HLA once more. The first pass is for the design analysis and the second pass is for the hourly analysis.

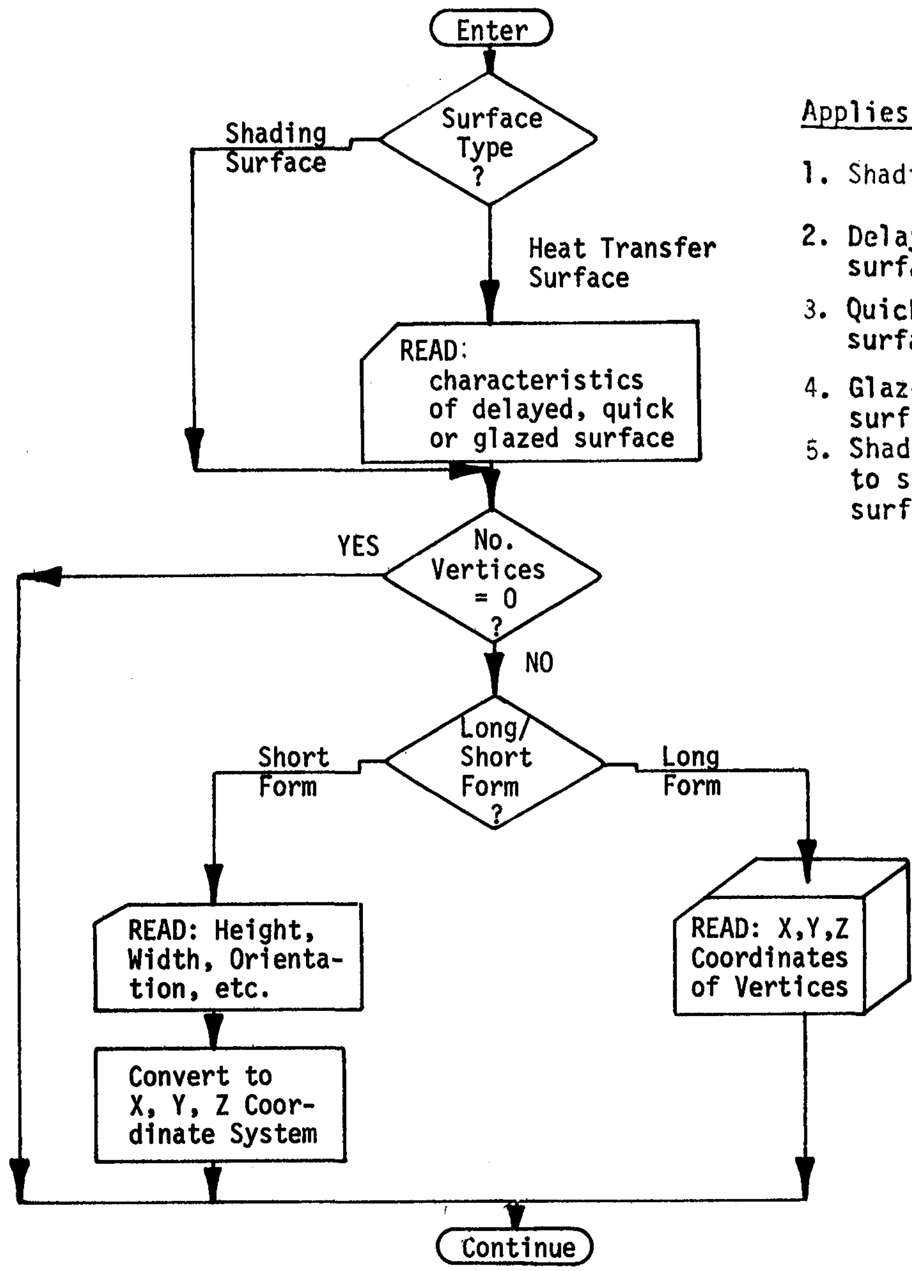
ROUTINE INITIAL

Read: Building Identification
Job Control Data
Design Day Weather from Cards (Cards L1-L4)
Compute Design Day Values
Read: NECAP Weather to Initialize Data
First Day of Weather

Print Title Page (REPRT1)
Echo Initial Portion of Input Data
Convert Farenheit Temperature to Kelvin
Generate Operating Schedules for People, Lights, and Equipment (SCHDUL) (Cards L5 & L6)
Set JSTART with respect to Starting Day
Determine the Day of the Month (DAYMO)
Read: Data of Shading Polygons (Card L7)
Properties of Walls and Roofs (Card L8-L10)
Data of Delayed Heat Transfer Surfaces (Card L11)
Quick Heat Transfer Surfaces (Card L12)
Windows (Card L13)
Read Data For: Shading Polygons Added to Windows
Internal Heat Transfer Surfaces (Card L15)
Underground Surfaces (Card L15)

Read: Ground Temperature (Card L16)
Number of Spaces (Card L17)
Write out schedules, and schedule indices
Calculate heat transfer through internal partitions (Card L18)
Determine design day temperature correction factors (DESDY)

NOTES



Applies to:

1. Shading surfaces
2. Delayed heat transfer surfaces
3. Quick heat transfer surfaces
4. Glazed heat transfer surfaces
5. Shading surfaces added to specific glazed surfaces

Figure 3.5 POLYGON INPUT FLOW DIAGRAM

Calculate Heat Transfer Through Internal Partitions ($QIHTS_i$)

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

where

i - is a subscript referring to the space

$FIHTS_{jj}$ - heat transfer factor (Btu/hr-^{o}F-sq ft)

NIHTS - number of internal partitions, space i

$TSPAC_i$ - setpoint temperature, space i (^{o}F)

$TSPAC_{iadj}$ setpoint temperature of space on other side of partition (^{o}F)

ROUTINE HLA

BEGIN HOURLY CALCULATION

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

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

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

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

$BHMAX = 0$

$BCMAX = 0$

$SSHMAX_i = 0$

$STCMAX_i = 0$

$QCBLDG_{\ell 1} = 0$

$QHBLDG_{\ell 1} = 0$

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

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

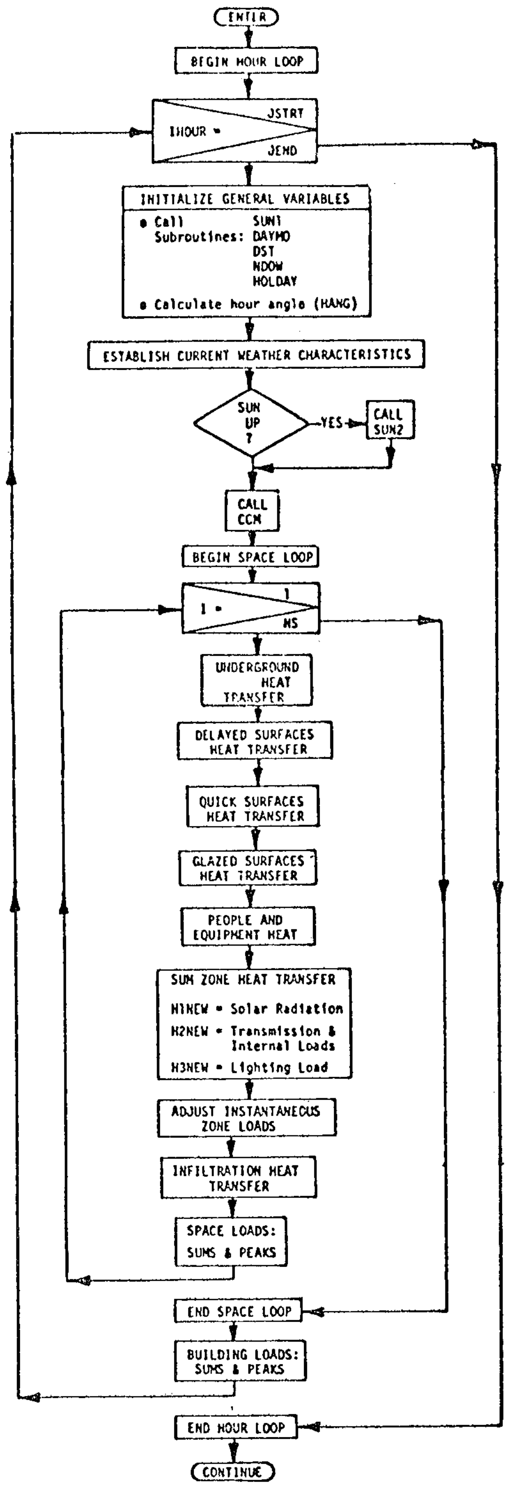


Figure 3.6 THERMAL LOAD ANALYSIS PROGRAM, HOURLY ENERGY ANALYSIS SEGMENT FLOW DIAGRAM

$ICALD_i$ = 0 (delayed surfaces)

$ICALQ_i$ = 0 (quick surfaces)

$ICALW_i$ = 0 (glazed surfaces)

- net hour number

  IHOURP = IHOUR - JSTART + 1

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

  BHEATT = 0

  BCOOLT = 0

  $QCCOMP_{icc}$ = 0

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

- establish time references for this hour

  IDOY - day of year

  ITIME - time of day

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

  1. Call subroutine SUN1 to calculate:

     SUNRAS - hour angle when solar altitude is zero

     DEABC(1) - tangent of declination angle

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

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

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

     DEABC(5) - sky diffuse factor

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

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

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

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

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

- calculate hour angle for current hour (HANG, radians)
- if Design Load Analysis, by-pass day type flag and weather tape call. Define hourly weather from design load weather tables.
- if Energy Consumption Analysis,

  1) Call subroutine SCHED to determine type of schedules for this day.
  2) Read in daily weather and store in IWTH.

- call subroutine PSY to calculate outside air psychrometric conditions:

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

  ENTH - Enthalpy (Btu/lbm-air)

  DENS - Density (lbsm/ft^3)

- if | HANG | $\leq$ | SUNRAS |, sun above horizon

  Call subroutine SUN2 to calculate:

  $RAYCOS_{X,Y,Z}$ - solar angle direction cosines (X,Y,Z)

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

  BS - sky brightness

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

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

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

  RDN = RDN * CC
  BS = BS * CC
  J1 = 0

- if | HANG | > | SUNRAS |, sun below horizon.

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

RDN = 0

BS = 0

BG = 0

J1 = 1

BEGIN SPACE LOAD CALCULATION (repeat for each space)

- calculate ground temperature,

  $TGROND = TGRND_{month} + 460.0$

- underground surface heat transfer

  $QUF_i = \Sigma\ [FUF_{ii} * (TGROND - TSPAC_i)]$ for ii = 1, NUF_i

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

  If | HANG | ≤ | SUNRAS |, sun above horizon.

  Call subroutine SUN3 to calculate:

  GAMMA - cosine of surface tilt angle (Cos(WT))

  ETA - angle of incidence of direct solar ray upon surface

  RDIR - direct solar radiation incident upon surface

  RDIF - diffuse solar radiation incident upon surface

  RTOT - direct + diffuse solar radiation

  BG - ground brightness (Btu/hr-ft^2)

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

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

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

- Calculate solar radiation on delayed surface.

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

  Solar radiation on surface = 0

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

  Call subroutine HD to calculate heat transfer through delayed surfaces.

  Sum heat transfer through delayed surfaces, zone i.

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

  If | HANG | ≤ | SUNRAS |, sun above horizon.

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

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

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

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

  Solar radiation on surface = 0

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

  Call subroutine HQ to calculate heat transfer through quick surfaces.

  Sum heat transfer through quick surfaces, zone i.

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

  If | HANG | ≤ | SUNRAS |, sun above horizon.

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

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

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

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

If | HANG | > | SUNRAS |, SUN BELOW HORIZON.

Solar radiation on surface = 0

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

Call subroutine SHG to calculate heat transfer through glazed surfaces.

Sum heat transfer through glazed surfaces, zone i.

H1NEW = QRAD

where QRAD - sum of instantaneous solar radiation into zone.

- Calculate people loads.

  People, sensible

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

  People, latent

  QPL = 260. - HASL(214.9 - 13.8 * HASL) - (T-460.) * (6.7-HASL * (4.44 - 0.222 * HASL))

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

  T - space temperature (^{o}F)

- Sum thermal loads entering zone at current hour.

  Solar radiation (H1NEW)

TRANSMISSION AND INTERNAL LOADS (H2NEW)

$$H2NEW = SCHD * QE + QQWAL + QDWALL + QUF_I + QIHTS_I + SCHD * QPS * NFOLK_I + QC + QQCEIL + QDCEIL$$

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

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

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

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

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

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

Q_u - sum of quick underground surface heat transfer (Btu/hr)

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

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

$SCHED_{peo}$ - Occupancy part load schedule

NFOLK - Maximum number of people in the space

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

Light heat (H3NEW)

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

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

PLITE - Peak lighting power of the space (KW)

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

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

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

- If energy consumption run, write weather and zone data to output tape and line printer (line printer write optional).
- Call subroutine QMAX to sum zone loads and calculate peak loads and thermal characteristics at peak conditions.

END OF SPACE LOAD CALCULATION.

- Calculate building peak loads and associated thermal conditions.

END HOURLY CALCULATION

- Call output report subroutines
- Rewind input and output tapes of energy consumption analysis.

Reports generated are done by the types of analysis requested. The thermal load analysis program may be operated in three modes as defined by input variable KODE (see input card type L2B).

1. Design load analysis only.
2. Design load analysis and hourly energy analysis.
3. Hourly energy analysis only.

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

If KODE = 1. (design load analysis only), summer design day analyses for the months of March through December are performed. Summer versus winter determined by month.

If CODE = 2, (design load analysis and hourly energy analysis),
let:

KODE = 1,
KODE = 2, } as per KODE = 1 above.
KODE = 3, hourly energy consumption analysis for the period specified.

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

3.4 ALGORITHMS OF SUBROUTINES

APOL

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

INPUT

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

OUTPUT

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

CALCULATION SEQUENCE

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

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

$j = 1$ when $i = n$

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

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

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

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

3. TILT $= \text{Cos}^{-1}$ (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 3.2 for the calculation of AZIM.

TABLE 3.2

EQUATIONS FOR THE CALCULATION OF AZIM

Sign of YCOMP	SIGN OF XCOMP: -	SIGN OF XCOMP: 0 or +
-	$\Pi + \text{Sin}^{-1} (\frac{-\text{XCOMP}}{\text{PROJ}})$	$\frac{\Pi}{2} + \text{Sin}^{-1} (\frac{-\text{YCOMP}}{\text{PROJ}})$
0 or +	$1.5\Pi + \text{Sin}^{-1} (\frac{\text{YCOMP}}{\text{PROJ}})$	$\text{Sin}^{-1} (\frac{\text{XCOMP}}{\text{PROJ}})$

CCM

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

INPUT

AL : Solar altitude angle, radians

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

ICLD : Weather Bureau total cloud amount index

OUTPUT

CC : Cloud Cover Modifier

CALCULATION SEQUENCE

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

TABLE 3.3

CLOUD COVER MODIFIER, CC

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

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

1a. STRATUS CLOUDS, AL $\leq 45^{o}$ (0.707=COS of 45^{o})

CC = 0.598 + CLD * (0.00026 + CLD * (0.00021 - 0.00035 * CLD))

1b. STRATUS CLOUDS, AL > 45^{o}

CC = 0.908 - CLD * (0.03214 - CLD * (0.01020 - 0.00114 * CLD))

2. CIRRUS, CIRROSTRATUS CLOUDS, AL $\leq 45^{o}$

CC = 0.849 - CLD * (0.01277 - CLD * (0.00360 - 0.00059 * CLD))

3. CIRRUS, CIRROSTRATUS CLOUDS, AL > 45^{o}

CC = 1.010 = CLD * (0.01394 - CLD * (0.00553 - 0.00068 * CLD))

Other than cirrus, cirrostratus, and stratus clouds:

3a. AL $\leq 45^{o}$

CC = 0.724 - CLD * (0.00625 - CLD * (0.00191 - 0.00047 * CLD))

3b. AL > 45^{o}

CC = 0.959 - CLD * (0.02304 - CLD * (0.00787 - 0.00091 * CLD))

CENTER

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

INPUT

IDEN : Left-justified title, name, etc.

KODE : processing indicator

KAGIT : print output device

OUTPUT

IDEN : Centered title, name, etc.

CALCULATION SEQUENCE

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

DAYMO

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

INPUT

LEAP : Leap year index = { 0 Non-leap year; 1 Leap year }

IDOY : Day of the year, from start of year

OUTPUT

IDAY : Day of the month

MONTH : Month of the year

CALCULATION SEQUENCE

1. Initialize array NUMDAY (values are the day of the year corresponding to the last day of each month, non-leap year).

2. IFACT = 0
   MONTH = 1

3. If IDOY $\leq$ 31 GO to 8

4. For I = 3, 12
   a. II = I-1
   b. NDAYS = IDOY - NUMDAY (I) - LEAP
   c. If NDAYS $\leq$ 0 Go to 6

5. II = 12

6. MONTH = II

7. If MONTH > 2 IFACT = LEAP

8. IDAY = IDOY - NUMDAY (MONTH) - IFACT

DST

A subroutine which determines if Daylight Saving Time is in effect and returns the proper flag.

INPUT:

MONTH	:	Month of the year
IDAY	:	Day of the month
M	:	Day of the week

OUTPUT:

IDST : Daylight Saving Time indicator = { 0 Standard Time Period; 1 Daylight Saving Time Period }

CALCULATION SEQUENCE

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

3a. If MONTH equal 4, set IDST=0.

3b. If (IDAY-M) is greater than or equal to 23, then reset IDST=1.

4a. If MONTH equals 10, set IDST=1.

4b. If (IDAY-M) is greater than or equal to 24, then reset IDST=0.

DESDY

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

INPUT

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

OUTPUT

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

REFERENCE

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

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

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

CALCULATION SEQUENCE

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

   a) IDD1 - DBT correction factors for 1 AM hour

      IDD2 - DBT correction factors for 2 AM hour

      : : : : : : :

      IDD24- DBT correction factors for 12 midnite.

   b) IDW1 - WBT correction factors for 1 AM hour

      IDW2 - WBT correction factors for 2 AM hour

      : : : : : : :

      IDW24- WBT correction factors for 12 midnite

   c) IMD1 - DBT correction factors for March

      IMD2 - " " " " April

      3 - " " " " May

      4 - " " " " June

      5 - " " " " July

      6 - " " " " August

      7 - " " " " September

      8 - " " " " October

      9 - " " " " November

   d) IMW1 - WBT correction factors for March

      IMW2 - " " " " April

      3 - " " " " May

      4 - " " " " June

      5 - " " " " July

      6 - " " " " August

      7 - " " " " September

      8 - " " " " October

      9 - " " " " November

2. Initialize correction factors

CORM1 = 0.0 Month correction for DBT

CORM2 = 0.0 Month correction for WBT

CORD1 = 0.0 Day correction for DBT

CORD2 = 0.0 Day correction for WBT

3. Calculate Month index

If March, M = 1

If April, M = 2

If May, M = 3

If June, M = 4

If July, M = 5

If August, M = 6

If September, M = 7

If October, M = 8

If November, M = 9

4. Calculate index corresponding to yearly temperature range

RY = TMAX - TMIN

If RY ≤ 50, L = 1

50 < RY ≤ 55, L = 2

55 < RY ≤ 60, L = 3

⋮

RY ≤ 115, L = 15

5. Calculate index corresponding to daily temperature range

RD = TMAX - TMIN

If RD ≤ 10, K = 1

10 < RD ≤ 15, K = 2

⋮

RD ≤ 45, K = 8

6. For months March through November:

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

      CORM2 = ICORM(L,M,2)

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

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

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

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

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

      CORD1 = ICORD(K,15,1)

      CORD2 = ICORD(K,15,2)

      TDNEW = TMAX - CORM1 - CORD1

      TWNEW = TWREF - CORM2 - CORD2

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

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

      CORD1 = ICORD(K,I,1)

      CORD2 = ICORD(K,I,2)

      TDB(I)= TMAX - CORM1 - CORD1

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

      TWB(I) = WBF(H,PATM)

      If (TWB(I)+3) ≤ TDB(I), set

         TWB(I) = TDB(I) - 3

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

   a) Let PI = 3.14

      ALFA = PI/12.0

```
        BETA = 2.0 * ALFA
        GAMA = PI/2.4
        TETA = 2.0 * GAMA
           A = (TMAX-TMIN) * COS(TETA)
           B = 0.5 * (TMAX-TMIN) * COS(GAMA)
           C = COS(GAMA)*SIN(TETA)-2.0*COS(TETA)*
               SIN(GAMA)
```

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

```
        TDB(I) = 0.5 * (TMAX + TMIN) - (A * SIN(ALFA *
                 (I-10)))/L + (B*SIN(BETA*(I-10)))
             H = 0.24 * TDB(J)+(1061. + 0.444 *
                 TDB(I)) * W
        TWB(I) = WBF(H,PATM)
        If (TWB(I)+3) ≤ TDB(I), set
        TWB(I) = TDB(I) - 3
```

FILM

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

INPUT

V : Wind velocity, mph

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

OUTPUT

FO : Outside surface heat transfer coefficient, Btu/hr-sq ft-°F

CALCULATION SEQUENCE

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

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

TABLE 3.4

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

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

HD

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

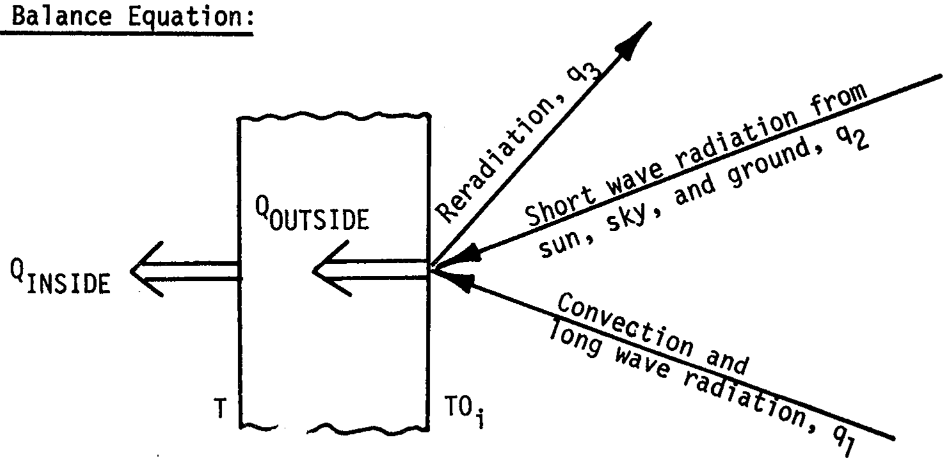
INPUT

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

OUTPUT

Q	:	Space heat gain (+) or loss (-) per unit area of surface, BTU/HR - Sq. ft.
QR	:	For Present Hour; Used to accomplish the recursive summation of the response factors and outside surface Temperature.
QN	:	
SUMN	:	
SUMR	:	

Heat Balance Equation:



re 3.7 CONCEPTS OF HD SUBROUTINE

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

By the use of response factors:

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

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

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

Outside Wall Surface Heat Balance:

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

where

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

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

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

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

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

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

Rearranging equation 7 as:

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

and solving equation 8 for TO_1 gives:

$$TO_1 = - 2. * A * (10. - CC) - X(1) * TM - FO * TDB - AB * SOLI + RATOS * (SUMN - SUMR) + SRNEW + X(IR) * (TOLD - TM / (X(1) + FO) \qquad \text{(EQ. 9)}$$

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

HL

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

INPUT

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

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

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

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

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

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

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

I = 1 equipment
2 quick walls
3 delayed walls
4 underground surfaces
5 not used
6 internal walls
7 people
8 window conduction
9 quick ceilings
10 delayed ceilings

OUTPUT

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

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

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

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

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

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

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

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

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

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

CALCULATION SEQUENCE

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

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

HOLDAY

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

INPUT

MO : Month of the year

JAY : Day of the month

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

OUTPUT

JOL : Holiday Indicator = { 0 Not holiday; 1 Holiday }

CALCULATION SEQUENCE

1. Set JOL equal to 0
2. Set JOL equal to 1 for the following situations:

If MO = 1 and JAY = 1
MO = 12, JAY, = 31, and NDAY = 6
MO = 1, JAY = 2, and NDAY =2
MO = 2, 15 $\leq$ JAY $\leq$ 22, and NDAY = 2
MO = 5, JAY $\geq$ 25 and NDAY = 2
MO = 7, and JAY = 4
MO = 7, JAY = 3, and NDAY = 6
MO = 7, JAY = 5, and NDAY = 2
MO = 9, JAY is less than 7 and NDAY = 2
MO = 12 and JAY = 25
MO = 12, JAY = 24, and NDAY = 6
MO = 12, JAY = 26, and NDAY = 2
MO = 10, 7 < JAY <13, and NDAY = 2
MO = 11, and JAY = 11
MO = 11, JAY = 10 and NDAY = 6
MO = 11, JAY = 12 and NDAY = 2
MO = 11, 22 $\leq$ JAY $\leq$ 28, and NDAY = 5

HQ

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

INPUT

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

OUTPUT

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

CALCULATION SEQUENCE

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

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

where U is the overall heat transfer coefficient.

The heat balance equation of the outside wall surface becomes:

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

Solving this equation for TO_1 gives:

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

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

INPUT1

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

INPUT

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

OUTPUT

XX, YY, ZZ } coordinates of vertices

CALCULATION SEQUENCE

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

2. Short form input for rectangular surface

   a) Read the following card input data:

      XCORN, YCORN, ZCORN } coordinates of lower lefthand vertex, ft

      HT - height, ft

      WD - width, ft

      AZIM - azimuth angle, degrees

      TILT - tilt angle, degrees

   b) Convert azimuth and tilt angles to radians

      AZIM = 0.01745 * AZIM

      TILT = 0.01745 * TILT

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

d) Call RECAP2 to echo data.

e) Reset NV = 4.

3. Long form input for any surface shape

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

b) Call RECAP2 to echo data.

INPUT2

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

INPUT

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

OUTPUT

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

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

CALCULATION SEQUENCE

1. Read input card identifying the following surface factors:

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

2. Convert these factors to integer number.

   NV = FNV + 0.1

   NX = FNX + 0.1

   NY = FNY + 0.1

   ND = FND + 0.1

   NA = FNA + 0.1

   ISR = FISR + 0.1

   IRF = FIRF + 0.1

   and echo data.

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

4. Short form input for rectangular surface

   a) Read the following card input data:

      XCORN, YCORN, ZCORN } coordinates of lower lefthand vertex, ft

      HT - height, ft

      WD - width, ft

AZIM - azimuth angle, degrees

TILT - tilt angle, degrees

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

AREA = HT * WD

AZIM = 0.01745 * AZIM

TILT = 0.01745 * TILT

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

d) Call RECAP2 to echo data.

e) Reset NV = 4.

f) Return

5. Long form input for any surface shape

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

b) Call APOL to return area; this yields height and width.

c) Call RECAP2 to echo data.

d) Return

INF

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

INPUT

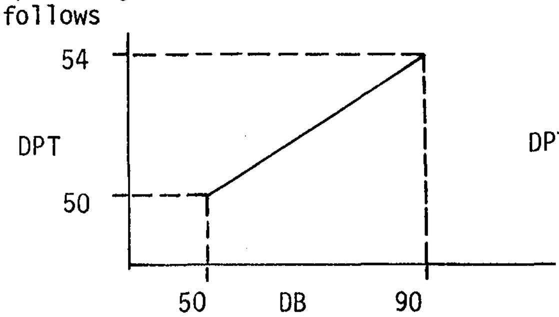
DB	:	Outside air dry-bulb temperature, °F
HUMRA	:	Outside air humidity ratio, lbs water/lb dry air
DEN	:	Outside air density, lbs dry air/cu ft
CFMINF	:	Infiltration rate
TSPA	:	Space temperature, °R

OUTPUT

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

CALCULATION SEQUENCE

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



DPT = dew point temperature of air leaving cooling coil

WRA = SPACE HUMIDITY RATIO

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

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

   WRA = HUMRA

3. QSIN = 14.4 * DEN * CFMINF * (DB + 460.0 - TSPA)

QLIN = 63000.0 * DEN * CFMINF * (HUMRA - WRA)

LEEP

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

INPUT

JAHR : Year AD

OUTPUT

LEEP : Leap year index = { 0 Not leap year; 1 Leap year }

CALCULATION SEQUENCE

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

MATCON

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

INPUT

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

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

See Figure 3.9 for example.

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

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

OUTPUT

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

CALCULATION SEQUENCE

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

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

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

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

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

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

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

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

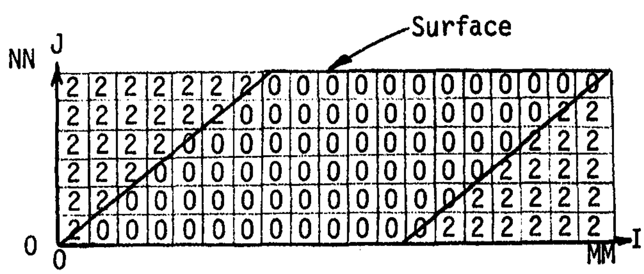


Figure 3.8

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

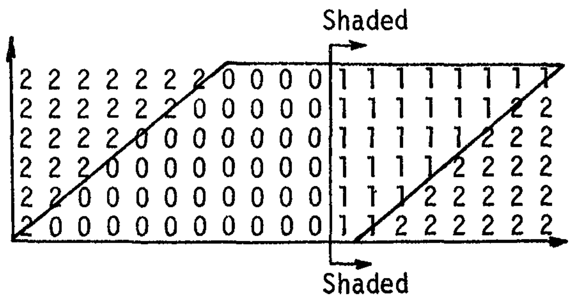


Figure 3.9

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

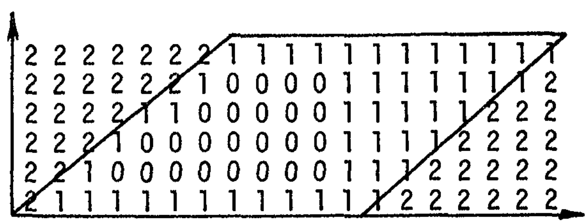


Figure 3.10

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

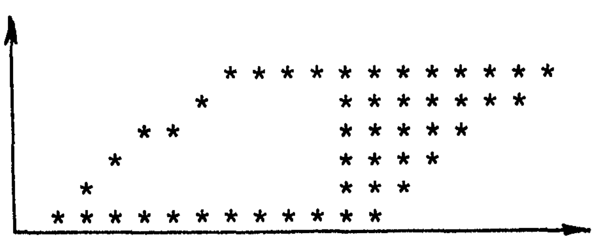


Figure 3.11

Step 4 - Transformed matrix ready for pictorial display

MONFIN

Subroutine MONFIN (in versions of NECAP prior to 4.1) was replaced with a data statement in the main routine. MONFIN would assign an alphabetical variable containing the name of the desired month. NECAP 4.1 uses an array which consists of alpha-numeric characters. The array, called MONTHS, is dimensioned by twelve.

ASSIGNMENT PROCESS

```
WRITE(KAGIT,FMT)MONTHS(MONTH)......
```

Where

KAGIT - OUTPUT UNIT

MONTHS - Alpha-numeric array

MONTH - Integer for month of the year

NDOW

A subroutine which determines the day of the week.

INPUT

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

OUTPUT

NDOW : Week day indicator =
- 1 if Sunday
- 2 if Monday
- 3 if Tuesday
- 4 if Wednesday
- 5 if Thursday
- 6 if Friday
- 7 if Saturday

CALCULATION SEQUENCE

1. Let ITAB (1)=1, ITAB(2)=4, ITAB(3)=4,
   ITAB (4)=0, ITAB(5)=2, ITAB(6)=5,
   ITAB (7)=0, ITAB(8)=3, ITAB(9)=6,
   ITAB(10)=1, ITAB(11)=4, ITAB(12)=6
2. I1 = JR-1900
3. If JR $\geq$ 2000, I1 = JR-2000
4. I2 = (I1/4) + I1 + ITAB(MO) + JAY
5. If LEEP = 1 and MO $\leq$ 2, I2 = I2 - 1
6. If JR $\geq$ 2000, I2 = I2 - 1
7. NDOW = integer part of (I2/7)
8. If NDOW = 0, NDOW = 7

PSY

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

INPUT

DBT	:	Outside air dry-bulb temperature, ^oF
WBT	:	Outside air wet-bulb temperature, ^oF
DPT	:	Outside air dew point temperature, ^oF
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)
```

PPWVMS

A function which calculates partial pressure of water in moisture-saturated air.

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

```
2.  Let A(1) = -7.90298            B(1) = -9.09718
        A(2) =  5.02808            B(2) = -3.56654
        A(3) = -1.3816 E-7         B(3) =  0.876793
        A(4) = 11.344              B(4) =  0.0060273
        A(5) =  8.1328 E-3
        A(6) = -3.49149
```

3. Let T = (TEMP + 460.0)/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) * ( -1)
        P2 = B(2) * Log10 (z)
        P3 = B(3) * (1-1/z)
        P4 = Log 10 (B(4))

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

QMAX

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

INPUT

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

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

SUMC	:	Space lighting load, Btu/hr
HLATP	:	Space latent load due to people, Btu/hr
QSINF	:	Space sensible load due to infiltration, Btu/hr
QLINF	:	Space latent load due to infiltration, Btu/hr
HRLDL	:	Space plenum return air load, Btu/hr
QLEQ	:	Space latent load due to equipment, Btu/hr
MONTH	:	Month number
DBT	:	Ambient dry-bulb temperature, ^{o}F
WBT	:	Ambient wet-bulb temperature, ^{o}F
ISKIP	:	Load summation indicator (0 = No, 1 = Yes)
IPLEN	:	Plenum indicator (0 = No, 1 = Yes)
IWSP	:	Wind Speed

HUMRAT : Ambient air humidity ratio, lb/lb

DENS : Ambient air density, lb/cu ft

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

FLORA : Space floor area, sq ft

TROOM : Space setpoint temperature, °F

MULT : Number of times space is repeated in building

ITIME : Time of day, 1 to 24

IDAY : Day of month

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

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

K = 1 delayed walls
2 window conduction
3 window solar
4 quick walls
5 internal walls
6 not used
7 underground surfaces
8 people sensible
9 people latent
10 lighting
11 equipment sensible
12 infiltration sensible
13 infiltration latent
14 plenum return air
15 equipment latent
16 quick ceilings
17 delayed ceilings

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

OUTPUT

QHCOMP(K) : Same definition as above

QCCOMP(K) : Same definition as above

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

M = 1 delayed walls
2 window conduction
3 window solar
4 quick walls
5 internal walls

7 underground surfaces
8 people sensible
9 people latent
10 lighting
11 equipment sensible
12 infiltration sensible
13 infiltration latent
14 plenum return air
15 equipment latent
16 month
17 ambient dry-bulb temperature
18 ambient wet-bulb temperature
19 ambient humidity ratio
20 hour of day
21 quick ceilings
22 delayed ceilings
23 day of month

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

CALCULATION SEQUENCE

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

2. Heating hour

   a) If ISKIP(I)=0, go to calculation 2d.

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

   BHEATT = BHEATT + (HRLDS + QOA) * MULT(I)

   If IPLEN(I)=0, QOA = 14.4*DENS*CFMSF*FLORA(I)*(DBT - TROOM(I))

   If IPLEN(I)=1, QOA = 0.0

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

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

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

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

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

3. Cooling hour

a) If ISKIP(I)=0, go to calculation 3d.

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

BCOOLT = BCOOLT + (TOTAL + QSOA + QLOA) * MULT(I)

If IPLEN(I)=0, QSOA = 14.4*DENS*CFMSF*FLORA(I)*(DBT - TROOM(I))
QLOA = 63000.*DENS*CFMSF*FLORA(I)*(HUMRAT - 0.0093)

If IPLEN(I)=1, QSOA = 0.0, QLOA = 0.0

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

If QLOA < 0.0 set QLOA = 0.0

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

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

RECTAN

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

INPUT

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

OUTPUT

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

CALCULATION SEQUENCE

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

2. XV(2) = X
XV(3) = X - W * CA
XV(4) = X - W * CA - H * CB * SA
XV(1) = X - H * CB * SA

YV(2) = Y
YV(3) = Y + W * SA
YV(4) = Y + W * SA - H * CB * CA
YV(1) = Y - H * CB * CA

ZV(2) = Z
ZV(3) = Z
ZV(4) = Z + H * SB
ZV(1) = Z + H * SB

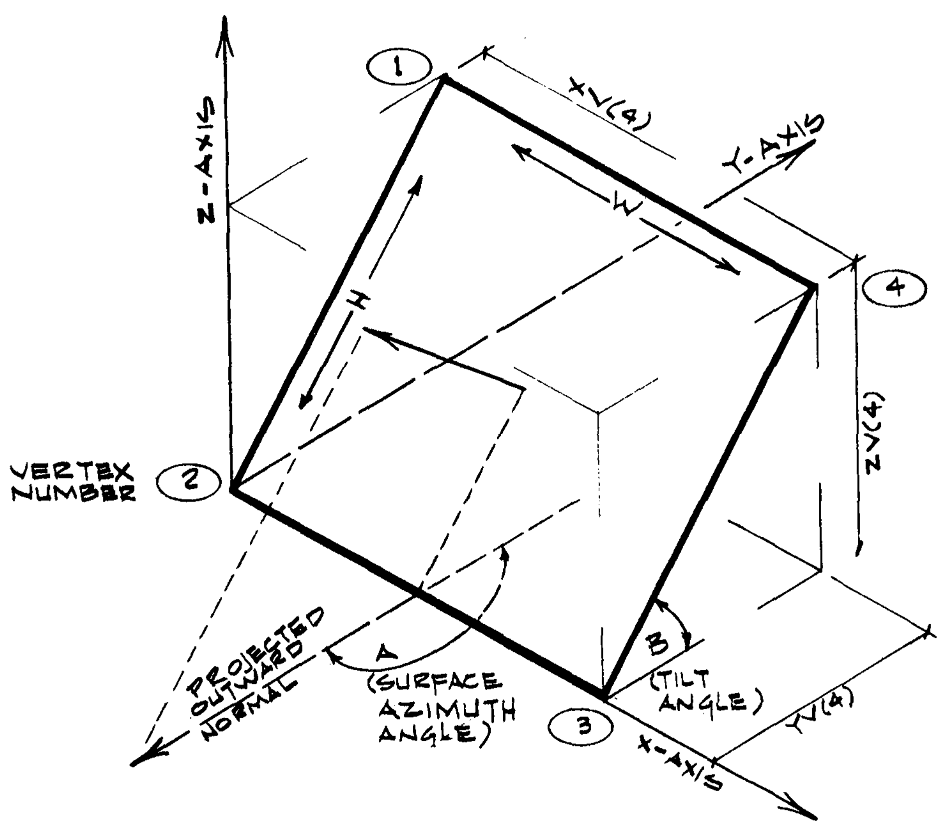


Figure 3.12 DEFINITION OF SURFACE ANGLES AND DIMENSIONS

RECAP1

A subroutine that echos beginning portion of input data, i.e., L1 through L4.

INPUT

STALAT	:	Station latitude, degrees
STALON	:	Station longitude, degrees
TZN	:	Time zone number
CNS	:	Summer clearness number
CNW	:	Winter clearness number
BAZ	:	Building azimuth angle, degrees
LCODE	:	Job processing code
CFMSF	:	Ventilation air rate, cfm/sq ft
FPRES	:	Estimated total fan pressure, inches of water
DTC	:	Cold air supply temperature, ^oF
DTH	:	Hot air supply temperature, ^oF
ALTUD	:	Building altitude, ft.
TDBS	:	Summer maximum DBT, ^oF
RANGS	:	Summer daily range of DBT, ^oF
TDPS	:	Summer dew point temperature, ^oF
WINDS	:	Summer wind speed, mph
TDBW	:	Winter minimum DBT, ^oF
RANGW	:	Winter daily range of DBT, ^oF
TDPW	:	Winter dew point temperature, ^oF
WINDW	:	Winter wind speed, mph
JAHR	:	Weather year
JMONTH	:	Starting month of analysis
MONTHS	:	Array of 3-letter abbreviations of names of the months

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

OUTPUT

A report similar to that shown in Figure 3.13.

RECAP2

A subroutine that echos surface geometric description input data.

INPUT

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

OUTPUT

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

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

     GEOGRAPHICAL DATA:

          LATITUDE  =  37.00   CLEARNESS NUMBER(SUMMER) =  .96  TIME ZONE    =   5.00
          LONGITUDE =  76.00   CLEARNESS NUMBER(WINTER) =  .96  BLDG AZMTH   = 300.00

     PROCESSING PARAMETERS:

          PROCESS CODE = 2     VENT AIR RATE  =    .100  COLD SUPPLY AIR TEMP =  55.0
                               EST. FAN PRES. =   2.000  HOT  SUPPLY AIR TEMP = 120.0

     DESIGN DAY PARAMETERS:

          ALTITUDE =   10.00
          SUMMER: DRY BULB =  95.0 DEW PT = 76.0 TEMP RANGE = 16.0 WIND SP =  8.00
          WINTER: DRY BULB =  16.0 DEW PT = 13.0 TEMP RANGE =  5.0 WIND SP = 12.00

     HOURLY ANALYSIS PARAMETERS:

          SELECTED YEAR  = 1962 LENGTH OF STUDY = 365 DAYS
          STARTING MONTH = JAN  LNGTH OF XMAS SCHD = 0 DAYS
          EST.TEMP =  39.0

     HOURLY PRINT SELECTED FROM   TO   (HOURS)
                                5089  5112

  NO. OF SCHEDULE TYPES         4.00
```

Figure 3.13 SAMPLE OUTPUT FROM RECAP1

```
THERE ARE   10 DELAYED SURFACES

      DELAYED SURFACE NO.  1
           ABSORBTANCE, REFLECTANCE, INF. COEFF. =       .75      .20      0.00
           INDICES =                                    1.00     1.00      1.00     1.00     2.00     1.00
           X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT =      0.00     0.00      0.00     7.27   243.00   180.00    90.00

      DELAYED SURFACE NO.  2
           ABSORBTANCE, REFLECTANCE, INF. COEFF. =       .75      .20      0.00
           INDICES =                                    1.00     1.00      1.00     1.00     2.00     1.00
           X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT =      0.00     0.00      0.00     7.27   243.00     0.00    90.00

      DELAYED SURFACE NO.  3
           ABSORBTANCE, REFLECTANCE, INF. COEFF. =       .75      .20      0.00
           INDICES =                                    1.00    20.00      3.00     0.00     2.00     1.00
           X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT =      0.00   213.00      0.00     7.90   213.00   270.00    90.00

      DELAYED SURFACE NO.  4
           ABSORBTANCE, REFLECTANCE, INF. COEFF. =       .75      .20      0.00
           INDICES =                                   10.00     4.00      4.00     1.00     2.00     1.00
           VERTEX COORDINATES =                       243.00     0.00      0.00
                                                      243.00    10.00      0.00
                                                      243.00     6.50      3.00
                                                      243.00     3.50      3.00
                                                      243.00     3.50      9.90
                                                      243.00     6.50      9.90
                                                      243.00     6.50      3.00
                                                      243.00    10.00      0.00
                                                      243.00    10.00     10.00
                                                      243.00     0.00     10.00

      DELAYED SURFACE NO.  5
           ABSORBTANCE, REFLECTANCE, INF. COEFF. =       .75      .20      0.00
           INDICES =                                    1.00     1.00      1.00     1.00     2.00     3.00
           X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT =      0.00     0.00     10.00     5.00   243.00   180.00    90.00

      DELAYED SURFACE NO.  6
           ABSORBTANCE, REFLECTANCE, INF. COEFF. =       .75      .20      0.00
           INDICES =                                    1.00     1.00      1.00     1.00     2.00     3.00
           X, Y, Z, HEIGHT, WIDTH, AZIMUTH, TILT =      0.00     0.00      0.00     5.00   243.00     0.00    90.00
```

Figure 3.14 SAMPLE OUTPUT FROM RECAP2

CALCULATION SEQUENCE

1. If NV = 1, go to calculation 2; otherwise go to calculation 3.
2. Echo input data for rectangular surface.
   a) Convert azimuth and tilt angle to degrees.

