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MAD: A Computer Program for ACES Design Using Monthly Thermal Loads

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M. L. Ballou,* E. A. Nephew, and L. A. Abbatiello

Department of Energy
Division of Buildings and Community Systems

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NOMENCLATURE

Cross Reference for Notation

Nomenclature	Computer code	Definition
A	A	Annual average air temperature, °F
A_{CH}	ACH ARCHG	Air changes per hour
A_I		Outer surface area of ice log, πDl, ft^2
A_{INF}	AIRFLW	Air introduced by infiltration, lb dry air/h
A_k	VAR(I)	Area of surface k, ft^2
α		Absorptivity of the panel surface for normally incident solar radiation, 0.93
$\alpha_I(C)$		Quantity of heat deposited in the ice bin for each unit of heat removed from the building when the system is operating in the ice-melt, space-cooling mode
$\alpha_I(H)$		Quantity of heat withdrawn from the ice bin for each unit of heat delivered for space or water heating when the system is operating in the winter heating mode
$\alpha_S(C)$	ALPCW	Quantity of heat deposited in the ice bin for each unit of heat removed from the building when the system is operating in the bin heat-rejection, space-cooling mode
$\alpha_S(H)$	ALPHW	Quantity of heat withdrawn from the ice bin for each unit of heat delivered for space or water heating when the system is operating in the summer heating mode
B	B	Amplitude of the annual cycle of monthly average outdoor air temperature
C_{BIN}	CBIN	Cost of ice storage tank, $
C_I	COPCHT	Compressor-only cooling COP (ice phase)
C_{INF}		Air-infiltration coefficient, Btu/(h·°F)
C_P		Collection coefficient of solar panel, Btu/(h·ft^2) (PAN is monthly sum of C_P)
C_S	COPCHW COPCBR	Compressor-only cooling COP (supplemental phase)
C_1	C1	Moisture in air from occupants (daytime), lb H_2O/h
C_2	C2	Moisture in air from occupants (nighttime), lb H_2O/h
$COP_S(BR)$	COPBR	COP of ACES for removal of heat from bin at night
COP_C	CCOP	COP of heat pump in cooling mode
COP_H	COPH	COP of heat pump in heating mode based on outside dry bulb temperature

Cross Reference for Notation (continued)

Nomenclature	Computer code	Definition
$COP_S(BD)$	COPCW	COP of ACES in chilled-water mode
$COP_I(H)$	COPH	COP of ACES in heating mode
$COP_S(H)$	COPHW	COP of ACES to make hot water during supplemental cooling mode
$COP_I(C)$	COPIM	COP of ACES in ice-melt mode
$COP_S(C)$	COPSC	System COP of ACES in supplemental cooling mode
D	D	Maximum ice-log diameter, ft
d		Inner diameter of heat-exchanger tubing, 0.85/12 ft
$\overline{D}$		Average daily diffuse radiation on a horizontal surface
D_G	D	Thermal diffusivity of soil, ft^2/h
E_A	DSHE	Energy available for desuperheater hot water heater, Btu
E_C	EC	Electrical draw of motor for heat pump compressor, Btu
E_{CB}	ECB	Electrical draw of motor for cold-brine pump, Btu
E_{CL}	HPEUC	Energy needed by heat pump to provide cooling, Btu
E_F	EF	Electrical draw of motor for indoor fan coil, Btu
E_{HB}	EHB	Electrical draw of motor for hot-brine pump, Btu
E_{HT}	HPEUH	Energy needed by heat pump to provide heating, Btu
E_{HW}	EHW	Electrical draw of hot water circulating pump, Btu
E_{OF}	EOF	Electrical draw of motor for outdoor fan coil, Btu
E_S	SATVH	Specific enthalpy for saturated water vapor, Btu/lb
E_w	HPEUW	Energy needed by desuperheater hot water heater, Btu
F_r	FR	Solar panel efficiency factor
G_d	GAL	Hot water usage rate, gpd
h		Convective heat-transfer coefficient at water-to-ice interface, $Btu/(h \cdot ft^2 \cdot {}^\circ F)$
$\overline{H}$	HBAR HBR	Monthly daily total radiation on a horizontal surface, Btu
$H(m,i)$	H	Temperature-time duration in bin i, for month m, h
H_{EV}		Design heat rating of the heat pump evaporator, Btu/h
H_I		Cooling rate of indoor fan coil in ice-melt mode, Btu/h
H_o	HOO	Daily total extraterrestrial radiation on a horizontal surface for a specific latitude and declination angle, Btu
H_S		Cooling rate of indoor fan coil in chilled-water mode, Btu/h
H_T	TH	Total hours in month, h