      AA = AZIM/0.01745

      BB = TILT/0.01745

   b) Print XCORN, YCORN, ZCORN, HT, WD, AA, and BB.
3. Echo input data for surface.
   a) Print column label.
   b) For each of NV surface vertices, print X, Y and Z coordinate.

REPRT1

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

INPUT

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

OUTPUT

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

```
**********************************************************************************
*                                                                                *
*                                                                                *
*                                                                                *
*                          DESIGN LOAD ANALYSIS FOR                              *
*                                                                                *
*                                                                                *
*                     SYSTEMS ENGINEERING BUILDING,LARC                          *
*                                                                                *
*                                                                                *
*                                BUILDING                                        *
*                                                                                *
*                                                                                *
*                               HAMPTON,VA.                                      *
*                                                                                *
*                                                                                *
*  ENGINEER     - R.N. JENSEN                                                    *
*  PROJECT NO.  - SEB BASE-LONG                                                  *
*  DATE         - DEC 15,1981                                                    *
*                                                                                *
*                                                                                *
**********************************************************************************
```

Figure 3.15 SAMPLE OUTPUT

```
*****************************************************************************
*                                                                           *
*                                                                           *
*                                                                           *
*                     ANALYSIS OF ENERGY UTILIZATION OF                     *
*                                                                           *
*                     SYSTEMS ENGINEERING BUILDING,LARC                     *
*                                                                           *
*                                                                           *
*                                 BUILDING                                  *
*                                                                           *
*                                                                           *
*                                HAMPTON,VA.                                *
*                                                                           *
*                                                                           *
*  ENGINEER    - R.N. JENSEN                                                *
*  PROJECT NO  - SEB BASE-LONG                                              *
*  DATE        - DEC 15,1981                                                *
*                                                                           *
*                                                                           *
*****************************************************************************
```

Figure 3.16 SAMPLE OUTPUT

CALCULATION SEQUENCE

1. Print upper part of border.

2. Print first line of report.

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

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

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

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

5. Print IDEN3, IDEN4 and IDEN5.

6. Print lower part of border.

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

REPRT2

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

INPUT

JSTAT	:	Weather station number
JAHR	:	Year when analysis is to start
LENGTH	:	Length of analysis in days
KAGIT	:	Logical unit number for line printer
FUTURE	:	Weather station name
IWTH	:	Weather tape data
MONTHS	:	Array of 3-letter abbreviations for the names of the months

OUTPUT

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

REPRT3

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

INPUT

KAGIT : Logical unit number of line printer.

OUTPUT

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

REPRT5

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

INPUT

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

```
*****************************************************************************
*                                                                           *
*                                                                           *
*                              IN THIS RUN                                  *
*                                                                           *
*                                                                           *
* - U. S. WEATHER BUREAU DATA FOR: LANGLEY AFB  VA      STATION #13702 IS USED *
*                                                                           *
*                                                                           *
* - THIS STUDY STARTS ON THE FIRST HOUR OF JAN  1, 1962.                    *
*                                                                           *
*                                                                           *
* - THE LENGTH OF THIS STUDY IS 365 DAYS.                                   *
*                                                                           *
*                                                                           *
* - THE CONDITIONS AT THE START OF THE STUDY ARE:                           *
*                                                                           *
*    DRY BULB =  39          WIND SPEED =   4          PRESSURE = 3021      *
*    WET BULB =  34          WIND DIR.  = 203          CLOUD TYP=    8      *
*    DEW POINT=  26                                    CLOUD AMT=    2      *
*                                                                           *
*                                                                           *
*****************************************************************************
```

Figure 3.17 SAMPLE OUTPUT

```
*****************************************************************************
*                                                                           *
*                                                                           *
*                        IN THE FOLLOWING PAGES                             *
*                                                                           *
*                                                                           *
*              THE FIRST LINE OF EACH PRINTED BLOCKS GIVES                  *
*                                                                           *
*   TIME              - HOURS, STANDARD TIME FROM FIRST HOUR OF JANUARY     *
*   SUN INDEX         - IF EQUAL TO ONE SUN IS DOWN, IF EQUAL TO ZERO SUN IS UP *
*   DRY-BULB TEMP.    - DEGREES FAHRENHEIT                                  *
*   WET-BULB TEMP.    - DEGREES FAHRENHEIT                                  *
*   WIND VELOCITY     - KNOTS                                               *
*   HUMIDITY RATIO    - LBS WATER PER LB DRY-AIR                            *
*   PRESSURE          - INCHES OF MERCURY                                   *
*   ENTHALPY          - BTU PER LB DRY-AIR                                  *
*   DENSITY           - LBS DRY-AIR PER CUBIC FOOT                          *
*   CLOUD COVER MODIFIER - FRACTION OF TOTAL SOLAR RADIATION INCIDENT       *
*                          UPON A HORIZONTAL SURFACE                        *
*                                                                           *
*           THE FOLLOWING LINES OF EACH PRINTED BLOCKS GIVES                *
*                                                                           *
*   SPACE NUMBER                                                            *
*   NUMBER OF IDENTICAL SPACES IN BUILDING                                  *
*   SPACE SENSIBLE LOAD - BTU PER HOUR                                      *
*   SPACE LATENT LOAD   - BTU PER HOUR                                      *
*   PLENUM RETURN AIR LIGHTING LOAD     - BTU PER HOUR                      *
*   SPACE LIGHTING AND EQUIPMENT POWER - KILOWATTS                          *
*                                                                           *
*                                                                           *
*****************************************************************************
*         NOTE - THE LOADS EXCLUDES OUTSIDE VENTILATION AIR LOADS           *
*****************************************************************************
```

Figure 3.18 SAMPLE OUTPUT

OUTPUT

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

CALCULATION SEQUENCE

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

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

   TMIN = TDBS - RANGS

3. For months March through November:

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

   b) Print TDB and TWB.

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

   TMAX = TDBW + RANGW

5. For month of December:

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

   b. Print TDB and TWB.

REPRT6

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

INPUT

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

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

SUMMER DAY INPUT PARAMETERS

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

WINTER DAY INPUT PARAMETERS

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

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

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

Figure 3.19 SAMPLE OUTPUT

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

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

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

CFMSF	:	Ventilation air rate, cfm/sq ft
DTC	:	Cold deck temperature
FPRES	:	Estimated total fan pressure, inches of water
DTH	:	Hot deck temperature
MULT	:	Space repetition factor
KODE	:	Processing indicator
ISKIP	:	Load summation indicator (0=No, 1=Yes)
IPLEN	:	Plenum indicator (0=No, 1=Yes)

OUTPUT

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

CALCULATION SEQUENCE

1. For each space, N, print following:

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

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

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

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

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

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

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

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

      CFM1 = TOT1/(14.4*DENS*(TSPAC(N) - DTC(1))
      CFM2 = TOT1/(14.4*DENS*(TSPAC(N) - DTC(2))

   where TOT1 is total summer sensible load.

HOURLY LOAD ANALYSIS RESULTS FOR SYSTEMS ENGINEERING BUILDING,LARC HAMPTON,VA. PAGE 1

SPACE NO. 1

SPACE REPETITION FACTOR 1

AREA (SQ.FT.) 3200.

VOLUME (CU.FT.) 32000.

SUMMER COOLING PEAK: JULY 16 AT HOUR 16
DBT= 79 WBT= 76 WND SP= 10

WINTER HEATING PEAK: JAN. 19 AT HOUR 2
DBT= 35 WBT= 33 WND SP= 10

	***** SUMMER LOAD *****		WINTER
	SENSIBLE (BTUH)	LATENT (BTUH)	LOAD (BTUH)
WALLS	3326.	0.	-5509.
CEILINGS	0.	0.	0.
WINDOW CONDUCTANCE	4645.	0.	-26301.
WINDOW SOLAR	18361.	0.	3486.
QUICK SURFACES	0.	0.	0.
INTERNAL SURFACES	0.	0.	0.
UNDERGROUND SURFACES	900.	0.	-8100.
OCCUPANTS	6304.	3697.	771.
LIGHT TO SPACE	19072.	0.	3427.
EQUIPMENT TO SPACE	3702.	0.	453.
INFILTRATION	11100.	71599.	-66566.
	---------	---------	---------
TOTAL	67411.	75296.	-98339.

TOTAL SPACE COOLING 142707. BTUH
TOTAL SPACE HEATING -98339. BTUH

SUPPLY AIR AT 55 F AT DIFFUSER 3920. CFM 1.23 CFM/SQ.FT.
SUPPLY AIR AT 120 F AT DIFFUSER 1690. CFM .53 CFM/SQ.FT.

Figure 3.20 SAMPLE OUTPUT

```
BUILDING LOAD SUMMARY FOR                                                          PAGE  13
          SYSTEMS ENGINEERING BUILDING,LARC
          HAMPTON,VA.

          SPACE NOS.                                  1  THRU  12

          TOTAL FLOOR AREA (SQ.FT.)                       52800.

          TOTAL VOLUME (CU.FT.)                          528000.

           SUMMER COOLING PEAK:    AUG. 20   AT HOUR 18
                                     DBT= 89   WBT= 79   WND SP= 12

           WINTER HEATING PEAK:    DEC. 31   AT HOUR  7
                                     DBT= 15   WBT= 12   WND SP= 14

                                     ***** SUMMER LOAD *****              WINTER
                                      SENSIBLE        LATENT                LOAD
                                       (BTUH)         (BTUH)               (BTUH)
               WALLS                   33493.            0.              -91356.
               CEILINGS               151127.            0.             -310884.
               WINDOW CONDUCTANCE      41736.            0.             -152520.
               WINDOW SOLAR            57815.            0.                3712.
               QUICK SURFACES              0.            0.                   0.
               INTERNAL SURFACES           0.            0.                   0.
               UNDERGROUND SURFACES    15540.            0.              -43560.
               OCCUPANTS               78531.        44360.                   5.
               LIGHT TO SPACE         295949.            0.                  27.
               EQUIPMENT TO SPACE      78791.            0.               17069.
               INFILTRATION            66133.       175971.             -284218.
                                     ---------     ---------            ---------
               SUBTOTAL               819415.       220330.             -851726.
               RETURN AIR             123130.            0.                   8.
               FAN HEAT                48815.            0.               48815.
               VENTILATION AIR         90798.       233772.             -364801.
                                     ---------     ---------            ---------
               TOTAL                 1082159.       454102.            -1177704.

          TOTAL BUILDING COOLING      1536261. BTUH          128.0 TONS
          TOTAL BUILDING HEATING     -1177704. BTUH        -1177.7 MBH

                                          *******  VARIABLE VOLUME SYSTEM *******          *******  CONSTANT VOLUME SYSTEM *******
          SUPPLY AIR AT  55 F AT DIFFUSER      47650. CFM      .90 CFM/SQ.FT. MAX.           60806. CFM     1.15 CFM/SQ.FT. CONST.
          SUPPLY AIR AT 120 F AT DIFFUSER      14811. CFM      .28 CFM/SQ.FT. MAX.           19051. CFM      .36 CFM/SQ.FT. CONST.
```

Figure 3.21 SAMPLE OUTPUT

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

SPACE NO.	HEATING EXTRACTION RATE (BTU/HR)	COOLING EXTRACTION RATE (BTU/HR)
1	-98339.	67411.
2	-48439.	47470.
3	-241693.	49553.
4	-161024.	89387.
5	-154910.	338887.
6	-35230.	29490.
7	-33438.	26016.
8	-35366.	25494.
9	-33122.	26009.
10	-254478.	302932.
11	-62546.	57079.
12	-12403.	43003.

Figure 3.22 SAMPLE OUTPUT

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

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

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

where TOT3 is total winter sensible load.

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

SQFT1 = CFM1/AREA(N)

SQFT2 = CFM2/AREA(N)

SQFT3 = CFM3/AREA(N)

SQFT4 = CFM4/AREA(N)

2. Calculate following summations for building.

a) Total floor area

If ISKIP(N)=0 or IPLEN(N)=1, skip to calculation 2d.

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

b) Total volume

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

c) Weighted space temperature summation

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

d) Total cooling cfm at both temperature conditions

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

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

e) Total heating cfm at both temperature conditions

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

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

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

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

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

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

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

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

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

g) Fan heat load

QFAN = 0.4014 * TCFM1 * FPRES

h) Ventilation air load for summer peak cooling hour

QSOAS = 14.4 * DENS * CFMSF * TAREA

* (T1(17) - TAVGB)

where TAVGB = AXT/TAREA

QLOA = 63000. * DENS * CFMSF * TAREA

* (T1(19) - 0.0093)

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

i) Ventilation air load for winter peak heating hour

QSOAW = 14.4 * DENW * CFMSF * TAREA

* (T2(17) - TAVGB)

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

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

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

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

- Cooling

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

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

  TSQFT5 = TCFM5/TAREA

  TSQFT6 = TCFM6/TAREA

- Heating

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

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

  TSQFT7 = TCFM7/TAREA

  TSQFT8 = TCFM8/TAREA

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

- Cooling

  TCFM1 = see 2d.

  TCFM2 = see 2d.

  TSQFT1 = TCFM1/TAREA

  TSQFT2 = TCFM2/TAREA

- Heating

  TCFM3 = see 2e.

  TCFM4 = see 2e.

  TSQFT3 = TCFM3/TAREA

  TSQFT4 = TCFM4/TAREA

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

RMRSS

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

INPUT

IL : Type of lighting fixture (see Figure 3.23)

= 1 Fluorescent fixture recessed into suspended ceiling, ceiling plenum not vented.

= 2 Fluorescent fixture recessed into suspended ceiling, return air through ceiling plenum.

= 3 Fluorescent fixture recessed into suspended ceiling, supply and return through ceiling plenum.

= 4 Incandescent lights exposed in the room air.

W : Weight of floor, lbs/sq ft

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

OUTPUT

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

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

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

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

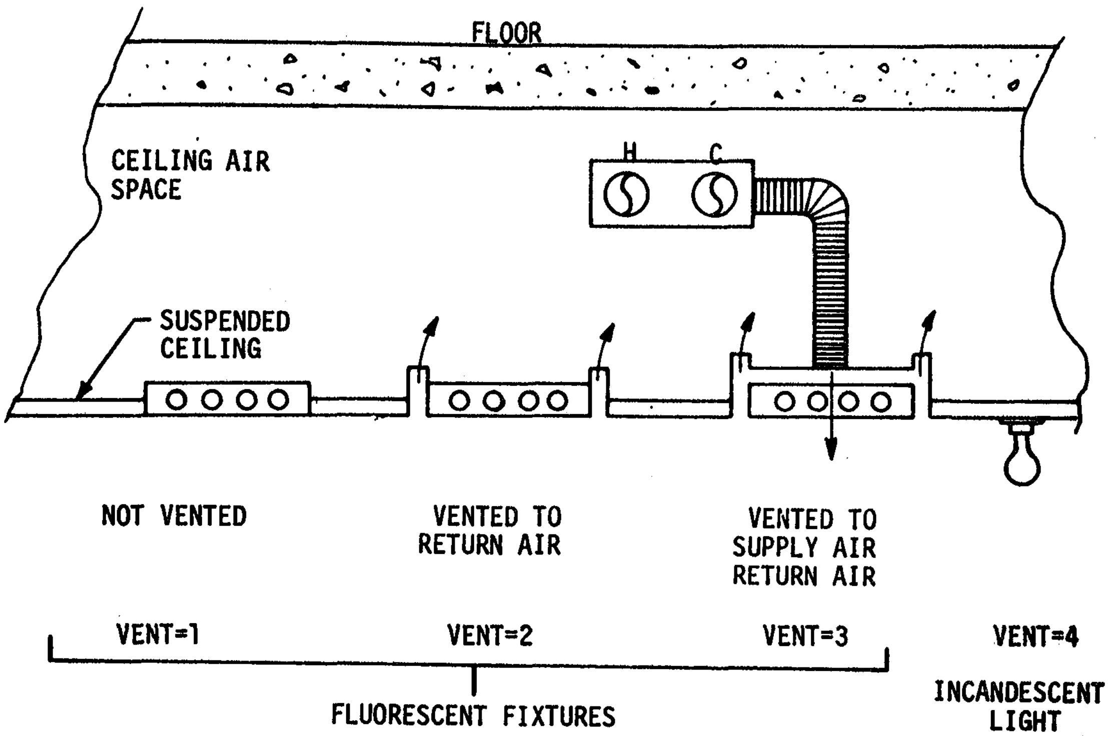


Figure 3.23 TYPES OF LIGHT FIXTURES

CALCULATION SEQUENCE

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

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

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

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

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

Table 3.5

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

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

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

Table 3.6

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

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

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

   RMRIS1 = RMRSI(IW,IL,1)

   RMRISC = RMRSI(IW,IL,2)

5. Set weighting factors for remainder of light heat which is assumed added to plenum space above. Obtain values of RMRIS1, RMRISC and RATRIS from Table 3.7 and then perform following:

   RMRPS1 = RMRSI(IW,IL,1)

   RMRPSC = RMRSI(IW,IL,2)

   RATRPS = RMRSI(IW,IL,3)

Table 3.7

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

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

SCHDUL

A subroutine for reading and generating operating schedules to be used for scheduling of people, lights and equipment.

INPUT

NUMT	:	Number of schedules to be input
KARD	:	Logical unit number for card input
KAGIT	:	Logical unit number for line printer
KKMAX	:	Number of daily schedules which are defined, set equal to 10 initially (standard schedules)
INEW	:	Processing flag (Version 4.0 and later=1, all else=0.

OUTPUT

SCHD(I,J,K,) : Fraction of full load (0.0 to 1.0), where

I = 1 to 15, schedule number

J = 1 to 9, type of day (Sunday through Saturday, Holiday and Special)

K = 1 to 24, Hour of day

CALCULATION SEQUENCE

1. Read from input data for each schedule from 1 to NUMT the values of FISCH(J,K).

2. Fill in matrix SCHD(I,J,K) for standard and non-standard schedules:

   a) For each type of day, if FISCH ≤ 10, standard schedule (Figure 3.24) is desired; therefore enter standard 24 hour schedule into matrix.

   b) For each type of day, if FISCH > 10, a user defined schedule is desired; therefore, read in all non-standard schedules and enter it into matrix.

3. Echo schedules.

SCHED

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

INPUT

IDST	:	Daylight Saving Time indicator = {0 Standard Time; 1 Daylight Saving Time}
ITIME	:	Hour of day, 1 to 24
IDOW	:	Day of week, 1 to 7
IFEAST	:	Holiday indicator = {0 No Holiday; 1 Holiday}
JC	:	Christmas period indicator = {0 non Christmas period; 1 Christmas period}

OUTPUT

J	:	Type of day, 1 to 9
K	:	Corrected time, 1 to 24

CALCULATION SEQUENCE

1. K = ITIME

2. J = 8

3. If IFEAST =0 ,J = IDOW

4. If JC =1,J = 9

5. If IDST = 1 then
   a. K = ITIME - 1
   b. If ITIME = 1,K = 24

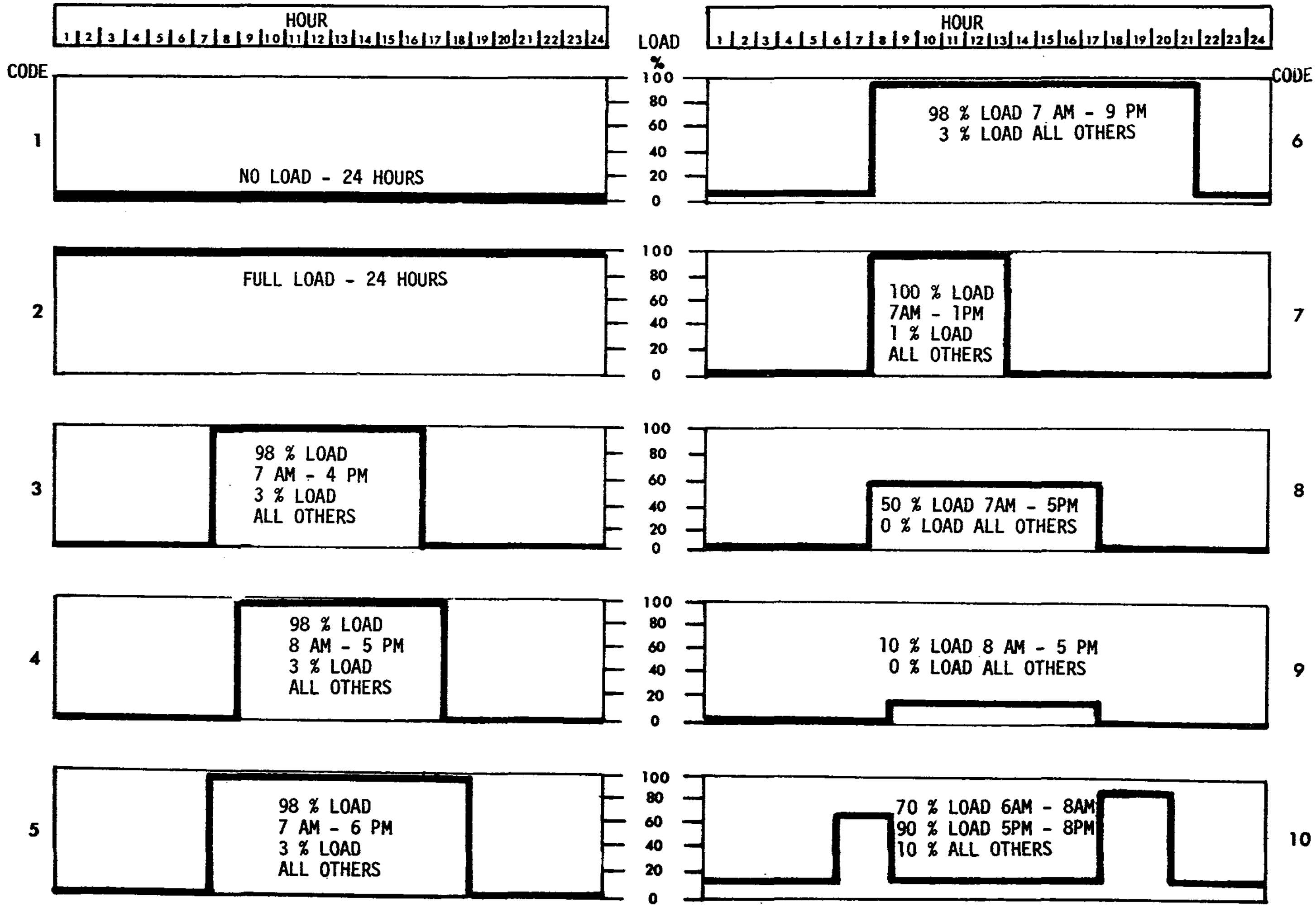


Figure 3.24 STANDARD CODED SCHEDULES

SEARCH

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

INPUT

N	:	Number of pictorial outputs desired
NA	:	Month for which pictorial outputs are desired
NB	:	Hour for which pictorial outputs are desired
NC	:	Surface index for which pictorial outputs are desired
IA	:	Present month number
IB	:	Present hour number
IC	:	Present surface index number
J	:	Pictorial output indicator 0 = no, 1 = yes

CALCULATION SEQUENCE

For I = 1 to N

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

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

SETBAK

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

INPUT

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

OUTPUT

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

CALCULATION SEQUENCE

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

2. VERTEX 1 of the first shading surface

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

   VERTEX 2 of the first shading surface

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

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

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

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

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

--and so on - -

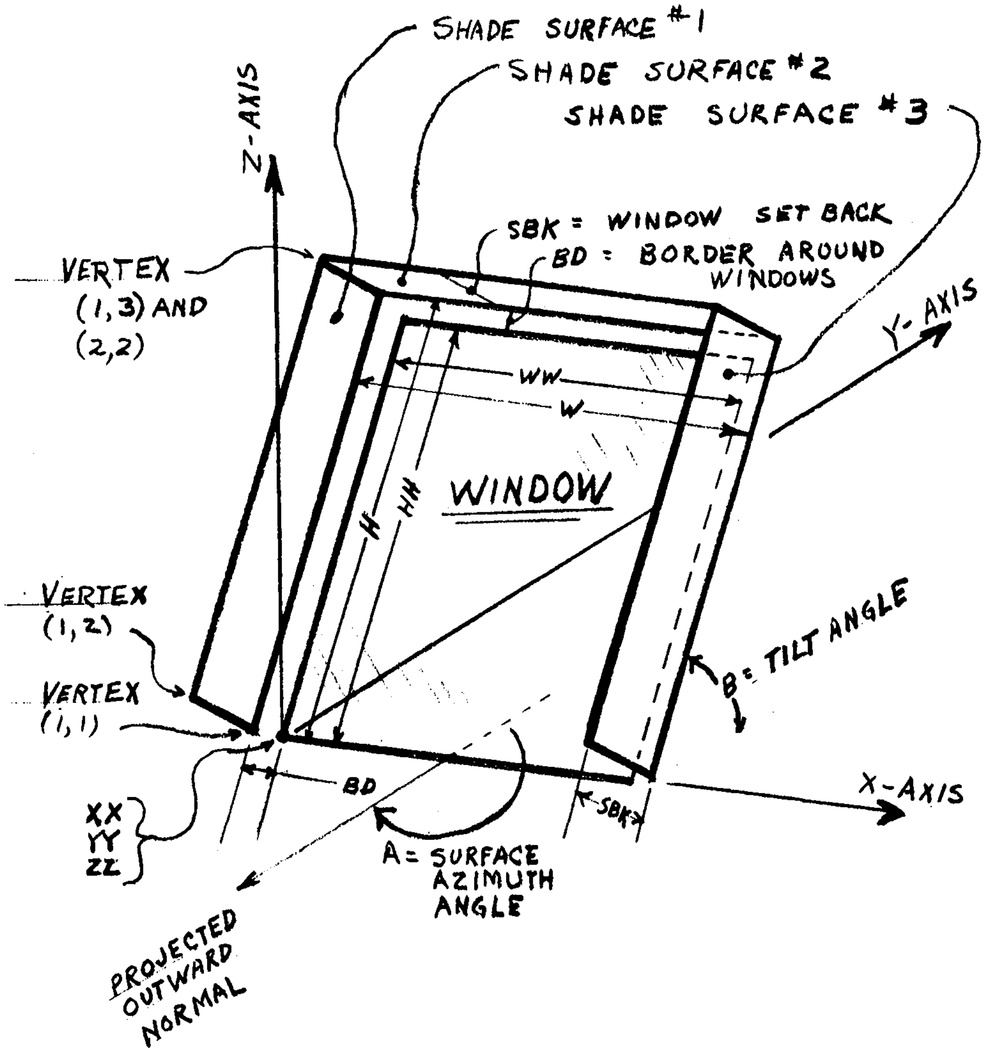


FIGURE 3.24A
DEFINITION OF SURFACE DIMENSIONS

SHADOW

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

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

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

INPUT

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

NPOLYD	:	Number of shading Polygons deleted
IDLETE	:	Index number of deleted Polygons
NPOLYA	:	Number of added Polygons
NVERTA	:	Number of vertices of added Polygons
PERMA	:	Permeability of added S.P.'s
XVERTA	:	x-coordinates of added Polygons
YVERTA	:	y - coordinates of added Polygons
ZVERTA	:	z-coordinates of added Polygons
RAYCOS	:	Direction cosines of solar ray
ARECI	:	Area of receiving Polygon
LOOK	:	Picture? { 0 = No picture 1 = Picture

OUTPUT

ASHADE	:	Shaded area of receiving Polygon

CALCULATION SEQUENCE

1. Coordinate Transformation

Designate the polygons which cast shadows as shading polygons (S.P.) and those upon which shadows are cast as receiving polygons (R.P.). The vertex coordinates of each R.P., and its relevant SP's are transformed from a base coordinate system, xyz, to a new coordinate system, x'y'z', with origin 0 attached to the plane of the R.P. The first three vertices V_1, V_2, V_3, of the R.P. being examined are used to define this new coordinate system. The x' axis passes through V_2 and V_3, while the y' axis passes through V_1. In order that the z' axis point outward from the surface, angle $V_1V_2V_3$ must be convex and the vertices must be numbered counterclockwise. The equation of transformation is written in matrix form as

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

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

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

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

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

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

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

$$x_s' = \begin{pmatrix} \sin\beta \cdot \cos\alpha \\ \sin\alpha \\ \cos\beta \quad \cos\alpha \end{pmatrix}$$

2. Clipping Transformation

Any part of an S.P. whose z' is negative cannot cast a shadow on the R.P. These "submerged" portions of the S.P.'s must be clipped off, prior to projection, lest they project "false" shadows (see Figure 3.25). This is done by finding, through linear interpolation, the points A and B, on the perimeter of the S.P. which pierce the plane of the R.P., and taking these points as new vertices. All submerged vertices are deleted. This results in a new polygon with line AB as a side, which will project only real shadows.

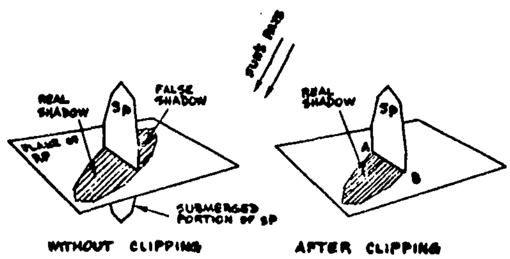


Figure 3.25 CLIPPING

3. Projection Transformation

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

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

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

4. Enclosure Test

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

R.P. plane. It remains only to find the points in the R.P. plane which lie inside the R.P. and inside one or more of the S.P. projections, i.e., points of the R.P. which are shaded. At this point, the two-space XY is divided into grid and the center of each element of this grid is tested for enclosure by the R.P. and the S.P. projections. A point, P, whose coordinates are $X_P Y_P$, is inside the polygon $V_1, V_2, \ldots V_n$ if the following inequality holds.

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

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

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

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

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

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

5. Display Matrix and Typical Problem

An alphameric matrix is created corresponding to the grid elements in the R.P. plane. A blank component represents a grid element either outside the R.P. or exposed on the sun. An asterisk component represents a shaded grid element or one on the R.P.'s boundary. Grid elements shaded by a transmissive structure are randomly asterisked with a probability equal to the fraction of incident light stopped by the shading structure. Figure 3.26 shows the solution of a typical problem involving a transmissive structure. Also see Figures 3.8 to 3.11.

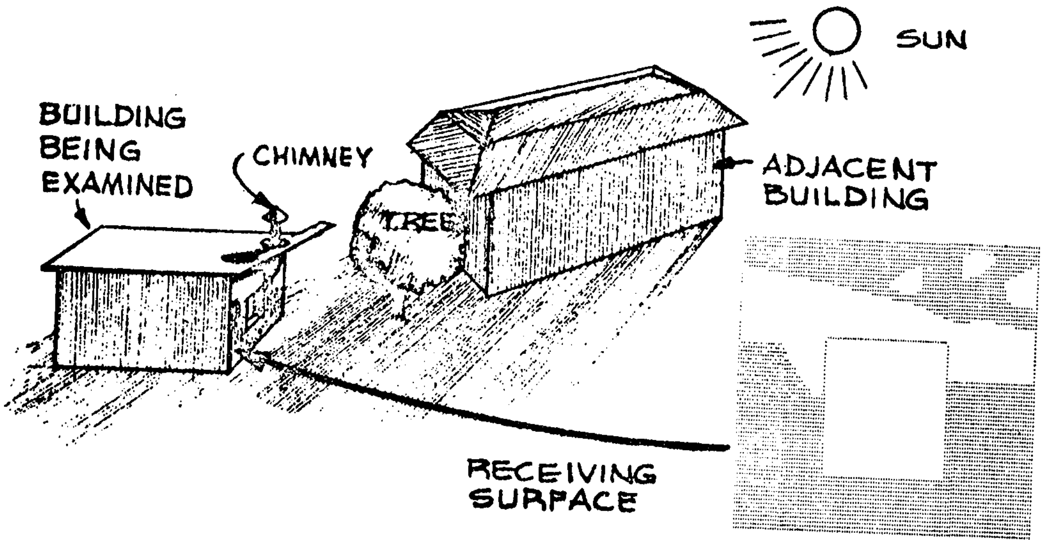


Figure 3.26 THE COMPUTER OUTPUT OF A TYPICAL PROBLEM

SHG

A subroutine which calculates solar heat gain through windows.

INPUT

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

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

SHAW : Sunlit area factor

SC : Shading coefficient if the window is shaded by drapes or blinds or if it has an interpane separation of more than 1 inch

TDIR :
TDIF : } Transmission factors of direct and diffuse radiation

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

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

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

T : Space temperature, °R

TDB : Ambient outside air temperature, °R

<u>OUTPUT</u>

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

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

<u>CALCULATION SEQUENCE</u>

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

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

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

2. Calculate components of solar load

   a) Direct

$$QDIR = SHAW * RDIR$$

b) Diffuse

QDIF = BS * FWS + BG * FWG

c) Transmitted

QTRANS = QDIR * TDIR + QDIF * TDIF

d) Absorbed

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

3. Calculate solar heat gain through glass

If SC = 0, QRAY = QTRANS + QABS

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

4. Calculate heat conduction through glass

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

STNDRD

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

INPUT

I	:	Index of surface being processed (references ISTD)
ISTD	:	Standard surface number, 1 to 16

OUTPUT

R1	:	Common ratio
NRFT	:	Number of response factor terms
RFX	:	X-Response factor set, Btu/hr-sq ft-°F
RFY	:	Y-Response factor set, Btu/hr-sq ft-°F
RFZ	:	Z-Response factor set, Btu/hr-sq ft-°F

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

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

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

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

Figure 3.27 WALL TYPE 1

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

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

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

Figure 3.28 WALL TYPE 2

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

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

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

Figure 3.29 WALL TYPE 3

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

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

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

Figure 3.30 WALL TYPE 4

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

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

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

Figure 3.31 WALL TYPE 5

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

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

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

Figure 3.32 WALL TYPE 6

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

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

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

Figure 3.33 WALL TYPE 7

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

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

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

Figure 3.34 WALL TYPE 8

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

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

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

Figure 3.35 WALL TYPE 9

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

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

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

Figure 3.36 WALL TYPE 10

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

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

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

Figure 3.37 ROOF TYPE 1

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

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

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

Figure 3.38 ROOF TYPE 2

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

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

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

Figure 3.39 ROOF TYPE 3

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

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

NUMBER OF HOURS REQUIRED TO REACH COMMON RATIO = 17
NUMBER OF RESPONSE FACTORS PER SET = 18
COMMON RATIO = 0.8786596114

Figure 3.40 ROOF TYPE 4

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

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

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

Figure 3.41 ROOF TYPE 5

DESCRIPTION OF CONSTRUCTION

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

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

RESPONSE FACTORS

HOUR	X	Y	Z
0	0.7041712189	0.0100444126	0.8569121506
1	-0.6588926193	0.0224665553	-0.5530683028
2	-0.0004555153	0.0082561150	-0.1764214705
3	-0.0001234544	0.0026371985	-0.0563432518
4	-0.0000394216	0.0008422350	-0.0179941836
5	-0.0000125900	0.0002689823	-0.0057467531
6	-0.0000040208	0.0000859041	-0.0018353248

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

Figure 3.42 ROOF TYPE 6

SUN1

A subroutine to calculate the daily solar radiation data.

INPUT

IDOY : Day of Year, 1 to 366

TL : Tangent of Latitude angle

OUTPUT

SUNRAS : Hourly angle (radians) when solar altitude is zero

DEABC(1) : Tangent of declination angle, TANδ

DEABC(2) : Equation of time, ET, hours

DEABC(3) : Apparent solar constant, A, BTU/hr-sq ft

DEABC(4) : Atmospheric extinction coefficient, B

DEABC(5) : Sky diffuse factor, C

Table 3.8 lists, as function of date, five variables related to solar radiation. These variables are declination angle, δ; the equation of time, ET; the apparent solar constant, A; the atmospheric extinction coefficient, B; and sky diffuse factor, C.

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

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

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

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

where ω = $2*\pi/366.$ = 0.01721

d = IDOY

The proper Fourier coefficients are given in Tabel 3.9.

Table 3.9 FOURIER COEFFICIENTS

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

<u>CALCULATION SEQUENCE</u>

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

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

Where

$$C1 = \cos(\omega*d)$$

$$S1 = \sin(\omega*d)$$

and by trigometric identity

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

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

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

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

2. Calculate sun rise angle

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

which is obtained from general equation

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

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

where

h = solar altitude, radians

L = latitude, radians

t = hour angle, radians

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

SUN2

A subroutine to calculate the hourly solar radiation data.

INPUT

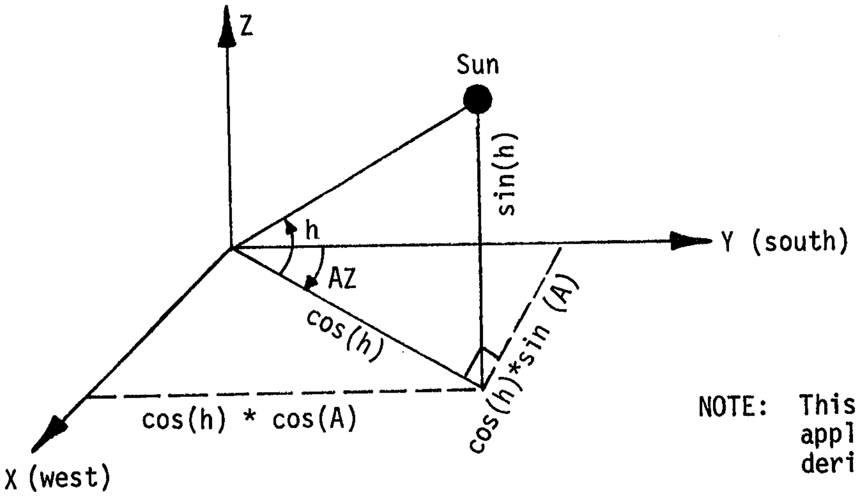
H	:	Hour angle, radians (calculated in main program)	
DEABC(1)	:	Tangent of declination angle	Calculated in SUN1
DEABC(2)	:	Equation of time, hours	Calculated in SUN1
DEABC(3)	:	Apparent solar constant, Btu/hr-sq ft	Calculated in SUN1
DEABC(4)	:	Atmospheric extinction coefficient	Calculated in SUN1
DEABC(5)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

OUTPUT

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

CALCULATION SEQUENCE

1. Calculate direction cosines of sun



NOTE: This coordinate system applies only to this derivation

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

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

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

RAYCOS(3) = SIN(h)

where h = altitude of sun measured from horizontal, degrees

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

From spherical trigonometry++, the following relationships hold

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

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

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

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

where δ = declination of sun, degrees

L = station latitude, degrees

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

Substitution gives

RAYCOS(1) = +cos(δ)*sin(t)

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

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

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

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

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

Substitution yeilds

RAYCOS(1) = -(cos(δ)*sin(t))*cos(A)

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

RAYCOS(2) = -(cos(δ)*sin(t))*sin(A)

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

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

To get into form in subroutine let

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

Finally, by substitution of these identities,

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

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

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

2. Calculate intensity of direct normal solar radiation

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

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

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

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

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

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

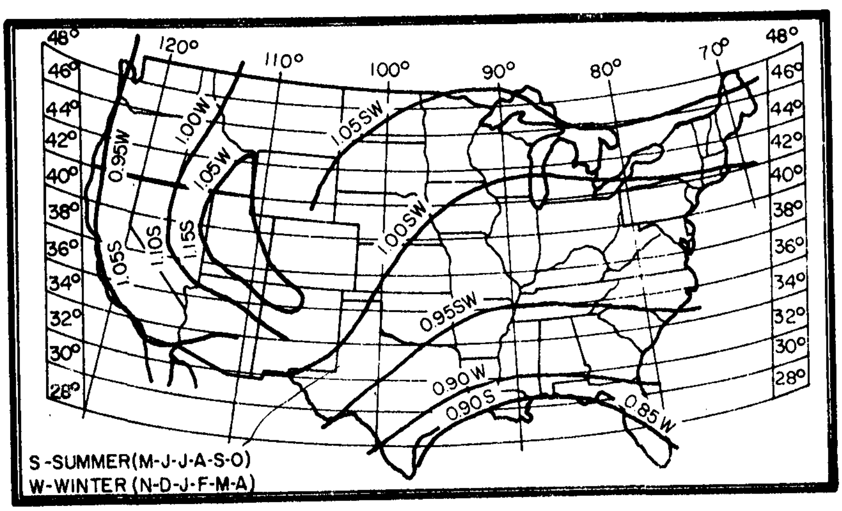


Figure 3.43 CLEARNESS NUMBERS OF NON-INDUSTRIAL ATMOSPHERE IN UNITED STATES

SUN3

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

INPUT

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

OUTPUT

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

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

CALCULATION SEQUENCE

1. Calculate brightness of ground

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

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

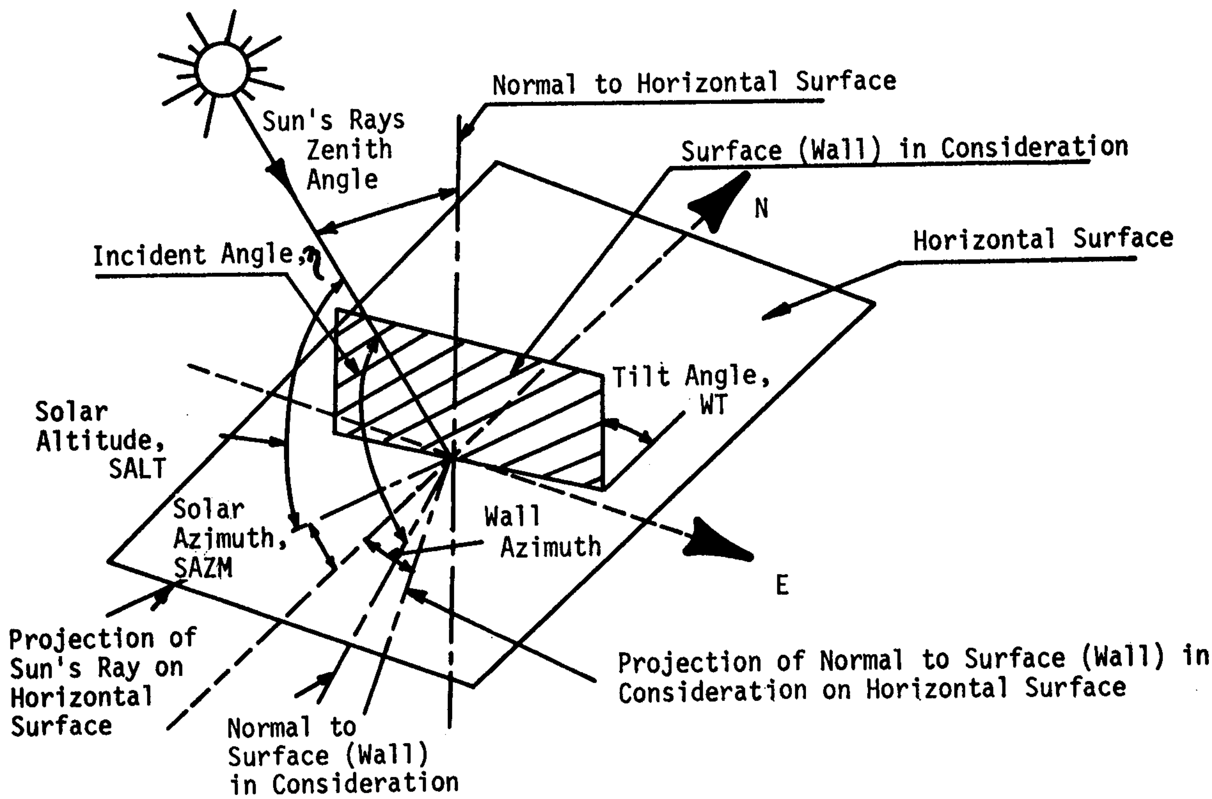


Figure 3.44 DEFINITION OF ANGLES

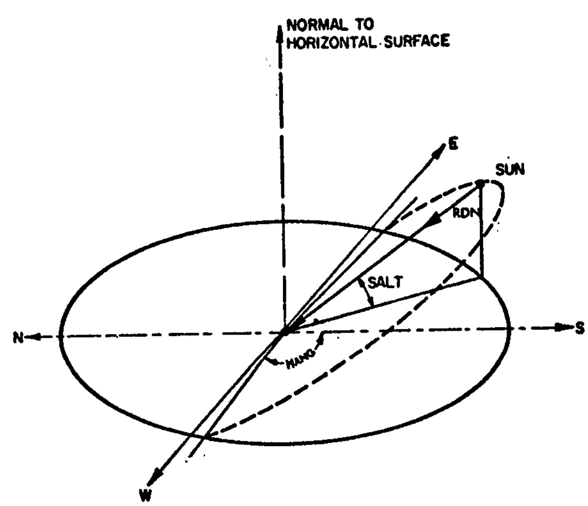


Figure 3.45 SCHEMATIC SHOWING APPARENT PATH OF SUN AND HOUR ANGLE

α = cos(WT) = CWT

β = sin(WA)*sin(WT) = SWA*SWT

γ = cos(WA)*sin(WT) = CWA*SWT

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

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

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

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

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

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

c) For all other tilt angles

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

d) If WA = 0.0 RAD (0°)

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

e) If WA = 1.5708 RAD (90°)

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

f) If WA = 3.1416 RAD (180°)

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

g) If WA = 4.7114 RAD (270°)

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

h) For all other azimuth angles

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

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

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

4. Calculate the intensity of the direct normal solar radiation

a) If ETA ≤ 0.0, sun is not up yet

RDIR = 0.0

b) If ETA > 0.0, sun is up

RDIR = RDN * ETA

5. Calculate the intensity of diffuse radiation

a) If WT ≤ 0.7854 RAD (45°) surface is oriented toward sky

RDIF = BS

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

RDIF = BG

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

If ETA < -0.2,
y = 0.45

If ETA ≥ -0.2,
y = 0.55 + 0.437*ETA + 0.313*ETA**2

Then RDIF = y*BS + 0.5*BG

6. Calculate total radiation incident upon surface

RTOT = RDIR + RDIF

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

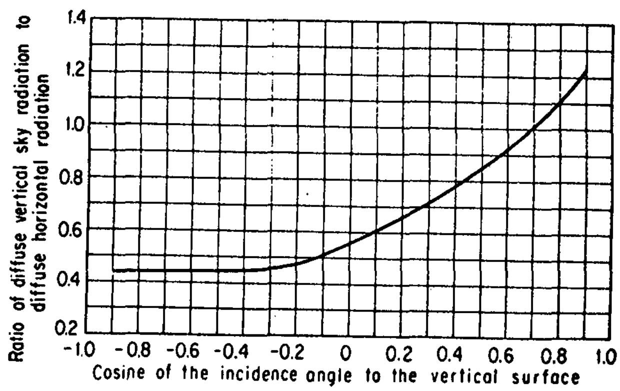


Figure 3.46 RATIO OF DIFFUSE SKY RADIATION INCIDENT UPON A VERTICAL SURFACE TO THAT INCIDENT UPON A HORIZONTAL SURFACE DURING CLEAR DAYS

TAR

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

INPUT

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

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

OUTPUT

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

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

CALCULATION SEQUENCE

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

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

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

Table 3.10

CODE FOR THICKNESS TIMES EXTINCTION COEFFICIENT

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

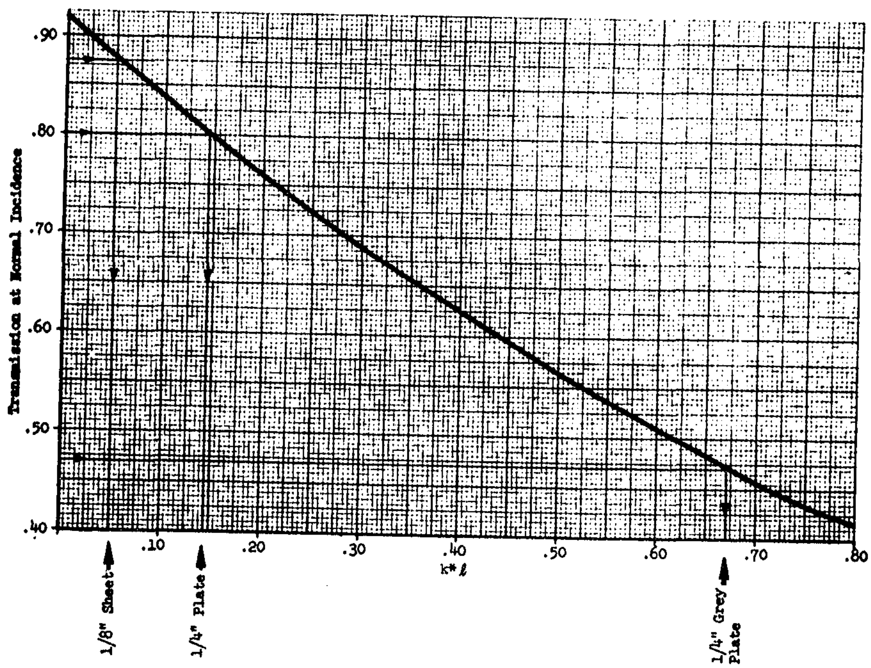


Figure 3.47 $k*\ell$ VS TRANSMISSION AT NORMAL INCIDENCE FOR SINGLE SHEET GLASS

Table 3.11

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

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

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

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

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

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

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

WBF

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

INPUT

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

OUTPUT

WBF	:	Wet-bulb temperature, °F

CALCULATION SEQUENCE

1. If PB = 29.92 and H > 0

   Let Y = log(H)

   For H < 11.758

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

   For H ≥ 11.758

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

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

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

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

   PV2 = PPWVMS (WBF)

SECTION 4
SYSTEMS ENERGY SIMULATION PROGRAM

4.1 OBJECTIVE AND DESCRIPTION

The hourly space and building load requirements calculated by the Thermal Loads Analysis Program are not necessarily the loads that are seen by the heating and cooling plant. Due to ventilation air requirements, periodic equipment shutdown, thermostat reset, inefficiencies caused by controls, etc., typically the hourly plant loads differ from the summation of the hourly space transmission and internal loads. The Systems Energy Simulation Program, therefore, performs two basic functions. First, it translates hourly space loads, including ventilation air requirements by means of simulation of each distribution system, into the hourly thermal requirements imposed upon the heating and cooling plants. Secondly, it converts these hourly thermal requirements into energy requirements based upon the part-load characteristics of the heating and cooling plant equipment.

The Systems Energy Simulation Program (SESP) is made up of a series of subroutines which are summarized in Table 4.1. The main routine, SESP, directs the flow of logic through the program and controls the order in which calculations are to be performed. The sequence of calculations is as follows.

1. Calculate zone and fan system supply air quantities if not user-defined.

2. Based upon heating, cooling and electrical plant capacities, size other auxiliary energy consuming equipment, i.e., pumps, fan motors, cooling tower fan, engine/generators sets, etc.

3. Perform an hourly simulation of the building's utility systems to determine hourly resource requirements. For each hour of analysis period perform following:

   a) Estimate plant heating and cooling capacity on basis of installed capacity, scheduled seasonal availability, ambient effects, and characteristics of the equipment.

   b) Set capacity of heating and cooling available to each zone on basis of defined design capacities and plant capacity adjustment factors.

   c) Perform variable temperature calculations to determine adjusted zone heating/cooling requirements and resulting zone temperature based upon zone temperature control characteristics and available capacity.

d) Simulate each distribution system to determine their requirements in terms of heating, cooling, reheating, preheating, baseboard heating, humidification, etc. on basis of type of distribution system, ventilation air requirements, temperature controls, etc. These system requirements are then summed to give plant requirements.

e) Process loads (direct or indirect), if any, are determined and added to the plant requirements.

f) The plant requirements are then compared to that available for the hour. If the amount available is greater than that required, then calculations may proceed. If however, the required plant capacity, heating and/or cooling, exceeds that available, the zone heating/cooling capacities are proportionately reduced and a new set of adjusted zone loads and zone temperatures calculated. Calculations 3b through 3f are repeated, up to a maximum of 5 iterations per hour, until plant requirements can be met, at which time calculations proceed to the next step.

g) Plant heating, cooling, and electrical equipment are simulated and on the basis of either built-in or user-supplied performance characteristics, the energy requirements for the building and its utility systems are determined.

4. Sum the hourly energy resource requirements to establish monthly and annual energy requirements.

5. At end of analysis period, print equipment summary report, monthly/annual energy summary, zone temperature distribution profile and executive summary.

In order to follow the notations of the engineering manual, an understanding of variable organization as it pertains to zone labeling is required (see Figure 4.2). The re-numbering of zones internally by the program has resulted in increased flexibility to the user and a reduction of computer storage requirements. As

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regards assigning zones to energy distribution systems, the user need not be concerned with zone sequence when generating the TLAP output data files. They may be specified in any order. Zones may be omitted or repeated.

Regarding the program structure, a storage requirement savings is realized since variables which were once doubly-subscripted may now be singly subscripted. An example of this potential savings, using the example of Figure 4.2 zone/system relationships are illustrated in Figure 4.3. Input file variables ("ℓ" numbers) are assigned via variable $SPACN_{k,j}$. Each zone "j" of system "k" has a corresponding "i". Thus one doubly-subscripted variable ($SPACN_{k,j}$) is used to identify the particular "ℓ" variable location of a given zone on a given system.

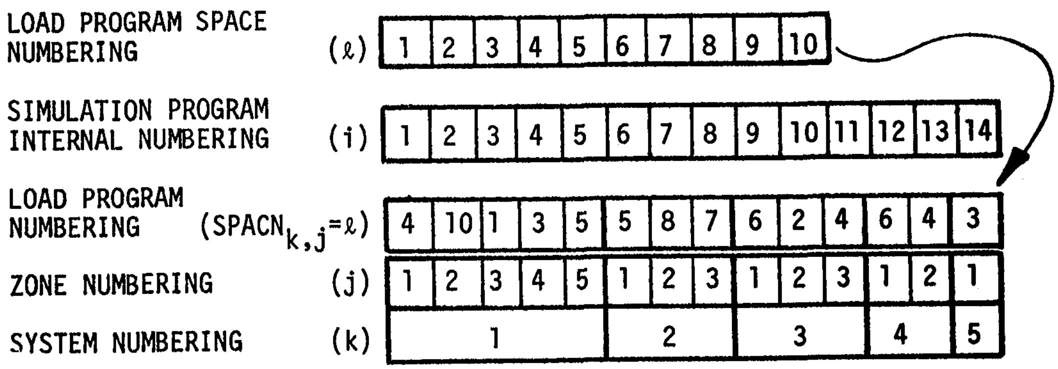

Figure 4.2 SYSTEM SIMULATION PROGRAM NUMBERING ORGANIZATION w/example

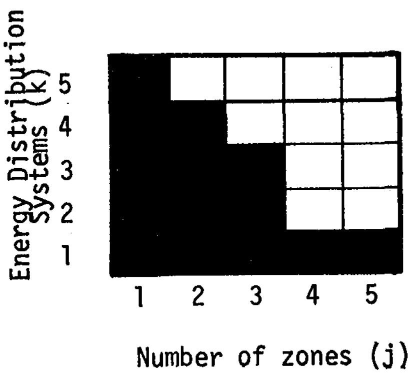

Figure 4.3 SYSTEM/ZONE MATRIX using doubly-subscripted variables (k,j)

TABLE 4.1

SYSTEMS ENERGY SIMULATION PROGRAM
SUBROUTINE DESCRIPTION

NAME	FUNCTION
SESP	Main routine which directs sequence of calculations
ABSOR	Steam absorption water chiller simulation
AHU	Air handling unit simulation
ALOG	Base 10 logarithm
BRAD	Baseboard radiation simulation
CCOIL	Cooling coil simulation
CENT	Centrifugal water chiller simulation
CHLADJ	Estimates chiller full load capacity at non-standard condition
CHLUSR	Determines performance characteristics for user-defined chillers
CLGTWR	Cooling tower simulation
CSIN	Reads SESP input data file
IUNI	Data interpolator
DENSY	Air density calculation
DXHP	Simulates heat pumps and DX cooling units
ECONO	Economizer cycle simulation
ENGY	Prints monthly and annual energy consumption summary
EQUI	Simulates boilers, chillers and onsite generation equipment
ESIZE	Sizes central plant equipment
EXSUM	Prints executive summary report
FANOF	Load handler when fans are off
FCOIL	Fan coil unit simulation (2-and 4-pipe)
FHTG	Floor panel heating system simulation
FILM	Calculates surface outside heat transfer film coefficient

TABLE 4.1 (CONT'D)

NAME	FUNCTION
FSIZE	Calculates supply air quantities and fan system properties
HUM	Humidity ratio calculation
H2OZN	Zone moisture change and requirement calculation
INDUC	Induction unit fan system simulation (2-and 4-pipe)
MAX	Maximum value calculation
MXAIR	Mixed air properties calculation
MZDD	Multi-zone and dual duct fan system simulation
NUMDEV	Determines number of central plant devices required to meet loads
PPWVMS	Psychrometric calculations
PROCES	Calculates process loads
PSYCH	Psychrometric calculations
PSY1	Psychrometric calculations
PSY2	Psychrometric calculations
PTLD	Part load fan power calculations
RECIP	Reciprocating water chiller simulation
RHFS	Simulation of: Single-zone fan system w/face and bypass dampers Unit ventilator, Unit heater, Constant volume reheat fan system
SESIN	Program module to read in and initialize data
SCLOSE	Program module to print out final reports
SMEXEC	Program module to perform hourly simulations
STEAM1	Calculates properties of steam
STTUR	Steam turbine simulation
SZRHT	Single-zone/sub-zone reheat fan system simulation
TBAND	Calculates indices of temperature band increment

TABLE 4.1 (CONT'D)

NAME	FUNCTION
TEMP	Fan system discharge temperature calculation
TOT	Totalizer
TRSET	Temperature reset calculation
VARVL	Variable volume fan system simulation
VTCSRF	Calculates space response factors
VTHOUR	Calculates interproducts for variable temperature calculation
VTIN	Reads building description data from TLAP data file
VTINIT	Initializes parameters for variable temperature calculations
VTLOAD	Simulates thermostats
VTPOHD	Schedules printouts
WZNEW	Humidity ratio calculation
ZLO	Zone load organizer which calculates reheat and recooling loads

4.2 MAIN ROUTINE ALGORITHMS

The main routine of the Systems Energy Simulation Program, SESP, controls the calculation sequence for the entire program. This routine is divided basically into three segments.

- SESIN. Subroutines are called to read card input data (CSIN) and to read building description data (VTIN). A third subroutine (FSIZE) is then called to size zone and system air flows. Finally, central system power consuming equipment (i.e., pumps, fans, cooling towers, motors, engine generators, steam turbines) are sized (ESIZE).

- SMEXEC. The function of this segment is to first read hourly weather data and zone loads from the TLAP file. Secondly, the appropriate energy distribution subroutines are called to calculate energy conversion system loads (heating, cooling, water and power requirements). Thirdly, subroutine EQUIP is called to calculate resource requirements necessary to satisfy heating, cooling and power needs.

- SCLOSE. The third segment indicates the activity of the program by printing a central equipment size summary, a table of energy and resource requirements (demand and consumption) for each month, a temperature frequency summary and executive summary.

INPUT

Cards - Card input variables which are generated by NIPP may be found in Appendix C, Table 3 of the NECAP User's Manual

I TAPE - Building description data read into SESP from TLAP Program. File format description may be found in Appendix D, Table 2 of the NECAP User's Manual.

A TAPE - Hourly loads and weather data processed by TLAP. File format description may be found in Appendix D, Table 3 of the NECAP User's Manual.

OUTPUT

Printer - Printed output is discussed in Table 4.3. Also refer to Section 5 of the User's Manual for examples of the program's output.

N TAPE - Hourly loads and weather data processed by SESP. File may be formatted or unformatted depending upon the value of IOTWF. A description of the formatted file is found in Appendix C, Table 3, of the NECAP User's Manual, and the unformatted file is described in Appendix D, Table 4 of the NECAP User's Manual.

COMMON

The Systems and Energy Simulation Program is organized such that use of common by second-, third-, etc. order subroutines and functions is the exception rather than the norm. However, most of the variables required by first-order subroutines are located in COMMON. These variables are defined in Table 4.4.

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TABLE 4.2

ORGANIZATION OF INPUT ON TLAP INPUT FILE TO SYSTEMS ENERGY SIMULATION PROGRAM

For each hour the following data is available:

IHOUR	:	Hour number, hour of year
IMOY	:	Month of year
IDOM	:	Day of month
NDOW	:	Day of the week
IHOD	:	Hour of the day
ISUN	:	Sun index which indicates whether or not the sun is up (0 = sun up; 1 = sun not up)
TOA	:	Outside air dry-bulb temperature (^{o}F)
TWB	:	Outside air wet-bulb temperature (^{o}F)
VEL	:	Wind velocity (knots)
WOA	:	Outside air humidity ratio (lb water/lb dry air)
PATM	:	Barometric pressure (inches of mercury)
DOA	:	Outside air density (lbm/ft^3)
HOA	:	Enthalpy of outside air (Btu/lb dry air)
JSC	:	Day type (i.e., weekday, Saturday, Sunday, Holiday, Xmas)
CCM	:	Cloud cover modifier

For each zone, the following data is available:

IS	:	Space number
QS_{ℓ}	:	Zone sensible load (Btu/hr)
QL_{ℓ}	:	Zone latent load (Btu/hr)
$QLITE_{\ell}$	:	Zone lighting load picked up by return air (Btu/hr)
$SLPOW_{\ell}$	:	Zone internal lighting and machinery power consumption (KW)

TABLE 4.2 (CONT'D)

$QSINF_{\ell}$	:	Zone sensible infiltration load (Btu/hr)
$QLINF_{\ell}$	:	Zone latent infiltration load (Btu/hr)

TABLE 4.3

OUTPUT OF SYSTEMS ENERGY SIMULATION PROGRAM
PROGRAM
(NOTE: optional printout not covered here)

PROGRAM VARIABLE		DESCRIPTION
Input Recap (REPORT 1)		
Recapitulation of input card data		
Energy Analysis Header (REPORT 2)		
FAC	-	Building or project name
CITY	-	Location
ENGR	-	Name of user
PROJ	-	Project number
DATE	-	Date
Energy Distribution System Summary (REPORT 3)		
$FBHPS_k$	-	Supply fan brake horsepower, system k
$FBHPR_k$	-	Return fan brake horsepower, system k
$FBHPE_k$	-	Exhaust fan brake horsepower, system k
$JMAX_k$	-	Number of zones on system k
$CFMAX_k$	-	Supply air, system k (CFM)
$CFMIN_k$	-	Minimum outside air, system k (CFM)
$CFMEX_k$	-	Exhaust air, system k (CFM)
$ALPCT_k$	-	Minimum outside air percent of supply air, system k
Zone Air Flow Summary (REPORT 4)		
$CFMS_i$	-	Supply air, zone i (CFM)
$CFMX_i$	-	Exhaust air, zone i (CFM)
$TSP\ell$	-	Set point temperature, zone ℓ (^oF)
$CCAPD_i$	-	Cooling capacity, zone i (BTU/HR)
$HCAPD_i$	-	Heating capacity, zone i (BTU/HR)
$IYZT_i$	-	Yearly thermostat schedule, zone i

TABLE 4.3 (CONT'D)

PROGRAM VARIABLE		DESCRIPTION
Loads Not Met (REPORT 5 - Optional)		
$QCLNM_i$	-	Monthly accumulation of cooling loads not met, zone i (KBTU)
$QCPNM_i$	-	Peak cooling load not met, zone i (KBH)
$IHCNM_i$	-	Number of hours in month cooling load not met, zone i
$QHLNM_i$	-	Monthly accumulations of heating loads not met, zone i (KBTU)
$QHPNM_i$	-	Peak heating load not met, zone i (KBH)
$IHHNM_i$	-	Number of hours in month heating load not met, zone i
QRCNM	-	Monthly accumulation of central cooling system loads not met due to undersized equipment (KBTU)
QRCNM	-	Peak central cooling system load not met (KBH)
IHRNM	-	Number of hours in month central cooling system load not met
QBCNM	-	Monthly accumulations of boiler loads not met due to undersized equipment (KBTU)
QBPNM	-	Peak boiler load not met (KBH)
IHBNM	-	Number of hours in month boiler load not met

NOTE: Loads not met are tabulated only once (i.e., zone loads not met are not carried over into central equipment loads not met).

TABLE 4.3 (CONT'D)

PROGRAM VARIABLE		DESCRIPTION
Summary of Equipment Sizes (REPORT 6)		
NUMC	:	Number of chillers
SZC	:	Size of chillers (tons)
NUMB	:	Number of boilers
SZB	:	Size of boilers (MBH)
NUMT	:	Number of steam turbines
SZT	:	Size of steam turbines (HP)
M4	:	Number of on-site generation engines
SZE	:	Size of on-site generation engines (KW)
CAPH	:	Total heating capacity (MBH)
CAPC	:	Total cooling capacity (tons)
CFMCT	:	Cooling tower air flows (CFM)
HPCTF	:	Horsepower of cooling tower fan motor (HP)
HPBLA	:	Horsepower of boiler auxiliaries (HP)
GPMCL	:	Chilled water flow (gpm)
HPCLP	:	Chilled water pump horsepower (HP)
GPMCN	:	Condenser water flow (gpm)
HPCNP	:	Condenser water pump horsepower (HP)
GPMBL	:	Boiler water flow (gpm)
HPBLP	:	Boiler water pump horsepower (HP)

TABLE 4.3 (CONT'D)

PROGRAM VARIABLE	DESCRIPTION
ENGY : (REPORT 8)	Monthly resource consumptions and demands. A 12 x 2 x 22 matrix with indices defined as indicated below. This variable is transferred to subroutine ENGY4 where the monthly tabulation is printed. FIRST SUBSCRIPT: MONTH 1 is January 2 is February 3 is March 4 is April 5 is May 6 is June 7 is July 8 is August 9 is September 10 is October 11 is November 12 is December SECOND SUBSCRIPT: MODE OF ENERGY 1 is Demand 2 is Consumption THIRD SUBSCRIPT: TYPE OF ENERGY 1 is not used 2 is not used 3 is Electric, internal lights and building equipment 4 is Electric, external lights 5 is Electric heat (boiler and auxiliaries, heat pumps and hot water pumps) 6 is Electric cool (chillers, DX, chilled water pumps, and cooling tower fan) 7 is Gas heating 8 is Gas cooling 9 is Gas generation 10 is Steam heating 11 is Steam cooling 12 is Oil heating 13 is Oil cooling 14 is Diesel fuel generation 15 is Heating plant output 16 is Cooling plant output 17 is City water 18 is Fan power 19 is Gas-process 20 is Oil-process 21 is Steam-process 22 is Electric-process

TABLE 4.3 (CONT'D)

PROGRAM VARIABLE		DESCRIPTION
Temperature Occurence Bands (REPORT 7)		
RANGE	:	Temperature ranges
I	:	Space No. (TLAP order)
ITMAT1,I,TEMP	:	Hours occupied at given temperature
ITMAT2,I,TEMP	:	Hours unoccupied at given temperature

TABLE 4.3

PROGRAM VARIABLE		DESCRIPTION
EXECUTIVE SUMMARY (REPORT 9)		
FAC	:	Facility name
CITY	:	Facility location
NODAYS	:	No of days for the simulation
ENGR	:	Engineer's name
AREA	:	Total floor area
DATE	:	Date
CAPH	:	Total heating capacity
CAPHA	:	Heating capacity/sq ft
CAPC	:	Total cooling capacity
CAPCA	:	Cooling capacity/sq ft
PROJ	:	Project number
SUPAIR	:	Supply air (CFM)
SUPSQF	:	Supply air (CFM/sq ft)
SNAME	:	Systems identificaiton name
VENT	:	Ventilation rate (CFM)
VSQF	:	Ventilation rate (CFM/sq ft)
ENGYS	:	Total energy storing 3x20 matrix
		FIRST SUBSCRIPT: UNITS
		1 is total building consumption
		2 is building line (KBTU/sq ft)
		3 is raw source (KBTU/sq ft)

TABLE 4.3 (CONT'D)

PROGRAM VARIABLE		DESCRIPTION
EXECUTIVE SUMMARY (Cont'd)		
		SECOND SUBSCRIPT: Type of energy 1 is electricity lights and miscellaneous equipment 2 is electricity heating 3 is electricity cooling 4 is electricity fans 5 is electricity process 6 is electricity cooling 7 is gas heating 8 is gas cooling 9 is gas generation 10 is gas process 11 is gas total 12 is steam heating 13 is steam cooling 14 is steam process 15 is steam total 16 is oil heating 17 is oil cooling 18 is oil process 19 is oil total 20 is diesel generation
GTENG	:	Total energy equipment KBTU
TOT1	:	Total building line (KBTU/sq ft)
TOT2	:	Total source (KBTU/sq ft)

NOTES

TABLE 4.4
DEFINITION OF
VARIABLES IN COMMON

/ENERGY/

ENGY	-	Monthly résource comsumptions and demands. A 12 x 2 x 27 matrix with indices defined as indicated below. This variable is transferred to subroutine ENGY4 where the monthly tabulation is printed. First Subscript : Month Second Subscript : Mode of energy Third Subscript : Type of energy
FLAREA	-	Total floor area simulated (ft^2)

/FAN1/

$KFAN_k$	-	Energy distribution system index
$JMAX_k$	-	Number of zones on system k
$CFMAX_k$	-	Design supply air of system k (ft^3/min)
$CFMEX_k$	-	Exhaust air, system k (ft^3/min)
$ALFAM_k$	-	Minimum fraction outside air, system k
$OACFM_k$	-	Minimum ventilation air, system k (ft^3/min)
$RHSP_k$	-	Relative humidity set point, system k (% R.H.)
WSP_k	-	Humidity ratio set point, system k ($\frac{\text{lbm-H20}}{\text{lbm-dry air}}$)
$DAVE_k$	-	Average air density, system k (lbm/ft^3)
WRA_k	-	Return air humidity ratio, system k ($\frac{\text{lbm-H20}}{\text{lbm-dry air}}$)
DRA_k	-	Return air density, system k (lbm/ft^3)
$PWGAL_k$	-	Process water volume, system k (gals)
$FMASS_k$	-	Supply air mass, system k (lbm-air/hr)
$FMASR_k$	-	Return air mass, system k (lbm-air/hr)
$FMASX_k$	-	Exhaust air mass, system k (lbm-air/hr)
$TFNPS_k$	-	Total supply fan pressure, system k (inches)
$TFNPR_k$	-	Total return fan pressure, system k (inches)

TABLE 4.4 (CONT'D)

$TFNPE_k$	-	Total exhaust fan pressure, system k (inches)
$FBHPS_k$	-	Supply fan brake horsepower, system k (bhp)
$FBHPR_k$	-	Return fan brake horsepower, system k (bhp)
$FBHPE_k$	-	Exhaust fan brake horsepower, system k (bhp)
$DTFNS_k$	-	Air temperature rise across supply fan, system k, at full load (^oF)
$DTFNR_k$	-	Air temperature rise across return fan, system k, at full load (^oF)
$MXAO_k$	-	Mixed air option, system k
$IVVRH_k$	-	Variable volume reheat option, system k
$ICZN_k$	-	Zone in which humidistat is located, system k, (a "j" number)
$ITMPC_{k,1}$	-	Air temperature control mode, system k
$ITMPC_{k,2}$	-	Air temperature control mode, system k
$NVFC_k$	-	Type of fan damper control, system k
$VVMIN_k$	-	Minimum air flow through variable volume boxes, system k
$TCOFC_k$	-	Two-pipe fancoil unit system changeover temperature (^oF)
$TOACO_k$	-	Two-pipe induction unit fan system changeover temperature or floor panel heating system hot water shut-off temperature, system k (^oF)
$TFIX1_k$	-	Fixed hot deck or AHU discharge temperature, system k (^oF)
$TFIX2_k$	-	Fixed cold deck temperature, system k (^oF)
$RIPA_k$	-	Ratio of induced to primary air, system k
$JDXHP_k$	-	DX or heat pump system number, system k
$PLOC_k$	-	Location of floor heating panels, system k
$PAREA_k$	-	Floor area covered by heating panels, system k (ft^2)
$PERIM_k$	-	Exposed perimeter of floor, system k (lin.ft)
$ISET_{k,m}$	-	Reset temperature schedule index, system k, reset item m (an "n" number)

TABLE 4.4(CONT'D)

$IFSO_k$	-	Fan system shut-off flag (0=fans run continuously, 1=fans may be shut off , 2=fans and baseboard radiators may be shut off , 3=fans operated by hourly schedule)
$IVENT_k$	-	Fan system ventilation air schedule index
/FANS/		
NRUN	-	Inactive, set equal to 1
FAN_k	-	Fan system label, system k
/HEADER/		
FAC	-	Facility
CITY	-	Location
ENGR	-	User Name
PROJ	-	Project ID.
DATE	-	Date
SNAME	-	SESP descriptor card
/HEAT/		
CAPH	-	Total heating capacity
QSC	-	Sensible heat extracted
QLC	-	Latent heat extracted
/IBLRUS/		
MAX8A	-	Number of boiler part load-vs-efficiency points
BPL	-	Boiler part load efficiency points
BPCT	-	Boiler part load points
/IBOIL/		
NBOIL	-	Number of different boiler types
$IBOPT_{nb}$	-	Boiler simulation option code; boiler type nb 0 = Built-in performance 1 = User-defined performance
$NUMB_{nb}$	-	Number of boilers, boiler type nb
SZB_{nb}	-	Size of each boiler (KBH), boiler type nb

TABLE 4.4 (CONT'D)

$M3_{nb}$	-	Source of general heating energy, boiler type nb
KREHT	-	Source of reheat coil energy
HVHO	-	Heating value of heating oil (Btu/gal)
HDBLP	-	Total boiler water pump head (ft)
BLRAUX	-	Total boiler auxiliary horsepower (bhp)
<u>/ICHIL/</u>		
NCHIL	-	Number of different chiller types
$ICOPT_{nc}$	-	Chiller simulation option code, chiller type nc 0 = Built-in performance 1 = User-defined performance
$NUMC_{nc}$	-	Number of chillers, chiller type nc
SZC_{nc}	-	Size of each chiller (tons), chiller type nc
$M1_{nc}$	-	Type of chiller, chiller types nc
$M2_{nc}$	-	Source of chiller energy, chiller types nc
FFLMN	-	Minimum part load cut-off for chillers (%)
TLCHL	-	Chilled water set point temperature (^{o}F)
HDCLP	-	Total chilled water pump head (ft)
HDCNP	-	Total condenser water pump head (ft)
<u>/ICHLUS/</u>		
$MAX9A_{nc}$	-	Number of chiller capacity/condenser temperature points, chiller type nc
$MAX9B_{nc}$	-	Number of chiller power/condenser temperature points, chiller type nc
$MAX9C_{nc}$	-	Number of % chiller power/% load points, chiller type nc
$TCON1_{nc,9A}$	-	Leaving condenser water for CCAP(^{o}F), chiller type nc
$TCON2_{nc,9B}$	-	Leaving condenser water for CPPWR(^{o}F), chiller type nc

TABLE 4.4 (CONT'D)

$CCAP_{nc,9A}$	-	Chiller capacity (tons), chiller type nc
$CPPWR_{nc,9B}$	-	Chiller power (KW or lb.), chiller type nc
$CPPL_{nc,9C}$	-	Chiller % peak load, chiller type nc
$CPPP_{nc,9C}$	-	Chiller % peak power, chiller type nc
/ICTWR/		
MAX9D	-	# Condenser water/amb. wet-bulb data points
MAX9E	-	# Cooling tower % load/condenser water ΔT data points
MAX9F	-	# Cooling tower % power/condenser water temp. data points
MAX9G	-	# Cooling tower Δ% power/% load data points
$CTWL_{9D}$	-	Cooling tower leaving water temperature (100% load)
$TWB1_{9D}$	-	Ambient WBT for CTWL
$DCTWL_{9E}$	-	Cooling tower ΔCTWL at part load
$CTPL1_{9E}$	-	% peak load for DCTWL
$CTPPP_{9F}$	-	Cooling tower % peak power (f(CTWL2) at 100% load)
$CTWL2_{9F}$	-	Cooling tower leaving water temp. at CTPPP
$DCTPP_{9G}$	-	Cooling tower ΔCTPPP at part load
$CTPL2_{9G}$	-	% peak load for DCTPP
/IDXHP/		
NDXHP	-	Number of DX and heat pump units
$IDXHP_{ndx}$	-	Unit type, unit ndx 1 = DX 2 = Heat pump
$DCCAP_{ndx}$	-	Design cooling capacity (MBH), unit ndx
$DCPOW_{ndx}$	-	Design cooling power (KW), unit ndx
$DHCAP_{ndx}$	-	Design heating capacity (MBH), unit ndx

TABLE 4.4 (CONT'D)

$DHPOW_{ndx}$	-	Design heating power (KW), unit ndx
NCP_{ndx}	-	Number of cooling performance data points, unit ndx
NHP_{ndx}	-	Number of heating performance data points, unit ndx
$TREFC_{ndx,ncp}$	-	Ambient dry bulb cooling reference temperature (^{o}F) unit ndx
$PVCCA_{ndx,ncp}$	-	Percent variation from design cooling capacity at temp. (TREFC), unit ndx
$PVCPO_{ndx,ncp}$	-	Percent variation from design cooling power at temp. (TREFC), unit ndx
$TREFH_{ndx,nap}$	-	Ambient drybulb heating reference temperature, unit ndx
$PVHCA_{ndx,nap}$	-	Percent variation from design heating capacity at temp. (TREFH), unit ndx
$PVHPO_{ndx,nap}$	-	Percent variation from design heating power at temp. (TREFH), unit ndx
/IEG/		
NENG	-	Number of different engine/generator types
$IEGOP_{ne}$	-	Engine/generator simulation option code, e/g type ne 0 = Built-in performance 1 = User defined performance
$M4_{ne}$	-	Number of engine/generator sets, e/g type ne
$M5_{ne}$	-	Type of engine/generator set, e/g type ne
$EGCAP_{ne}$	-	Capacity of engine/generator set (KW), e/g type ne
HVDF	-	Heating value of diesel fuel (Btu/gal)
$EFUEL_{ne}$	-	Engine fuel consumption at full load (GPH or CFH), e/g type ne
$EQBAK_{ne}$	-	% heat recovery at full load, e/g type ne
$EFPCT_{ne,5}$	-	% fuel consumption at load EGPCT, e/g type ne
$EQPCT_{ne,5}$	-	% heat recovery at load EGPLD, e/g type ne
$EGPCT_{ne}$	-	% load (0%, 25%, 50%, 75%, 100%), e/g type ne
$EGPLD_{ne}$	-	% load (0%, 25%, 50%, 75%, 100%), e/g type ne

TABLE 4.4 (CONT'D)

MAX7A	-	Number of data points
MAX7B	-	Number of data points
/IGPM/		
GPMCL	-	Chilled water flow rate (gpm)
GPMCN	-	Condenser water flow rate (gpm)
GPMBL	-	Boiler water flow rate (gpm)
/IHP/		
HPCTF	-	Cooling tower fan power (bhp)
HPBLA	-	Boiler accessory power (bhp)
HPBLP	-	Boiler water pump power (bhp)
HPCLP	-	Chilled water pump power (bhp)
HPCNP	-	Condenser water pump power (bhp)
HPCEQ	-	Total horsepower of cooling equipment (bhp)
HPHEQ	-	Total horsepower of heating equipment (bhp)
/IO1/		
KO	-	Line printer unit number
IC	-	Card reader unit number
IT	-	Input tape unit number
IANALT	-	TLAP input file unit number
ITOUT	-	SESP output file number
/IO2/		
IBUG	-	Series of internal debugging switches
IPO	-	Number of user defined printout periods
IPOS	-	Starting hour for each printout period

TABLE 4.4 (CONT'D)

IPOE	-	Ending hour for each printout period
IPRNT1	-	Print level 1 indicator
IPRNT2	-	Print level 2 indicator
IOTWF	-	Output file option code
IPRT1	-	Optional print flag-1
IPRT2	-	Optional print flag-2
IPRT3	-	Optional print flag-3
/IPROC/		
NPROC	-	Number of process loads
$PRPK_{pr}$	-	Peak load, process pr
$IPREN_{pr}$	-	Energy source, process pr
$IPRSC_{pr}$	-	Operating schedule, process pr
$PRSTMP_{pr}$	-	Entering steam pressure, process pr
$PRSTMT_{pr}$	-	Entering steam temperature, process pr
/ITURB/		
SZT	-	Steam turbine size (hp)
NUMT	-	Number of steam turbines
RPM	-	Steam turbine speed (rpm)
/IWEATH/		
IBON	-	Hour of seasonal boiler start-up (hour of year)
IBOFF	-	Hour of seasonal boiler shut-down (hour of year)
ICON	-	Hour of seasonal chiller start-up (hour of year)
ICOFF	-	Hour of seasonal chiller shut-down (hour of year)
/IXYZ/		
$IXYZ_{1-9}$	-	Error counter array for subroutine EQUI5

TABLE 4.4 (CONT'D)

/MISC/		
EFF	-	Pump and fan motor efficiency
PWOL	-	Power of external lighting (KW)
KFLCV	-	Type of floor covering (1=bare concrete; 2=tile; 3=carpeting)
CINSL	-	Floor insulation conductance (Btu/hr-sq-ft-^{o}F)
DINSL	-	Floor insulation thickness (ft)
DDF	-	Density of diesel fuel, set = 1.0
DHO	-	Density of heating oil, set = 1.0
CFMBN	-	Building total minimum outside air (cu ft/min)
CFMBX	-	Building total design load supply air (cu ft/min)
CFMBE	-	Building total exhaust air (cu ft/min)
PWBIL	-	Building peak base power load (KW)
TFBHP	-	Total fan brake horsepower (bhp)
IHSRT	-	Hour of year at which simulation may begin
IHSTP	-	Hour of year at which simulation may end
NCASE	-	Number of cases to be run
QRCNM	-	Monthly accumulation of chiller loads not met due to undersizing (KBTU)
QRPNM	-	Monthly peak chiller load not met (KBH)
IHRNM	-	Number of hours chiller load not met
QBCNM	-	Monthly accumulation of boiler loads not met due to undersizing (Btu)
QBPNM	-	Monthly peak boiler load not met (Btu)
IHBNM	-	Number of hours boiler load not met
$CFMIN_k$	-	Fan system minimum outside air (CFM)

TABLE 4.4 (CONT'D)

/RESF/		
NRES	-	Number of user defined internal response factor surfaces
IRFL	-	Number of response factor terms
CRFL	-	Common ratio
FLRY	-	Y-series of response factor values
FLRZ	-	Z-series of response factor values
/RSET/		
NRSET	-	Number of reset schedules
$TOALO_{nr}$	-	Low outside air temperature at which system temperature is THI_{nr} reset schedule nr (^{o}F)
$TOAHI_{nr}$	-	High outside air temperature at which system temperature is TLO_{nr}, reset schedule nr (^{o}F)
TLO_{nr}	-	Low system fluid temperature, reset schedule nr (^{o}F)
THI_{nr}	-	High system fluid temperature, reset schedule nr (^{o}F)
/SCHDI/		
NDTS	-	Number of daily thermostat schedules
IVTSD	-	Thermostat type (0=none, 1=proportional, 2=deadband)
VTSD1	-	Thermostat hi limit temperature (^{o}F)
VTSD2	-	Thermostat lo limit temperature (^{o}F)
NRSCH	-	Number of temperature reset schedule
NSCHM	-	Unused
STDS	-	User defined operating schedule profiles
SCHD	-	Operating schedule matrix
NWSC	-	Number of weekly schedules
IWSCT	-	Unused
ISTT	-	Weekly schedule day indices
NYTS	-	Number of yearly thermostat schedules
IWTS	-	Seasonal schedule week indices
IYTS	-	Seasonal starting hours

TABLE 4.4 (CONT'D)

/STEAM/		
TESTM	-	Boiler supply and absorption chiller entering steam temperature (°F)
PESTM	-	Boiler supply and absorption chiller entering steam pressure (psig)
TPS	-	Steam turbine entering steam temperature (°F)
PPS	-	Steam turbine entering steam pressure (psig)
/SYSTEM/		
ISYS	-	Unused
SF	-	Monthly building electrical demand
/TWR/		
NCTWR	-	Number of cooling towers
ICTOPT	-	Cooling tower simulation option code 0 = Built-in performance 1 = User-defined performance
TECMN	-	Cooling tower water low limit temperature (°F)
TCRIS	-	Cooling tower water temperature rise (°F)
CTPKW	-	Cooling tower peak KW
CFMCT	-	Cooling tower air flow (cu ft/min)
/UNITS/		
IBOIL	-	Boiler on/off flag (1=on; 0=off)
ICHIL	-	Chiller on/off flag (1=on; 0=off)
IFAN	-	Fan system shut-off flag (0=fans run continuously, 1=fans may be shut off, 2=fans and baseboard radiators may be shut off)
/VTCNTR/		
IPL	-	Plenem indicator
/VTDATA/		
AD	-	Area of delayed surface
AQ	-	Area of the quick surface
AUF	-	Area of underground floor

TABLE 4.4 (CONT'D)

AW	-	Area of window
FIHTS	-	The U*A for the quick internal surface
FLORB	-	Floor area of space, sq. ft.
FUF	-	U-factor for underground floor
ID	-	Indices of the delayed surfaces associated with each space
IHTS	-	Indices of internal heat transfer surface associated with each space
IMULT	-	Space multiplier, or number of repeats
IQ	-	Indices of quick surfaces associated with each space
IR	-	Number of response factors
IRF	-	Index of delayed surface response factor type
ISPC1	-	Spaces connected to internal surface
ISPC2	-	" " " " "
ISQ	-	Surface roughness index
IUF	-	Indices of underground floors associated with each space
IW	-	Indices of windows associated with each space
NC	-	Number of delayed ceilings in the space
ND	-	Number of delayed surfaces in space
NDB	-	Number of delayed surfaces
NFN	-	Number of delayed furnishings in the space
NF	-	Number of delayed floors in the space
NIHT	-	Number of internal heat transfer surfaces
NIHTS	-	Number of internal heat transfer surfaces
NQ	-	Number of quick surfaces in space

TABLE 4.4 (CONT'D)

NQB	-	Number of quick surfaces
NRF	-	Number of response factor types
NS	-	Number of spaces
NUFB	-	Number of underground floors
NUF	-	Number of underground floors
NW	-	Number of windows in space
NWB	-	Number of windows
RATOS	-	Limiting ratio of response factors
RX	-	Response factors
RY	-	" "
RZ	-	" "
TSPAC	-	Temperature that the constant load was outside air file
UGW	-	Heat transfer coefficient of glass without outside air film
UQ	-	Heat transfer coefficient without the outside air film
WOF	-	Weight of floor in lb./sq. ft.
<u>/VTHRLY/</u>		
SUM4	-	Numerator for variable temperature calculation equation
SUM5	-	Denominator for variable temperature calculation equation
JDAY	-	Type of day
IDT	-	Weekday/weekend indicator (1=weekday, 2=weekend)
IITIME	-	Hour of day index
IPOSE	-	Hourly print flag
KEASON	-	Season of year indicator
IWS	-	Wind speed (knots)

TABLE 4.4 (CONT'D)

ITIME	-	Hour of day (D-23)
ISTRT	-	Hour of year analysis begins
IEND	-	Hour of year analysis ends
/VTSRF/		
NSRF	-	Number of space response factors
ETEMP	-	Difference between initial space temperature and corrected space temperature (^{o}F)
SRF	-	Space response factors
/VTTEMP/		
SMH	-	Maximum space heating (Btu)
SMC	-	Maximum space cooling (Btu)
SLT	-	Lowest space temperature (^{o}F)
SHT	-	Highest space temperature (^{o}F)
ITSMH	-	Time of occurance of maximum space heating
ITSMC	-	Time of occurance of maximum space cooling
ITSLT	-	Time of occurance of lowest space temperature
ITSHT	-	Time of occurance of highest space temperature
SIHTC	-	Sum of U*A for internal heat transfer surfaces
ITMAT	-	Space temperature frequency matrix
RANGE	-	Temperature ranges for report
/ZONE1/		
QS_z	-	Zone sensible load (Btu/hr)
QL_z	-	Zone latent load (Btu/hr)
$QLITE_z$	-	Light heat into ceiling plenum above zone (Btu/hr)
$SLPOW_z$	-	Space light and power (KW)
$QSINF_z$	-	Zone sensible loss due to infiltration (Btu/hr)
$QLINF_z$	-	Zone latent loss due to infiltration (Btu/hr)
$STEMP_z$	-	Space temperature at a given hour (^{o}F)
$UCFM_z$	-	Air flow through zone if it is a plenum space (ft^3/min)

TABLE 4.4 (CONT'D)

TSP_z	-	Zone set point temperature (^oF)
VOL_z	-	Zone volume (ft^3)
TOA	-	Outside air dry-bulb temperature (^oF)
WOA	-	Outside air humidity ratio ($\frac{lbm\text{ -}H2O}{lbm\text{-}dry\ air}$)
HOA	-	Outside air enthalpy (Btu/lbm)
DOA	-	Outside air density (lbm/ft^3)
PATM	-	Barometric perssure (in.Hg.)
TCO	-	Changeover temperature (^oF)
KBLDG	-	Heat conservation building flag
KMAX	-	Number of energy distribution systems
IZNMX	-	Number of zones to be studied
MSTRT	-	Month in which study begins
NDAYS	-	Length of study (days)
MEND	-	Last month of study
$IMAX_m$	-	Number of hours in month m (m = 1,12)
/ZONE2/		
CFM_i	-	Supply air flow rate, zone i (constant)(cu ft/min)
$CFMS_i$	-	Supply air flow rate, zone i (variable)(cu ft/min)
$CFMR_i$	-	Return air flow rate, zone i (cu ft/min)
$CFMX_i$	-	Exhaust air flow rate, zone i (cu ft/min)
$ZMASS_i$	-	Supply air mass flow, zone i (constant)(lbm-air/hr)
$ZMAS_i$	-	Supply air mass flow, zone i (variable)(lbm-air/hr)
$ZMASR_i$	-	Return air mass flow, zone i (lbm-air/hr)
$ZMASX_i$	-	Exhaust air mass flow, zone i (lbm-air/hr)
QSI_i	-	Sensible thermal load, zone i (Btu/hr)
TS_i	-	Supply air temperature, zone i (^oF)
WZ_i	-	Calculated humidity ratio, zone i (lbm-H2O/lbm-dry air)
$WREQD_i$	-	Required humidity ratio, zone i (lbm-H2O/lbm-dry air)

TABLE 4.4 (CONT'D)

$ALFBR_i$	-	Active length baseboard radiation, zone i (lin.ft)
$CBTU_i$	-	Baseboard radiation heat output per linear foot at standard conditions, zone i (Btu/hr-lin.ft)
$QCLNM_i$	-	Monthly accumulation of cooling loads not met, (zone i) * $MULT_i$ (Btu)
$QCPNM_i$	-	Monthly peak cooling load not met, zone i (Btu/hr)
$IHCNM_i$	-	Number of hours cooling load not met, zone i (hrs)
$QHLNM_i$	-	Monthly accumulation of heating loads not met, (zone i) * $MULT_i$ (Btu)
$QHPNM_i$	-	Monthly peak heating load not met, zone i (Btu/hr)
$IHHNM_i$	-	Number of hours heating load not met, zone i (hrs)
$IPLEN_i$	-	LOAD program space number of plenum above zone i
$SPACN_{k,j}$	-	Number of space as per LOAD program, applied to system k, zone j
$MULT_i$	-	Multiplication factor, zone i
I	-	Variable subscript i
/ZONE3/		
$IPLS_i$	-	Space plenum indicator (0=no, 1=yes)
$HCAPD_i$	-	Heating capacity (Btu/hr), zone i
$CCAPD_i$	-	Cooling capacity (Btu/hr), zone i
$WOFN_i$	-	Weight of furnishings in space i (lbs/ft^2)
IVS_i	-	Space number below plenum space
$CFMP_i$	-	Plenum airflow (CFM), space i
$ISURF_{i,3}$	-	Type of internal surface type (1=floor, 2=ceiling, 3=furnishing)
$IFD_{i,3}$	-	Response factor index number
$AFLOR_{i,3}$	-	Area of surface (ft^2)
$IVON_{i,2}$	-	Plenum fan hour on
$IVOFF_{i,2}$	-	Plenum fan hour off
$IPSA_i$	-	Flag indicating that a space has a plenum (0=no, 1=yes)

TABLE 4.4 (CONT'D)

$KSPA_{50}$	-	Fan system index zone is connected to
$JSPA_{50}$	-	Internal SESP fan/zone sequence number
NSPA	-	Total number of fan system zones

CALCULATION SEQUENCE : ROUTINE SESIN

1. Call subroutine VTIN, which reads the building description data file created by TLAP.

2. Call subroutine CSIN, which reads card input data.

3. Call subroutine VTCSRF, which calculates the space response factors.

4. Call subroutine VTINIT, which performs initialization for variable temperature calculations.

5. If output tape file is desired, write output tape header data which includes variables FAC, CITY, ENGR, PROJ, and DATE.