Cross Reference for Notation (continued)

Nomenclature	Computer code	Definition
HP_{AUX}	AUXX	Auxiliary heating needed by air-to-air heat pump system, Btu
HP_{CAP}	HPCAP	Air-to-air heat pump capacity based on size of unit and capacity data, Btu/h
HP_{FCAP}	HPCAPF	Air-to-air heat pump capacity adjustment factor based on input ARI ratings
HP_{FCOP}	HPCOPF	Air-to-air heat pump COP adjustment factor based on input ARI ratings
I_{ACH}		Infiltration rate in air changes per hour
$\bar{I}_{DV}$	EDIF	Hourly diffuse radiation on a vertical surface, Btu/(h·ft^2)
$\bar{I}_{dv}$	EDIR SDIR	Hourly direct radiation on a vertical surface, Btu/(h·ft^2)
$\bar{I}_{gv}$	EREF	Hourly reflective radiation on a vertical surface, Btu/ft^2
$\bar{I}_p$	SOL(M,10)	Average daytime intensity of solar radiation on tilted panel, Btu/(h·ft^2)
I_{SC}		Solar constant, 442 Btu/(h·ft^2)
$\bar{I}_{TV}$		Hourly total radiation on a vertical surface, Btu/(h·ft^2)
k		Thermal conductivity of ice and plastic tube, Btu/(h·ft^2·°F)
$\bar{K}_T$	AKBAR	Fraction of extraterrestrial radiation transmitted through atmosphere
L	ALAT	Latitude, radians or degrees
l	COILFT	Total active length of ice-bin exchanger tubing, ft
N	YRS	Lifetime of ACES system, years
N_{ACH}		Normalization factor in air changes per hour
P	P	Phase angle of the earth temperature cycle
P_C	FUELPW	Present worth of power cost
PB	PAYPER	Simple payback period, years
PF	PF	Ice-packing fraction
P_o	FFCOS	Annual cost of electricity consumed
P_W	PWF	Present-worth factor
Q_{BR}		Bin heat removal for supplemental cooling
Q_C	QC	Space cooling load of building, Btu
Q_{COL}	PCOL	Heat collection by solar/convection panel, Btu
Q_{CON}		Conduction loss of building, Btu/h

Cross Reference for Notation (continued)

Nomenclature	Computer code	Definition
Q_{DC}	DCOOL	Design-hourly cooling load, Btu/h
Q_{DP}		Heat deposit in ice bin, Btu/h
Q_E	ETOT	Electricity consumption by ACES, Btu
$Q_H(m)$	QH	Space heating during month m, Btu
$Q_{HW}(m)$	QW	Heat load for production of hot water, Btu
Q_{INF}	XNFIL	Infiltration heat loss, Btu/h
Q_L	BLEAK	Heat leakage from ice storage bin, Btu/h
Q_{LAT}	SLATD SLATN	Latent-heat load, Btu/h
Q_S	QS	Standby heat loss of hot water storage tank, Btu/h
Q_{SC}		Cooling load of building met by supplemental cooling, Btu
Q_{WD}		Heat withdrawal from ice bin, Btu
R		Heat loss rate from long-wave radiation to sky and surroundings, Btu/h
r		Ratio of solar intensity at normal incidence outside the earth's atmosphere to the solar constant
r_d	RATEDC	Annual discount rate
r_D	RDV	Ratio of hourly diffuse radiation to daily diffuse radiation
r_e	RATEFL	Annual price escalation rate of electricity
r_L	RATIO	Ratio of total cooling to sensible cooling
r_T	RTV	Ratio of hourly total radiation to daily total radiation
$\rho(I)$		Ice density, 57.0 lb/ft^3
$\rho(W)$		Water density, 62.4 lb/ft^3
ρ_g	RHO	Ground reflectance
S	DEC	Solar declination angle, radians
S_{HG}	SHG	Solar heat gain through glass, Btu/h
S_O	SO	Internal sources, Btu/h
S_{OP}	SOP	Solar heat gain through opaque surfaces, Btu/h
S_{TONS}	TONS	Size of unit in mechanical package, tons
S_T	HWT(1)	Surface area of hot water tank, ft^2
$T(i)$	T	Mid-temperature of bin i, °F
T_a		Temperature of ambient air, °F
$\overline{T}_a$	TAV	Monthly average temperature of ambient air, °F
T_B	TB	Average temperature of brine in evaporator shell, °F