6. Call subroutine FSIZE to calculate the following quantities:

   PWBIL - Peak building base power (KW)

   CFM_i - Peak supply air volume, zone i (CFM)

   $CFMR_i$ - Return air volume, zone i (CFM)

   $CFMAX_k$ - Total air supplied by fan system k (CFM)

   $CFMEX_k$ - Auxiliary exhaust air removed from zones served by system k (CFM)

   $CFMIN_k$ - Minimum outside air required, fan system k (CFM)

   $ALFAM_k$ - Fraction of minimum outside air required for fan system k

   $OACFM_k$ - Minimum outside air, system k (CFM)

   DRA_k - Initialize return air density, system k (lbm/ft^3)

   WRA_k - Initialize return air humidity ratio, system k ($lbm\text{-}H_2O/lbm\text{-}dry\ air$)

   $FBHPS_k$ - Supply fan brake horsepower required, fan system k (bhp)

   $FBHPR_k$ - Return fan brake horsepower required, fan system k (bhp)

   $FBHPE_k$ - Exhaust fan brake horsepower required, fan system k (bhp)

   TFBHP - Summation of fan brake horsepowers, all systems (bhp)

   $DTFNS_k$ - Temperature rise across supply fan, system k (^oF)

$DTFNR_k$ - Temperature rise across return fan, system k (^oF)

$ZMAS_i$ - Supply air mass flow to zone i at design load (lbm/hr)

$ZMASX_k$ - Exhaust air mass flow from zone i (lbm/hr)

$ZMASR_i$ - Return air mass flow from zone i at design load (lbm/hr)

$FMASS_k$ - Total supply air mass flow of system k at design conditions (lbm/hr)

$FMASX_k$ - Total exhaust air mass flow of system k (lbm/hr)

$FMASR_k$ - Total return air mass flow of system k at design conditions (lbm/hr)

CFMBE - $\sum_{k=1,\ KMAX} CFMEX_k$

CFMBX - $\sum_{k=1,\ KMAX} CFMAX_k$

CFMBN - $\sum_{k=1,\ KMAX} CFMIN_k$

7. Call subroutine ESIZE to calculate the following quantities.

CAPH - Total heating plant capacity (MBTU/hr)

CAPC - Total cooling plant capacity (tons)

SZT - Size of steam turbines (hp)

NUMT - Number of steam turbines

CFMCT - Cooling tower air flow (CFM)

GPMCL - Chilled water flow (gpm)

GPMCN - Condenser water flow (gpm)

GPMBL - Boiler water flow (gpm)

HPCTF - Cooling tower fan horsepower (bhp)

CTPKW - Cooling tower peak KW (KW)

HPCLP - Chilled water pump horsepower (bhp)

HPCNP - Condenser water pump horsepower (bhp)

HPBLP - Boiler water pump horsepower (bhp)

HPBLA - Boiler auxiliary horsepower (bhp)

HPHEQ - Total heating equipment horsepower (bhp)

HPCEQ - Total cooling equipment horsepower (bhp)

BKWDM - Building peak electrical demand (KW)

EGCAP - Capacity of engine/generators (KW)

M4 - Quantity of engine/generators

8. Initialize the cooling tower fan switch KCTF=0

ROUTINE SMEXEC

9. Begin monthly simulation performing calculations 10 through 36 for period from MSTRT to MEND

10. Begin hourly simulation performing calculations 11 through 35 for period from 1 to IMAXM

11. Read hourly weather data which includes:

IHOUR - Hour number, hour of year

IMOY - Month of year

IDOM - Day of month

NDOW - Day of the week

IHOD - Hour of the day

ISUN - Sun index which indicates whether or not the sun is up

TOA - Outside air dry-bulb temperature (^{o}F)

TWB - Outside air wet-bulb temperature (^{o}F)

VEL - Wind velocity (knots)

WOA - Outside air humidity ratio (lb water/lb dry air)

PATM - Barometric pressure (inches of mercury)

DOA - Outside air density (lbm/ft^3)

HOA - Enthalpy of outside air (Btu/lb dry air)

JSC - Day type (i.e., weekday, Saturday, Sunday, Holiday, Christmas)

CCM - Cloud cover modifier (0 = opaque, 1 = clear)

11.1 Determine if boiler is on (0 = off, 1 = on)

IBOIL = 0

If IBON $\leq$ IHOUR $\leq$ IBOFF, then IBOIL = 1

11.2 Determine if chiller is on (0 = off, 1 = on)

ICHIL = 0

If ICON $\leq$ IHOUR $\leq$ ICOFF, the ICHIL = 1

11.3 Convert wind velocity from knots to miles/hour

VWIND = VEL * 1.151

12. Call subroutine VTPOHD, which sets the printout switches.

13. Read following zone load data for each zone on tape.

IS_z - Space number

$HRLDS_z$ - Zone sensible load (Btu/hr)

QL_z - Zone latent load (Btu/hr)

$HRLDL_z$ - Zone lighting load picked up by return air (Btu/hr)

$SLPOW_z$ - Zone internal lighting and machinery power consumption (KW)

$QSINF_z$ - Zone sensible infiltration load (Btu/hr)

$QLINF_z$ - Zone latent infiltration (Btu/hr)

$STEMP_z$ - Zone temperature (^oF)

$UCFM_2$ - Zone air flow if plenum space (CFM)

14. Locate proper starting point on load tape.

If IHOUR is for 1st day of the 1st month, i.e., if M=MSTRT and IH $\leq$ 24, go to calculation 33.

If IHOUR < IHSRT, go to calculation 33.

If IHOUR > IHSTP, go to calculation 34.

15. Set exterior lights

If ISUN < 1, exterior lights are OFF; therefore, set PWEL = 0.0

If ISUN > 1, exterior lights are ON; therefore, set PWEL = PWOL

16. Determine plant capacities for this hour.

16.1 Cooling

16.1.1 Call subroutine CLGTWR to determine the entering and leaving condenser water temperatures (TECON and TLCON) and the tower fan switch status (KCTF).

16.1.2 Call subroutine CHLADJ to determine the adjusted capacity of each chiller type (CAPCA) and sum into CAPCAT.

CAPCAT = Σ CAPCA * NUMC(NNUMC)

For NNUMC = 1 to NCHIL

16.2 Heating

Sum the size of each boiler type (SZB) into CAPHAT.

CAPHAT = Σ SZB(NNUMB) * NUMB(NNUMB)

For NNUMB = 1 to NBOIL

16.3 DX/HEAT PUMPS

For each unit IDX = 1 to NDXHP, determine following:

16.3.1 If NDXHP = 0, go to calculation 17.

16.3.2 Call DXHP to determine cooling (MODE = 1) capacity, DXCAPC(IDX)

16.3.3 If unit is DX only (IDXHP = 1), go to calculation 17.

16.3.4 Call DXHP to determine heating (MODE = 2) capacity, DXCAPH(IDX).

17. Initialize plant adjustment flags and counter

IFGAD1 = 0

KFGAD2 = 0

KADJ = 1

18. Initialize central plant and DX/heat pump heating and cooling capacity adjustment factors

If first iteration this hour (KADJ = 1), initialize

RHOC = 1.0 central plant cooling

RHOH = 1.0 central plant heating

RHOCHP = 1.0 DX or heat pump cooling

RHOHHP = 1.0 heat pump heating

19. For each space IS1 = 1 to NSPA perform following calculations:

19.1 If first iteration for this hour, call subroutine VTHOUR, which calculates the hourly interproducts of the space temperatures and response factors, SUM4(IS1) and SUM5(IS1).

19.2 Set the space heating and cooling adjustment factors depending upon if its source of energy is the main plant or DX/heat pumps.

19.2.1 If main plant set

RRHOH = RHOH(KADJ)

RRHOC = RHOC(KADJ)

Go to calculation 19.3.

19.2.2 If DX/HEAT PUMPS set

RRHOH = RHOHHP(KADJ,IDX)

RRHOC = RHOCHP(KADJ,IDX)

19.3 Call subroutine VTLOAD, which calculates the space temperature STEMP(IS), heating/cooling extraction rate, QS(IS), depending upon values of RRHOH and RRHOC.

19.4 End of space loop.

20. Begin air distribution system simulation loop performing calculations 20 through 22. For each AHU, K = 1 to KMAX.

Check type of fan system.

If $KFAN_k$ = 1, call RHFS
2, call MZDD
3, call MZDD
4, call SZRHT
5, call RHFS
6, call RHFS
7, call FHTG
8, call FCOIL
9, call FCOIL
10, call INDUC
11, call INDUC
12, call VARVL
13, call RHFS

Each of the above subroutines simulates the performance of a given system and returns the following quantities:

- $QFPC_k$ - system cooling requirement (Btu/hr)
- $QFPH_k$ - system primary heating requirement (Btu/hr)
- $QFPRH_k$ - system reheat coil heating requirement (Btu/hr)
- $QFPPH_k$ - system preheat coil heating requirement (Btu/hr)
- TQB_k - heating requirement of baseboard radiation in zones served by system k (Btu/hr)
- $WATER_k$ - steam humidifier water requirement (lbm/hr)
- PWL_k - base power (KW)
- TNFBP - total net fan brake horsepower, all fan systems (bhp)

21. Sum building hourly cooling, heating, reheat, zone power, and water resource requirements.

21.1 Main plant

$QHBC = \Sigma\ QFPC_k$, for k=1, KMAX

$QHBH = \Sigma\ (QFPH\ \ + QFPPH\ \ + TQB$ for k=1, KMAX

$QHBRH = \Sigma\ QFPRH_k$, for k=1 KMAX

$PWILM = \Sigma\ PWL_k$, for k=1, KMAX

$H2O\ = \Sigma\ WATER_k$, for k=1, KMAX

$CPLOAD = \Sigma\ QFPC_k$, for k=1, KMAX

$HPLOAD = \Sigma\ (QFPH_k + QFPPH_k + TQB_k(-WATER_k * 1000.))$, for k=1, KMAX

If REHEAT is same as boiler, (KREHT=0), HPLOAD = HPLOAD + Σ QFPRH, for k=1, KMAX

21.2 DX/HEAT PUMPS

21.2.1 Cooling

21.2.1.1 Call DXHP to determine power (CPOWI) required to meet cooling load (QFPC)

21.2.1.2 Adjust cooling plant load parameters

CPLOAD = CPLOAD - QFPC

HPCLG(IDX) = HPCLG(IDX) + QFPC

21.2.2 Heating

21.2.2.1 If unit is DX, go to calculation 22.

21.2.2.2 Call DXHP to determine power (HPOWI) required to meet heating load (QFPH) and supplementary heat (QHSUP) requirements.

21.2.2.3 Adjust heating plant load parameters

HPLOAD = HPLOAD - QFPH

HPHTG(IDX) = HPHTG(IDX) + QFPH

21.2.2.4 Calculate net load to central equipment

QHBR2 = QHBR2 + QHSUP

QHBC2 = QHBC2 - QFPC

21.2.2.5 DXHP Power accounting

ELEH2 = ELEH2 + HPOWI

ELEC2 = ELFC2 + CPOWI

21.2.2.6 If reheat is same as boiler, (KREHT=0) add supplementary heat to heating plant.

HPLOAD = HPLOAD + QHSUP

22. End of air distribution system loop.

23. Process loads

23.1 Call subroutine PROCES to determine process loads energy requirements.

BOILER-PRBLR
GAS-PRGAS
OIL-PROIL
STEAM-PRSTM
ELECTRICITY-PRELEC

23.2 Add boiler process load to heating plant

QHBH = QHBH + PRBLR

HPLOAD = HPLOAD - PRBLR

(PRBLR is a (-) quantity)

24. Compare plant capacity to requirements for the hour.

24.1 If iteration (KADJ) is greater than 5, go to calculation 25.

24.2 Cooling plant check

24.2.1 Set CRHO = 1.0

CRATIO = 1.0 E10

If CAPACAT $\neq$ 0. , CRATIO = CPLOAD/CAPCAT

If ICHIL = 0, or SZC(1) $\leq$ 0., CRATIO = 0.0

24.2.2 If CRATIO > 1.02, adjust cooling plant capacity factor

CRHO = RHOC(KADJ)/CRATIO

Set IFGAD2 = 1

If CRATIO $\leq$ 1.02, CRHO = RHOC(KADJ)

24.3 Heating plant check

24.3.1 Set HRHO = 1.0

24.3.2 Set HRATIO = 1.0 E10

CAPAVL = CAPHAT + PRBLR

If CAPAVL > 0. , HRATIO = (HPLOAD + PRBLR)/CAPAVL

If IBOIL = 0, or SZB(1) ≤ 0. , HRATIO = 0.0

24.3.3 If HRATIO ≤ 1.02, HRHO = RHOH(KADJ), go to 24.4

24.3.4 If HRATIO > 1.02

HRHO = RHOH(KADJ)/HRATIO

If CAPAVL _ 0. , HRHO = 0.0

IFGT = IFGAD2, IFGAD2 = 1

If CAPAVL ≤ 0. , and KADJ > 1, and IFGT = 0, IFGAD = 0

24.4 DX Cooling check

For each DX unit, IDX = 1 to NDXHP, perform the following calculations.

24.4.1 HPHTG(IDX) = HPHTG(IDX) * (-1.0) [i.e., change sign]

DXRHOC(IDX) = 1.0

DXRHOH(IDX) = 1.0

24.4.2 HPRATC = 1. E10

If DXCAP(IDX) ≠ 0, HPRATC = HPCLG(IDX)/DXCAPC(IDX)

24.4.3 If HPRATC ≤ 1.02, go to calculation 24.5

24.4.4 If HPRATC > 1.02, set

DXRHOC(IDX) = RHOCHP(KADJ,IDX)/HPRATC

IFGAD2 = 1.

24.5 Heat pump heating check

For each heat pump unit, IDX = 1 to NDXHP, perform the following calculations.

24.5.1 DXRHOC(IDX) = RHOCHP(KADJ,IDX)

24.5.2 If IDXHP(IDX) = 2, HPRATH = 1.0 E10

If DXCAPH(IDX) ≠ 0.0

HPRATH = HPGTG(IDX)/DXCAPH(IDX)

24.5.3 HPRATH = HPHTG(IDX)/DXCAPH(IDX)

24.5.4 If HPRATH ≤ 1.02, go to calculation 24.6.

24.5.5 If HPRATH > 1.02, set

DXRHOH(IDX) = RHOHHP(KADJ,IDX)/HPRATH

IFGAD2 = 1

24.6 Check to see if any of the capacity adjustment factors have been changed during this iteration.

24.6.1 If IFGAD2 = 1, go to calculation 24.7.

24.6.2 If IFGAD2 = 0, go to calculation 25.

24.7 KADJ = KADJ + 1

RHOC(KADJ) = CRHO

RHOH(KADJ) = HRHO

If NDXHP > 0

For IDX = 1 to NDXHP

RHOCHP(KADJ,IDX) = DXRHOC(IDX)

RHOHHP(KADJ,IDX) = DXRHOH(IDX)

24.8 Reset IFGAD2 = 0 and return to calculation 18 for another iteration.

25. Determine plant energy requirements

QHBC = (QHBC - TQCCNM)/12000.

QHBH = QHBH - H2O * 1000.

QHBH2 = QHBH2 - H2O * 1000.

If KREHT = 4, go to 26.

QHBH = QHBH + QHBR4

QHBH2 = QHBH2 + QHBR2

QHBRH = 0.

QHBR2 = 0.

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

ELDEM = PWILM + PWEL + TNFBP * 0.7457

27. Cooling Tower Simulation

27.1 If chiller is off (ICHIL = 0) go to calculation 28.

27.2 Call subroutine CLGTWR to determine electrical power requirements (TWRELC) for the cooling tower.

27.3 Adjust ELDEM for cooling equipment

ELDEM = ELDEM + (HPCNP + HPCLP) * 0.7457 + TWRELC

28. Add heating plant electrical power requirement to ELDEM

28.1 If boiler is off (IBOIL=0) go to calculation 29.

28.2 Adjust ELDEM for heating equipment

ELDEM = ELDEM + HPHEQ * 0.7457

29. Sum space temperatures into temperature distribution profile matrix. For each space, IS = 1 to NSPA, perform the following calculations.

29.1 Make assignments:

STP = STEMP(IS)

IREF = IWOP(IS)

HERE = FOLK(IREF,JSC,IHOD)

CALL TBAND to return ITM, ISOC

30. Call EQUI to calculate:

GASC - natural gas required for cooling

GASH - natural gas required for heating

GASG - natural gas required for on-site generation

OILC - oil required for cooling

OILH - oil required for heating

STMC - steam required for cooling

STMH - steam required for heating

ELEC - electricity required for cooling

ELEH - electricity required for heating

FUEL - diesel fuel required for on-site generation

31. Add in DX/HP tower requirements

ELEC = ELEC + ELEC2

ELEH = ELEH + ELEH2

32. Keep running total of hourly energy and resource consumption for each month. Update the following quantities each hour. See subroutine ENGY for explanation of variables.

ENGY (M, 2, 3)	ENGY (M, 2, 13)
ENGY (M, 2, 4)	ENGY (M, 2, 14)
ENGY (M, 2, 5)	ENGY (M, 2, 15)
ENGY (M, 2, 6)	ENGY (M, 2, 16)
ENGY (M, 2, 7)	ENGY (M, 2, 17)
ENGY (M, 2, 8)	ENGY (M, 2, 18)
ENGY (M, 2, 9)	ENGY (M, 2, 19)
ENGY (M, 2, 10)	ENGY (M, 2, 20)
ENGY (M, 2, 11)	ENGY (M, 2, 21)
ENGY (M, 2, 12)	ENGY (M, 2, 22)

33. Keep a record of maximum hourly energy and resource demands by checking, at the end of each hour's calculation, and updating the following energy demand quantities. See subroutine ENGY for explanation of variables.

ENGY (M, 1, 1)	ENGY (M, 1, 12)
ENGY (M, 1, 2)	ENGY (M, 1, 13)
ENGY (M, 1, 3)	ENGY (M, 1, 14)
ENGY (M, 1, 4)	ENGY (M, 1, 15)
ENGY (M, 1, 5)	ENGY (M, 1, 16)
ENGY (M, 1, 6)	ENGY (M, 1, 17)
ENGY (M, 1, 7)	ENGY (M, 1, 18)
ENGY (M, 1, 8)	ENGY (M, 1, 19)
ENGY (M, 1, 9)	ENGY (M, 1, 20)
ENGY (M, 1, 10)	ENGY (M, 1, 21)
ENGY (M, 1, 11)	ENGY (M, 1, 22)

34. Write hourly weather and system loads to output tape, if required. These include the following variables.

IHOUR - Current Hour (hour of year)

IMOY - Month of Year (1 - 12)

IDOM - Day of Month (1 - 31)

IHOD - Hour of Day

ITOA - Ambient Dry-Bulb Temperature (^oF)

ITWB - Ambient Wet-Bulb Temperature (^oF)

WOA - Ambient Humidity Ratio (lbs-H_2)/lb-dry air)

PATM - Barometric Pressure (in. Hg)

DOA - Ambient Air Density (lbm/ft^3)

TNFBP - Total Net Fan Brake horsepower (bhp)

TABCD - Total Power of Building (KW)

BGAS - Building Natural Gas Requirement (therms)

OILH - Building Heating Oil Requirement (gals)

Repeat for each distribution system:

$KFAN_k$ - Energy Distribution System Type No. (1 - 13)

QKC_k - System Cooling Requirement (Btu)

QKH_k - System Heating Requirement (less elect. resist. rehtg.) (Btu)

$QKKW_k$ - Electric Resistance Reheat Requirement (Btu)

$PWLK_k$ - Base Power Requirement of Zones served by this system (KW)

$H2OK_k$ - Humidification Water Requirement (lbs. H_2O)

ZERO - Reserved (=0.0)

$TKHL_k$ - Hot Deck Temperature or AHU Leaving Temperature (^oF)

$TKCD_k$ - Cold Deck Temperature (^oF)

35. End of hourly simulation loop for current month.

36. End of monthly loop.

ROUTINE SCLOSE

37. Write out summary of equipment sizes. See User's Manual.

38. Write out temperature distribution profile. See User's Manual.

39. Call ENGY4 to write out annual summary of building monthly energy and resource consumption and demands. See User's Manual.

40. Call EXSUM to write out executive summary. See User's Manual.

41. Call ECON to write out economic summary. See User's Manual.

42. End of program.

4.3 ALGORITHMS OF SUBROUTINES

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

If RAT > 1.18, RAT = 1.18

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

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

3. Calculate the total capacity factor.

RAT = 0.91 * CMULT * RAT

where 0.91 is fouling factor.

4. Calculate the full load steam rate (lb/hr-ton).

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

5. Determine the part load steam consumption.

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

6. Calculate saturation temperature

TSAT = 1.0/(0.0017887-0.00011429*ALOG(PESTM+14.7))-460.0

7. Calculate H1 and H2

H1 = 0.35333 * TSAT + 1075.666667

H2 = TSAT - 32.0

AHU

A routine to simulate the performance of air handling units calculating thermal requirements of coils, fan heat, and humidifier.

INPUT

NAHU : Air handling unit type:

1) Draw-through unit--heating coil, cooling coil, fan, discharge
2) Draw-through unit--heating coil, cooling coil with face and bypass dampers, fan, discharge. When heating required, bypass full open and heating coil modulates to meet load, cooling coil off. When cooling required, heating coil locked out, cooling coil runs wild, dampers modulate to meet required dry bulb temperature.

PATM : Barometric pressure (in. Hg).

MFAN : Fan mass air flow (lbm-air/hr).

NVFC : Fan volume control index (see PTLD).

PCTLD : Fan full load fraction.

DTFAN : Temperature rise across fan at full load (°F).

TLVG : Desired air temperature leaving AHU (°F).

TCD : Cold deck temperature (°F).

H2ORD : Net humidity control zone water requirement.

MZONE : Humidity control zone mass air flow (lbm-air/hr).

WZ : Humidity control zone humidity ratio (lbm-H_2O/lbm-dry air).

TMA : Inlet dry bulb temperature (°F).

WMA : Inlet humidity ratio (lbm-H_2O/lbm-dry air).

DMA : Inlet air density (lbm/ft^3).

OUTPUT

QCC : Cooling coil load (Btu/hr).

SHR : Sensible heat ratio.

QHC : Heating coil load (Btu/hr).

WLVG : Humidity ratio entering humidifier section (lbm-H_2O/lbm-dry air) air).

DLVG : Air density entering humidifier section (lbm/ft^3).

WSUP : Humidity ratio after humidifier section (lbm-H_2O/lbm).

WATER : Water added to air by humidifier (lbm-H_2O/hr).

CALCULATION SEQUENCE

1. Determine air handler type

   If NAHU = 1 (single draw-through unit)

   Go to calculation 2.

   If NAHU = 2 (draw-through unit with bypass around cooling coil)

   Go to calculation 3.

2. Simple draw-through unit simulation (If NAHU = 1)

   Calculate required leaving coil air temperature

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

   Check mixed air temperature vs. leaving coil temperature

   If TMA < TLC,

   Calculate heating load and humidity rate

   QHC = MFAN * 0.245 * (TMA - TLC)

   QCC = 0.0

   WLVG = WMA

   SHR = 1.0

   GO TO 3.

If TMA = TLC, no load condition

QHC = 0.0

QCC = 0.0

WLVG = WMA

SHR = 1.0

GO TO 3.

If TMA > TLC,

Call subroutine CCOIL to calculate cooling coil load and humidity ratio.

QHC = 0.0

GO TO 4.

3. Draw-through unit with bypass around cooling coil (If NAHU = 2)

Calculate required leaving coil air temperature

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

Check mixed air temperature vs. leaving coil air temperature

If TMA < TLC,

Calculate heating load and humidity ratio

QHC = MFAN * 0.245 * (TMA - TLC)

QCC = 0.0

WLVG = WMA

SHR = 1.0

GO TO 3.

If TMA = TLC, no load condition

QHC = 0.0

QCC = 0.0

WLVG = WMA

SHR = 1.0

GO TO 3.

If TMA > TLC,

Call subroutine CCOIL to calculate cooling coil performance for 1.0 lbm-air/hr (QCC1).

Call subroutine MXAIR to calculate position of face and bypass dampers (ALFA = portion of air through bypass).

If ABS[(TLC-TLC2)/TLCZ] ≥ .01
TLVG = TLC2 + DTFAN * PTLD(NVFC, PCTLD)

Calculate cooling load and humidity ratio

QCC = MFAN * (1.0 - ALFA) * QCC1

4. Humidifier simulation

Using function DENSY, calculate density of air leaving fan.

If QCC > 1.0, no humidifier load

WATER = 0.0

WSUM = WLVG

If QCC ≤ 1.0, calculate supply air humidity ratio and steam humidifier water requirement.

WSUP = -H2ORD/ZONEM + WZ

Call HUM1 to limit WSUP by high limit switch on humidifier set at 80% R.H.

WATER = -MFAN * (WLVG - WSUP)

ALOG

A function to calculate the logarithm to the base 10 for a given number.

INPUT

X - Number of which logarithm to base 10 is desired.

OUTPUT

ALOG1 - Logarithm to base 10 for given x.

CALCULATION SEQUENCE

1. Calculate logarithm of X to base 10.

   $ALOG1 = 0.434294481 * LOG_e(X)$

NOTES

BRAD

A subroutine to calculate the heat (QB) added to a zone by a baseboard radiation heating system and to correpondingly adjust the zone's base sensible heat load (QS).

INPUT

RHOH - Ratio of heating plant capacity to heating plant load

QS - Base sensible heating load (Btu/hr)

TSP - Set point temperature of zone (^oF)

CBTU - Heat output of baseboard radiation at standard condition (215^oF average water temperature, 65^oF entering air temperature) (Btu/hr-lin.ft.)

ALFBR - Active length baseboard radiation (lin.ft.)

TOA - Dry-bulb temperature outside

THWHI - (^oF)

THWLO - (^oF)

TOAHI - (^oF)

TOALO - (^oF)

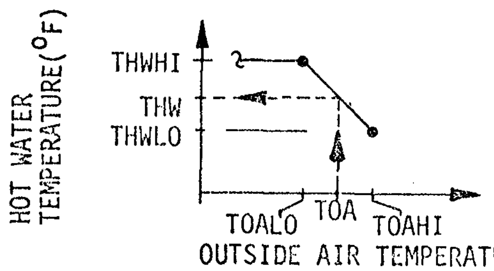


Figure 7.4 Graphic illustration of baseboard hot water temperature reset as function of outside air temperature

OUTPUT

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

CALCULATION SEQUENCE

If CBTU $\leq$ 0.0 and ALFBR $\leq$ 0.0, QB = 0.0, END

1. Baseboard heating off.

   If TOA > TOAHI,

   QB = 0.

2. Baseboard heating on.

If TOA $\leq$ TOAHI,

TAIR = TSP - 10.

Calculate THWRD using function RESET.

If THWRD < TAIR, THWRD = TAIR

Calculate baseboard heat

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

3. Adjust QS.

QS = QS - QB

CCOIL

A subroutine to simulate the performance of a cooling coil. It calculates the sensible and latent heat extracted by a cooling coil assuming it to be of adequate capacity. The coil cools air to dry bulb temperature (TDBO) and calculates the humidity ratio at that condition.

INPUT

MASS : Rate of air flow through coil (lbm-air/hr)

PATM : Barometric pressure (inches Hg.)

TDBI : Dry bulb temperature of entering air (°F)

WI : Humidity ratio of entering air (lb-H_2O/lb-dry air)

TDBO : Dry bulb temperature of leaving air (°F)

OUTPUT

WO : Humidity ratio of leaving air (lb-H_2O/lb-dry air)

QCC : Total heat extracted by coil (Btu)

SHR : Sensible heat ratio

CALCULATION SEQUENCE

1. Estimate leaving wet bulb temperature.

   TWBO = TDBO - 1.5

2. Simulate cooling coil.

   DT = TDBI - TDBO

   If DT $\leq$ 0.0,

   QCC = 0.0

   SHR = 1.0

   WO = WI

If DT > 0.0,

QSC = MASS * 0.245 * DT

Use subroutine PSY1 to calculate leaving air humidity ratio (WO)

DW = WI - WO

If DW < 0.0, WO = WI, QLC = 0.

If DW = 0.0, QLC = 0.

QCC = QSC + QLC

SHR = QSC/QCC

If DW > 0.0,

QLC = MASS * 1090.0 * DW

QCC = QSC + QLC

SHR = QSC/QCC

The functioning of the cooling coil simulation is illustrated graphically in Figure 4.5, where it is plotted on an HVAC equipment manufacturer's psychrometric chart.

It shows a strong correlation with the manufacturer's published cooling coil performance curves and it is also in accord with recommendations of Stoecker, et.al. (1973) (ASHRAE Publication No. 2290-RP-131), recommending cooling coil discharge air conditions to be 90% RH for simulation purposes when latent heat is being extracted.

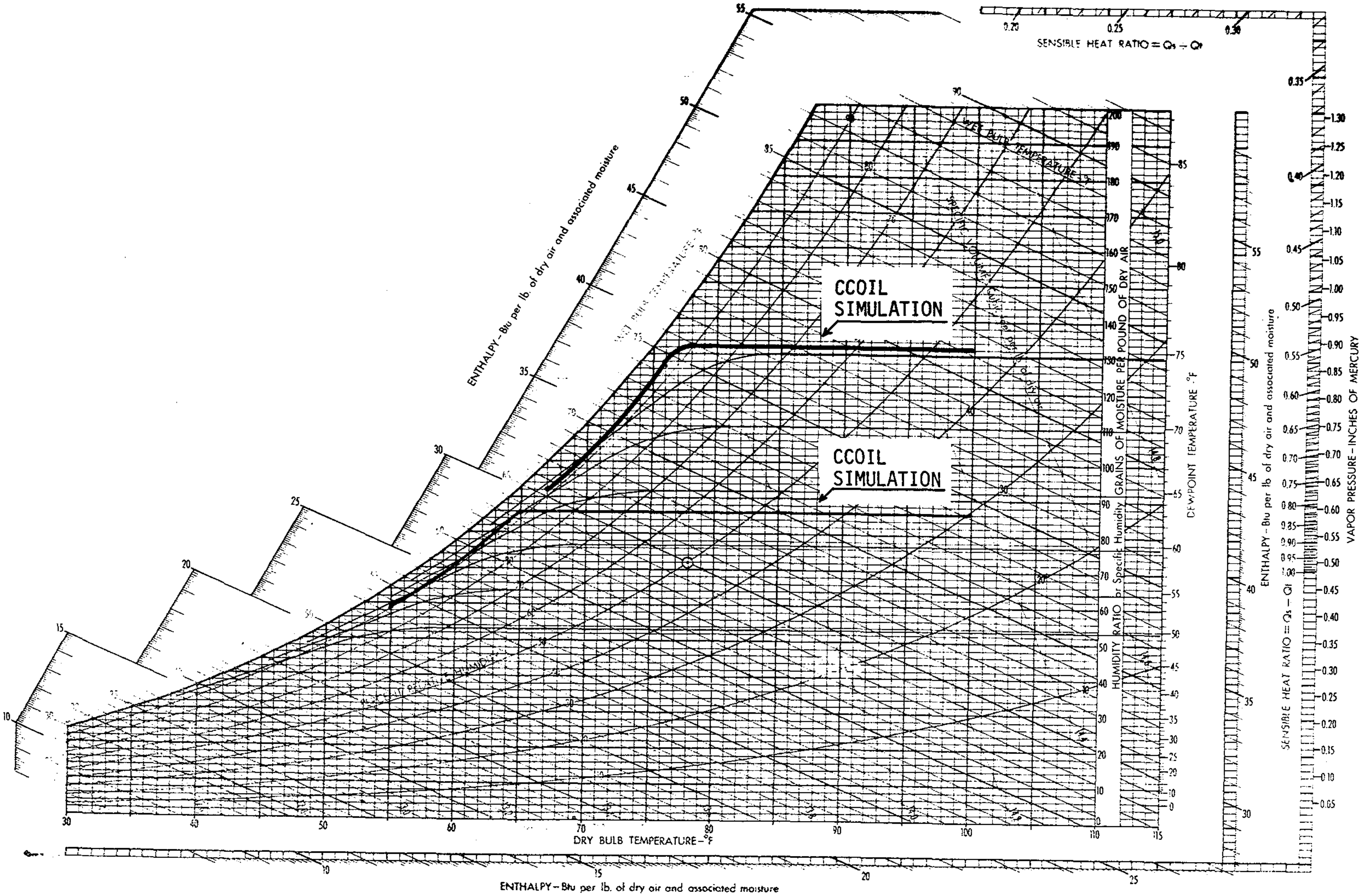


Fig. 4.5 Manufacturer's psychrometric chart illustrating the performance of CCOIL.

CENT

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

INPUT

QHBC : Hourly building cooling load (tons)

TECON : Temperature of entering condenser water (°F)

TLCHL : Temperature of leaving chilled water (°F)

FFL : Fraction of full load (decimal)

OUTPUT

POWER : Hourly electrical power consumption (kilowatt hours)

CALCULATION SEQUENCE

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

   TLCON = TECON + 10.0

2. Calculate the full load power per ton.

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

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

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

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

4. Calculate the full load power per ton.

   POPTN = POPTN - ERROR

5. Determine the total hourly part load power consumption.

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

CHLADJ

A subroutine to determine the full load capacity of cooling plants at non-standard conditions.

INPUT

NNUMC : Chiller input sequence number.

ICHIL : Chiller type.

1 = Reciprocating chiller

2 = Centrifugal chiller, hermetic

3 = Centrifugal chiller, open

4 = Absorption chiller

5 = Centrifugal chiller, steam turbine driven

IOPT : Chiller simulation code.

0 = Built-in performance

1 = User defined performance

CAPC : Chiller capacity at standard conditions (tons)

TLCHL : Leaving chilled water temperature (^{O}F)

TECON : Entering condenser water temperature (^{O}F)

TLCON : Leaving condenser water temperature (^{O}F)

PESTM : Steam pressure (PSIG)

Various items held in COMMON

OUTPUT

CAPCA : Chiller capacity at non-standard conditions (tons).

CALCULATION SEQUENCE

1. Check chiller simulation code.

   If IOPT = 1, go to calculation 6.

   If IOPT = 0, continue

2. Check chiller type for built-in performance.

If ICHIL = 1, go to calculation 3.

If ICHIL = 2,3,5, go to calculation 4.

If ICHIL = 4, go to calculation 5.

3. Reciprocating Chiller.

Determine the capacity factor which adjusts for operation at conditions other than the standard of 44°F leaving chilled water temperature and 85°F entering condenser water temperature.

3.1 A = (-4.58 E-5) * TLCHL -(4.135 E-3)

B = (2.0839 E-2) * TLCHL + (6.0706 E-1)

ADJUST = A * TECON + B

ADJUST is based on a least squares curve fit of Trane Catalog Data (Model CGWA).

3.2 If ADJUST $\leq$ 0., ADJUST = 0.

3.3 Determine adjusted capacity.

CAPCA = CAPC * ADJUST

3.4 RETURN

4. Centrifugal Chillers.

Determine the capacity factor which adjusts for operation at conditions other than the standard of 44°F leaving chilled water and 95°F leaving condenser water.

4.1 A = (-1.1439 E-4) * TLCHL -(5.7654 E-3)

B = (2.6815 E-2) * TLCHL + (8.4678 E-1)

ADJUST = A * TLCON + B

ADJUST is based on a least squares curve fit of Trane Catalog Data (Models PCV & CV).

4.2 If ADJUST $\leq$ 0., ADJUST = 0.

4.3 Determine adjusted capacity.

CAPCA = CAPC * ADJUST

4.4 RETURN

5. Absorption Chillers.

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

5.1 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

RAT is based on a least squares curve fit of Carrier Catalog Data (Model 16HA)

5.2 ADJUST = 0.91 * RAT

where 0.91 is a correction factor for average fooling factors.

5.3 If ADJUST $\leq$ 0., ADJUST = 0.

5.4 Determine adjusted capacity

CAPCA = CAPC * ADJUST

5.5 RETURN

6. User Defined Chiller.

6.1 Call subroutine CHLUSR which determines CAPCA at 100% load.

6.2 RETURN

CHLUSR

A subroutine to determine the performance characteristics of user-defined chillers.

INPUT

NNUMC : Chiller input sequence number

TLCON : Leaving condenser water temperature (^{o}F)

FFL : Fraction of full load (decimal)

Various items held in COMMON.

OUTPUT

CAPC : Chiller capacity (tons)

CPOW : Chiller power (KW)

CALCULATION SEQUENCE

1. Obtain proper used-defined input data.

   TCON11(J) = TCON1 (NNUMC,J)

   TCON22(J) = TCON2 (NNUMC,J)

   CCAPP(J) = CCAP (NNUMC,J)

   CPPWRR(J) = CPPWR (NNUMC,J)

   CPPLL(J) = CPPL (NNUMC,J)

   CPPPP(J) = CPPP (NNUMC,J)

   where J = 1 thru 5, the number of points on curve for which user data is entered.

2. Determine peak capacity.

   Call subroutine IUNI using TCON11 and CCAPP to determine CAPMAX at condition TLCON

3. Determine peak power.

   Call subroutine IUNI using TCON22 and CPPWRR to determine PKPOW at condition TLCON.

4. Calculate actual chiller capacity.

   CAPC = CAPMAX * FFL

5. Determine chiller percent peak power at fraction of full load, FFL.

   Call subroutine IUNI using CPPLL and CPPPP to determine PCTCP at condition FFL.

6. Calculate actual chiller power.

   CPOW = PKPOW * PCTCP

7. RETURN

CLGTWR

A subroutine to determine the performance of cooling towers.

INPUT

TWB : Ambient air wet bulb temperature (^{o}F)

CAPC : Chiller capacity (tons)

QHBC : Building cooling load (tons)

Various items held in COMMON.

OUTPUT

TECON : Entering condenser water temperature (^{o}F)

TLCON : Leaving condenser water temperature (^{o}F)

KCTF : Cooling tower fan switch

0 = fans are off

1 = fans are on

TWRELC : Cooling tower power (KW)

CALCULATION SEQUENCE

1. Calculate the percentage of building load compared to chiller size.

1a. If CAPC = 0.0, then CTFFL = 0.0 and

GO TO 11

CTFFL = QHBC/CAPC

2. Determine ideal cooling tower leaving temperature:

Based on 7F approach temperature at 100% load.

For user-defined curves:

Call IUNI to determine TECON at TWB and CTFFL conditions.

For built-in performance curves:

TECON = TWB + 7.0 * CTFFL ** 0.5

3. Set ideal temperature for cooling tower power calculation.

   If TECON $\nless$ TWB, TECON = TWB

   TEC = TECON

4. Reset cooling tower leaving temperature to minimum temperatured allow.

   If TECON < TECMN, TECON = TECMN

5. Calculate leaving condenser water temperature.

   TLCON = TECON + TCRIS * CTFFL

6. Shut off cooling tower if percentage of building load less than 5%.

   If CTFFL < 0.05, GO TO 11.

7. If ideal cooling tower water temperature $\geq$ minimum cooling tower temperature, set power at maximum power.

   If TEC $\geq$ TECMN, GO TO 12.

8. Calculate percentage cooling tower power.

   For built-in performance curves (ICTOPT $\neq$ 1)

   CTPCT = (CTFFL ** 0.15) * (1.0 - 0.14 * (TECMN - TEC) ** 0.5)

   For user-defined curves (ILTOPT = 1)

   Call subroutine IUNI to determine fraction of full load power at TECON and CTFFL conditions.

9. Shut off cooling tower if power percentage is less than 5%.

   If CTPCT < 0.05, GO TO 11.

10. Calculate cooling tower power

    TWRELC = CTPKW * CTPLT

    KCTF = 1

    RETURN

11. Set cooling tower power to zero.

    TWRELC = 0.0

    KCTF = 0

    RETURN

12. Set cooling tower power to cooling tower peak power.

```
TWRELC = TPKW
KCTF   = 1
RETURN
```

NOTES

CSIN

A subroutine which reads the NECAP Input Processor Program output file containing the Systems ENERGY Simulation Program (SESP) user input data.

INPUT

Read in from cards. Data and variable are given in Appendix C, Table 3 of the NECAP User's Manual.

OUTPUT

Various items in COMMON.

CALCULATION SEQUENCE

1. Read card
2. Check items read in.
3. Assign item to proper storage in COMMON.
4. GO TO 1 until all data has been read in.

IUNI

A subroutine which interpolates a univariate function using conventional first or second order Lagrangian interpolation. The routine will perform multiple table look-up for a set of functions defined over the same set of independent parameter points. The points in the independent parameter array can be unequally spaced.

INPUT

NMAX : an input integer specifying the maximum first dimension of the functional value array as given in the dimension statement of the calling program.

N : an input integer specifying the actual number of independent parameter points, where N $\leq$ NMAX.

X : an input array dimensioned at least N in the calling program. This array contains the values of the independent parameter. The elements of the X array must be strictly monotonic.

NTAB : an input integer specifying the number of dependent variable tables.

Y : a two-dimensional input array whose columns contain the dependent variable tables. The Y array should have first dimension NMAX and second dimension at least NTAB.

IRODER : an input integer specifying the order of interpolation to be used.

= 0 Zero order interpolation: The first value in the dependent variable table is assigned as the interpolated value of the function.

= 1 First order interpolation.

= 2 Second order interpolation.

XO : the point at which interpolation is to be performed.

OUTPUT

YO : an output array containing the interpolated value of each function. This array should be dimensioned NTAB in the calling program.

IPT : an input/output integer parameter with the following functions:

INPUT: Initialize routine IUNI and check monotonicity of the X array.

= -1 Whenever a call to IUNI is made, this value of IPT must be specified by the user so that a monotonicity check of the X array will be performed.

OUTPUT: INDEX POINTER

= k Indicates that $x_K \leq x_0 \leq x_{k+1}$

Whenever the point x_0 is not contained in the interval delimited by the X array, extrapolation is performed to estimate the function value. In this case the value of IPT is returned as:

= 0 Indicates $x_0 < x(1)$ if the X array is in increasing order, or $x_0 > x(1)$ if the X array is arranged in decreasing order.

= N Indicates $x_0 > x(N)$ if the X array is in increasing order, or $x_0 < x(N)$ if the X array is arranged in decreasing order.

IERR : integer error parameter generated by the routine.

= 0 Normal return

= J The J-th element of the X array was out of order. No interpolation performed.

= -1 Zero order interpolation performed because IORDER = 0.

= -2 Zero order interpolation performed because only one point was in the X array.

= -3 Insufficient number of points supplied for second order interpolation. No interpolation performed.

= -4 Extrapolation was performed.

NOTE: The points in the X array must be arranged in strictly increasing or decreasing order of magnitude.

Whenever a call to INUI is made, the parameter IPT = -1 must be input by the user to insure the routine will be properly initialized and the monotonicity of the X array checked.

CALCULATION SEQUENCE

1. Initialize data

1.1 NM1 = N-1
1.2 IERR = 0
1.3 J = 1
1.4 DELX = X(2) - X(1)

2. Check for zero order interpolation

   2.1 If IØRDER = 0:

       Set IERR = -1
       Go to 2.3
       Go to 2.3

   2.2 If N < 2:

       Set IERR = -2

       Go to 2.3

   2.3 For NT = 1,NTAB:

       Set Y(NT) = Y(1,NT)

       RETURN

   2.4 Else go to 3.

3. Check if X data is strictly monotonic

   3.1 If X data is jumbled:

       Set IERR = J+1

       RETURN

   3.2 Else go to 4.

4. Reset IPT to be within the interval

   4.1 IPT = 1

       IN = SIGN (1.0,DELX*(XO-X(IPT)))

   4.2 P = X(IPT) = XO

       IF P * (XCIPT+1) - XO) < 0, go to 6.

       If P * (X(IPT+1) - XO) = 0:

          If P ≠ 0: set IPT = IPT+1

          For NT = 1,NTAB:

             Set YO(NT) = Y(IPT,NT)

       RETURN

       If P * (X(IPT+1) - XO) > 0, go to 5.

5. Check if extrapolation is necessary

   5.1 IPT = IPT + IN

   5.2 If IPT > 0 and IPT < N, go to 4.2

   5.3 IERR = -4

   IPT = IPT - IN

   Go to 6.

6. Interpolate

   6.1 If IORDER = 1:

   For NT = 1,NTAB:

   ```
   Set YO(NT) = Y(IPT,NT) + ((Y(IPT+1,NT) - Y(IPT,NT)) *
                (XO-X(IPT))) / (X(IPT+1) - X(IPT))
   ```

   If IERR = -4: set IPT = IPT + IN

   RETURN

   Else go to 6.2

   If N = 2:

   Set IERR = -3

   RETURN

   Else go to 6.3

   6.3 If IPT = NM1: set L = IPT-1

   If IPT = 1: set L = IPT

   If (DELX * (XO-X(IPT-1)) < DELX * (X(IPT+2) - XO)):

   Set L = IPT-1

   V1 = X(L) - XO

   V2 = X(L+1) - XO

   V3 = X(L_2) - XO

   For NT = 1, NTAB: set

   ```
   YY1 = (Y(L,NT) * V2 - Y(L+1,NT) * V1) / (X(L+1) - X(L))
   YY2 = (Y(L+1,NT) * V3 - Y(L+2,NT) * V2) / (X(L+2) - X(L+1))
   YO(NT) = (YY1 * V3 - YY2 * V1) / (X(L+2) - X(L))
   ```

If IERR = -4: set IPT = IPT + IN

RETURN

NOTES

DENSY

A function to calculate the density of moist air (lb-air/cu.ft.) given

T - dry-bulb temperature (^{o}F)

W - humidity ratio (lb-H_2O/lb-dry air)

PATM - barometric pressure (in. Hg.)

DENSY = 1.0/(0.754 * (T+460.0) * (1.0+7000.0 * W/4360.)/PATM)

DXHP

A subroutine to simulate a DX or a heat pump unit.

INPUT

MODE : Operating mode.

1 = cooling

2 = heating

IDX : Unit identification number.

QLOAD : Load on the system (Btu/Hour).

QLOAD must be positive for cooling.

QLOAD must be negative for heating.

OAT : Ambient air dry bulb temperature (^{o}F).

Various items held in COMMON.

OUTPUT

CAPY : Capacity of unit (Btu/Hour).

CAPY is always positive.

QLNM : Load not met by the unit (Btu/Hour).

POWI : Power required (KW).

QHSUP : Supplementary heat required (Btu/Hour).

CALCULATION SEQUENCE

1. Set-up arrays according to mode.

ARRAY		COOLING		HEATING	UNITS
DCAP	=	DCCAP	or	DHCAP	MBTU/HR
DPOW	=	DCPOW	or	DHPOW	KW
NMAXC	=	NCP	or	NHP	INTEGER
NMAXP	=	NCP	or	NHP	INTEGER
PVC	=	PVCCA	or	PVHCA	%
PVP	=	PVCPO	or	PVHPO	%
CTREF	=	TREFC	or	TREFH	^{o}F
PTREF	=	TREFC	or	TREFH	^{o}F

2. Calculate capacity available. Call subroutine IUNI using CTREF and PVC to determine percent design capacity (PVCAP) at condition OAT.

   CAPY = DCAP * PVCAP * 1000.

3. Calculate power required. Call subroutine IUNI using PTREF and PVP to determine percent design power (PVPOW) at condition OAT.

   POWER = DPOW * DVPOW

4. Check operating mode.

   If MODE = 1, go to calculation 5 (cooling).

   If MODE = 2, go to calculation 6 (heating).

5. Cooling mode.

   If CAPY $\geq$ QLOAD, go to calculation 7.

   If CAPY < QLOAD there is a cooling load not met.

   QLNM = QLOAD - CAPY

   Go to calculation 7.

6. Heating mode.

   If CAPY $\geq$ (-QLOAD), go to calculation 7.

   If CAPY < (-QLOAD),

   Supplementary heat is required.

   QHSUP = QLOAD + CAPY

   Go to calculation 7.

7. Calculate actual power.

   POWI = POWER * ABS(QLOAD/CAPY)

ECONO

A subroutine to simulate the operation of a temperature type economizer cycle, calculating that portion of outside air yielding a mixed air temperature closest to the desired mixed air dry bulb temperature.

INPUT

OA	:	Outside air dry bulb temperature (°F)
DOA	:	Outside air density (lbm/ft^3)
RA	:	Return air dry bulb temperature (°F)
DRA	:	Return air density (lbm/ft^3)
LVG	:	Desired mixed air dry bulb temperature (°F)
ALFAM	:	Minimum fraction of outside air

OUTPUT

ALFA	:	Portion of outside air yielding mixed temperature closest to desired mixed air temperature

CALCULATION SEQUENCE

1. Select appropriate return air/outside air temperature relationship.

   1.1 Return air temperature (RA) greater than outside air temperature (ØA).

   If desired mixed air temperature (LVG) less than or equal to outside air temperature (ØA),

   ALFA = 1.0

   RETURN

   If desired mixed air temperature (LVG) greater than outside air temperature (ØA), and

   If desired mixed air temperature (LVG) less than return air temperature (RA),

   ALFA = (DRA * (RA - LVG))/(RA * DRA - ØA * DØA + LVG * (DØA - DRA))

   GO TO 2.

If desired mixed air temperature (LVG) greater than or equal to return air temperature (RA),

ALFA = ALFAM

RETURN

1.2 Return air temperature (RA) equals outside air temperature (ØA).

ALFA = 1.0

RETURN

1.3 Return air temperature (RA) less than outside air temperature (ØA).

If desired mixed air temperature (LVG) less than or equal to return air temperature (RA),

ALFA = ALFAM

RETURN

If desired mixed air temperature (LVG) greater than return air temperature (RA), and

If desired mixed air temperature less than outside air temperature (ØA),

ALFA = (DRA * (RA - LVG))/(RA * DRA - ØA * DØA + LVG * (DØA - DRA))

Go to calculation 2.

(The equation used above is derived from that given in subroutine MXAIR, paragraph 6.1, solving instead for ALFA.)

If desired mixed air temperature greater than or equal to outside air temperature (ØA),

ALFA = 1.0

RETURN

2. Check range of ALFA.

If fraction of outside air (ALFA) less than minimum fraction of outside air (ALFAM).

ALFA = ALFAM

RETURN

If fraction of outside air (ALFA) greater than 1.0,

ALFA = 1.0.

RETURN

NOTES

ENGY

A subroutine for printing the monthly energy consumption summary.

INPUT

FAC : Name of facility

CITY : Location of facility

PROJ : Project number

DATE : Date of program run

ENGR : Name of engineer

SNAME : Case identification

ENGY : Monthly energy consumptions and demands. A 12x2x27 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. Not used
2. Not used
3. Electric, internal lights and building equipment
4. Electric, external lights
5. Electric heat (boiler and auxiliaries, heat pumps, and hot water pumps)
6. Electric cool (chiller, DX, pumps and cooling tower fan)
7. Gas heat
8. Gas cool
9. Gas generation
10. Steam heat
11. Steam cool
12. Oil heat
13. Oil cool
14. Diesel fuel generation
15. Total heating load
16. Total cooling load
17. City water
18. Fans (electric)
19. Gas - process
20. Oil - process
21. Steam - process
22. Electric - process

23-27. Not used

SF	:	An array of monthly maximum electric demand
TPKGAS	:	An array of monthly maximum gas demand
TPKOIL	:	An array of monthly maximum oil demand
TESTM	:	Temperature of low pressure steam (^{o}F)
PESTM	:	Pressure of low pressure steam (psig)
TPS	:	Temperature of high pressure steam (^{o}F)
PPS	:	Pressure of high pressure steam (psig)
PRSTMT	:	Process steam temperature (^{o}F)
PRSTMP	:	Process steam pressure (psig)

OUTPUT

Tabular summary of monthly energy consumption. See Section 5 in the User's Manual).

CALCULATION SEQUENCE

1. Print two pages each of report by repeating calculations 2 through 7 first for months January through June (III = 1) and then for July through December (III = 2).
2. Print page title block by writing headers.
3. Print proper monthly column headers.
4. Call subroutine TOT1 to sum heating and cooling loads.
5. Printl total heating and cooling loads.
6. Call subroutine TOT1 to sum electrical loads for lights and building equipment, external lighting, heating, cooling, fans, and process electricity.
7. Print electrical loads.
8. Print second two pages of report by repeating calculations 9 through 20 first for months January through June (III = 1) and then for July through December (III = 2).
9. Print page title block by writing headers.
10. Print proper monthly column headers.
11. Call TOT1 to sum all gas loads.

12. Print total gas loads for heating, cooling, generation, and process.

13. Call TOT1 to sum purchased steam loads.

14. Print total steam loads.

15. Call TOT1 to sum oil loads.

16. Print total oil loads.

17. Call TOT1 to sum diesel fuel consumption.

18. Print diesel fuel load.

19. Call TOT1 to sum city water consumption.

20. Print city water load.

21. RETURN

NOTES

EQUI

A subroutine for calculating the energy consumption of conventional heating and cooling systems and on-site generation systems.

INPUT

QHBC	:	Hourly building cooling load (Btu/hr)
QHBH	:	Hourly building heating load (Btu/hr)
QHBRH	:	Hourly building reheat load (Btu/hr)
TECON	:	Entering condensing water temperature (^{o}F)
ELDEM	:	Hourly electrical demand of the building (KW)
TLCHL	:	Chilled water set point temperature (^{o}F)

Various items held in COMMON.

OUTPUT

GASC	:	Hourly gas consumption for cooling (therms)
GASH	:	Hourly gas consumption for heating (therms)
GASG	:	Hourly gas consumption for on-site generation (therms)
OILC	:	Hourly oil consumption for cooling (gals)
OILH	:	Hourly oil consumption for heating (gals)
STMC	:	Hourly steam consumption for cooling (lbs)
STMH	:	Hourly steam consumption for heating (lbs)
ELEC	:	Hourly electrical consumption for cooling (KW)
ELEH	:	Hourly electrical consumption for heating (KW)
FUEL	:	Hourly diesel fuel consumption for on-site generation (gals)
IPRT3	:	Print flag

CALCULATION SEQUENCE

1. Convert hourly building cooling load into tons and initialize energy variables to 0.0.

QHBC = QHBC/12000.0

2. Calculate the enthalpy of entering and leaving steam (for boilers and absorption chillers).

   2.1 For leaving conditions, assume saturated water, therefore

   HLSTM = 180.07

   where HLSTM is enthalpy of leaving steam (Btu/lb)

   2.2 For entering condition, use

   AH = 1068.0 - 0.485 * (PESTM + 14.7)

   BH = 0.432 + 0.000953 * (PESTM + 14.7)

   CH = 0.000036 - 0.000000496 * (PESTM + 14.7)

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

   where HESTM is enthalpy of entering steam (Btu/lb).

3. Check the type of system.

   If NENG < 1, then conventional system

   Go to calculation 5.

   If NENG ≥ 1, then on-site generation system.

   Go to calculation 9.

<u>CONVENTIONAL SYSTEM</u>

4. Check for cooling load

   If ABS(QHBC) ≤ 0.001, or QHBC = 0, go to 6.

   If QHBC < 0, RETURN.

5. Calculate the energy consumption required for cooling.

   5.1 Call NUMDEV, which calculates the number of units required and the fraction of full load (FFL) on each chillers using the following loading conditions:

   Minimum Load Point = FFLMN

   Normal Load Point = 0.9

   Maximum Load Point = 1.1

5.2 Iterate for each chiller type (NCH = 1 to NCHIL) and quantity (NUM = 1 to NUMC(NCH)).

5.2.1 Calculate load on a specific chiller,

QLOAD = SZC(NCH) * FFL(NCH,NUM)

5.2.2 If user defined chiller,

ICOPT = 1 Go to calculation 5.2.5

5.2.3 Built-in chiller performance. Check type of chiller and call appropriate simulation routine.

5.2.3.1 <u>Reciprocating Chiller</u> (MM1 = 1)

Call RECIP to calculate electrical power (ELEC) required. Go to calculation 5.2.6.
ELEC = ELEC + ELE

5.2.3.2 <u>Hermetic Centrifugal Chiller</u> (MM1 = 2)

Call CENT to calculate electrical power (ELEC) required. Go to calculation 5.2.6.
ELEC = ELEC + ELE

5.2.3.3 <u>Open Centrifugal Chiller</u> (MM1 = 3)

Call CENT to determine electrical power (ELEC) required for a hermetic machine. Correct ELEC for an open machine where compressor work does not become a direct load on chiller.

ELEC = ELEC/(1.+ 0.02133 * ELEC/QLOAD)

where 0.02133 is

$$\frac{3413 \text{ Btu/hr-KW}}{12000 \text{ Btu/hr-ton}}\left[1.0 - \text{EFF}\right]$$

and motor efficiency of a hermetic machine is assumed to be 0.925. Go to calculation 5.2.6.

5.2.3.4 <u>Steam Absorption Chiller</u> (MM1 = 4)

Call ABSOR to calculate quantity of steam (STM) required and entering (H1) and leaving (H2) steam enthalpy. Convert steam consumption to equivalent heat requirement (QHMC).

QHMC = STM * (H1 - H2)

Go to calculation 5.2.4.

5.2.3.5 Steam Turbine Driven Open Centrifugal Chiller Combination (MM1 = 5)

Call CENT to determine electrical power (POWER) required. Correct POWER for an open machine where compressor work does not become a direct load on chiller.

POWER = 0.925 * POWER/(1.+ 0.02133 * POWER/QLOAD)

(See calculation 5.2.3.3 for explanation of constants.)

Call STTUR to calculate steam (STM) required to produce POWER and entering (H1) and leaving (H2) steam enthalpy. Convert steam consumption to equivalent heat requirement.

QHMC = STM * (H1 - H2)

Go to calculation 5.2.4.

5.2.4 Check type of chiller source energy.

5.2.4.1 Gas Cooling (MM2 = 1)

GASC = QHMC/80000. + GASC

where units are therms and boiler efficiency is assumed to be 80%. Go to calculation 5.2.6.

5.2.4.2 Oil Cooling (MM2 = 2)

OILC = IOLC + QHMC/(0.8*DHO*HVHQ)

where units are gallons and boiler efficiency is assumed to be 80%. Go to calculation 5.2.6.

5.2.4.3 Purchased Steam Cooling (MM2 = 3)

STMC = STMC + STM

where units are pounds. Go to calculation 5.2.6.

5.2.4.4 Electric Cooling (MM2 = 4)

ELEC = QHMC/3413.0 + ELEC

where units are KW. Go to calculation 5.2.6.

5.2.5 User Defined Chiller

5.2.5.1 Call CHLUSR to determine power (CPOW) required.

5.2.5.2 If electric cooling (MM1 = 1,2,3)

ELEC = CPOW + ELEC

If steam cooling (MM1 = 4,5)

STMC = CPOW + STMC

Go to calculation 5.2.6

5.2.6 End of chiller iteration loop.

6. Check for heating load

If QHBH > 0, RETURN

If QHBH = 0, go to

If QHBH < 0

QHBH1 = QHBH/(-1000.0)

7. Calculate the energy consumption required for heating.

7.1 Call NUMDEV, which calculates the fraction of full load (FFL) on all boilers using the following loading conditions:

Minimum load point = 0.0
Normal load point = 0.9
Maximum load point = 1.0

7.2 Iterate for each boiler type (NBL = 1 to NBOIL) and quantity, (NUM = 1 to NUMB(NBL)).

7.2.1 Calculate load on a specific boiler

QLOAD = SZB(NBL) * FFL(NBL,NUM) * 1000.

7.2.2 If user defined boiler,

IBOPT = 1, Go to calculation 7.2.4.

7.2.3 Determine heating energy required by checking type of heating source energy (M3), and performing proper conversion.

7.2.3.1 Gas Heating (MM3 = 1)

GASH = QLOAD/80000.+ GASH

where units are in therms and assumed boiler efficiency is 80%. Go to calculation 7.2.5.

7.2.3.2 Oil Heating (MM3 = 2)

OILH = OILH + QLOAD/(0.8*HVHD*DHO)

where units are in gallons and assumed boiler efficiency is 80%. Go to calculation 7.2.5.

7.2.3.3 Steam Heating (MM3 = 3)

STMH = QLOAD/(HESTM - HLSTM) + STMH

where units are in pounds. Go to calculation 7.2.5.

7.2.3.4 Electric Heating (MM3 = 4)

ELEH = QLOAD/3413.0 + ELEH

where units are in KW and assumed efficiency is 100%. Go to calculation 7.2.5.

7.2.4 User Defined Boilers

7.2.4.1 Call IUNI using BPCT and BBPL which calculates the boiler part load efficiency (PLEFF) at at condition FFL

BQIN = QLOAD * 1000./PLEFF

7.2.4.2 Calculate heating energy required.

If MM3 = 1, (gas-fired boiler), GASH = BQIN/100000.+GASH

If MM3 = 2, (oil-fired boiler), OILH = BQIN/HVHO + OILH

If MM3 = 3, (purchased steam heat), STMH = BQIN/(HESTM - HLSTM) + STMH

If MM3 = 4, (electric boiler), ELEH = BQIN/3413.0 +ELEH

Go to calculation 7.2.5.

7.2.5 End of boiler iteration loop.

8. Calculate the energy consumption required for reheat.

8.1 Set KRH = KREHT + 1

8.2 If KRH = 1, (heat from gas-fired boiler),
GASH = GASH - QHBRH/80000.0

8.3 If KRH = 2, (heat from oil fired boiler),
OILH = OILH - QHBRH/(0.8 * DHO * HVHO)

8.4 If KRH = 3, (heat from purchased steam),
STMH = STMH - QHBRH/(HESTM - HLSTM)

8.5 If KRH = 4, (heat from electric boiler),
ELEH = ELEH - QHBRH/3413.0

RETURN

ON-SITE POWER GENERATION ANALYSIS

9. Calculate the energy consumption for generation.

9.1 Call NUMDEV which calculates the fraction of full load (FFL) on all engine/generators using the following loading points:

Minimum load point = 0.0
Normal load point = 1.0
Maximum load point = 1.1

9.2 Iterate for each engine/generator type (NEN = 1 to NENG) and quantity (NUM = 1 to MM4).

9.2.1 Calculate load on a specific engine/generator

QLOAD = EGCAP(NEN) * FFL(NEN,NUM)

9.2.2 If user defined engine/generator,

IEGOP = 1, go to calculation 9.2.4.

9.2.3 Perform simulation of engine/generator sets to determine fuel requirements and amount recoverable heat.

9.2.3.1 <u>Diesel Fuel Powered Engine/Generator Set</u> (MM5 = 1)

Calculate amount of diesel fuel (FUEL) required to supply electrical load (ELDEM).

FUEL = (8900. * FFL + 2000.) * QLOAD/HVDF + FUEL

The above equation was derived by curve fit of performance data contained in the 1967 Caterpillar Tractor Company "Total Energy Handbook" and is applicable for a range of 60 to 600 KW capacity.

Calculate amount of total heat (QEN) that can be recovered from engines operating.

QEN = (9590.7 + FFL * (-14132.2 + FFL *

(12164.87 + FFL * (-1809.54)))) * FFL * QLOAD

The above equation was derived by curve fit of performance data contained in 1967 Caterpillar Tractor Company "Total Energy Handbook" and represents the total amount of heat that can be recovered from exhaust gas, jacket water, and oil cooler/after cooler. Go to calculation 9.2.5.

9.2.3.2 Natural Gas Powered Engine/Generator Set (MM5 = 2)

Calculate amount of fuel (GASG) required to supply electrical load (ELDEM).

GASG = (0.085 + 0.0289/FFL) * QLOAD + GASG

Calculate amount of total heat (QEN) that can be recovered from engine operating.

QEN = (60.51 + 16.64/FFL + 14.0 * FFL) * QLOAD

See calculation 9.2.3.1 for comments concerning the above equation. Go to calculation 9.2.5.

9.2.4 User Defined Engine/Generator Set

9.2.4.1 Call IUNI using EGPCT and PCTEF which calculates the percent fuel required (PCTFU) at condition FFL.

Call IUNI using EGPCT and QEQPCT which calculates the percent of total heat that can be recovered (PCTEQ) at condition FFL.

9.2.4.2 Determine fuel requirements and recoverable heat.

9.2.4.2.1 Diesel Fuel Powered Engine/Generator Set (MM5 = 1)

FUEL = ΣFUEL * PCTFD

Go to calculation 9.2.4.2.3

9.2.4.2.2 Natural Gas Powered Engine/Generator Set (MM5 = 2)

GASG = ΣFUEL * PCTFU

9.2.4.2.3 Recoverable Heat

QEN = EQBAK * PCTEQ

9.2.5 End of engine/generator iteration

10. Calculate the energy consumption required for cooling.

Check if building requires any cooling.

If QHBC > 0.0, cooling is required.

Go to calculation 8.1.

If QHBC = 0.0, cooling not required.

Set QHMC = 0.0

Go to calculation 11.
If QHBC < 0.0, RETURN

10.1 Call NUMDEV which calculates the fraction of full load (FFL) of all chillers using the same loading points as in calculation 5.1.

10.2 Iterate for each chiller type (NCH = 1 to NCHIL) and quantity (NUM = 1 to NUMC(NCH))

10.2.1 Determine load on a specific chiller

QLOAD = SZC(NCH) * FFL(NCH,NUM)

10.2.2 If user defined chiller,

ICOPT = 1, go to calculation 10.2.4.

10.2.3 Perform chiller simulation. Check type of chiller and call appropriate simulation routine.

10.2.3.1 Reciprocating Chiller (MM1 = 1)

This is not a valid choice for an onsite generation system. Print error message and STOP.

10.2.3.2 Hermetic Centrifugal Chiller (MM1 = 2)

This is not a valid choice for an onsite generation system. Print error message and STOP.

10.2.3.3 Open Centrifugal Chiller (MM1 = 3)

This is not a valid choice for an onsite generation system. Print error message and STOP.

10.2.3.4 Steam Absorption Chiller (MM1 = 4)

Call ABSOR to calculate quantity of steam (STM) required to supply cooling load (QLOAD) and entering (H1) and leaving (H2) steam enthalpy. Convert steam consumption to equivalent heat requirement (QHMC).

QHMC = STM/(H1 - H2) + QHMC

Go to calculation 10.2.5.

10.2.3.5 Steam Turbine Driven Open Centrifugal Chiller Combination (MM1 = 5)

Call CENT to determine electrical power (POWER) required to supply cooling load (QLOAD). Correct POWER for an open machine where compressor work does not become a direct load on chiller

POWER = 0.925 * POWER/(1.0 + 0.02133 * POWER/QLOAD)

(See calculation 5.2.3.3 for explanation of constants.)

Call STTUR to calculate steam required (STM) to supply POWER and entering (H1) and Leaving (H2) steam enthalpy. Convert to equivalent heat requirement.

QHMC = STM/(H1 - H2)

Go to calculation 10.2.5.

10.2.4 User Defined Chiller

10.2.4.1 Call CHLUSR to determine power (CPOW) required.

10.2.4.2 Electric Cooling (MM1 = 1,2,3)

This is not a valid choice for an onsite generation system. Print error message and STOP.

10.2.4.3 Steam Cooling (MM1 = 4,5)

Steam requirements,

STMC = CPOW

at steam conditions HESTM, HLSTM.

10.2.5 End of chiller iteration.

11. Calculate the energy consumption required for heating.
If QHBH $\leq$ 0, otherwise return.

11.1 The net heating required is,

QHBH = QHBH - QHMC + QEN

Note that the signs of these terms are:

QHBH (-)
QHMC (+)
QEN (+)

11.2 Call NUMDEV which calculates the fraction of full load (FFL) on all boilers using the same loading points as in calculation 5.1.

11.3 Iterate for each boiler type (NBL = 1 to NBOIL) and quantity (NUM = 1 to NUMB(NBL))

11.3.1 Determine load on each boiler,

QLOAD = SZB(NBL) * FFL(NBL,NUM) * 1000

11.3.2 If user defined boiler,

IBOPT = 1, go to calculation 11.3.4.

11.3.3 Perform simulation of boiler by checking type of heating source energy (MM3) and performing proper conversion.

11.3.3.1 <u>Gas Heating</u> (MM3 = 1)

GASH = QLOAD/80000.

where units are in therms and assumed conversion efficiency is 80%. If GASH < 0.0, reset to GASH = 0.0. Go to calculation 11.3.5.

11.3.3.2 <u>Oil Heating</u> (MM3 = 2)

OILH = OILH + QLOAD/(0.8*DHO*HVHO)

where units are in gallons and assumed conversion efficiency is 80%. If OILH < o.o, reset to OILH = 0.0. Go to calculation 11.3.5.

11.3.3.3 <u>Steam Heating</u> (MM3 = 3)

This is not a valid choice for onsite generation system. Print error message and STOP.

11.3.3.4 Electrical Heating (MM3 = 4)

This is not a valid choice for onsite generation system. Print error message and STOP.

11.3.4 User Defined Boiler.

11.3.4.1 Call IUNI using BPCT and BBPL which calculates the boiler part load efficiency (PLEFF) at condition FFL.

BQIN = (QLOAD/PLEFF) * 1000

11.3.4.2 Gas Heating (MM3 = 1)

GASH = BQIN/100000.+ GASH

Go to calculation 11.3.5.

11.3.4.3 Oil Heating (MM3 = 2)

OILH = BQIN/HVHO + OILH

Go to calculation 11.3.5.

11.3.4.4 Steam Heating (MM3 = 3) or Electric Heating (MM3 = 4

These are not valid choices for an onsite generation system. Print error message and STOP.

11.3.5 End of boiler iteration.

12. Determine reheat energy required by checking type of reheat source energy (KRH) where

KRH = KREHT + 1

and add it to any heating energy already used.

12.1 Gas Reheat (KRH = 2)

GASH = GASH - QHBRH/80000.
QHBH = -GASH * 80000

where units are in therms and conversion efficiency is assumed to be 80%.

12.2 Oil Reheat (KRH = 3)

Not a valid choice for onsite generation system. Print error message and STOP.

12.3 Steam Reheat (KRH = 4)

Not a valid choice for onsite generation system. Print error message and STOP.

12.4 Electric Reheat (KRH = 5)

Not a valid choice for onsite generation system. Print error message and STOP.

NOTES

ESIZE

A subroutine to size central plant equipment consisting of boilers, chillers, cooling tower, pumps, engine/generators, and boiler accessories.

INPUT

EFF : Motor efficiency (fraction)

PWBIL : Building interior lighting load (KW)

PWOL : Outdoor lighting load (KW)

TFBHP : Total fan brake horsepower (BHP)

Various items held in COMMON.

OUTPUT

CAPC : Total cooling capacity (tons)

CAPH : Total heating capacity (MBtu/hr)

CALCULATION SEQUENCE

1. If user has not sized boilers then compute capacity (Kbtu's/hr) using total heating capacity of occupied zones.

$$TCAP = \Sigma \ HCAPD(I)$$

If $SZB_i = 0$, then $SZB_i = (TCAP/\text{number of boilers})/1000.0$

2. If user has not sized chillers, then compute capcaity (tons) using total cooling capacity of occupied zones.

$$TCAP = \Sigma \ HCAP(I)$$

If $SZC_i = 0$, then $SZC_i = (TCAP/\text{number of chillers})/12000$

3. If user has not sized Heat Pump/DX unit, then compute capacity and/or point for zones on fan systems that use the heat pump being sized.

$$TCAPC = \Sigma \ HCAP(I) \ (I\text{=ZONES USING DX/HP})$$

$$TCAPH = \Sigma \ HCAP(I) \ (I\text{=ZONES USING DX/HP})$$

If $DCCAP_n$ = 0 then $DCCAP_n$ = TCAPC/1000.0

If *$DCPOW_n$ = 0 then $DCPOW_n$ = (TCAPC/12000.0) * 1.5

If heat pump then

If $DHCAP_n$ = 0 then $DHCAP_n$ = TCAPH/1000.0

If *$DHPOW_n$= = then $DHPOW_n$ = (TCAPH/12000.0) * 1.5

* Uses an ERR of 8 or a COP of 2.6.

4. Heating Equipment

Sum SZB for all boiler types (NBOIL), and number of units (NUMB), to determine total heating plant capacity.

$$CAPH = \Sigma(NUMB(I) * SZB(I)) \text{ for } I = 1 \text{ to } NBOIL$$

5. Cooling Equipment

Perform the following series of calculations for each chiller type (NCHIL) where I = 1 to NCHIL

5.1 Determine cooling capacity for each category and for total plant

$$CAPCC = NUMC(I) * SZC(I)$$

$$CAPC = \Sigma\ CAPCC$$

5.2 If M1 = 4 (steam absorption chiller), go to calculation 2.5.

5.3 If M1 ≠ 5 (centrifugal/steam turbine), go to calculation 5.4, otherwise determine size of steam turbines required, if used, assuming 1 HP per ton of cooling.

$$SZT = \Sigma\ SZC(I)$$

$$NUMT = \Sigma\ NUMC(I)$$

5.4 Size condenser water flow rate at 3.0 gpm/ton and cooling tower air flow at 300 cfm/ton

$$GPMCN = \Sigma\ (3.0 * CAPCC)$$

$$CFMCT = \Sigma\ (300.0 * CAPCC)$$

Go to calculation 2.6.

5.5 Size condenser water flow rate at 3.5 gpm/ton and cooling tower air flow at 350 cfm/ton

$$GPMCN = \Sigma\ (3.5 * CAPCC)$$

$$CFMCT = \Sigma\ (350.0 * CAPCC)$$

6. Determine cooling tower fan horsepower requirement assuming 1.0 inch water total pressure.

6.1 HPCTF = CTPKW/0.7457

6.2 If user lets program size cooling tower fan, i.e., CTPKW=0.0,

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

CTPKW = HPCTF * 0.7457

7. Determine chilled water flow rate (gpm)

GPMCL = 2.4 * CAPC

8. Determine boiler water flow rate (gpm)

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

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

9.1 Chilled water pump horsepower

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

9.2 Condenser water pump horsepower

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

9.3 Boiler water pump horsepower

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

10. Size boiler auxiliary horsepower.

10.1 HPBLA = BLRAUX

10.2 If user lets program size auxiliaries, i.e., BLRAUX = 0.0,

HPBLA = CAPH * 1000.0/(33472.0 * 20.0)

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.

11. Sum heating and cooling equipment brake horsepower demand.

HPHEQ = HPBLA + HPBLP (where HPHEQ has units of horsepower)

HPCEQ = HPCTF + HPCLP + HPCNP (where HPCEQ has units of horsepower)

12. Size on-site generation plants.

Calculate maximum building electrical demand assuming all electrical equipment operating (electric resistance heating and electrically-driven compressive cooling not allowable with on-site generation).

BKWDM = PWBIL + PWOL + (TFBHP + HPCEQ + HPHEQ)

* 0.7457

13. Engine/Generator Sizing

13.1 If NENG < 0, RETURN

For NEN = 1 to NENG

CAPEG = Σ EGCAP(NEN) * M4(NEN)

13.2 If program sized capacity (EGCAP(I) = 0.), set

EGCAP(1) = 500.

13.3 If program sized quantity (M4(1) = 0), set

M4(1) = 2

Required size of engines is then

$$SZE = BKWDM/M4(1)$$

If $SZE \leq EGCAP(1)$, RETURN

Otherwise increase M4(1) until

$$SZE \leq EGCAP(1)$$

EXSUM

A subroutine for printing an executive summary of annual energy consumption.

INPUT * Via COMMON

*FAC	:	Name of facility
*CITY	:	Location of facility
*PROJ	:	Project number
*DATE	:	Date of program run
*ENGR	:	Name of engineer
*SNAME	:	Case identification
*ENGY	:	Monthly energy consumptions and demands. A 12x2x27 matrix with indices as described in ENGY4.
*NBOIL	:	Number of boiler types
*NUMB	:	Number of boilers for each given type
*SZB	:	Size of boiler for each given type
*NCHIL	:	Number of chiller types
*NUMC	:	Number of chillers for each given type
*SZC	:	Size of chiller for each given type
*FLAREA	:	Total floor area of spaces on energy distribution system(s)
NDXHP	:	Number of DX units and heat pumps
IDXHP	:	An array of DX-heat pump indicators 1 - DX unit 2 - Heat pump
DCCAP	:	An array of cooling capacities for DX units and and heat pumps
DHCAP	:	An array of heating capacities for heat pumps

KMAX	:	Number of energy distribution systems
CFMAX	:	An array of supply air quantities (cfm) for energy distribution systems
CFMIN	:	An array of ventilation air quantities (cfm) for energy distribution systems
HVDF	:	Heating value of diesel fuel
HVHO	:	Heating value of heating oil

OUTPUT

CAPH	:	Total heating capacity (MBtu)
CAPHA	:	Total heating capacity per unit area (MBtu/sq. ft.)
CAPC	:	Total cooling capacity (tons)
CAPCA	:	Total cooling capacity per unit area (tons/sq. ft.)
SUPAIR	:	Supply air (cfm)
SUPSQF	:	Supply air per unit area (cfm/sq. ft.)
VENT	:	Ventilation air (cfm)
VSQF	:	Ventilation air per unit area (cfm/sq. ft.)
ENGYS	:	Annual energy consumptions. A 3x20 matrix with indices as indicated below.
NODAYS	:	Number of days of study

FIRST SUBSCRIPT: Units

1. Same as received from ENGY matrix:

   Electricity - KWHR
   Gas - Therms
   Steam - K-lbs
   Oil - K-gals
   Diesel fuel - k-gals

2. KBTU

3. Raw source - KBTU

SECOND SUBSCRIPT: Type of Energy

1. Electric, lights and misc. equip.
2. Electric, heating
3. Electric, cooling
4. Electric, fans
5. Electric, process
6. Total annual electric consumption
7. Gas, heating
8. Gas, cooling
9. Gas, generation
10. Gas, process
11. Total annual gas consumption
12. Steam, heating
13. Steam, cooling
14. Steam, process
15. Total annual steam consumption
16. Oil, heating
17. Oil, cooling
18. Oil, process
19. Total annual oil consumption
20. Total annual diesel fuel consumption

CALCULATION SEQUENCE

1. Establish conversion matrix. The conversion matrix is used to calculate annual consumption of energy types in terms of KBTU and raw source KBTU.

2. Calculate and print installed capacities:

   a) Sum chiller capacities

      CAPC = Σ NUMC(I) * SZC(I)

   b) Sum boiler capacities

      CAPH = Σ NUMB(I) * SZB(I)

   c) Sum DX/heat pump capacities

      CAPC = Σ DCCAP(I)/12.0

      CAPH = Σ DHCAP(I)

   d) Calculate ventilation and supply air quantities

      VENT = Σ CFMIN(I)

      SUPAIR = Σ CFMAX(I)

   e) Calculate installed capacities per unit area

      CAPCA = CAPC/AREA

      CAPHA = CAPH/AREA

      VSQF = VENT/AREA

      SUPSQF = SUPAIR/AREA

3a. Print page header, FAC, CITY, ENGR, PROJ, DATE, and FLAREA; rename FLAREA, AREA.

3b. Print SNAME, CAPH, CAPHA, CAPC, CAPCA, SUPAIR, SUPSQF, VENT, VSQF

4. Calculate the first column of the ENGYS matrix from the matrix ENGY:

   4.1 Electrical

      ENGYS(1,1) = ENGYS(1,1) + ENGY (I,2,3) + ENGY(I,2,4)

      ENGYS(1,2) = ENGYS(1,2) + ENGY(I,2,5)

      ENGYS(1,3) = ENGYS(1,3) + ENGY(I,2,6)

      ENGYS(1,4) = ENGYS(1,4) + ENGY(I,2,18)

      ENGYS(1,5) = ENGYS(1,5) + ENGY(I,2,22)

4.2 Gas

ENGYS(1,7) = ENGYS(1,7) + ENGY(I,2,7)

ENGYS(1,8) = ENGYS(1,8) + ENGY(I,2,8)

ENGYS(1,9) = ENGYS(1,9) + ENGY(I,2,9)

ENGYS(1,10) = ENGYS(1,10) + ENGY(I,2,19)

4.3 Purchased Steam

ENGYS(1,12) = ENGYS(1,12) + ENGY(I,2,10)

ENGYS(1,13) = ENGYS(1,13) + ENGY(I,2,11)

ENGYS(1,14) = ENGYS(1,14) + ENGY(I,2,21)

4.4 Heating Oil

ENGYS(1,16) = ENGYS(1,16) + ENGY(I,2,12)

ENGYS(1,17) = ENGYS(1,17) + ENGY(I,2,13)

ENGYS(1,18) = ENGYS(1,18) + ENGY(I,2,20)

4.5 Diesel Fuel

ENGYS(1,20) = ENGYS(1,20) + ENGY(I,2,14)

5. Use the conversion matrix to fill the report matrix ENGYS

ENGYS(I+1,J) = ENGYS(I,J) * CONV(I,J)

6. Calculate the totals for each energy type

ENGYS(I,6) = ENGYS(I,6) + ENGYS(I,J)   (J = 1 to 5)

ENGYS(I,11) = ENGYS(I,11) + ENGYS(I,J)   (J = 7 to 10)

ENGYS(I,15) = ENGYS(I,15) + ENGYS(I,J)   (J = 12 to 14)

ENGYS(I,19) = ENGYS(I,19) + ENGYS(I,J)   (J = 16 to 18)

7. Calculate Kbtu/sq. ft. and raw source Kbtu/sq. ft.

ENGYS(I,J) = ENGYS(I,J)/AREA

8. Calculate grand totals

$$TOT(I-1) = ENGYS(I,6) + ENGYS(I,11) + ENGYS(I,15) + ENGYS(I,19) + ENGYS(I,20)$$

Calculate total source energy

$$ENGYS(1,6) = \Sigma\ ENGYS(1,MN) \quad (MN=1 \text{ to } 5)$$

$$ENGYS(1,11) = \Sigma\ ENGYS(1,MN) \quad (MN=7 \text{ to } 10)$$

$$ENGYS(1,15) = \Sigma\ ENGYS(1,MN) \quad (MN=12 \text{ to } 14)$$

$$ENGYS(1,19) = \Sigma\ ENGYS(1,MN) \quad (MN=16 \text{ to } 18)$$

Convert totals to DBTU

GTENG = 0

GTENG = GTENG + ENGYS(1,7) * 3.143

GTENG = GTENG + ENGYS(1,11) * 100.0

GTENG = GTENG + ENGYS(1,15) * 1000.0

GTENG = GTENG + ENGYS(1,19) * HVHO

GTENG = GTENG + ENGYS(1,20) * HVDF

9. Print out ENGY's matrix and grand totals for types of energy that have non-zero values.

NOTES

FANOF

A subroutine to handle loads for a given hour when a fan system is off. This routine should only be called when IFAN = 1.

INPUT

k : Energy distribution system number.

Various items held in COMMON (see Table 4.4 for definition of variables in COMMON).

OUTPUT

RHOH : Heating capacity adjustment factor

IOO : Fan operation indicator (0, fan on; 1, fan off).

QCC : Cooling load (Btu/hr).

QHC : Heating load (Btu/hr).

QTRHC : Reheat coil load (Btu/hr).

QPHC : Preheat coil load (Btu/hr).

TQB : Baseboard radiation load (Btu/hr).

WATER : Steam humidification supplied at air handling unit (lbm-H_2O/hr).

BPKW : Base power (KW).

TNFBP : Ttotal net [updated] fan brake horsepower (Bhp).

Various items held in COMMON.

CALCULATION SEQUENCE

1. Check for zero sensible zone load.

If $\Sigma_{j=1,jmax}$ QSSUM > 0, **

Where QSSUM = $\Sigma \left\{ ABS\left[QS(L)\right] + ABS\left[SINF(L)\right] \right\}$

RETURN.