Cross Reference for Notation (continued)

Nomenclature	Computer code	Definition
T_{BAL}		Outdoor temperature at which heat losses of buildings are balanced by heat input from internal sources and solar sources, °F
T_C		Period of temperature cycle, 8766 h
T_{CAP}	TCAP	Thermal capacity of bin, Btu
T_{DD}	DD	Design-day ambient air temperature, °F
$T_G(\theta, x)$	TG	Ground temperature at time θ and depth x, °F
T_{MAX}	TMX	Maximum temperature of ice bin (45°F)
T_{SET}		Interior room temperature, °F
T_S	HWT(3)	Temperature of water in hot water tank, °F
T_{SS}	TSS	Thermostat summer setting, °F
T_{SW}	TSW	Thermostat winter setting, °F
θ_v		Angle of incidence between the sun's direct beams and a vertical or tilted surface, radians
θ_h		Angle of incidence between the sun's direct beams and a horizontal surface, radians
u	uu	Convection coefficient for solar panel, Btu/(h·ft^2·°F)
U_k	u	Heat-transfer coefficient of surface k, Btu/(h·ft^2·°F)
U_T	HWT(2)	U-value of hot water tank, Btu/(h·ft^2·F)
V	VLM TVOL	Volume of ice storage bin, ft^3
V_{DW}	VAV(1)	Design-day wind speed, mph
V_H	VOL	Conditioned volume of building, ft^3
V_S	V	Specific volume of moist air, ft^3/lb dry air

ABSTRACT

MAD, the computer program for designing and evaluating annual cycle energy systems (ACES) for single-family residences, is described, and the theoretical basis of the program is explained. The program uses average-year weather conditions to calculate the monthly requirements (loads) for space heating, water heating, and space cooling for a specified house design and uses the computed loads to determine sizes and capacity ratings of ACES components. Optimal design sizes are calculated for the following ACES components: ice storage bin, solar-collector panel, mechanical package, blower, and ice-bin heat exchanger. The algorithms used for calculating house loads and for sizing equipment give results in good agreement with actual data obtained at the Knoxville ACES demonstration house.

The program computes the monthly power consumption, annual coefficients of performance, and life-cycle costs of the ACES and three conventional, electrically driven space heating and cooling systems. The conventional HVAC systems are (1) an electric furnace, central air conditioning, and electric-resistance water heater, (2) an air-to-air heat pump with electric-resistance water heater, and (3) an air-to-air heat pump with a desuperheater water heater. This capability makes possible the comparison of the performance and economics of the ACES with other systems delivering identical energy services to a house. MAD has been used to determine the feasibility of the ACES concept in the various climatic regions of the United States.

1. INTRODUCTION

This report describes MAD, the computer program for monthly ACES design. The algorithms used in the program are described briefly. This report does not propose to present every aspect of ACES design and economic evaluation nor the many possible variations in the ACES concept, which are the subjects of other reports.[1,2] Instead, the primary objectives of this report are to provide a basic understanding of the ACES design and evaluation process and, more important, to provide information for using the program MAD and correctly interpreting the results.

The report is structured into three areas. One, the factors that must be taken into account in designing an ACES are explained in general terms (Sect. 2), and the algorithms developed for computing house loads and for sizing system components are described (Sect. 3). Two, the overall structure of the computer program—input data requirements and optional output alternatives—are described in general terms (Sects. 4 and 5). Three, a sample problem (Sect. 6) illustrates the actual use of the program: the types and sequences of input data required by it. Output from the sample problem provides a check on the functioning of the MAD program in any particular computer facility.