**NOTE: There is a corresponding L for each i; a relationship defined by the variable $SPACN_{k,j}$. Hence, i and L are defined by system number (k) and zone number (j). See Section 4.1 for zone labeling organization.

If $\sum_{j=1, jmax}$ QSSUM $\leq$ 0, (** see NOTE previous page)

CONTINUE.

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

2.1 Initialize general variables.

QCC = 0.

QHC = 0.

WATER = 0.

QTRHC = 0.

QPHC = 0.

TQB = 0.

BPKW = 0.

2.2 Zone load distribution.

2.2.1 Sum base power requirements.

$$BPKW = \sum_{j=1, jmax} SLPOW_i * MULT_i$$

2.2.2 Sum baseboard radiation heat.

Q = QS(L) + QSINF(L)

If boiler on, call subroutine BRAD to calculate baseboard radiation heat (QB_i) and adjust $QLNM_i$.

If boiler off, CONTINUE.

2.2.3 Distribute sensible load not met ($QLNM_i$).

If Q < 0

QHLNM(I) = QHLNM(I) + Q * MULT(I)

CALL MAX

IHHNM(I) = IHHNM(I) + 1

Go to 2.2.4

If $QLNM_i$ = 0.0

Go to 2.2.4

If Q > 0

QCLNM(I) = QCLNM(I) + Q * MULT(I)

CALL MAX

IHCNM(I) = IHCNM(I) + 1

Go to 2.2.4

2.2.4 Turn off all system fans.

Adjust total fan brake horsepower.

$TNFBP = TNFBP - FBHPS_k - FBHPR_k - FBHPE_k$

IOO = 1.

FCOIL

A subroutine to simulate the operation of two- and four-pipe fancoil systems consisting of blow-through fancoil units.

INPUT

k : Energy distribution system number

RHOH : Heating capacity adjustment factor

Various items held in COMMON (see Table 5.4 for definition of variables in COMMON).

OUTPUT

QC : Cooling load (Btu/hr) ($QC = \sum_{j=1,jmax} QC_i$)**

QTRHC : Reheat coil load (Btu/hr)

QH : Heating load (Btu/hr) ($QH = \sum_{j=1,jmax} QH_i$)**

QPHC : Preheat coil load (Btu/hr)

TQB : Baseboard heating load (Btu/hr)

WATER : Steam humidification supplied at air handling unit (lbm-H_2O/hr)

BPKW : Base power (KW)

IHOUR : Hour of year for which calculations are to be performed

TNFBP : Total net (updated) fan brake horsepower (BHP)

TSA : Dry bulb air temperature leaving fancoil

**NOTE: There is a corresponding ℓ for each i, a relationship defined by the variable $SPACN_{k,j}$. Hence, i and ℓ are defined by system number (k) and zone number of system (j). See Para. 4.1 for zone labeling organization.

CALCULATION SEQUENCE

1. Fan off/on check.

   Using subroutine FANOF, determine whether fancoil units have been turned off for the current hour.

   If fancoil units are off, terminate fancoil simulation.

   If fancoil units are on, continue.

2. For two-pipe fancoil units, use subroutine TEMP to determine process water mode (i.e., hot water, chilled water, or changeover) for the current hour.

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

$$BPKW = \sum_{j=1,\ jmax} SLPOW_{\ell} * MULT_{i} **$$

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

4. Calculate sensible thermal load.

$$QSI_{i} = QS_{\ell} + QLITE_{\ell} ** + QSINF(L)$$

5. Baseboard radiation.

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

   Sum baseboard radiation heat.

$$TQB = \sum_{j=1,\ jmax} QB_{j} * MULT(I)$$

   If boiler is off, continue.

6. Calculate mixed air conditions.

   Call subroutine MXAIR to calculate thermal properties (temperature, humidity ratio, and density) of mixing outside air and room air by the fancoil unit.

7. Calculate mass flow through fancoil unit.

$$ZMAS = ZMASS(I)$$

8. Calculate required supply air temperature.

$$TSA_i = TSP_\ell - QSI_i/(0.245 * ZMAS_i) \;**$$

**NOTE: There is a corresponding ℓ for each i, a relationship defined by the variable $SPACN_{k,j}$. Hence, i and ℓ are defined by system number (k) and zone number of system (j). See Para. 7.1 for zone labeling organization.

9. Calculate fan heat and mixed air temperature downstream of blower.

$$QFAN = CFM_i * TFNPS_k * 0.4014$$

$$TMA = TMA + QFAN/(0.245 * ZMAS_i)$$

10. Zone humidity calculations.

Using subroutine H2ØZN, calculate total moisture requirements including set point recovery load ($H2ØRD_i$) and moisture changes in current hour due to environmental and room effects ($H2ØAD_i$).

11. Calculate fancoil performance and distribute thermal loads.

11.1 <u>Two-Pipe Fancoil System</u>

11.1.1 <u>Heating Mode (IPW = -1)</u>

If TMA < TSA, heating required.

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

If boiler off, heating load not met,

$$Q = ZMAS_i * 0.245 * (TMA - TSA)$$

Update as required:

$QHLNM_i$: Sum of all heating loads not met, zone i.

$QHPNM_i$: Peak heating load not met, zone i.

$IHHNM_i$: Hours heating load not met, zone i.

If TMA > TSA, cooling load not met.

Call subroutine CCOIL to calculate cooling load not met.

Update as required the following variables:

$QCLNM_i$: Sum of all cooling loads not met, zone i.

$QCPNM_i$: Peak cooling load not met, zone i.

$IHCNM_i$: Hours cooling load not met, zone i.

If TMA = TSA

WSA = WMA

TSA = TMA

11.1.2 Changeover Mode (IPW = 0)

During the changeover hour, it is assumed that both heating and cooling loads may be met. Therefore, the four-pipe fancoil system zone analysis is used (see 11.2). In addition, there is a thermal load due to changing the tempdrature of the hydronic system (see 13.).

11.1.3 Cooling Mode (IPW = +1)

If TMA > TSA, cooling required.

If chiller on, call subroutine ZLØ3 to calculate QC_i and distribute unmet load, if any.

If chiller off, cooling load not met. Call subroutine CCOIL to calculate cooling loads not met.

Update as required:

$QCLNM_i$: Sum of all cooling loads not met, zone i.

$QCPNM_i$: Peak cooling load not met, zone i.

$IHCNM_i$: Hours cooling load not met, zone i.

WSA = WMA

TSA = TMA

If TMA < TSA, heating load not met.

$Q = ZMAS_i * 0.245 * (TMA - TSA)$

Update as required:

$QHLNM_i$: Sum of all heating loads not met, zone i.

$QHPNM_i$: Peak heating load not met, zone i.

$IHHNM_i$: Hours heating load not met, zone i.

If TMA = TSA

WSA = WMA

TSA = TMA

11.2 Four-Pipe Fancoil System

If TMA ≤ TSA, heating required.

If boiler on, call subroutine ZLØ to calculate QH_i and distribute unmet load, if any.

If boiler off, heating load not met.

$Q = ZMAS_i * 0.245 * (TMA - TSA)$

Update as required the following variables:

$QHLNM_i$: Sum of all heating loads not met, zone i.

$QHPNM_i$: Peak heating load not met, zone i.

$IHHNM_i$: Hours heating load not met, zone i.

If TMA > TSA, cooling required.

If chiller on, call subroutine ZLØ to calculate QC_i and distribute unmet load, if any.

If chiller off, cooling load not met. Call subroutine CCOIL to calculate cooling load not met.

Update as required the following variables:

$QCLNM_i$: Sum of all cooling loads not met, zone i.

$QCPNM_i$: Peak cooling load not met, zone i.

$IHCNM_i$: Hours cooling load not met, zone i.

12. Calculate zone humidity ratio.

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

13. Calculate heat of changeover (for two-pipe fancoil systems only).

If IPW = 0, changeover.

Calculate hot water temperature (THW) using function TRSET.

Calculate changeover heat : QCO

$$QCO = PWGAL_k * 8.3 * (THW - TLCHL)$$

where $PWGAL_k$: Water volume of two-pipe system (GALS)

TLCHL : Chilled water temperature (°F)

If heating-to-cooling changeover:

$$QC = QC + QCO$$

If cooling-to-heating changeover:

$$QC = QH - QCO$$

If IPW $\neq$ 0, continue.

NOTES

FHTG

A subroutine for simulating the system performance of the floor panel heating system.

INPUT

*TOA	:	Dry-bulb temperature of outside air, ^oF
K	:	Fan system number
*JMAXK	:	Number of zones on fan system No. K
*QS_ℓ	:	Hourly sensible load for zone No. ℓ Btu/hr
*QL_ℓ	:	Hourly latent load for zone No. ℓ Btu/hr
*$QLITE_\ell$	:	Hourly lighting load picked up by return air in zone No. ℓ Btu/hr.
*$SLPOW_\ell$	:	Hourly zone internal lighting and machinery power consumption, KW, for zone No. ℓ
*TCO	:	Building changeover temperature, ^oF
*$PERIM_k$	:	Exposed perimeter of floor for distribution system No. k, ft.
*$PAREA_k$	:	Floor area available for heating panels, system k sq. ft.
*$PLOC_k$	:	Location of floor heating panel for system No. k
*CINSL	:	Floor insulation conductance, Btu/hr-sq.ft.-^oF
*DINSL	:	Floor insulation thickness, ft.
*TSP_ℓ	:	Set point temperature of zone No. ℓ, ^oF

OUTPUT

QFPC : Hourly cooling requirement, Btu/hr.

TQB : Baseboard heating load, Btu/hr.

QFPH : Hourly heating requirement, Btu/hr.

WATER : Steam humidification supplied at air handling unit, lbm-H_2O/hr.

QFPRH : Hourly reheat requirement, Btu/hr.

TNFBP : Total net (updated) fan brake housepower, BHP.

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

TPAN : Panel temperature

CALCULATION SEQUENCE *

1. Read load input tape for zones required and calculate

System heating load base power requirements:

QS1(I) = QS(L) + QLITE(L) + QSINF(L)

Initialize general variables

QFPC = 0.0

QFPRH = 0.0

QPHC = 0.0

TQB = 0.0

WATER = 0.0

BPKW = 0.0

QSSUM = 0.0

Calculate base power (includes internal power, lights, receptacles, equipment, miscellaneous)

$$BPKW = \sum_{j=1,\, jmax_k} SLPOW_\ell * MULT(I)$$

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

Calculate system heating load

$$QSSUM = \sum_{j=1,jmax_k} (QS_\ell + QLITE_\ell + QSINF_\ell)$$

2. Check for heating load. If no load (IBOIL = 0), go to 2.1.

2.1 No heating available since building system is operating in cooling mode, therefore set

QFPC = 0.0

QFPH = 0.0

QFPRH = 0.0

Go to 3.

2.2 Heating available within building, therefore perform the following:

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

$QPAN = QSSUM/PAREA_k$

Calculate set point temperature of system $TSPJ1 = TSP_\ell$ where TSP_ℓ is the set point of the first zone.

Initially, set TPAN = TSPJ1 + 1.0

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

** 4.0 - 0.15 ((TSPJ1 + 460.0)/100.0)

** 4.0 + 0.32 * (TPAN - TSPJ1) ** 1.31

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

TPAN = TPAN + 0.5 * (QPAN - QCALC)

If TPAN ≥ 155.0 then
reset TPAN=150.0 and go to 2.2.2
Else
repeat QCALC calculation until QCALC is within (0.01 * QPAN).

2.2.2 Calculate downward and edgewise heat loss, QLOSS.

If $PLOC_k$ = 1, then

$$QLOSS = PERIM_k * C3 * (TPAN - TOA)/PAREA_k$$

2.2.3 Calcualte the downward and edgewise loss coefficient, C3.

2.2.3.1 If CINSL $\leq$ 0.0, no insulation, therefore

$$C3 = 1.8$$

2.2.3.2 If CINSL > 0.0, and DINSL $\leq$ 0.0, then only perimeter insulation, therefore

$$C3 = 1.32 + 0.25 * CINSL$$

2.2.3.3 If CINSL > 0.0 and DINSL > 0.0, then

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

2.2.3.4 If PLOC (K) = 2, then

$$QLOSS = 0.15 * ((TPAN + 460.0)/100.0) ** 4.0 - 0.15 * (TSPJ1 + 460.0)/100.0) ** 4.0 + 0.021 * (TPAN - TSPJ1) ** 1.25$$

2.2.4 Calculate heating requirement of system.

$$QFPH = 1.0 * (QPAN + QLOSS) * PAREA_k$$

3. Distribute unmet heating and cooling loads, finding:

   Heating and cooling peak, consumption, and number of hours heating and cooling loads were not met.

NOTES

FILM

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

INPUT

V : Wind velocity, mph

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

OUTPUT

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

CALCULATION SEQUENCE

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

The values of A, B, and C as a function of type of exterior surface are given in Table 4.5.

TABLE 4.5

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

FSIZE

A subroutine to size energy distribution system characteristics. These properties include:

Zone peak heating and cooling loads
Zone air flows
Fan system air quantities and motor brake horsepower
Fan system
Minimum outside air percentage

INPUT

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

INPUT (CONT'D)

$KFAN_k$	:	Type of energy distribution system, system k
TSP_ℓ	:	Set point temperature, zone ℓ (^oF)
$JMAX_k$	:	Number of zones on system k
$TFNPS_k$	:	Total supply fan pressure of system k
$TFNPR_k$	:	Total return fan pressure of system k
$TFNPE_k$	:	Total exhaust fan pressure of system k
$OACFM_k$	:	Minimum outside ventilation air of system k (cfm)
$RHSP_k$	:	Relative humidity set point of system k (% RH)
$RIPA_k$	:	Ratio of induced to primary air for induction units of system k
EFF	:	Efficiency of fan and pump motors (decimal)
KBLDG	:	Type of building system (1.-conventional; 2.-heat conservation)
$CFMX_i$	:	Auxiliary exhaust air quantity for zone i (cfm)

OUTPUT

CFM_i	:	Supply air volume required for zone i (cfm at standard density)
$CFMR_i$	:	Return air volume for zone i at standard density
$ZMASS_i$	:	Supply air mass flow of zone i (lbm/hr)
$ZMASR_i$	:	Return air mass flow of zone i (lbm/hr)
$ZMASX_i$	:	Exhaust air mass flow of zone i (lbm/hr)
$CFMAX_k$	:	Total air supplied by fan system k (cfm)
$CFMIN_k$	:	Minimum outside air required for fan system k (cfm)
$ALFAM_k$	:	Percent of minimum outside air required for fan system k (fraction)
$FBHPS_k$	:	Supply fan brake horsepower required for fan system k (bhp)

OUTPUT (CONT'D)

$FBHPR_k$: Return fan brake horsepower required for fan system k (bhp)

$FBHPE_k$; Exhaust fan brake horsepower required for fan system k (bhp)

$CFMEX_k$: $\sum_{j=1,jmax} CFMX_j$ (cfm)

WSP_k : Humidity ratio set point for system k ($lbm\text{-}H_2O/lbm\text{-}dry$ air)

CFMBX : $\sum_{k=1,kmax} CFMAX_k$ (cfm)

CFMBN : $\sum_{k=1,kmax} CFMIN_k$ (cfm)

CFMBE : $\sum_{k=1,kmax} CFMEX_k$ (cfm)

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

$DTFNS_k$: Temperature rise across supply fan at full load, system k (^oF)

$DTFNR_k$: Temperature rise across return fan at full load, system k (^oF)

CALCULATION SEQUENCE

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

   $QSZCM_i$ Maximum zone sensible cooling load for each zone, i

   $QSZHM_i$ Maximum zone sensible heating load for each zone, i

   PWBIL Maximum hourly building internal lighting and machinery power consumption

2. Segment Two. Calculate zone and system peak load air quantities and system peak load power requirements for each zone within the building.

   2.1 Calculate cooling and heating temperature differences.

$$TDC = TSPAC_\ell - \frac{(TPAC_{kf} + TIAC * ARIPA_k)}{(1. + ARIPA_k)}$$

CALCULATION SEQUENCE (CONT'D)

$$TDH = TSPAC_{\ell} - \frac{(TPAH_{kf} + TIAH * ARIPA_k)}{(1. + ARIPA_k)}$$

where TDC : terminal unit cooling design temperature difference (^oF)

TDH : terminal unit heating design temperature difference (^oF)

$ARIPA_k$: ratio of induced to primary air (equals zero for all but induction unit fan systems), system k

TIAC : design dry-bulb temperature of induced air after passing through coil, cooling mode = 62^oF

TIAH : design dry-bulb temperature of induced air after passing through coil, heating mode = 120^oF

$TPAC_{kf}$: primary air design temperature, cooling mode, for system type kf. See table below.

$TPAH_{kf}$: primary air design temperature, heating mode, for system type kf. See table below.

TABLE 4.6 HEATING & COOLING PRIMARY AIR DESIGN TEMPERATURE

SYSTEM TYPE (kf)	SYMBOL	PRIMARY AIR COOLING DESIGN (^oF)	PRIMARY AIR HEATING DESIGN (^oF)	INDUCED AIR HEATING (^oF)	INDUCED AIR COOLING (^oF)
1	SZFB	55.	120.	-	-
2	MZS	55.	120.	-	-
3	DDS	55.	120.	-	-
4	SZRH	52.	95.	-	-
5	UVT	55.	120.	-	-
6	UHT	55.	120.	-	-
7	FPH	0.	0.	-	-
8	2PFC	55.	110.	-	-
9	4PFC	55.	110.	-	-
10	2PIU	53.	53.	120.	62.
11	4PIU	53.	53.	120.	62.
12	VAVS	55.	120.	-	-
13	RHFS	55.	120.	-	-

2.2 Calculate zone supply air quantities

If $\left|\frac{QSZCM_i}{TDC}\right| < \left|\frac{QSZHM_i}{TDH}\right|$,

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

If $\left|\frac{QSZHM_i}{TDH}\right| < \left|\frac{QSZCM_i}{TDC}\right|$,

$$CFM_i = \frac{QSZCM_i}{(0.245*0.075*60.*TDC)(1.+ARIPA)}$$

If $CFMX_i > CFM_i$

$$CFM_i = CFMX_i$$

2.3 Calculate zone return air

$$CFMR_i = CFM_i - CFMX_i$$

2.4 Sum system supply and exhaust air flows

$$CFMAX_k = \sum_{j=1,jmax} CFM_i^{**} * MULT_i$$

$$CFMEX_k = \sum_{j=1,jmax} CFMX_i^{**} * MULT_i$$

2.5 Average system temperature -$TAVE_k$

$$TAVE_k = \frac{\sum_{j=1,jmax} (CFM_i * TSP * MULT_i)}{\sum_{j=1,jmax} (CFM_i * MULT_i)}$$

** NOTE: There is a corresponding ℓ for each i; a relationship defined by the variable $SPACN_{k,j}$.

2.6 Minimum outside air fraction - $ALFAM_k$

If $CFMAX_k > 0$, $ALFAM_k = CFMEX_, / CFMAX_k$

If $CFMEX_k \leq OACFM_k > CFMAX_k$,

$$CFM_i = CFM_i * (OACFM_k/CFMAX_k)$$

$$CFMAX_i = OACFM_k$$

$$ALFAM_k = OACFM_k/CFMAX_k = 1.0, \text{ if } CFMAX_k > 0$$

If $CFMEX_k < OACFM_k < CFMAX_k$,

$$ALFAM_k = OACFM_k/CFMAX_k, \text{ if } CFMAX_k > 0$$

If $CFMEX_k > OACFM_k < CFMAX_k$, go to calculation 2.7.

2.7. Calculate system humidity ratio setpoint. Call subroutine HUM1 to calculate distribution system humidity ratio setpoint (WSP_k). Input average zone setpoint temperature (TAVE), barometric pressure at sea levels (29.92 in. Hg.), and system relative humidity setpoint ($RHSP_k$).

2.8 Initialize return air humidity ratio (WRA_k) and density (DRA_k).

$$WRA_k = WSP$$

$$DRA_k = 0.075$$

2.9 Calculate fan power.

Supply Fan:

$$FBHPS_k = \frac{CFMAX_k * TFNPS_k}{6346 * EFF * .6}$$

Return Fan:

$$FBHPR_k = \frac{(CFMAX_k - CFMEX_k) * TFNPR_k}{6346 * EFF * .6}$$

Exhaust Fan:

$$FBHPE_k = \frac{CFMEX_k * TFNPE_k}{6346 * EFF * .6}$$

2.10 Sum building fan power

$$TFBHP = \sum_{j=1,kmax} (FBHPS_k + FBHPR_k + FBHPE_k)$$

2.11 Calculate temperature rise across fans at full load

Supply Fan:

$$DTFNS_k = \frac{(TFNPS * 0.4014)}{(0.245 * 0.075 * 60.0)}$$

Return Fan:

$$DTFNR_k = \frac{(TFNPR_k * 0.4014)}{(0.245 * 0.075 * 60.0)}$$

2.12 Calculate mass flows

Zones:

$$ZMASS_i = CFM_i * 0.075 * 60.0$$

$$ZMASX_i = CFMX_i * 0.075 * 60.0$$

$$ZMASR_i = ZMASS_i - ZMASX_i$$

Systems:

$$FMASS_k = CFMAX_k * 0.075 * 60.0$$

$$FMASX_k = CFMEX_k * 0.075 * 60.0$$

$$FMASR_k = FMASS_k - FMASX_k$$

3. Segment Three. Write FSIZE information.

3.1 For each fan system, write out the following:

K
FAN_{kf}
$FBHPS_k$
$FBHPR_k$
$FBHPE_k$
$JMAX_k$
$CFMAX_k$
$CFMIN_k$
$CFMEX_k$
ALPCT

3.2 For each zone, write out the following:

k

j

λ

$MULT_i$

CFM_i

$CFMX_i$

$TSPAC_\ell$

NOTES

HUM

A subroutine to calculate the humidity ratio (lb-H_2O/lb-dry air) of air given

T - dry-bulb temperature (^oF)

RH - relative humidity (%)

PATM - barometric pressure (in. Hg.)

1. Using subroutine PSY2, calculate humidity ratio of saturated air (WSAT) at temperature, T.

2. Humidity ratio (W) = RH * 0.01 * WSAT

H2OZN

A subroutine to calculate hourly moisture changes and net moisture requirements.

INPUT

QL : Latent load from zone (Btu/hr)

ZMASS : Mass flow through zone (lbm-air/hr)

WSP : Zone humidity ratio set point (lbm-H_2O/lbm-dry air)

QLINF : Latent load due to infiltration from load tape (Btu/hr)

WZON : Current zone humidity ratio (lbm-H_2O/lbm-dry air)

WOA : Outside air humidity ratio (lbm-H_2O/lbm-dry air)

OUTPUT

H2OAD : Zone water change in current hour (lbm-H_2O)

H2ORD : Net zone water requirement

CALCULATION SEQUENCE

1. Zone load water.

   H2ORM = QL/1090.0

2. Infiltration water.

   H2OIN = (QLINF/1090.0) * (WOA - WZON)/((WOA - WSP)

3. Set point recovery load.

   H2OVL = (WZON - WSP) * ZMASS

4. Summaries.

   H2OAD = H2ORM + H2OIN

   H2ORD = H2OAD + H2OVL

INDUC

A subroutine to simulate the operation of two and four pipe induction unit fan systems having induction units whose primary and induced room air streams mix after induced air is tempered. Induction unit cooling coil limited to sensible cooling only.

INPUT

K : Energy distribution system number.
RHOH : Heating capacity adjustment factor
Various items held in COMMON (See Table 4.4 for definition of variables in COMMON).

OUTPUT

QCC : Total cooling load (Btu/hr) $(QCC = \sum_{J=1,\ jmax} QC_i)$

QHC : Heating load at AHU (Btu/hr) $(QHC = \sum_{j=1,\ jmax} QH_i)$

QPHC : Preheat coil load (Btu/hr)

QTRHC : Heating load at induction unit (Btu/hr)
$(QTRHC = \sum_{j=1,\ jmax} QRHC_i)$**

TQB : Baseboard heating load (Btu/hr)
IHOUR : Hour of year for which calculations are to be performed
WATER : Steam humidification supplied at air handling unit ($lbs\text{-}H_2O/hr$).

BPKW : Base power (KW)
TLVG : Required dry-bulb temperature of air leaving air handler
TNFBP : Total net [updated] fan brake horsepower (Bhp)

Various items held in COMMON.

CALCULATION SEQUENCE

1. Fan off/on check.

Using subroutine FANOF, determine whether air handler has been turned off for the current hour

If the system is off, terminate induction system simulation.

If the system is on, continue.

2. Calculate temperature leaving air handler (TLVG).

If two-pipe induction unit fan system, call subroutine TEMP to calculate primary air temperature and induction unit water mode indicator (IPW). This is graphically represented as follows:

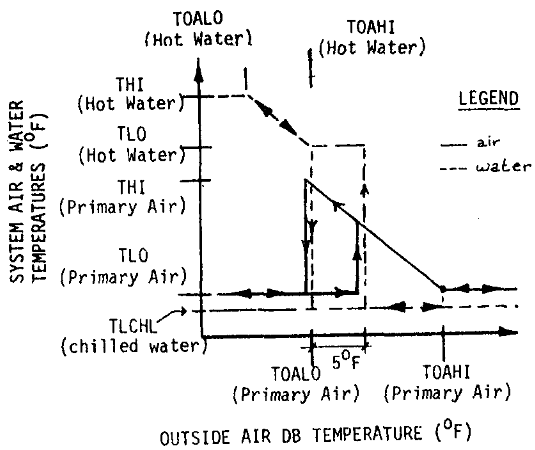


Figure 5.3 TWO-PIPE INDUCTION UNIT AIR AND WATER SCHEDULING

NOTE: TOAHI [hot water] should be set equal to TOALO (primary air).

If four-pipe induction unit fan system, primary air is held constant (set equal to $TFIX1_k$).

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

$$ALFIU = 1.0/(1.0 + RIPA_k)$$

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

$$BPKW = \sum_{j=1,\ jmax} SLPOW_\ell * MULT_i \ **$$

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

$$QSI_i = QS_\ell \ **$$

**NOTE: There is a corresponding ℓ for each i, a relationship defined by the variable $SPACN_{k,j}$. Hence, i and ℓ are defined by system number (k) and zone number of system (j). See Table 4.1 for zone labeling organization.

6. Baseboard radiation.

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

Sum baseboard radiation heat.

$$TQB = \sum_{j=1,\ jmax} QB_j$$

If boiler off, continue.

7. Calculate return air temperature (TRA_k).

NOTE: Since the system and equipment simulation program is capable of using LOAD or VARIABLE TEMPERATURE tapes as input, the following logic sequence is required.

If ceiling plenum is calculated as a separate zone,

If LOAD tape is used,

$$DTL2_i = 0.0$$

$$QLITI = QLITE_\ell + QS_{p\ell} + QLITE_{p\ell} + QSINF_{p\ell} \ **$$

If VARIABLE TEMPERATURE tape is used,

$$DTL2_i = STEMP_{p\ell} - TSP_\ell$$

$$QLITI = QLITE_\ell$$

If ceiling plenum is not calculated as a separate zone,

$$DTL2_i = 0.0$$

$$QLITI = QLITE_\ell$$

$$DTL_i = QLITI/(0.245 * ZMASR_i)$$

$$TRA_k = \left[\frac{\left(\sum_{j=1,\ jmax} (TSP_\ell + DTL_i + DTL2_i) * ZMASR_i * MULT_i\right)}{\left(\sum_{j=1,\ jmax} ZMASR_i * MULT_i\right)}\right] + DTFNR_k$$

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

QLITI -- Thermal load of plenum $p\ell$ above zone ℓ as calculated by LOAD program.

8. Zone humidity calculations.

   Using subroutine H2OZN, calculate total moisture requirements including set point recovery load ($H2ORD_i$) and moisture changes in current hour due to environmental and room effects ($H2OAD_i$).

9. Calculate economizer approach temperature (EAT).

   If TLVG > 125.0^{o}F,

   TLVG = 125.0^{o}F

   EAT = TLVG - $DTFNS_k$

   If EAT < 40.0^{o}F

   EAT = 40.0^{o}F

   TLVG = EAT + $DTFNS_k$

10. If there is an outside air reset schedule, calculate the minimum fraction of outside air.

   ALFAM(K) = ALFAM(K) * SCHD(IVENT(K), KEASON, ITIME)

11. Calculate mixed air conditions.

   Call subroutine MXAIR to simulate the performance of:

   1. Fixed outside and return air dampers
   2. An enthalpy/temperature type economizer cycle.
   3. A temperature type economizer cycle

   Subroutine MXAIR also calculates the thermal properties (temperature, humidity ratio, and density) of the mixed air stream.

12. Air handling unit.

   Call subroutine AHU (mode 1) to simulate the functioning of a central system air handling unit. Calculate heating and cooling coil thermal response (QHC and QCC) of fan heat, and operation of steam humidifier on discharge side of unit (WATER).
   The heating coil is locked out when the boiler scheduled off.
   The cooling coil is locked out when the chiller scheduled off.
   The humidifier is locked out when the cooling coil is functioning.

13. Calculate induction unit coil sensible thermal load and induced air mass flow.

$QSI_i = QSI_i + ZMASS_i * 0.245 * (TLVG - TSP_\ell)$

$ZMAS_i = ZMASS_i * RIPA_k$

14. Induction unit simulation.

14.1 Two-pipe induction unit.

14.1.1 Hot water mode (IPW = -1).

If $QSI_i \leq 0.0$,

If boiler on,

$TLC_i = -QSI_i/(ZMAS_i * 0.245) + TSP_\ell$

where TLC_i - Temperature of induced air after coil (°F).

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

If boiler off, heating load not met.

$QLNM_i = QSI_i$

Update as required the following variables:

$QHLNM_i$ -
$QHPNM_i$ -
$IHHNM_i$ -

If $QSI_i > 0.0$, cooling load not met.

$QLNM_i = QSI_i$

Update as required the following variables:

$QCLNM_i$ -
$QCPNM_i$ -
$IHCNM_i$ -

14.1.2 Changeover mode (IPW = 0).

During the changeover hour, it is assumed that both heating and cooling loads may be met. Therefore, the four-pipe fan-coil system zone analysis is used (see 14.2.). In addition, there is a thermal load due to changing the temperature of the hydronic system (see 18.).

14.1.3 Cooling mode (IPW = +1)

If $QSI_i > 0.0$, cooling required.

If chiller on,

$TLC_i = -QSI_i/(ZMAS_i * 0.245) + TSP_\ell$

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

If chiller off, cooling load not met.

$QLNM_i = QSIU_i$

Update as required the following variables:

$QCLNM_i$ -
$QCPNM_i$ -
$IHCNM_i$ -

If $QSI_i < 0.0$, heating load not met.

$QLNM_i = QSI_i$

Update as required the following variables:

$QHLNM_i$ -
$QHPNM_i$ -
$IHHNM_i$ -

14.2 Four-pipe induction unit.

If $QSI_i \leq 0.0$, heating required.

If boiler on,

$TLC_i = -QSI_i/(ZMAS_i * 0.245) + TSP_\ell$

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

If boiler off, heating load not met.

$QLNM_i = QSI_i$

Update as required the following variables:

$QHLNM_i$ -
$QHPNM_i$ -
$IHHNM_i$ -

If $QSI_i > 0.0$, cooling required,

If chiller on,

$TLC_i = -QSI_i/(ZMAS_i * 0.245) + TSP_\ell$

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

If chiller off, cooling load not met.

$QLNM_i = QSI_i$

Update as required the following variables:

$QCLNM_i$ -
$QCPNM_i$ -
$IHCNM_i$ -

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

$TTLVG_i = (TLVG * ZMASS_i + TLC * ZMAS_i)/(ZMASS_i + ZMAS_i)$

$WTLVG_i = (WSUP * ZMASS_i + WCLVG * ZMAS_i)/(ZMASS_i + ZMAS_i)$

16. Calculate zone humidity ratio.

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

17. Calculate return air humidity ratio and density.

$WRA_k = (\sum_{j=1,jmax} WZ_i * ZMASR_i * MULT_i)/(\sum_{j=1,jmax} ZMASR_i * MULT_i)$

$DRA_k = PATM/((0.754 * (TRA_k + 460.0)*(1.0 + 7000.0 * WRA_k/4360.0))$

18. Calculate heat of changeover (for two-pipe induction systems only).

If IPW = 0 (changeover),

Calculate hot water temperature using function TRSET.

Calculate changeover heat, QCO

$QCO = PWGAL_k * 8.3 * (THW - TLCHL)$

where, $PWGAL_k$ - Water volume of two-pipe induction unit system (gal.)
TLCHL - Chilled water temperature (°F)

If heating to cooling changeover:

$QC = QC + QCO$

If cooling to heating changeover:

$QH = QH - QCO$

If IPW $\neq$ 0, continue.

MAX

A subroutine to replace current values of A with X and IB with IY if the absolute value of X exceeds A. A and X are real numbers. IB and IY are integers.

VARIABLE ORDER

A, X, IB, IY

CALCULATION SEQUENCY

1. If $|X|$ exceeds $|A|$,

   $A = X$

   $IB = IY$

MXAIR

A subroutine to calculate the thermal properties of mixed air given the properties of the two mixing air streams. The basic application of this routine is in simulating the function of three types of outside air control.

INPUT

	MXAO	:	Type of outside air control. 1 Fixed percent outside air. 2 Enthalpy/temperature type economizer cycle control. 3 Temperature type economizer cycle control.
Air Stream #1	TOA	:	Outside air dry bulb temperature (°F)
	DOA	:	Outside air density (lbm/ft^3)
	HOA	:	Outside air enthalpy (Btu/lbm)
	WOA	:	Outside air humidity ratio (lbm-H_2O/lbm-dry air)
	PATM	:	Barometric pressure (in. Hg)
Air Stream #2	TRA	:	Return air temperature (°F)
	DRA	:	Return air density (lbm/ft^3)
	WRA	:	Return air humidity ratio (lbm-H_2O/lbm-dry air)
	EAT	:	Desired mixed air temperature (economizer approach temperature) (°F)
	ALFAM	:	Minimum fraction of outside air (for MXAO type 1, ALFAM is the fixed portion of outside air.

OUTPUT

ALFA : Actual portion of outside air which meets or approaches EAT.

TMA : Mixed air dry bulb temperature (°F)

WMA : Mixed air himidity ratio (lbm-H_2O/lbm-dry air)

OUTPUT (Concluded)

DMA : Mixed air density (lbm/ft^3)

CALCULATION SEQUENCE

1. Using subroutine PSYCH, calculate return air enthalpy (HRA).
2. MXAO = 1 (fixed percent outside air)

   ALFA = ALFAM

   GO TO 5.
3. MXAO = 2 (enthalpy/temperature type economizer cycle control)

   If HOA < HRA,

   Calculate ALFA using subroutine ECONO

   If HOA > HRA,

   ALFA = ALFAM

   GO TO 5.
4. MXAO = 3 (temperature type economizer cycle control)

   Calculate ALFA using subroutine ECONO.

   GO TO 5.
5. Mixed air thermal properties.

   TMA = (TOA * DOA * ALFA + TRA * DRA * (1. - ALFA))/(DOA * ALFA
   + DRA * (1. - ALFA))

   WMA = (WOA * DOA * ALFA + WRA * DRA * (1. - ALFA))/(DOA * ALFA
   + DRA * (1. - ALFA))

   DMA = PATM/((.754 * (TMA + 460.)) * (1. + (7000. * WMA/4360.)))

MZDD

A subroutine to simulate the performance of a multi-zone or dual duct fan system.

INPUT

K - Energy distribution system number

RHOH - Heating capacity adjustment factor

Various items held in COMMON (see Table 4.4 for definitions of variables in COMMON).

OUTPUT

QCC - Cooling coil load (Btu/hr)

THC - Leaving air temperature of heating coil

QHC - AHU heating coil load (Btu/hr)

TCC - Leaving air temperature of cooling coil

QRHC - Reheat coil load (Btu/hr)

QPHC - Preheat coil load (Btu/hr)

TQB - Baseboard heating load (Btu/hr)

WATER - Steam humidification supplied at air handling unit (lbm-H_2O/hr)

BPKW - Base power (KW)

TNFBP - Total net [updated] fan brake horsepower (bhp)

Various items held in COMMON.

CALCULATION SEQUENCE

1. Fan off/on check.

   Using subroutine FANOF, determine whether the fan has been turned off for the current hour.

   If the system is off, terminate MZDD simulation for the current hour.

   If the system is on, continue.

2. If there is an outside air reset schedule, calculate the minimum fraction of outside air.

ALFAM(K) = ALFAM(K) * SCHD(IVENT(K), KEASON, ITIME)

If ALFMN * CFMAX(K) < CFMEX(K), $\text{ALFMN} = \frac{\text{CFMEX(K)}}{\text{CFMAX(K)}}$

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

$$QSI_i = QS_\ell^{**} + QSINF(L)$$

4. Baseboard radiation.

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

Sum baseboard radiation heat,

$$TQB = \sum_{j=1,jmax} QB_j * MULT(I)$$

If boiler off, continue.

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

$$BPKW = \sum_{j=1,jmax} SLPOW_\ell * MULT_i^{**}$$

6. QLITI = QLITE(L)

DTL2 = 0.

If ceiling plenum is calculated as a separate zone
For load run adjustment only: If STEMP(IPL) ≤ 0.1

QLITI = QLITE(L) + QS(IPL) + QLITE(IPL) + QSINF(IPL)

For variable temperature adjustment only

DTL2 = STEMP(IPL) - TSP(L)

If ceiling plenum is not calculated as a separate zone

DLT = 0.0

DLT = QLITI/(0.245*ZMASR(I))

SMTRA = Σ[(TSP(L) + DTL + DTL2) * ZMASR(I) * MULT(I)]

FMR = Σ{ZMASR(I) * MULT(I)]

7. Calculates required supply air temperature of each zone.

If ZMASS(I) $\leq$ 0

TS(I) = TSP(L)

If ZMASS(I) > 0
TS(I) = TLP(I) - QSI(I)/(.245 * ZMASS(I))

8. Calculate zone humidification requirements

CALL H2OZN

9. Calculate return air temperature for fan system

TRA = SMTRA/FMR + DTFNR(K)

10. Calculate hot deck and cold deck air temperatures. Generally, three control options are available:

    1. Fixed settings for both hot and cold decks.

    2. Fixed cold deck temperature but allowing hot deck temperature to vary inversely with outside air temperature.

    3. Reset temperature control as governed by the spaces. Control for this mode involves setting the hot deck leaving air temperature equal to that of air supplied to the space requiring warmest air. The cold deck leaving air temperature is set equal to the temperature of air supplied to the space requiring coolest air.

Calculate desired heating coil leaving air temperature

CALL TEMP to return THC

Calculate desired cooling coil leaving air temperature

CALL TEMP to return TCC

11. Calculate desired economizer approach temperature entering supply fan.

$$EAT = TCC - DTFNS_k$$

12. Calculate mixed air conditions.

Call subroutine MXAIR to simulate the performance of:

1. Fixed outside and return air dampers.

2. An enthalpy/temperature type economizer cycle.

or

3. A temperature type economizer cycle.

Subroutine MXAIR also calculates the thermal properties (temperature, humidity ratio, and density) of the mixed air stream.

13. Calculate preheat coil load by comparing to mixed air temperature desired.

If boiler on,

If TMA < EAT,

$$QPHC = 0.245 * FMASS_k * (TMA-EAT)$$

$$TMABF = EAT$$

If TMA $\geq$ EAT,

$$QPHC = 0.$$

$$TMABF = TMA$$

(TMABF = temperature of mixed air before fan (^{o}F))

If boiler off,

$$QPHC = 0.$$

$$TMABF = TMA$$

14. Calculate mixed air temperature after supply fan.

$$TMAAF = TMABF + DTFNS_k$$

15. Check boiler and chiller operation to update deck temperatures.

If chiller off,

$TCC = TMAAF$

If boiler off,

$THC = TMAAF$

16. Calculate air mass through hot and cold decks.

16.1 Calculate fraction of cold deck air required by zone.

$PCTC_i = (THC - TS_i)/(THC - TCC)$

If $PCTC_i \leq 0.0$, heating load not met.

$PCTC_i = 0.$

$QTH = 0.245 * ZMASS_i * (THC - TS_i)$ (QTH =load not met)

Update as required the following variables:

$QHLNM_i$ -

$QHPNM_i$ -

$IHHNM_i$ -

$TS_i = THC$

IF PCTC > 1.0, cooling load not met.

$QTC = 0.245 * ZMASS_i * (TCC - TS_i)$

Update as required the following variables:

$QCLNM_i$ -

$QCPNM_i$ -

$IHCNM_i$ -

$TS_i = TCC.$

17. Sum cold and hot deck mass flows.

$$CMASS = \sum_{j=1,jmax} ZMASS_i * PCTC_i$$

$$HMASS = FMASS_k - CMASS$$

18. Calculate heating coil load.

$OHC = HMASS * 0.245 * (TMAAF - THC)$

$WHC = WMA$

19. Calculate cooling coil load.

Call subroutine CCOIL to calculate cooling coil load (QCC), cold deck humidity ratio (WCC), and sensible heat ratio (SHR).

20. Calculate humidification requirements.

20.1 Calculate required hot deck humidity ratio (WHRQD).

$CMESS = ZMASS_{icz} * PCTC_{icz}$

$HMESS = ZMASS_{icz} * (1. - PCTC_{icz})$

$WICZ = (CMESS * WCC + HMESS * WHC)/ZMASS(ICZ)$

$WZRQD = WZ_{icz} - H2ORD_{icz}/ZMASS_{icz}$

$WHRQD = (ZMASS_{icz} * WZRQD - WCC * CMESS)/HMESS$

where:

icz - zone in which humidistat is located.

20.2 Check that WHRQD does not exceed a high limit of 80% R.H. within the duct. Call subroutine HUM1 to do this.

20.3 Hot deck humidity ratio.

If $WHRQD \leq WHC$ Go to 20.4

If $WHRQD > WHMAX$, $WHRQD = WHMAX$

$WHC = WHRQD$

20.4 Calculate amount of humidification water required.

$WATER = HMASS * (WHC - WMA)$

21. Calculate zone humidity ratio.

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

22. Calculate return air humidity ratio and density.

$$WRA_k = \frac{\sum_{j=1,jmax} WZ_i * ZMASR_i * MULT_i}{\sum_{j=1,jmax} ZMASR_i * MULT_i}$$

DRA using DENSY function.

NUMDEV

A subroutine to determine the number of central plant devices (boilers, chillers and engine generators) required to meet a plant load, and the fraction of full load of each.

INPUT

XX : Load to be met.

NTYPE : Number of different types of central plant devices available to meet XX.

NUM : Number of units per NTYPE.

SIZE : Size of each unit per NTYPE.

XLIM : Lowest fraction of full load allowable.

YLIM : Normal fraction of full load allowable.

ZLIM : Highest fraction of full load allowable.

OUTPUT

FFL : Fraction of full load on each unit per NTYPE.

CALCULATION SEQUENCE

1. Set load positive.

   X = ABS(XX)

2. Initialize FFL for each unit

   FFL(M,N) = 0

   where M = type of device

   N = unit number

3. Allowing devices to come on line in order that they were inputted do following for M = 1 to NTYPE

   3.1 Define low, normal and high loads for device TYPE M.

   CAP = SIZE(M)

   CAPL = CAP * XLIM

   CAPN = CAP * YLIM

   CAPH = CAP * BLIM

3.2 Allow each unit (N=1 to NUM) to be brought online one at a time and check if load can be met

3.2.1 If $CAPL \leq X \leq CAPH$, go to calculation 5.

3.2.2 If $X < CAPL$, go to calculation 6.

3.2.3 Need additional units. Reset X and set FFL to normal operating point for unit

$$X = X - CAPN$$

$$FFL(M,N) = YLIM$$

3.2.4 Bring next unit online and go to calculation 3.2.1, otherwise go to next device type.

4. All units are loaded. Check for load conditions on the last device. Actual FFL on last device is

4.1 $FFL(M,N) = (X + CAPN)/CAP$

4.2 If $FFL(M,N) < XLIM$, then $FFL(M,N) = XLIM$

4.3 If $FFL(M,N) > ZLIM$, then $FFL(M,N) = ZLIM$

4.4 RETURN

5. Last unit on is within operated range.

$$FFL(M,N) = X/CAP$$

RETURN

6. Last unit on is less than minimum load.

$$FFL(M,N) = XLIM$$

RETURN

PPWVM

A function which calculates the partial pressure of water in moisture-saturated air.