2. ACES DESIGN

The basic problems of ACES design and evaluation that are addressed by the MAD program are (1) to compute the design hourly and monthly space-heating, water-heating, and space-cooling loads for a single-family house in a specified climatic region, (2) to determine the smallest-size (lowest cost) components that will enable the ACES to deliver the required house loads over an annual period, (3) to calculate the electrical energy consumed by the operation of the ACES in delivering the house loads, and (4) to calculate the life-cycle cost of acquiring and operating the ACES over its anticipated lifetime. These functions of the computer program can be better understood by first understanding the ACES concept and the considerations involved in ACES design and evaluation.

2.1 ACES Concept

ACES is an integrated system for providing space heating, hot water, and air conditioning to a single-family residence by utilizing an electrically driven unidirectional heat pump that extracts heat from water stored in an insulated underground bin. As heat is extracted from the bin during the heating season, most of the water freezes and the ice formed is stored to provide air conditioning in the summer. Thus, the heat of fusion of water is available as a heat source in winter and as a heat sink in summer. Because both the heating and cooling outputs of the heat pump are used, the annual coefficient of performance (ACOP) of the system is very high. Figure 2.1 is a simplified schematic diagram of the system. A detailed description of the design, construction, and operation of an ACES appears in another document.[1,2]

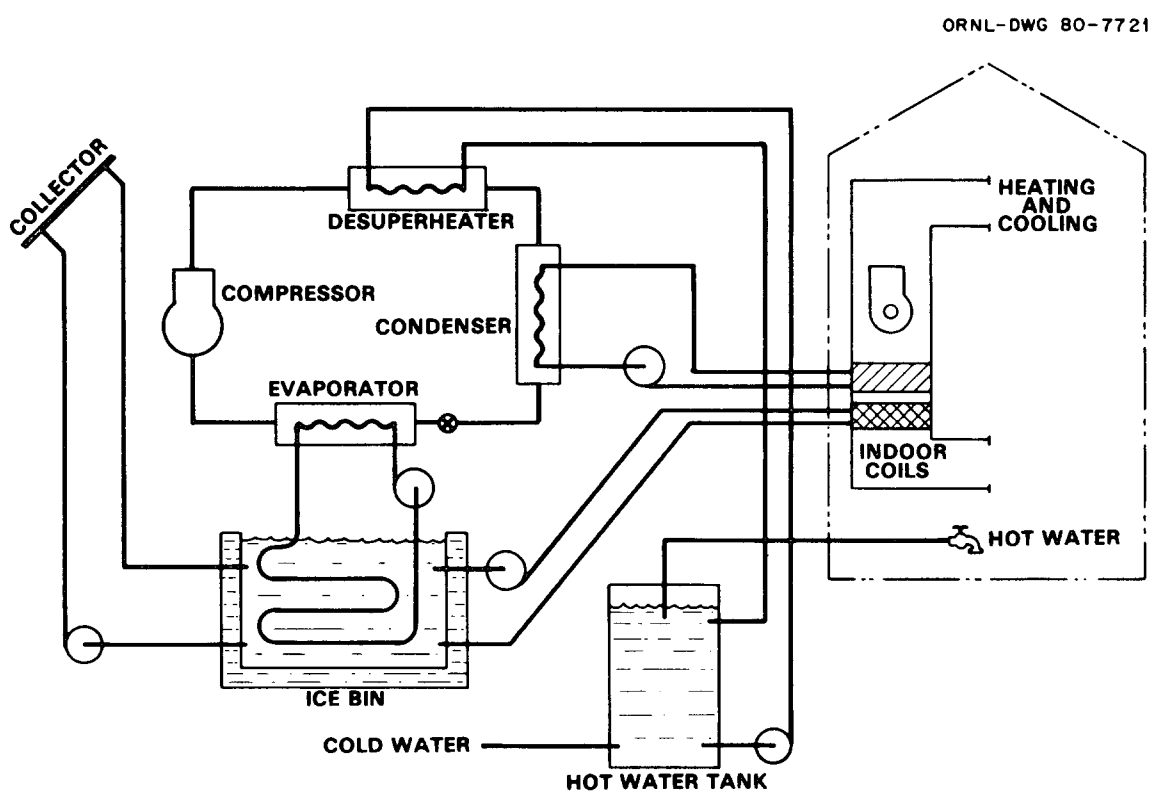

Fig. 2.1. Schematic of a brine-chiller ACES.