INPUT

TEMP : may be a wet-bulb, dry-bulb, or dewpoint temperature (^{o}F)

OUTPUT

PPWVM : partial pressure of water in moisture-saturated air (in. Hg)

CALCULATION SEQUENCE

1. Let A(1) = -7.90298
   A(2) = 5.02808
   A(3) = -1.3816 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

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

   If T is less than 273.16, go to 3.

   Otherwise

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

   Go to 4.

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

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

PROCES

A subroutine to calculate hourly values for process loads of which there can be five types.

INPUT

NPROCS : Number of process loads

PRPK : A real array of process load peaks

IPS : An integer array indicating the energy source of process loads.

Code	Description
0	indirect process (mbh)
1	gas (therms)
2	oil (k-gals)
3	steam (k-lbs)
4	electric (kw)

IPRSC : An integer array pointing to the weekly operating schedule of each process load type.

SCHD : A three dimensional array of operating schedules

KEASON : Day type (Sunday through Saturday, holiday)

ITIME : Hour of day (1-24)

HVHO : Heating value of oil

PRSTMT : Process steam temperature (^{o}F)

PRSTMP : Process steam pressure (psig)

IPREN : An integer array indicating the energy source for each process load.

OUTPUT

PRBLR : Indirect process load to be added directly to boiler loads (Btu, a negative number)

PRGAS : Direct process - gas (therms)

PROIL : Direct process - oil (k-gals)

PRSTM : Direct process - steam (k-lbs)

PRELEC : Direct process - electric (kw)

CALCULATION SEQUENCE

1. Rename variables for day type, hour of day, and operating schedule:

   JSC = KEASON

   IHOD = ITIME

   ISCHD = IPRSC(N)

2. For each process load, calculate energy consumed according to energy source type:

   a) Energy source - indirect process

      PRBLR = PRBLR + PRPK(N) * SCHD(ISCHD,JSC,IHOD) * (-1000.)

   b) Energy source - gas

      PRGAS = PRGAS + PRPK(N) * SCHD(ISCHD,JSC,IHOD) * 1000./100000.

   c) Energy source - oil

      PROIL = PROIL + PRPK(N) * SCHD(ISCHD,JSC,IHOD) *
      (1000./HVHO)/1000.

   d) Energy source - steam

      - Calculate enthalpy difference between entering and leaving steam (assume condensate at 0 psig, 212^{o}F):

        H2 = 180

        H1 = STEAM1 (PRSTMP, PRSTMT)

        DELTAH = H1 - H2

      - Calculate energy consumed:

        PRSTM = PRSTM + PRPK(N) * SCHD(ISCHD,JSC,IHOD) *
        (1000./DELTAH)/1000.

   e) Energy source - electric

      PRELEC = PRELEC + PRPK(N) * SCHD(ISCHD,JSC,IHOD)

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

PSY1 AND PSY2

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

INPUT

DBT : Outside air dry-bulb temperature (°F)

WBT : Outside air wet-bulb temperatjre (°F)

DPT : Outside air dew point temperature (°F)

PATM : Atmospheric pressure (inches of mercury)

OUTPUT

HUMRAT : Humidity ratio (lbs water/lbs dry air)

ENTH : Enthalpy (Btu/lb dry air)(PSY1 only)

DENS : Density (lbs dry air/cu ft)(PSY1 only)

CALCULATION SEQUENCE

In the calculation of psychrometric properties of moist air partial pressure of water vapor is needed. This is calculated by the PPWVM sub-function.

1. Calculate partial pressure of water vapor in moisture-saturated air for WBT and obtain partial pressure of water (applies when dewpoint temperature is greater than 32.0 °F).

   PPWV = PPWVM(WBT) - 0.000367 * PATM * (DBT - WBT)/

   (1.0 + (WBT - 32.0)/1571.0)

2. HUMRAT = 0.622 * PPWV/(PATM - PPWV)

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

4. DENS = 1.0/(0.754 * (DBT + 460.0) * (1.0 + 7000.0 * HUMRAT/

   4360.0)/PATM)

PTLD

A function to calculate the part load power requirement of variable volume fans.

INPUT

NC : Curve Number

- 1 : Variable Speed Motor.
- 2 : Inlet Vane Damper
- 3 : Discharge Damper

PC : Fraction of full load for a volume

OUTPUT

PTLD : Percent part load power

LIMIT VALUES

$0.20 \leq PC \leq 1.10$

CALCULATION SEQUENCE

1. Variable Speed Motor

$$PTLD = 0.0015302776 + PC * (0.0052080574 + PC * (1.1086242 + PC * (-0.11635563)))$$

2. Inlet Vane Damper

PTLD = 0.35071223 + PC * (0.3080535 + PC * (-0.54137364 + PC * (0.87198823)))

3. Discharge Damper

PTLD = 0.37073425 + PC * (0.97250253 + PC * (-0.34240761))

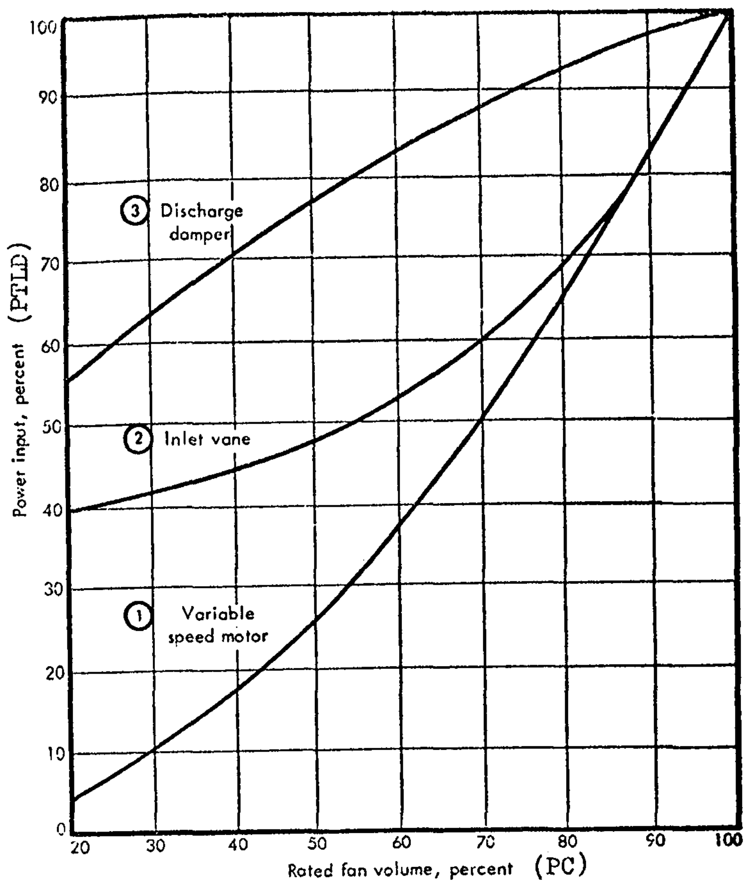


Figure 4.6 POWER SAVINGS VS AIR QUANTITY REDUCTION FOR THREE COMMON METHODS OF CONTROLLING DUCT STATIC PRESSURES

STEAM

A function to calculate the enthalpy of low pressure steam at a given temperature and pressure. Equations accurate from a psig to 1000.0 psig.

INPUT

PESTM : Steam pressure (psig)

TESTM : Steam temperature (^{o}F)

OUTPUT

STESM1 : Enthalpy of steam (Btu/lbm)

CALCULATION SEQUENCE

AH = 1068.0 - 0.485 * (PESTM + 14.7)

BH = 0.4320 + 0.000953 * (PESTM + 14.7)

CH = 0.000036 - 0.000000496 * (PESTM + 14.7)

STEAM1 = AH + BH * TESTM + CH * TESTM * TESTM

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).

   DELTA = FFL * 10.0

   DMULT2 = 0.868 + 0.01333 * DELTA

   DMULT = .840 + .174/FFL

   POPTN = (0.3371 + 0.01223 * TECON - 0.009747 * TLCHL) * DMULT

   * (.868 + 0.133 * FFL)

   where POPTN has units of kilowatts per ton.

2. Determine total hourly power consumption.

   POWER = POPTN * QBHC

RHFS

A subroutine to simulate the operation of a single-zone fan system with face and bypass dampers, a unit ventilator, a unit heater, or a constant volume reheat fan system.

INPUT

K - Energy distribution system number

Various items held in COMMON (see Table 4.4 for definitions of variables in COMMON).

RHOH - Heating capacity adjustment factor

OUTPUT

QCC - Cooling coil load (Btu/hr)

QHC - AHU heating coil load (Btu/hr)

QTRHC - Reheat coil load (Btu/hr)

QPHC - Preheat coil load (Btu/hr)

TQB - Baseboard heating load (Btu/hr)

WATER - Steam humidification supplied at air handling unit (lbm-H_2O/hr)

BPKW - Base power (Kw)

TNFBP - Total net updated fan brake horsepower (bhp)

TVLG - Required dry bulb temperature of air leaving air handler

Various items held in COMMON.

CALCULATION SEQUENCE

1. Fan off/on check.

   Using subroutine FANOF, determine whether the fan has been turned off for the current hours.

   If the system is off, terminate RHFS2 simulation for the current hours.

   If the system is on, continue.

2. Identify sensible thermal loss of each zone on this system.

   $$QSI_i = QS_L + QSINF_L$$

3. Baseboard radiation.

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

Sum baseboard radiation heat,

$$TQB = \sum_{j=1,jmax} QB_j * MULT(I)$$

If boiler off, continue.

4. Calculate required zone supply air temperatures.

$$TS_i = TSP_\ell - QSI_i/(0.245 - ZMASS_i)$$

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

$$BPKW = \sum_{j=1,\ jmax} SLPOW_\ell * MULT_i \ **$$

6. Calculate return air temperature, TRA_k

NOTE: Since the System and Equipment Simulation Program is capable of using LOAD or VARIABLE TEMPERATURE tapes as input, the following logic sequence is required.

QLITI = QLITE(L)

If ceiling plenum is calculated as a separate zone

For load run adjumtment only: If STEMP(IPL) $\leq$ 0.1

QLITI = QLITE(L) + QS(IPL) + QLITE(IPL) + QSINF(IPL)

For variable temperature adjustment only

DTL2 = STEMP(IPL) - TSP(L)

If ceiling plenum is not calculated as a separate zone

DTL = 0.0

DTL = QLITI/(0.245 * ZMASR(I))

$$SMTRA = \Sigma \left[(TSP(L) + DTL + DTL2) * ZMASR(I) * MULT(I)\right]$$

Calculate return air temperature

TRA = SMTRA/FMASR(K) + DTFNR(K)

where $DTL2_i$ - difference between zone and plenum temperatures as calculated by VARIABLE TEMPERATURE program.

QLITI - thermal load of plenum $p\ell$ above zone ℓ as calculated by LOAD program.

$p\ell$ - load program space number of plenum above zone ℓ

7. Zone humidity calculations

   Using subroutine H2OZN, calculate total moisture requirements including setpoint recovery load ($H2OAD_i$) and moisture changes in current hour due to environmental and room effects ($H2OAD_i$)

8. Calculate air temperature leaving unit

   8.1 For single-zone fan system, unit ventilator, and unit heater, $TLVG = TS_1$ (one)

   8.2 For constant volume heat fan system, air handler discharge temperature (TLVG) is controlled in one of three ways:

   1. Constant leaving air temperature

   2. Set equal to lowest TS_i

   3. Reset as an inverse function of ambient air temperature.

   Call subroutine TEMP to calculate TLVG for one of the above control modes.

9. Calculate economizer approach temperature (EAT).

   If TLVG > TLCMX, TLVG = TLCMX

   EAT = TLVG - DTFNS(K)

   If EAT < THCMN, EAT = THCMN, TLVG = EAT + DTFNS(K)

10. If there is an outside air reset schedule, calculate the minimum fraction of outside air.

    ALFAM(K) = ALFAM(K) * SCHD (IVENT(K), KEASON, ITIME)

11. Calculate mixed air conditions.

Call subroutine MXAIR to simulate the performance of:

1. Fixed outside and return air dampers.

2. An enthalpy/temperature type economizer cycle.

or

3. A temperature type economizer cycle.

Subroutine MXAIR also calculates the thermal properties (temperature, humidity ratio, and density) of the mixed air stream.

12. Air handling unit.

12.1 Single-zone system with face and bypass dampers around cooling coil. i.e., KFANK = 1

Call subroutine AHU (mode 2) to simulate the functioning of this air handling unit. Calculate bypass damper operation, heating and cooling coil thermal response (QHC and QCC), effect of fan heat, and steam humidifier functioning (WATER).

12.2 Unit ventilator.

Heating and the addition of outside air are provided by this system type.

Call subroutine AHU (mode 1) to calculate the functioning of the heating coil (QHC) and effect of fan heat.

12.3 Unit heater.

Same as unit ventilator, without outside air option.

12.4 Constant volume reheat fan system.

Call subroutine AHU (mode 1) to simulate the operation of a central system air handling unit. Calculate heating and cooling coil operation (QHC and QCC), the effect of fan heat, and the addition of steam (WATER) by a humidifier on the discharge side of the unit.

12.5 Controls applicable to all system types.

The heating coil is locked out when the boiler is scheduled off.

The cooling coil is locked out when the chiller is scheduled off.

The humidifier is locked out when the cooling coil is functioning.

13. Calculate reheat coil loads (QT_i) and distribute loads not met.

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

$QT = ZMASS_i * 0.245 * (TLVG_i - TS_i)$

If QT < 0.0,

If boiler on,

Call subroutine ZL03 to calculate and sum reheat coil loads and distribute loads not met, if any.
Go to 14.

If boiler off, heating load not met.

$QLNM_i = QT * MULTi$

Update as required the following variables:

$QHLNM_i$ -

$QHPNM_i$ -

$IHHNM_i$ -

$TS_i = TLVG$

$WTLVG_i = WSUP$ (WSUP = supply air humidity ratio. It is calculated in subroutine AHU.)

If QT = 0.0,

$TS_i = TLVG$

$WTLVG_i = WSUP$
Go to 14.

If QT > 0.0, cooling load not met.

Call subroutine CCOIL to calculate cooling load not met ($QLNM_i$).
Update as required the following variables:

$QCLNM_i$ -

$QCPNM_i$ -

$IHCNM_i$ -

$TS_i = TLVG$

$WTLVG_i$ = WSUP

Go to 14.

13.2 Unit ventilator and unit heat systems.

$$QT_i = ZMASS_i * 0.245 * (TLVG_i - TS_i)$$

If $QT_i < 0.0$, heating load not met.

$$QLNM_i = QT_i$$

Update as required the following variables:

$QHLNM_i$ -

$QHPNM_i$ -

$IHHNM_i$ -

TS_i = TLVG

$WTLVG_i$ = WSUP

Go to 14.

If $QT_i > 0.0$, cooling load not met.

$$QLNM_i = QT_i$$

Update as required the following variables:

$QCLNM_i$ -

$QCPNM_i$ -

$IHCNM_i$ -

TS_i = TLVG

$WTLVG_i$ = WSUP

Go to 14.

14. **Calculate zone humidity ratio.**

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

15. **Calculate return air humidity ratio and density.**

$$WRA_k = \frac{\sum_{j=1,\ jmax} WZ_j * ZMASR_j * MULT_j}{\sum_{j=1,jmax} ZMASR_j * MULT_j}$$

Call DENSY to calculate return air density (DRA)

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)
- H1 : Entering steam enthalpy
- H2 : Leaving steam enthalpy

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 = 2545.0/(H1 - H2)

7. Calculate base steam rate.

BSR = SLOPE * TSR + B

where

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

B1 = -19.7 + 0.001025 * SZT

B2 = 1.4

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

S0 = 3.88 - 0.011865 * SZT + 0.1173 * ((SZT/1000.0) ** 2.0)

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

S2 = 0.116 - 0.000057 * SZT + 0.00709 * ((SZT/1000.0) ** 2.0)

SLOPE = S0 + S1 * RPM/1000.0 + S2 * ((RPM/1000.0) ** 2.0)

The base steam rate calculation was made by equation-fitting the Elliott YR single stage steam turbine data.

8. Calculate the horsepower loss again determined by equation-fitting the Elliott YT single stage steam turbine catalog data for condensing turbine (2 psia).

HPLSS = 0.0334 * ((RPM/1000.0) ** 2.42)

* ((SZT/1000.0) ** 1.47)

9. Calculate the superheat correction factor determined by equation-fitting the Elliott YR single stage steam turbine catalog data.

   See computer listing of STTUR subroutine for equation of SC.

10. Determine the full load steam rate (lb/HP-hr).

    FLSR = (BSR/SC) * ((SZT + HPLSS)/SZT)

11. Determine the part load steam rate for one turbine (lb/hr).

    STEAM = FLSR * SZT (PLB + PLM * POWER/SZT)

12. Calculate the total hourly steam consumption (lb/hr).

    STEAM = STEAM * NSTON

SZRHT

A subroutine to simulate the operation of a single zone fan system with sub-zone reheat.

INPUT

K - Energy distribution system number

RHOH - Heating capacity adjustment factor

Various items held in COMMON (see Table 4.4 for definitions of variables in COMMON).

OUTPUT

QCC - Cooling coil load (Btu/hr)

QHC - AHU heating coil load (Btu/hr)

QTRHC - Reheat coil load (Btu/hr)

QPHC - Preheat coil load (Btu/hr)

TQB - Baseboard heating load (Btu/hr)

WATER - Steam humidification supplied at air handling unit (lbm-H_2O/hr)

BPKW - Base power (KW)

TNFBP - Total net [updated] fan brake horsepower (bhp)

TLVG - Required DRV bulb temperature of air leaving air handler

Various items held in COMMON.

CALCULATION SEQUENCE

1. Fan off/on check.

   Using subroutine FANOF, determine whether the fan has been turned off for the current hour.

   If the system is off, terminate SZRHT simulation for the current hour.

   If the system is on, continue.

   Calculate base power

   BPKW = Σ SLPOW(L) * MULT(I)

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

$QSI_i = QS_\ell ** + QSINF_\ell$

3. Baseboard radiation

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

Sum baseboard radiation heat,

$$TQB = \sum_{j=1,jmax} QB_j * MULT_I$$

If boiler off, continue.

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

$$BPKW = \sum_{j=1,jmax} SLPOW_\ell * MULT_i$$

5. Calculate required supply air temperature to each zone.

$TS_i = TSP - QSI_i/(0.245 * ZMAS_i)$

6. Calculate humidification requirements for each zone

CALL HZOZN

7. Calculate supply and induced air characteristics based on zone 1.

Calculate AHU discharge temperature.

$TLVG = TS_i$ (equals supply air temperature of air to central zone which in "j" sequence is assumed to be No. 1)

EAT = TLVG

TLVG2 = TLVG

$CMASR = ZMASR * MULT_i$

8. Calculate return air temp

$QLITI = QLITE_\ell$

DTL2 = 0

If ceiling plenum is calculated as a separate zone

For load run adjustment only

$QLITI = QLITE + QS_{ip\ell} + QLITE_{ip\ell} + QSINF_{ip\ell}$

For variable temperature adjustment only

$DTL2 = STEMP_{ip\ell} - TSP_{\ell}$

DTL = 0

If $ZMASR_i > 0$, $DTL = QLITI/(.245 * ZMASR_i)$

$TRA1 = TSP_{\ell} + DTL + DTL2$

9. Calculate minimum percentage primary air

$BMIN2 = 1.0 - ((FMASS_k - ZMAS1)/ZMASR_i$

10. Calculate fraction primary air required

CALL MXAIR

11. Sum induced air mass

$RMASI = \Sigma\ ZMASS_i * (1.-BETA) * MULT_i$

12. Sum supply air mass

$FMAS = \Sigma\ ZMASS_i * BETA * MULT_i$

13. Return air temp CACL - PART 1

$QLITI = QLITE_{\ell}$
DLT2 = 0.0

If ceiling plenum calculated as separate zone

If load tape used

$QLITI = QLITE + QS_{ip\ell} + QLITE_{ip\ell} + QSINF_{ip\ell}$

If variable temperature tape used

$DTL2 = STEMP_{ip\ell} - TSP_{\ell}$

$DTL = 0.0$

$TRA = SMTRA/FMR + DTFNR_k * PTLD(NVFC_k, PCTRA)$

where

$$SMTRA = \Sigma\left[(TSP_\ell + DTL + DTS2) * ZMASR_i * MULT_i\right] + (TSP1 + DTL1 + DTS21) * CMASR$$

$FMR = FMASR_k - RMASI$

14. Calculate percent of full load

$PCTSA = FMAS/FMASS_k$

$PCTRA = FMAR/FMASR_k$

15. Check minimum and maximum coil temps and calculate EAT

If $TLVG > TLCMX$, $TLVG = TLCMX$

$EAT = TLVG - DTFNS_k * PTLD(NVFC_k, PCTSA)$

If $EAT < THCMN$, $EAT = THCMN$

$TLVG = EAT + DTFNS_k * PTLD(NVFC_k, PCTSA)$

16. Calculate mixed air conditions entering preheat coil.

Call subroutine MXAIR to simulate the performance of:

1. Fixed outside and return air dampers.
2. An enthalpy/temperature type economizer cycle.

or

3. A temperature type economizer cycle.

Subroutine MXAIR also calculates the thermal properties (temperature, humidity ratio, and density) of the mixed air stream.

17. **Air Handling Unit (AHU).**

17.1 If boiler and chiller on, if chiller on and cooling called, or if boiler and heating called,

Call subroutine AHU (mode 2) to simulate the operation of a central system air handling unit. Calculate heating and cooling coil operation (QHC and QCC), the effect of fan heat, and the addition of steam (WATER) by a humidifier on the discharge side of the unit.

Go to 14.

17.2 If boiler off and heating required at AHU,

$$TLVG = TMA + DTFNS_k * PTLD(NVFC_k, PCTSA)$$

Go to 13.4.

17.3 If chiller off and cooling required at AHU,

$$TLVG = TMA + DTFNS_k * PTLD(NVFC_k, PCTSA)$$

Go to 13.4.

17.4 If $\frac{TLVG - TLVG2}{TLVG} < 0.001$,

Call subroutine AHU (mode 2) to simulate the operation of a central system air handling unit. Calculate heating and cooling coil operation (QHC and QCC), the effect of fan heat, and the addition of steam (WATER) by a humidifier on the discharge side of the unit.

Go to 14.

If $\frac{TLVG - TLVG2}{TLVG} \geq 0.001$,

TLVG = TLVG2 = TLVG.

Go to Step 2.

18. Adjust total fan brake horsepower.

$$TNFBP = TNFBP + (PTLD(NVFC_k, PCTSA) - 1.0) * FBHPS_k + (PTLD(NVFC_k, PCTRA) - 1.0) * FBHPR_k$$

19. Check reheat requirement

QT = ZMASS(I) * .245 * (TLVG - TS(I))

If QT < 0

If boiler is on, call ZL03 to calculate terminal unit thermal loads to reheat and recooling coils.

If boiler is off and reheating required, adjust

QHLNM(I), QHPNM(I), IHHNM(I), TS(I), and WTLVG

Go to 20

If QT = 0, WTLVG = WSUP, go to 20

If QT > 0, call CCOIL and adjust variables

QCLNM, QCPNM, IHCNM, TS, WTLVG

20. Calculate water supplied or removed from zone by supply air

CFMS(I) = ZMAS(I)/(DAVE(K) * 60)

Calculate space humidity ration, call WZNEW

21. Calculate air humidity ratio

$$WRA(K) = \frac{\Sigma\ WZ(I) * ZMASR(I) * MULT(I)}{FMASR(K) - RMASI}$$

22. Calculate return air density, by calling DENSY

TBAND

A subroutine for checking the temperature and time then returns the indices for the temp band increment

INPUT

TEMP - Current space temperature

HERE - Percentage of people in space

RANGE - Thresholds of temperature bands

OUTPUT

ITM - Temperature band index

ISOC - Occupied flag

CALCULATION SEQUENCE

1. Set building in use flag

   ISOC = 2

2. Is building occupied?

   If here > 0.25, ISOC = 1

3. Determine value of ITM by iterating through range until temp exceeds range.

NOTES

TEMP

A subroutine to calculate the dry bulb air temperature of air leaving an air handler and/or indicate the mode (heating or cooling) of process water in a two-pipe distribution system.

INPUT

ICO : Type of control option selected:

1) Fixed or predefined (constant).
2) Determined by room with coldest supply air requirement.
3) Reset as inverse function of outside air dry bulb temperature.
4) Reset as direct function of outside air dry bulb temperature to a maximum, then lower to a minimum (spike). For two-pipe induction units with waterside changeover.
5) High/low step function with hysteresis at changeover. Used for two-pipe fancoil waterside changeover.
6) Determined by room with warmest supply air requirement.

K : Fan system number.

JMAXK : Number of zones on currently analyzed system.

TOA : Dry bulb outside air temperature (°F)

TFIX : Fixed leaving air temperature for control mode one (°F)

IBGIN : Beginning zone index

TS(I) : Required supply air temperatures to each zone (°F)

Following variables used for control mode three:

TLAHI : Highest air temperature leaving AHU (°F)

TLALO : Lowest air temperature leaving AHU (°F)

TDBLO : Low ambient DB temperature corresponding to high leaving AHU temperature (TLAHI) (°F)

TDBHI : High ambient DB temperature corresponding to low leaving AHU temperature (TLALO) (°F)

TCOFC : Two-pipe fancoil unit changeover temperature.

OUTPUT

TLVG : Required dry bulb temperature of air leaving air handler.

TOACO : Induction unit changeover temperature.

IPW : Induction or fancoil unit process water temperature indicator: -1 = Hot water available.
0 = Changeover condition and/or hot and chilled water available.
+1 = Chilled water available.

CALCULATION SEQUENCE

1. Fixed or predefined.

   TLVG = TFIX

2. Determined by room with coldest air requirement.

   Scan applicable TS_i values. Set TLVG equal to lowest TS_i.

3 Reset as inverse function of outside air dry bulb temperature

   Use function TRSET to calculate TLVG.

   Input variables:

   TOA

   TLAHI

   TLALO

   TDBHI

   TDBLO

4. Two-pipe induction unit primary air schedule and process water mode indicator. See INDUC for graph of this TEMP function.

If TOACO < TOA,

- If TDBHI ≤ TOA,
  - TLVG = TLALO
  - IPW = 1
  - TOACO = TDBLO
- If TDBHI > TOA,
  - Calculate TLVG using function TRSET.
  - IPW = 1
  - TOACO = TDBLO

If TOACO = TOA,

- Calculate TLVG using function TRSET.
- If TOACO ≤ TDBLO,
  - TOACO = TDBLO + 5.0
  - IPW = -1
- If TOACO > TDBLO,
  - TOACO = TDBLO
  - IPW = -1

If TOACO > TOA,

- TLVG = TLALO
- TOACO = TDBLO + 5.0
- IPW = -1

5. Two-pipe fancoil waterside changeover. Based on changeover temperature with (+) or (-) 2.5°F lag.

If TOA < TOACO,

If TOACO > TCOFC

IPW = -1

If TOACO ≤ TCOFC

TOACO = TCOFC + 2.5

IPW = 0

If TOA = TOACO,

If TOACO ≤ TCOFC

TOACO = TCOFC + 2.5

IPW = 0

If TOA > TCOFC,

TOACO = TCOFC - 2.5

IPW = 0

If TOA > TOACO,

If TOACO ≥ TCOFC

TOACO = TCOFC - 2.5

IPW = 0

If TOACO < TCOFC

IPW = +1

6. Determined by room with warmest supply air requirement.

Scan applicable TS_i values. Set TLVG equal to largest TS_i.

TOT

A function for summing the monthly energy consumption for each energy type in the ENGY matrix.

INPUT

CONS - Resource consumption

CALCULATION SEQUENCE

$TOT1 = \Sigma\ CONS_i$ For I=1 to 12

TRSET

A function to calculate TRSET as a linear function of TOA between the coordinates (THI,TOALO) and (TLO, TOAHI). TRSET is allowed to float between THI and TLO but not to exceed those bounds as illustrated in the figure below.

INPUT

TOA :

THI :

TLD :

TOAHI :

TOALO :

OUTPUT

TRSET -

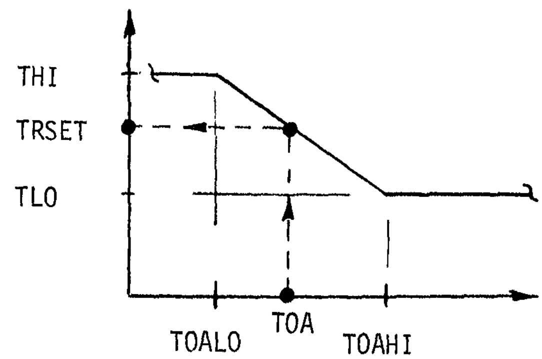


Figure 4.7 GRAPHIC ILLUSTRATION OF FUNCTION TRSET.

CALCULATION SEQUENCE

1. If TOA <TOAHI, Go to 2

   TRSET = TLO

   RETURN

2. TRSET = THI

   2a. If TOA .GE. TOAHI, RETURN

   2b. If TOALO .EG. TOAHI, RETURN

3. TRSET = THI - (THI-TLO) * (TOA-TOALO)/(TOAHI-TOALO)

VARVL

A subroutine to simulate the operation of a variable volume fan system with optional reheat.

INPUT

K - Energy distribution system number

RHOH - Heating capacity adjustment factor

Various items held in COMMON (see Table 4.4 for definitions of variables in COMMON).

OUTPUT

QCC - Cooling coil load (Btu/hr)

QHC - AHU heating coil load (Btu/hr)

QTRHC - Reheat coil load (Btu/hr)

QPHC - Preheat coil load (Btu/hr)

TQB - Baseboard heating load (Btu/hr)

WATER - Steam humidification supplied at air handling unit (lbm-H_2O/hr)

BPKE - Base power (KW)

TNFBP - Total net [updated] fan brake horsepower (bhp)

TLVG - Required dry buld termperature of air leaving air handler

Various items held in COMMON

CALCULATION SEQUENCE

1. Fan off/on check.

   Using subroutine FANOF, determine whether the fan has been turned off for the current hour.

   If the system is off, terminate VARVL simulation for the current hour.

   If the system is on, continue.

2. Identify leaving AHU air temperature,

$$TLVG = TFIX1_k$$

$$TLVG2 = TLVG$$

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

$$QSI_i = QS_{\ell}^{**} + QSINF(L)$$

4. Baseboard radiation.

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

Sum baseboard radiation heat,

$$TQB = \sum_{j=1,jmax} QB_j * MULT(I)$$

If boiler off, continue.

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

$$ZMAS_i = QSI_i/(0.245 * (TSP_{\ell} - TLVG))$$

If $ZMAS_i > ZMASS_i$

$$ZMAS_i = ZMASS_i$$

If $ZMAS_i < ZMASS_i * VVMIN_k$

$$ZMAS_i = ZMASS_i * VVMIN_k$$

$$ZMASR_i = ZMAS_i - ZMASX_i$$

If $ZMASR_i < 0.0$,

$$ZMASR_i = 0.$$

6. Calculate system mass flows.

$$FMAS_k = \sum_{j=1,jmax} ZMAS_i * MULT_i$$

$$FMR_k = \sum_{j=1,jmax} ZMASR_i * MULT_i$$

** There is a corresponding ℓ for each i; a relationship defined by the variable $SPACN_{k,j}$. Hence, i and ℓ are defined by system number (k) and zone number (j). See Para. 4.1 for zone labeling organization.

7. Calculate return air temperature (TRA_k).

NOTE: Since the System and Equipment Simulation Program is capable of using LOAD or VARIABLE TEMPERATURE tapes as input, the following logic sequence is required.

If ceiling plenum is calculated as a separate zone,

If LOAD tape is used,

$$DTL2_i = 0.$$

$$QLITI = QLITE_\ell + QS_{p\ell} + QLITE_{p\ell} + QSINF_{p\ell} \ **$$

If VARIABLE TEMPERATURE tape is used,

$$DTL2_i = STEMP_{p\ell} - TSP_\ell$$

$$QLITI = QLITE_\ell$$

If ceiling plenum is not calculated as a separate zone,

$$DTL2_i = 0.$$

$$QLITI = QLITE_\ell$$

$$DTL_i = QLITI/(0.245 * ZMASR_i)$$

$$TRA_k = \frac{\sum_{j=1,jmax} (TSP_\ell + DTL_i + DTL2_i) * ZMASR_i * MULT_i}{\sum_{j=1,jmax} ZMASR_i * MULT_i} + DTFNR_k * PTLD(NVFC_k, PCTRA)$$

where $DTL2_i$ - difference between zone and plenum temperatures as calculated by VARIABLE TEMPERATURE program.

QLITI - thermal load of plenum $p\ell$ above zone ℓ as calculated by LOAD program.

$p\ell$ - LOAD program space number of plenum above zone ℓ.

8. Zone humidity calculations.

Using subroutine H2OZN, calculate total moisture requirements including set point recovery load ($H2OAD_i$) and moisture changes in current hour due to environmental and room effects ($H2OAD_i$).

9. Calculate supply and return air full load flows.

$$PCTSA = FMAS_k/FMASS_k$$

$$PCTRA = FMR_k/FMASR_k$$

10. Calculate economizer approach temperature (EAT).

If TLVG > TLCMX

TLVG = TLCMX

$EAT = TLVG - DTFNS_k * DTLD (NVFC_k, PCTSA)$

If EAT < THCMN

EAT = THCMN

$TLVG = EAT + DTFNS_k * PTLD (NVFC_k, PCTSA)$

11. If there is an outside air reset schedule, calculate the minimum fraction of outside air.

$ALF = ALFAM_k * SCHD(IVENT_k, KEASON, ITIME)$

12. Calculate mixed air conditions.

Call subroutine MXAIR to simulate the performance of:

1. Fixed outside and return air dampers.
2. An enthalpy/temperature type economizer cycle.

or 3. A temperature type economizer cycle.

Subroutine MXAIR also calculates the thermal properties (temperature, humidity ratio, and density) of the mixed air stream.

13. Air Handling Unit (AHU).

13.1 If boiler and chiller on, if chiller on and cooling called, or if boiler and heating called,
Call subroutine AHU (mode 1) to simulate the operation of a central system air handling unit. Calculate heating and cooling coil operation (QHC and QCC), the effect of fan heat, and the addition of steam (WATER) by a humidifier on the discharge side of the unit.

Go to 14.

13.2 If boiler off and heating required at AHU,

$TLVG = TMA + DTFNS_k * PTLD(NVFC_k,PCTSA)$

Go to 13.4.

13.3 If chiller off and cooling required at AHU,

$TLVG = TMA + DTFNS_k * PTLD(NVFC_k,PCTSA)$

Go to 13.4.

13.4 If $\frac{TLVG-TLVG2}{TLVG} < 0.001$,

Call subroutine AHU (mode 1) to simulate the operation of a central system air handling unit. Calculate heating and cooling coil operation (QHC and QCC), the effect of fan heat, and the addition of steam (WATER) by a humidifier on the discharge side of the unit.

Go to 14.

If $\frac{TLVG-TLVG2}{TLVG} \geq 0.001$,

TLVG = TLVG2 = TLVG.

Go to Step 3.

14\. Adjust total fan brake horsepower.

$PCTSA = SMCFM/CFMAX_k$

$$TNFBP = TNFBP + (PTLD(NVFC_k, PCTSA)-1.0)*FBHPS_k + (PTLD(NVFC_k, PCTRA)-1.0)*FBHPR_k$$

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

$$BPKW = \sum_{j=1,jmax} SLPOW_\ell * MULT_i$$

16\. Terminal unit performance.

$QT_i = ZMAS \quad 0.245 * (TLVG - TS_i)$

If no reheat coils,

If $QT_i < 0.0$, heating load not met.

Update as required the following variables:

$QHLNM_i$ -

$QHPNM_i$ -

$IHHNM_i$ -

TS_i = TLVG

WTLVG = WSUP (WSUP = supply air humidity ratio. It is calculated in subroutine AHU.)

If $QT_i = 0.0$,

WTLVG = WSUP

If $QT_i > 0.0$, cooling load not met.

Update as required the following variables:

$QCLNM_i$ -

$QCPNM_i$ -

$IHCNM_i$ -

TS_i = TLVG

$WTLVG_i$ = WSUP

If terminal has reheat coil,

If $QT_i < 0$,

If boiler on,

Call subroutine ZL03 to calculate and sum reheat coil loads and distribute loads not met, if any.

If boiler off, heating load not met.

Update as required the following variables:

$QHLNM_i$ -

$QCLNM_i$ -

$IHHNM_i$

TS_i = TLVG

$WTLVG_i$ = WSUP

If QT_i = 0.0,

WTLVG = WSUP

If QT_i > 0.0, cooling load not met.

Call subroutine CCOIL to calculate load not met ($QLNM_i$).

Update as required the following variables:

$QCLNM_i$ -

$QCPNM_i$ -

$IHCNM_i$ -

TS_i = TLVG

$WTLVG_i$ = WSUP

Go to 14.

17. Calculate zone humidity ratio.

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

18. Calculate return air humidity ratio and density.

$$WRA_k = \frac{\sum_{j=1,jmax} WZ_i * ZMASR_i * MULT_i}{\sum_{j=1,jmax} ZMASR_i * MULT_i}$$

Calculate DRA using DENSY

VTCSRF

A subroutine which calculates the space response factors. The first term of each response factor set is lacking the conductive contributions from exterior quick surfaces and windows. Their contribution depends upon the outside surface film coefficient, which in turn depends upon the wind velocity at the hour of the calculation.

INPUT

VTDATA	:	A block common which contains data read by subroutines VTIN and CSIN.

OUTPUT

NSRF(I)	:	Number of response factor terms in space response factor set for space I.
SRF(I,J)	:	Values of space response factors for space I and terms 1 to NSRF(I).

CALCULATION SEQUENCE

Calculate each space's set of response factors by accounting for heat storage effect of delayed surfaces, underground surfaces, ceilings, intermediate floors, and furnishings. Effects of quick surfaces and windows will be added within the hour loop, where the outside film coefficient can be calculated as a function of wind speed. For each space I=1 to NS, perform the following:

1. Determine the highest number of response factor terms that any delayed surface in the space has.

   - MNRF = 1 (initialization)

     NC(I) = 0

     NF(I) = 0

   - Set index J-1 (first term of space response factor set)

   - If ND(I) $\leq$ 0, go to 2.

   - For each delayed surface J4=1 to ND(I),

     J1 = ID(I,1) (delayed surface index)

     J3 = IRF(J1) (response factor surface type index)

MNRF = IR(J3)

If MNRF < MNRFT, reset MNRF = MNRFT.

2. Limit the minimum number of response factor terms to 10.

   If MNRF < 10, reset MNRF = 10.

3. Initialize space response factor variable corresponding to J.

   SRMRT(J) = 0.0

4. skip to calculation 5

5. Underground Surfaces - calculate and add into SRMRT a correction factor to correct the underground surface load for space temperatures other than that assumed in basic load calculation.

   - This correction factor should only be added in one time; therefore if J > 1, skip to calculation (6).
   - If NUF(I) $\leq$ 0, space has no underground surfaces ; therefore skip to calculation (6).
   - For each underground surface J1 = 1 to NUF(I),

     SRMRT(J) = SRMRT(J) - AUF(J2) * FUF(J2)

     where J2 = IUF(I,J1).

6. Delayed Surfaces - calculate response factor term for all delayed heat transfer surfaces and add their contribution into SRMRT(J).

- Let number of delayed surfaces in space ND1 = ND(I).

- If ND1 ≤ 0, skip to calculation (8).

- For each delayed surface J2 = 1 to ND1,

  J1 = ID(I,J2) (delayed surface index)

  A = AD(J1) (area)

  J3 = IRF(J1) (response factor index)

  If J > IR(J3), use common ratio to determine response factor.

  RZ(J3,J) = RATOS(J3) * RZ(J3,J-1)

  SRMRT(J) = SRMRT(J) - A * (RZ(J3,J))

7. If surface is floor, go to 9.

   If surface is furnishing, go to 10.

   If surface is ceiling, continue

   otherwise go to 11.

8. NC(I) = NC(I) + 1

   J2 = IFD(I,II)

   A = ALFOR(I,II)

   If J ≤ IRFL(J2), go to 8.1

   R = CRFL(2)

   FLRY(J2,J) = R * FLRY(J2,J-1)

   FLRZ(J2,J) = R * FLRZ(J2,J-1)

8.1 SRMRT(J) = Σ A * (FLRY(J2,J) - FLRZ(J2,J))

   Go to 11.

9. Non-underground Floors - calculate response factor term for all non-underground floors, if any, in space and add their contribution into SRMRT(J).

- For each non-underground floor J1 = 1 to NF1,

  J2 = IFD(I,II) (floor index type)

  A = AFLOR(I,II) (area)

  If J > IRFL(J2), use common ratio to determine response factor.

  FLRY(J2,J) = CRFL(J2) * FLRY(J2,J-1)

  FLRZ(J2,J) = CRFL(J2) * FLRZ(J2,J-1)

  SRMRT(J) = SRMRT(J) + A * (FLRX(J2,J) - FLRZ(J2,J)

10. Furnishings - calculate response factor term for all furnishings in space, if any, and add their contribution into SRMRT(J).

- Let area of furnishings in space AFN1 = AFLOR(I,II)
- If AFN1 ≤ 0.0, skip to calculation 12.
- If J > IRFL(J2), use common ratio to determine response factor.

  FLRZ(J2,J) = CRFL(J2) * FLRZ(J2,J-1)

  where J2 = IFD(I,II)
- SRMRT(J) = SRMRT(J) - AFN1 * FLRZ(J2,J).

11. Add in default values for floors, ceilings, and underground surfaces, if required.

- Check to see if default values are required.

  If user entered his own floor, underground surface, and ceiling via input data, (i.e., NC(I) + NF(I) > 0, then skip to calculation 15.

12. Underground Surfaces - account for the heat storage effect of underground surfaces and their contribution to SRMRT.

- If space has no underground surfaces (i.e., NUF(I) $\leq$0, skip to calculation 13.

- For each underground surface J1=1 to NUF(I):
  J2=IUF(I,J1) (underground surface number)
  if J=1, calculate thickness of underground surface by dividing weight of floor per sq. ft by default concrete density of 140 lbs per cubic ft.

  XL(2) = WOF(I)/140.0

  using this thickness and material default values++, calculate response factors DFURZ(J2,100), number of response factors NRFUS(J2), and common ratio DFUCR(J2)
  if J > NRFUS(J2), use common ratio to calculate response factor

  DFURZ(J2,J) = DFURZ(J2,J-1) * DFUCR(J2)

  update SRMRT

  SRMRT(J)=SRMRT(J)-AUF(J2)*DFURZ(J2,J)

++ Default values taken from Dr. T. Kusuda, "Thermal Response Factors for Multi-layer Structures of Various Heat Condition Systems", p.V.3.23, "Basement Floor", ASHRAE Semiannual Meeting, January, 1969.

13. If user entered his own ceiling (i.e., NC(I)>0) and his own floor (i.e., NF(I)>0 or NUF(I)>0) go to calculation 15.

14. Ceiling and non-underground floor -

- if J=1, calculate thickness of ceiling/non-underground floor by dividing weight of floor per sq. ft. by default concrete density of 140 lbs. per cubic ft..

  XL(3) = WOF(I)/140.0

  using this thickness and material default values[++], calculate response factors for ceiling DFCRZ), common ratio DFCCR, and number of response factor terms NRFCF

- if default ceiling is required - if J>NRFCF, use common ratio to calculate response factor

  DFCRZ(J) = DFCRZ(J-1) * DFCCR

  Update SRMRT

  SRMRT(J) = SRMRT(J) - FLORB(I) * DFCRZ(J)

- if default non-underground floor is required - if J>NRFCF, use common ratio to calculate response factor

  DFFRZ(J) = DFFRZ(J-1) * DFCCR

  update SRMRT

  SRMRT(J) = SRMRT(J) - FLORB(I) * DFFRZ(J)

++ Default values taken from Dr. T. Kusuda, "Thermal Response Factors for Multi-layer Structures of Various Heat Condition Systems", p. V.3.22, "Concrete Floor", ASHRAE Semiannual Meeting, January, 1969.

15. Furnishings - if user entered his own furnishings go to calculation 16.

- if J=1, calculate thickness of furnishings by dividing weight of furnishings per sq. ft. by default density of 80 lbs. per cubic ft.

  XL(2) = WOFN(I)/80.0

  using this thickness and material default values++, calculate response factors DFNRZ, common ratio DFNRZ, and number of response factor terms NRFFN

- if J> NRFFN, use common ratio to calculate response factor

  DFNRZ(J) = DFNRZ(J-1) * DFNCR

  update SRMRT

  SRMRT(J) = SRMRT(J) - FLORB(I) * DFNRZ(J)

16. Go to calculation 17.

17. Store the space response factor into a matrix for later use.

    SRF(I,J) = SRMRT(J)

18. Check to ensure at least 3 space response factor terms have been calculated, and if not, go to calculation 23 and proceed to next term calculation.

19. Perform check to determine if space is fast responding, i.e., J = 3 and |SRMRT(J)| $\leq$ 1.0 * E-15, and if so, go to calculation 24.

++ Default values taken from Dr. T. Kusuda, "Thermal Response Factors for Multi-layer Structures of Various Heat Condition Systems", p. V.3.23, "Solid Slab", ASHRAE Semiannual Meeting, January, 1969.

20. Check to determine if all space response factor terms have been calculated. If J ≤ MNRF, go to calculation 23.

21. Perform the relative end test. If |SRF(I,J)/SRF(I,1)| ≤ 1.0*E-3, go to calculation 24.

22. Limit the number of space response factor terms to 100. If J ≥ 100, go to calculation 24.

23. Increment J = J + 1 and go to calculation 3 to begin calculation for next term.

24. Set the number of terms defined for space in question.

    NSRF(I) = J

NOTE: For further information on the algorithms concerning variable temperature calculations refer to the following additional references.

1. K. Kimura, "Simulation of Cooling and Heating Loads Under Intermittent Operation of Air Conditioning, ASHRAE Semiannual Meeting, New Orleans, January 1972.

2. G. Mitalas and D. Stephenson, "Room Thermal Response Factors", ASHRAE Semiannual Meeting, Detroit, January 1967.

3. ASHRAE Handbook of Fundamentals, Chapter 22, Air Conditioning Cooling Loads Part II - Extension of Cooling Load Calculation For Intermittent and Variable Operating Conditions, P. 425, 1972.

VTHOUR

A subroutine that calculates the hourly interproducts of the temperatures and space response factors. The outside air film coefficient is calculated using the hourly wind velocity. Resulting values of SUM4 and SUM5 are placed in block common VTHRLY for use in subroutine VTLOAD.

INPUT

VTDATA	:	A block common which contains data read by subroutines VTIN and CSIN.
I	:	TLAP space number
VTSRF	:	A block common which contains space response factors data.
VTHRLY	:	A block common which contains values of SUM4 and SUM5 for each space.
I1	:	Systems space number
IWS	:	Wind speed, mph.

OUTPUT

SUM4(I)	:	Value of numerator for space I to be used in space temperature calculation equation.
SUM5(I)	:	Value of denominator for space I to be used in space temperature calculation equation.

CALCULATION SEQUENCE

1. Begin space calculation repeating the following calculations for I = 1 to NS.

   a) Initialize space parameters.

      UQT = 0.0 sum of U * A for quick surfaces (outside film included)

      UGWT= 0.0 sum of U * A for glass surfaces (outside film included)

      PIHT= 0.0 partial internal heat transfer term

      SUM1= 0.0 response factor sum for space

b) Calculate the sum of U * A for quick surfaces. For each quick surface in space J1 = 1 to NQ(I), perform following calculations:

```
JQ    =  IQ(I,J1)  (quick surface index)

U     =  UQ(JQ)  (surface U-factor)

IRUF  =  ISQ(JQ)  (roughness factor index)

CALL FILM (VEL,IRUF,F)

F     =  1/F

where VEL = IWS

      F   = outside film resistance

UQT   =  UQT + AQ(JQ) * (U/(1.0 + F * U))
```

c) Calculate the sum U * A for window surfaces. For each window in space J1 = 1 to NW(I) perform following calculations:

```
JW    =  IW(I,J1)  (window index)

U     =  UGW(JW)  (U-factor)

ITYPE =  6

CALL FILM (VEL,ITYPE,F)

F     =  1/F

where  VEL = IWS

         F = outside film resistance

UGWT  =  UGWT + AW(JW) * (U/(1.0 + F * U))
```

d) Calculate the internal surface load correction factor. For each internal surface in space J1 = 1 to NIHTS(I), perform following calculations:

```
J2  =  IHTS(I,J1)  (surface index)

J3  =  ISPC1(J2)  (adjacent space number)

If J3 = I, set J3 = ISPC2(J2)

PIHT = PIHT + FIHTS(J2) * ETEMP(J3,1)
```

e) Calculate final space response factors and set value of ETEMP. For J1 = 1 to JL1M1 where JL1M1 = NSRF(I)-1, perform the following calculations:

J2 = JL1M - J1

ETEMP(I,J2+1) = ETEMP(I,J2)

SUM1 = SUM1 + SRF(I,J2+1) * ETEMP(I,J2+1)

f) Initialize plenum variables.

CFM1 = 0.0

CFM2 = 0.0

UCFM = 0.0

g) Check if space is a ceiling plenum, and if so, perform the following calculations:

- If IPLS(I) = 0, space is not a plenum, therefore skip to calculation (o).
- Check if fan is operating. If

  ITIME < IVON(I,IDT)

  or ITIME > IVOFF(I,IDT)

  fan is off; therefore skip to calculation (o).
- Fan is operating; therefore perform the following:

  J1 = IVS(I)

  UCFM = CFM(I)

  CFM1 = 1.08 * CFM(I)

  CFM2 = -1.08 * CFM(I) * (TSPAC(I) - ETEMP(J1,1) - TSPAC(J1)) + HRLDL(J1)

h) Calculate temperature difference between outside dry-bulb and constant space temperature assumed in basic load calculation.

TOMCS = KA - TSPAC(I)

If |TOMCS| ≤ 0.1, set TOMCS = 1.0E35

i) Define various terms to be used in equations later.

SUM3 = UQT + UGWT

SUM4 = SUM1 + PIHT + HRLDS + CFM2 + QSINF(I)

SUM5 = -SRF(I,1) + SUM3 + SIHTC(I)

+ QSINF/TOMCS + CFM1

VTIN

A subroutine which reads all of the building description data from a file created by the Thermal Loads Analysis Program.

INPUT

IT : Logical unit number for TLAP building description data file

KO : Line printer logical unit number

OUTPUT

All data as read from TLAP file and as described below.

CALCULATION SEQUENCE

1. Read building description data from TLAP output file. Order of data is as follows:

1.1 Job Description Variables

IDEN1 - Facility name

IDEN2 - Facility location

IDEN3 - Engineer's name

IDEN4 - Project number

IDEN5 - Date

1.2 Building Surface Description Data

a) NRF - Number of types of response factor surfaces

b) For each surface type

NRFT - Number of response factor terms

R1 - Common ratio

RX, RY, RZ - Surface response factors

c) NDB - Number of delayed surfaces

d) For each delayed surface

IRF - Response factor type index

AD - Surface area, sq. ft.

e) NQB - Number of quick surfaces

f) For each quick surface

ISQ - Surface roughness index

UQ - Surface U-factor less outside film coefficient, Btu/hr-sq ft-^{o}F

AQ - Surface area, sq. ft.

g) NWB - Number of windows

h) For each window

h.1) NPW - Number of panes of glass

AW - Window area, sq. ft.

For each window, calculate the resistance and U-factor (less the outside film coefficient).

h.2) For single pane windows

REI = 0.5 inside film resistance

REA = 0.0 interpane resistance

R = REI + REA total resistance

UGW = 1.0/R U-factor

h.3) For multi-pane windows

REI = 0.5 inside film resistance

REA = 1.6 interpane resistance

R = REI + REA total resistance

UGW = 1.0/R U-factor

i) NIHT - Number of internal heat transfer surfaces

j) For each internal heat transfer surface

ISPC1]
ISPC2] - Spaces connected to surface
FIHTS - Surface U*A, Btu/hr. ^{o}F

k) NUFB - Number of underground surfaces

l) For each underground surface

AUF - Underground surface area, sq. ft.

FUF - U-factor, Btu/hr-sq ft-^{o}F

1.3 Zone description data

FOLK - Traction of people for space

a) NS - Number of spaces in building

b) For each space

ND - Number of delayed surfaces in space

NQ - Number of quick surfaces in space

NW - Number of windows in space

NIHTS - Number of internal H.T. surfaces in space

NUW - Number of underground walls in space

NUF - Number of underground floors in space

IMULT - Space repetition factor

FLORB - Floor area, sq. ft.

VOL - Space volume, cu. ft.

TSPAC - Set point temperature, ^{o}F

WOF - Weight of floor, lbs/sq. ft.

IWOP - Loads schedule index for people

ID - Index associated with each of ND delayed surfaces

IQ - Index associated with each of NQ quick surfaces

IW - Index associated with each of NW windows

IHTS - Index associated with each of NIGHTS internal H.T. surfaces

IUF - Index associated with each of NUF underground surfaces

1.4 Run description data

MSTRT - Starting month, 1 to 12

NDAYS - Number of days

IMAX - Number of hours in each month

ISTRT - Starting hour of analysis, 1 to 8760

IEND - End hour of analysis, 1 to 8760

VTINIT

A subroutine which initializes various variables required by subroutines VTLOAD and VTHOUR.

INPUT

VTDATA	:	A block common which contains data read by subroutines VTIN and CSIN.
VTSRF	:	A block common which contains space response factor data.
VTTEMP	:	A block common which contains various book-keeping parameters for variable temperature calculations.

OUTPUT

SIHTC(I)	:	Summation of U*A for all internal heat transfer surfaces in space I.
ITMAT(I,J)	:	Space temperature frequency distribution matrix.
SMH(I)	:	Space maximum heating, Btu/hr.
SMC(I)	:	Space maximum cooling, Btu/hr.
SLT(I)	:	Space lowest temperature, ^{o}F.
SHT(I)	:	Space highest temperature, ^{o}F.
ETEMP(I,J)	:	Difference between space temperature at which initial heat transfer was calculated and the corrected space temperature.

CALCULATION SEQUENCE

1. Calculate the sum of U * A for all internal heat transfer surfaces in each space. For each space I = 1 to NS,

   JLIM = NIHTS(I) (number of surfaces)

   SIHTC(I) = Σ FIHTS(J2) for J1=1 to JLIM

   J2 = IHTS(I,J1) (surface index)

2. Initialize run parameters for each space I = 1 to NS.

SMH(I) = 1.0E10 space maximum heating

SMC(I) = -1.0E10 space maximum cooling

SLT(I) = 1.0E10 space lowest temperature

SHT(I) = -1.0E10 space highest temperature

ETEMP(I,J) = 0.0 space temperature deviation

where J = 1 to NSRF(I)

VTLOAD

A subroutine which calculates the heating and cooling rates for a space, the resulting space temperature, tracks the space maximum heating and cooling rates, and tracks the high and low space temperatures.

INPUT

VTDATA	:	A block common which contains data read by subroutines VTIN and CSIN.
VTEMP	:	A block common which contains various bookkeeping parameters for variable temperature calculations.
VTSRF	:	A block common which contains space response factor data.
VTHRLY	:	A block common which contains values of SUM4 and SUM5 for each space.
SCHDI	:	A block common containing thermostat scheduling data.
I	:	Space number TLAP
IHOUR	:	Hour of the year.
RHOH	:	Heating capacity adjustment factor.
RHOC	:	Cooling capacity adjustment factor.
I1	:	Systems space number.

OUTPUT

STEMP	:	Resulting space temperature, ^{o}F.
HE	:	Heat extracted (or supplied) from space for hour IHOUR.

CALCULATION SEQUENCE

1. Set proper weekly thermostat schedule index

   IWT = 0

   If IHOUR $\geq$ IYTS(I,1)   IWT = IWTS(I,1)

   If IHOUR $\geq$ IYTS(I,2)   IWT = IWTS(I,2)

   If IHOUR $\geq$ IYTS(I,3)   IWT = IWTS(I,3)

   If IHOUR $\geq$ IYTS(I,4)   IWT = IWTS(I,4)

   If IHOUR $\geq$ IYTS(I,5)   IWT = IWTS(I,5)

2. Set space thermostat type and check for no thermostat, i.e., floating space temperature. Also set thermostat schedule that applies.

   IJUMP = ISTT (IWT,KEASON)

   If IJUMP = 0, skip to calculation 6.

   JUMP = IVTSD(IJUMP, ITIME)

3. Set the high and low thermostat limits deviations and space heating and cooling capacity.

   TL = VTSD2(IJUMP, ITIME) - TSPAC(I)

   TH = VTSD1(IJUMP, ITIME) - TSPAC(I)

   HEAT = -HCAP(I) * IBOIL * RHOH

   COOL = CCAP(I) * ICHIL * RHOH

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

   - Calculate slope of thermostat function line.

     D = (HEAT + COOL)/(TH - TL)

   - Calculate intercept of thermostat function line.

     C = -(HEAT + D * TL)

   - Calculate space temperature deviation from TSPAC(I) that exists at end of hour.

     TEMPS = (SUM4 - C)/(SUM5 + D)

   - Calculate heat extracted from or supplied to space during hour.

     HE = TEMPS * D + C

   - Check if more heat is required than the space has capacity for.

     If TEMPS < TL, set

       HE = -HEAT

       TEMPS = (SUM4 + HEAT)/SUM5

- Check if more cooling is required than the space has capacity for.

  If TEMPS > TH, set

  HE = COOL

  TEMPS = (SUM4 - COOL)/SUM5

- Go to calculation 7.

5. Analysis for a Type 2 thermostat (hi-low or on-off control) (see Table 4.7). This thermostat supplies no heating or cooling between the high and low limits. If the limits are hit, the extraction rate (+ or -) at that temperature is calculated and compared to the heating or cooling capacity of the space. If the space capacity is exceeded, the temperature is allowed to float the necessary amount to satisfy heat balance equation.

   - Calculate space temperature deviation from TSPAC(I) that exists at end of hour.

     TEMPS = SUM4/SUM5

   - Initialize heat extraction rate.

     HE = 0.0

   - Check if lower thermostat temperature limit is exceeded and if so, reset TEMPS and HE.

     If TEMPS < TL, set

     TEMPS = TL

     HE = SUM4 - TEMPS * SUM5

   - Check if space heating capacity has been exceeded and if so, reset TEMPS and HE.

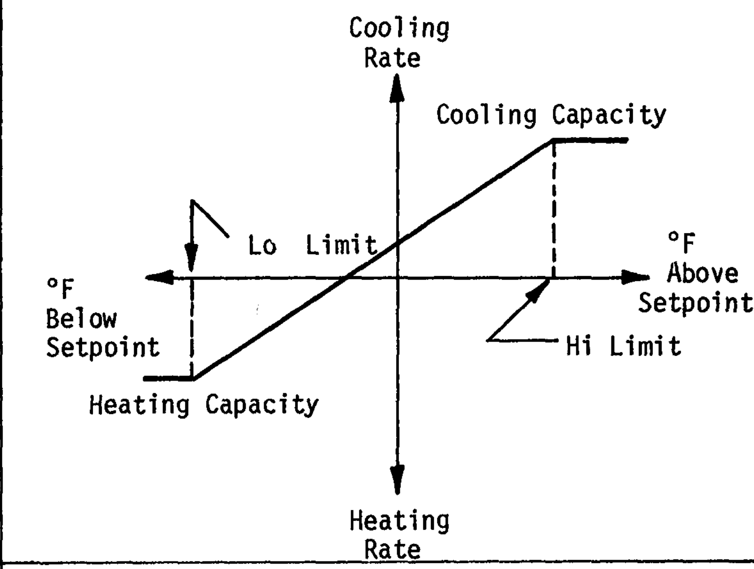
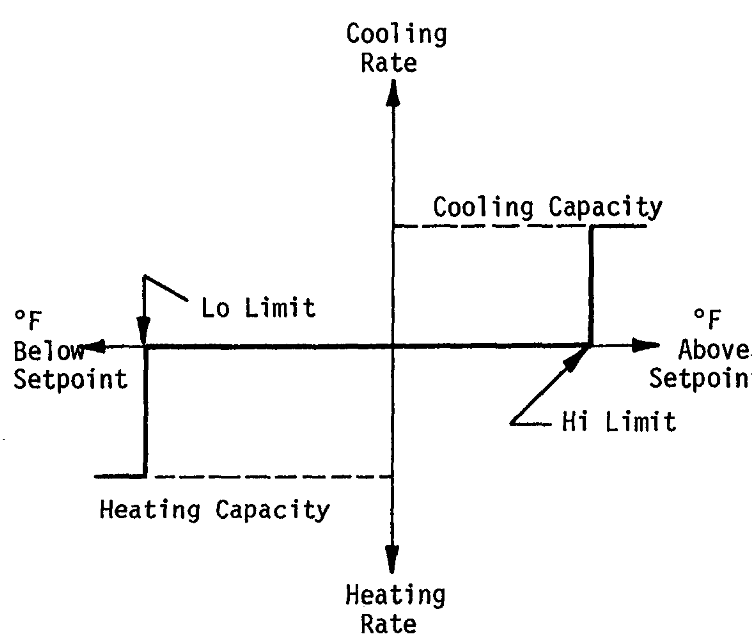
     If |HE| > HEAT, set

     TEMPS = (SUM4 + HEAT)/SUM5

     HE = -HEAT

Table 4.7

TYPES OF THERMOSTATS

TYPE	DESCRIPTION	ACTION
1	LINEAR OR PROPORTIONAL CONTROL	
2	HI-LOW OR ON-OF CONTROL	

- Check if high thermostat temperature limit is exceeded and if so, reset TEMPS and HE.

  If TEMPS > TH, set

  TEMPS = TH

  HE = SUM4 - TEMPS + SUM5

- Check if space cooling capacity has been exceeded and if so, reset TEMPS and HE.

  If |HE| > COOL, set

  TEMPS = (SUM4 - COOL)/SUM5

  HE = COOL

- Go to calculation 7.

6. Analysis for a Type 0 thermostat (floating control or no thermostat at all). This will be simulated using a Type 2 thermostat analysis, but with high and low limit set at extremely large values.

   - Set limit values at quantities that will never be exceeded.

     TL = -1.0E10

     TH = 1.0E10

   - Zero out space heating and cooling capacities.

     HEAT = 0.0

     COOL = 0.0

   - Proceed to calculation 5.

7. Store space end-of-hour temperature deviation for use next hour.

   ETEMP(I,1) = TEMPS

8. Calculate end-of-hour space temperature.

   STEMP = TEMPS + TSPAC(I)

9. Set up variables for fan system simulation.

TSP(I) = STEMP

If (TEMPS < TL), TSP(I) = TL + TSPAC(I)

If (TEMPS > TH), TSP(I) = TH + TSPAC(I)

QSINF(I) = 0.0

10. Keep track of space maximum heating and cooling rates and their time of occurrence.

- Maximum heating check

  If SMH(I) > HE, reset maximum

  SMH(I) = HE

  ITSMH(I,1) = ITIME

  ITSMH(I,2) = IDAY

  ITSMH(I,3) = MONTH

- Maximum cooling check

  If SMC(I) < HE, reset maximum

  SMC(I) = HE

  ITSMC(I,1) = ITIME

  ITSMC(I,2) = IDAY

  ITSMC(I,3) = MONTH

11. Keep track of maximum and minimum space temperatures and their time of occurence.

- Lowest space temperature check

  If SLT(I) > STEMP, reset minimum

  SLT(I) = STEMP

  ITSLT(I,1) = ITIME

  ITSLT(I,2) = IDAY

  ITSLT(I,3) = MONTH

- Highest space temperature check

  If SHT(I) < STEMP, reset maximum

  SHT(I) = STEMP

  ITSHT(I,1) = ITIME

  ITSHT(I,2) = IDAY

  ITSHT(I,3) = MONTH

VTPOHD

A subroutine which is called each hour to determine if hourly printouts are required, and if so, print flags are set.

INPUT

IPO : Number of hourly printouts requested

IPOS(I) : Hour of year that hourly printout I is to start

IPOE(I) : Hour of year that hourly printout I is to end

IHOUR : Hour of year for which calculations are to be performed

IPRNT1(I): Print level 1 desired (0=no, 1=yes)

IPRNT2(I): Print level 2 desired (0=no, 1=yes)

OUTPUT

IPOSE : Hourly printout flag (0=no, 1=yes)

IPRT1 : Print level 1 desired (0=no, 1=yes)

IPRT2 : Print level 2 desired (0=no, 1=yes)

CALCULATION SEQUENCE

1. If IPO = 0, RETURN
2. Initialize print flags

   IPOSE = 0

   IPRT1 = 0

   IPRT2 = 0
3. For each hourly printout I = 1 to IPO, perform the following:

   If IHOUR $\geq$ IPOS(I) and IHOUR $\leq$ IPOE(I)

   set IPOSE = 1

   IPRT1 = 1

   IPRT2 = 1
4. RETURN

WZNEW

A function to calculate space humidity ratios based on a water balance of the following sources: QL moisture, infiltration moisture, supply air moisture.

INPUT

TSP : Set point tepperature (°F)

TLC : Supply air temperature (°F)

WLC : Supply air humidity ratio (lbm-H_2O/lbm-dry air)

PATM : Barometric pressure (inches Hg)

CFMS : Supply air flow rate (ft^3/min)

VOL : Zone volume (ft^3)

H2OAD : Zone water change incurrent hour (lbm-H_2O)

WZ : Current zone humidity ratio (lbm-H_2O/lbm-dry air)

OUTPUT

WZNEW : New humidity ratio (lbm-H_2O/lbm-dry air)

CALCULATION SEQUENCE

1. Calculate moisture (lbm-H_2O/hr) introduced by zone supply air.

1.1 If CFMS greater than or equal to 0.0,

H2ØS2 = CFMS * DLVG * 60.0 * (WLC - WZ)

where DLVG is density of zone supply air and is obtained by calling function DENSY using parameters TLC, WLC, and PATM.

Go to calculation 2.

1.2 If CFMS is less than 0.0, set

H2ØS2 = 0.0

2. Calculate net moisture (DH2Ø) entering zone.

$$DH2Ø = H2ØS2 + H2ØAD$$

3. Calculate new zone humidity ratio (WZNEW).

 3.1 Determine the amount of air circulated in one hour by fan system.

$$AIR = CFMS * 60.0$$

 3.2 To remain within the parameters of the water balance technique, limit the amount of air seen by the zone in one hour (AIR) to a minimum of one air change per hour; therefore, if AIR less than VØL, reset.

$$AIR = VØL$$

 3.3 Calculate zone end-of-hour humidity ratio.

$$WZNEW = WZ + DH2Ø/(AIR * DLVG)$$

4. Check to ensure resulting humidity ratio (WZNEW) is within limits.

 4.1 Call subroutine HUM1 and determine the humidity ratio (WCØND) corresponding to 100% relative humidity.

 4.2 If WZNEW greater than WCØND, reset

$$WZNEW = WCØND$$

RETURN

 4.3 If WZNEW less than 0.0, reset

$$WZNEW = 0.0$$

RETURN

NOTES

ZLO

Zone load organizer. A subroutine to calculate terminal unit thermal loads to reheat and recooling coils. These are then checked against maximum and minimum leaving coil temperatures. Thermal loads met and unmet, positive and negative are broken out and summed.

INPUT

IQ : Coil type index (1 = heating; 2 = cooling).

AMULT : Zone multiplication factor.

TLC : Desired leaving coil temperature (°F).

TEC : Entering coil temperature (°F).

WEC : Entering coil humidity ratio (lbm-H_2O/lbm-dry air).

TLCMX : Maximum allowable leaving coil temperature (°F).

TLCMN : Minimum allowable leaving coil temperature (°F).

Variables in COMMON. See Table 5.4 for definitions.

OUTPUT

WLVG : Leaving humidity ratio (lbm-H_2O/lbm-dry air).

QTRHC : System reheat load (Btu/hr).

QTRCC : System recooling load (Btu/hr).

Also, some variables in COMMON.

CALCULATION SEQUENCE

1. Heating supplied.

If TLC > TLCMX,

$$TDIF = TLCMX - TLC$$

$$TLC = TLCMX$$

$$QTDIF = ZMAS_i * 0.245 * TDIF$$

Update as required the following variables:

$QHLNM_i$

$QHPNM_i$

$IHHNM_i$

$QT = ZMAS_i * 0.245 * (TEC - TLC)$

QTRHC = QTRHC + QT * AMULT

WLVG = WEC

If TLC $\leq$ TLCMX,

$QT = ZMAS_i * 0.245 * (TEC - TLC)$

QTRHC = QTRHC + QT * AMULT

WLVG = WEC

2. Cooling supplied.

If TLC < TLCMN,

Call subroutine CCOIL to calculate cooling load (QCTLC) if TLC were allowed to be met.

Call subroutine CCOIL to calculate cooling load (QT) with TLC limited to TLCMN.

TLC = TLCMN

QTDIF = QCTLC - QT

Update the following variables as required:

$QCLNM_i$

$QCPNM_i$

$IHCNM_i$

QTRCC = QTRCC + QT * AMULT

If TLC $\geq$ TLCMN,

Call subroutine CCOIL to calculate cooling load QT

QTRCC = QTRCC + QT * AMULT

SECTION 5
OWNING AND OPERATING COST ANALYSIS PROGRAM

5.1 OBJECTIVE AND DESCRIPTION

The Owning and Operating Cost Analysis Program performs a life cycle cost analysis for each building heating and cooling system analyzed by the Systems and Energy Simulation Program. Life cycle costs are those expenditures which occur singularly or periodically over the life of the building and includes cost of energy, cost of equipment in terms of first costs and replacement costs which occur if the expected life of the equipment is less than that of the building, cost of maintenance (material and labor), salvage value of equipment at end of building life, and opportunity costs for floor space occupied by equipment.

Most of the burden of assembling the cost data required by the program is placed upon the user. During these times of escalating costs for energy, fuel, material and labor, it is impractical to expect the Owning and Operating Cost Analysis Program to accurately and automatically account for these factors.

5.2 INPUT

Only the punched card form of input data is required for the Owning and Operating Cost Analysis Program. Instructions for the preparation of this data are given in Table 6.1 of User's Manual.

5.3 OUTPUT

An owning and operating cost report similar to that shown in Figures 5.1 through 5.3 is received for each set of input data given to the program. Most of the information appearing on this report is simply a recap of input data. The real results of the analysis are the annuities for each equipment category and for the total HVAC system. These annuities are calculated utilizing present worth techniques.

5.4 MAIN ROUTINE ALGORITHMS

The calculations performed sequentially by the Owning and Operating Cost Analysis Program are summarized below:

1. Read all card input data as follows:

   a) FAC - name of facility

   b) CITY - location of facility

OWNING AND OPERATING COST ANALYSIS FOR

LRC SYSTEMS ENGINEERING

BUILDING

HAMPTON, VA

```
ENGINEER   - R. JENSEN
PROJECT NO - NAS1-12843
DATE       - JULY 10, 1974
```

Figure 5.1 OWNING AND OPERATING COST ANALYSIS PROGRAM OUTPUT REPORT

**************** INPUT ASSUMPTIONS *************

BUILDING LIFE	40.00 YEARS
ANNUAL INTEREST RATE	12.00 PERCENT
ESTIMATED LABOR WAGE ANNUAL INCREASE	8.00 PERCENT
ESTIMATED MATERIAL COST ANNUAL INCREASE	15.00 PERCENT
ESTIMATED FLOOR SPACE COST ANNUAL INCREASE	10.00 PERCENT
ESTIMATED ENERGY COST ANNUAL INCREASE	10.00 PERCENT

Figure 5.2 OWNING AND OPERATING COST ANALYSIS PROGRAM OUTPUT REPORT

ANALYSIS FOR - SYSTEM NO. 1 - MULTI ZONE W/BASEBOARD, CENTRIFUGAL CHILLERS, STEAM HEAT OC-10

ENERGY COST SUMMARY

	UNIT COST ($)	CONSUMPTION	TOTAL COST ($)	ANNUITY ($)
ELECTRICITY				
LIGHTING	0.03	520000. KW	15600.	
HEATING-BOILER PUMPS, CONTROLS	0.03	57658. KW	1729.	
COOLING-CHILLER, PUMPS, TOWER	0.03	205446. KW	6163.	
FANS-SUPPLY, RETURN, EXHAUST	0.03	359160. KW	10774.	
		1142264. KW	34267.	117423.
STEAM				
HEATING	1.50	1830. K LBS	2745.	9406.
WATER				
TOWER MAKE-UP	0.75	389. K GALS	291.	999.
		GRAND TOTALS	37304.	127829.

SYSTEMS AND EQUIPMENT COST

	INITIAL COST	ANTICIPATED LIFE	SALVAGE CONSID.	MAJOR OVERHAUL PERIOD	MAJOR OVERHAUL LABOR	MAJOR OVERHAUL MATERIAL	ANNUAL LABOR	MAINTENANCE MATERIAL	FLOOR SPACE COST	ANNUITY
CHILLER, TOWER, PUMPS, PIPING	80000.	40	YES	10	800.	200.	16000.	8000.	8000.	147538.
BOILER, PUMPS, PIPING	20000.	40	YES	10	200.	50.	1000.	1000.	2000.	20617.
DISTRIBUTION SYSTEMS, CONTROLS	175000.	40	YES	10	1750.	440.	8750.	8750.	10000.	154702.
TOTAL SYSTEMS AND EQUIPMENT ANNUITY										322857.

TOTAL OWNING AND OPERATING ANNUITY 450687. DOLLARS

NOTE -- ANNUITY IS CONSTRUED TO MEAN THE UNIFORM ANNUAL COST, CONSIDERING ALL THE LISTED COSTS, TO THE OWNER DURING THE LIFE TIME OF THE BUILDING.

Figure 5.3 OWNING AND OPERATING COST ANALYSIS PROGRAM OUTPUT REPORT

c) ENGR - engineer's name

d) PROJ - project number

e) DATE - date of program run

f) BLGLF - building life, years

g) RINT - annual interest rate, %

h) RINL - annual increase of labor cost, %

i) RINM - annual increase of material cost, %

j) RINF - annual increase of floor space cost, %

k) RINE - annual increase of energy and fuel cost, %

l) CELE - unit cost of electricity, $/KW

m) CGAS - unit cost of gas, $/therm

n) COIL - unit cost of oil, $/gal

o) CSTM - unit cost of steam, $/1000 lbs

p) CWAT - unit cost of water, $/1000 gals

q) CFUL - unit cost of diesel fuel, $/gal
r) DELEC - demand cost electricity
r) CASES - number of cases or equipment combinations to be analyzed

For "CASES" number of combinations, repeat (1s) through (1ah).

s) DESC - system description label

t) ENCAT - number of energy categories

For "ENCAT" number of energy categories, repeat (1u) through (1w).

u) ETYPE - energy type coded as follows:

1 electricity
2 gas
3 oil
4 steam
5 water
6 diesel fuel

v) ECONS - annual consumption

w) ENLAB - energy category label
w̄) DELE - electrical energy demand
x) EQCAT - number of equipment categories

For each of "EQCAT" equipment categories, repeat (1y) through (1ah).

y) EQLAB - equipment category label

z) COST - installed cost of equipment, $

aa) LIFE - expected life of equipment, years

ab) SV - is resale value to be considered at end of building life?, 0 = no, 1 = yes

ac) OHPD - major overhaul period, years

ad) AML - estimated annual maintenance labor cost, $

ae) AMM - estimated annual maintenance material cost, $

af) OHL - estimated major overhaul labor cost, $

ag) OHM - estimated major overhaul material cost, $

ah) FLR - estimated cost of floor space occupied by equipment, $

2. Print title page as indicated in Figure 5.1.

3. Echo constants to be used for all analyses (see Figure 5.2).

4. Print first part of final report (Figure 5.3) summarizing energy cost results.

   a) Print system description label.

   b) For each type of energy J = 1 to 6, and each category (I = 1 to ENCAT) entered for each type, calculate and print the following:

      - ENLAB(I,N) - energy category label
      - UCOST(J) - unit cost
      - DCOST(J) - demand cost

- ECONS(I) - energy consumption
- Total cost of energy for category

  $$TOTAL = UCOST(J) * ECONS(I) + DCOST(J) * EDEMD(I)$$

- Total consumption of J energy type

  $$TCONS(J) = \Sigma\ ECONS(I)$$

- Total cost of energy type J

  $$TENGY(J) = \Sigma\ TOTAL$$

- Annuity for energy type J

  $$AE(J) = PE *((RINT * 100)/(1.0-1.0/(1.0+RINT) ** BLGLF))$$

where PE the present value is

$$PE = \Sigma\ (TENGY(J) *((1.0 + RINE * 100)/ (1.0 + RINT)) ** L) \text{ for } L = 1 \text{ to } BLGLF$$

c) Grand total cost for all energy consumed

$$UA = \Sigma TENG(J) \text{ for } J = 1 \text{ to } 6$$

d) Grand total annuity for all energy consumed

$$UE = \Sigma\ AE(J) \text{ for } J = 1 \text{ to } 6$$

5. Print second part of final report (Figure 5.3) summarizing equipment cost results. For each equipment category I = 1 to EQCAT, calculate the following:

a) Present-value of installed equipment cost

$$PC = \Sigma\ [COST(I) * ((1.0 + RINM)/(1.0 + RINT)) ** ((J-1) * LIFE(I))] \text{ for } J = 1 \text{ to } L$$

where L = BLGLF/LIFE(I) + 1

If salvage value is considered, adjust the present-value, PC, as follows:

$$PC = PC-COST(I) * (L-AL)/((1.0+RINT)**BLGLF)$$

where AL = BLGLF/LIFE(I)

b) Present-value of floor space cost

$$PF = \Sigma[FLR(I) * ((1.0 + RINF)/(1.0 + RINT)) ** J] \text{ for } J = 1 \text{ to } LF$$

where LF = BLGLF

c) Present-value analysis of annual maintenance labor cost

• $$PAML = \Sigma[AML(I) * ((1.0 + RINL)/(1.0 + RINT)) ** J] \text{ for } J = 1 \text{ to } LF$$

d) Present-value analysis of annual maintenance material cost

$$PAMM = \Sigma[AMM(I) * ((1.0 + RINM)/(1.0 + RINT)) ** J] \text{ for } J = 1 \text{ to } LF$$

e) Present-value analysis of major overhaul labor cost

$$POHL = \Sigma[OHL(I) * ((1.0 + RINL)/(1.0 + RINT)) ** (J * OHPD(I))] \text{ for } J = 1 \text{ to } K$$

where K = BLGLF/OHPD(I)

f) Present-value analysis of major overhaul material cost

$$POHM = \Sigma[OHM(I) * ((1.0 + RINM)/(1.0 + RINT)) ** (J * OHPD(I))] \text{ for } J = 1 \text{ to } K$$

g) Total present-value of system

$$P(I) = PC + PF + PAML + PAMM + POHL + POHM$$

h) Total owning and operating annuity for equipment I

$$A(I) = P(I) * (RINT/(1.0 - 1.0/(1.0 + RINT ** BLGLF)))$$

6. Print total owning and operating annuity for entire system.

$$TOOA = \Sigma A(I) + UE$$

7. If there is another system combination to be analyzed, return to calculation (4) and repeat calculations 4 through 6 with the new set of data.

SECTION 6

RESPONSE FACTOR PROGRAM

6.1 OBJECTIVE AND DESCRIPTION

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

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

Using this data, the Response Factor Program calculates the set of response factors peculiar to the surface construction in question. Previous versions of NECAP required that the data then be written onto cards or a file for insertion into the Thermal Load Analysis Program or Variable Temperature Program input stream. For NECAP-4, the Response Factor Program has been made a part of the Input Data Preprocessor Program which accepts the descriptive layer data described above, calls the Response Factor Program, and then places the actual response factor data in proper sequence in the program compatible data files.

6.2 ALGORITHMS OF SUBROUTINES

RESFAC
and
DER, FALSE, MATRIX, SLOPE, ZERO

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

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

2. "FORTRAN IV Program to Calculate Heat Flux Response Factors for a Multi-layer 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 Read in from the L9 or S9 card.

DEFC : Alphanumeric description of material

NOC : Number of surfaces to be analyzed

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

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

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

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

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

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

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

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

OUTPUT

RFX_i, RFY_i, RFZ_i : Response factors series for j = 1, 2, . . ., M where the value of M, number of the factors in the series. and depends upon the type of wall, roof or floor construction

R1 : Common ratio between successive terms of each series beyond M calculated by

$$R1 = X_{M+1}/X_M = Y_{M+1}/Y_M = Z_{M+1}/Z_M$$

Definitions of X, Y and Z Response Factors

Consider the wall in Figure 6.1 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.

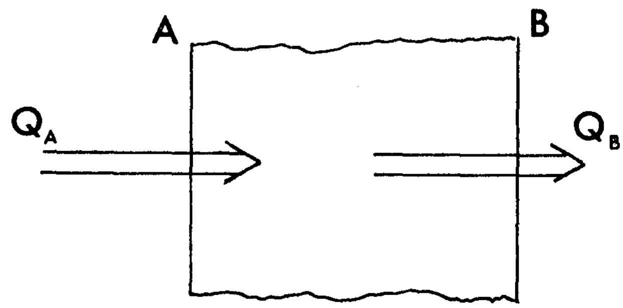


Figure 6.1 A WALL

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 6.2

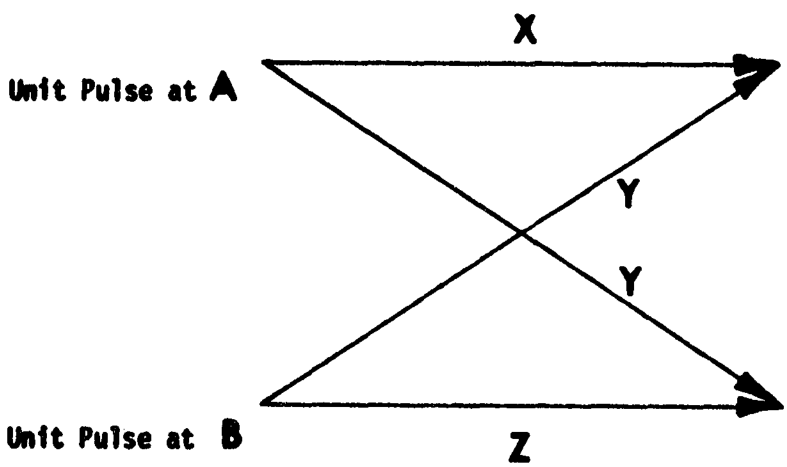


Figure 6.2 MEANING OF X, Y AND Z

SECTION 7

PROGRAM WETHER

7.1 OBJECTIVE AND DESCRIPTION

Program WETHER converts the NOAA formatted tapes into the NECAP input file which is used by TLAP. The NECAP formatted file is unformatted to allow faster processings whereas the NOAA tapes are usually in EBCDIC format. The local data for a given locality is input to WETHER to allow for defaults that reflect the proper design day conditions and ground temperatures In versions of NECAP prior to NECAP 4.1, the program exists as a subroutine called WEATHER as part of the TLAP program.

In addition to providing local data defaults, WEATHER also converts two types of NOAA tapes. The 1440 (10-YR) type, which is used by the earlier versions of NECAP, and the Test Reference Year (TRY) tapes; both are processed by WETHER.

Program WETHER was written for a CDC 6600 and CYBER 170 series computer. If WETHER is to be used on another type of computer, some conversion may be required.

7.2 ALGORITHMS OF SUBROUTINES

WETHER

This weather routine reads either a 1440 Magnetic tape (10 yr) or a Test Reference Year (TRY) tape and copies the selected period of weather data into a NECAP compatible file. The user is required to input the information listed below to complete the file to be used in NECAP.

INPUT:

ALTUD	:	Altitude of building
IPRFLG	:	Printing flag (1=YES, 0=NO)
TDBS	:	Summer dry-bulb temperature
RANGS	:	Summer dry-bulb temperature range
TDPS	:	Summer dew point temperature
WINDS	:	Summer windspeed
TDBW	:	Winter dry-bulb temperature
RANGW	:	Winter dry-bulb temperature range
TDPW	:	Winter dew point temperature
WINDW	:	Winter windspeed
JAHR	:	Year of study
ISTANO	:	Weather station number
ITAPNO	:	Weather tape flag 1=1440 tape 6 hrs/blk 2=1440 tape 24 hrs/blk 3=TRY tape
STANAM	:	Station name
ITGRND(I)	:	Ground temperatures

CALCULATION SEQUENCE:

1. Read altitude of building and printing flag.
2. Read summer weather data.
3. Read winter weather data.
4. Read station data.

5. Read Ground temperatures.
6. Write the input data to an unformatted file to be read in the LOADS program.
7. If printing is desired, echo input data.
8. If a NOA tape is to be used, go to 11.
9. Call subroutine MST to process weather data from the tape.
10. END
11. Call subroutine N01440 to process weather data from the tape.
12. END

NO1440

This 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.

INPUT:

IYR	:	Year of study
IPRFLG	:	Printing flag (1=YES, 0=NO)
INDA	:	Type of NOA tape
DBT	:	Dry-bulb temperature, ^oF
DPT or WPT	:	Dew point or wet-bulb temperature, ^oF
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, NWCR, Ashville, N.C. Detailed information on these data may be found in:

1. Reference Manual WBAN Hourly Surface Observations 144, April 1966.
2. Reference Manual WBAN Solar Radiation-Hourly 280, April 1967.
3. Tape Reference Manual, Airways Surface Observations, TDF 14.

See Appendix C of Volume I, User's Manual for Decoding Algorithms.

CALCULATION SEQUENCE:

1. Read data from tape:

   STATION NUMBER
   YEAR
   MONTH
   DAY
   HOUR

2. If this is not the place to start processing (if IYEAR < IYR?) go to 1.

3. Set HOUR = 1.

4. For each day - set dry bulb, wet bulb, and dew point.

5. Fix windspeed and direction.

6. Fix atmospheric pressure (station pressure)

7. Fix cloud amount.

8. Fix cloud type.

9. Stuff weather array.

10. Read in new data.

11. Go to 4, until HOUR = 24.

12. Write new tape.

13. RETURN.

MST

This subroutine obtains the hourly values of the data listed below, together with Station Number, Year, Month, Day and Hour (Standard Time) from TEST REFERENCE YEAR TAPES of the National Weather Record Center, which are required by the hourly load calculation procedure.

INPUT:

JSTAT	:	Weather station number
IPRFLG	:	Printing flag (1=YES, 0=NO)
DBT	:	Dry-bulb temperature, ^oF
DPT or WBT	:	Dew point or wet-bulb temperature, ^oF
TCA	:	Total cloud amount index
TOC	:	Cloud type index
V	:	Wind velocity, knots
PATM	:	Atmospheric pressure, in. Hg

CALCULATION SEQUENCE:

1. Call LIMERR to record errors in data.
2. Buffer in first weather record.
3. Decode station number.
4. Go to 2 until find correct station number.
5. If all the weather data for the station been processed (JST > JSTAT), go to 10.
6. For each hour of the day decode the weather data.
7. Write the data to the output tape to be read in TLAP.
8. If printing desired, write data.
9. Go to 2.
10. Write informative and error messages.
11. RETURN.

NOTES AND COMMENTS

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15. Supplementary Notes

16. Abstract

NASA's Energy-Cost Analysis Program (NECAP) is a powerful computerized method to determine and to minimize building energy consumption. The program calculates hourly heat gain or losses taking into account the building thermal resistance and mass, using hourly weather and a "response factor" method. Internal temperatures are allowed to vary in accordance with thermostat settings and equipment capacity.

NECAP 4.1 is a updated version of NECAP published in 1975 (see CR2590, Parts I and II). It has a simplified input procedure and numerous other technical improvements. Documentation consists of a Users Manual, Engineering Manual, Input Manual, Fast Input Manual and Example, Engineering Flow Chart Manual and an Operations Manuals (specifically for LaRC's Computer System).

This manual provides the detailed procedure and algorithums used by the program for the calculations. It can be used by the program user to more fully understand the program.

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