The primary components of the ACES are an ice storage bin, a solar energy collector, a heat pump mechanical package with a desuperheater for producing hot water, and a hot water storage tank. The energy flows of the system are discussed in Sect. 3.3.1 of this report. The ACES mechanical package consists of a compressor, desuperheater, condenser, evaporator, accumulator, control logic package, and brine-circulating pumps. The three cold-brine pumps in Fig. 2.1 are actually a single multiple-service pump contained the mechanical package. Secondary components of the ACES are air ducts, an indoor fan, thermostats, and a backup heating system consisting of electric-resistance heating elements located in the air ducts.

ACES systems can be characterized by the amount of interseasonal energy transfer they achieve. To achieve full interseasonal energy transfer, the ice storage bin must have a capacity great enough to store all of the ice that can be produced during the winter or all of the ice needed for summer air conditioning, whichever is smaller. An ACES that achieves this level of interseasonal energy transfer as a result of bin size is termed a *full* ACES. For practical reasons, the smallest bin to be considered for an ACES should have a thermal capacity sufficient for two weeks of heat pump operation during the coldest month of the year without any solar heat collection. A system with this minimum energy transfer capacity is termed a *minimum* ACES and requires a larger solar panel than a full ACES to make up the energy shortfall of the smaller bin during the heating season. The smaller bin of the minimum ACES reduces its initial cost, but the reduced interseasonal energy transfer lowers the annual efficiency of the system.

2.2 Component Sizing

The ACES must be capable of supplying heating and cooling to the house at the maximum rates anticipated for the particular building and geographical location. These peak load requirements are calculated from the known thermal characteristics of the building and the design-day summer and winter temperatures of the locality. The design-hourly heating load, in Btu/h, is the rate of heat loss of the building when the outdoor air is at the winter design-day temperature. As such, the design-hourly heating load is also the rate at which the ACES must supply heat to the building to maintain the desired interior temperature if solar heat gains and heat from lights and appliances are disregarded. Similarly, the design-hourly cooling load represents the required rate of cooling under summer design-day conditions. Components of the ACES that must be designed or selected to meet these hourly peak load conditions are: house air-duct system, backup heating system, indoor fan coil, heat pump mechanical package, and ice-bin heat exchanger. Conventional design procedures are used for sizing these components of the ACES.

The ACES must also be capable of supplying integrated or seasonal heating and cooling needs of the building. This means that the sizes of the ice storage bin and solar-collector panel are interdependent. To determine the required sizes of these two ACES components for a given house design and location, running totals of the energy available in the bin must be calculated, taking into account withdrawals to meet house thermal needs, deposits by the solar panel, and heat leakage from the earth. If the size of the ice bin is arbitrarily selected, within the range of a minimum- to full-ACES, the size of the solar-collector panel must be such that the energy available in the bin will not be exhausted at any time during the heating season. (In the MAD program, this sizing procedure is accomplished by an iterative process in subroutine DIGEST.)

2.3 System Evaluation

Two forms of output, basic and economic, may be selected by the MAD program user. The basic output of the program compares three HVAC systems: an air-to-air heat pump with an electric-resistance water heater, a minimum ACES, and a full ACES. Each system is designed and components sized according to the thermal requirements of the specified house type and climatic region. In the economic output option, the set of HVAC systems is extended to include an electric furnace system having a central air conditioner, an electric-resistance water heater, and an air-to-air heat pump system having a desuperheater for producing hot water. For both forms of output, the computer program lists the computed efficiencies and life-cycle costs of the alternative HVAC systems for easy comparison and ranking.

2.3.1 System Efficiency

The efficiency of each HVAC system is measured by its annual coefficient of performance, ACOP, defined as the number of units of energy service delivered to the house per unit of electrical energy consumed annually by the system. If the annual delivered loads for space heating, space cooling, and water heating are Q_H, Q_C, and Q_{HW}, respectively, and Q_E is the annual electricity consumption:

$$ACOP = \frac{Q_H + Q_C + Q_{HW}}{Q_E} . \tag{2.1}$$

The MAD program obtains the annual power consumption of the ACES by summing the electrical-draw values of all components engaged during a given mode and the energy consumption values of all modes of operation for a year.

2.3.2 System Economics

The economic attractiveness of each HVAC system is measured by its life-cycle cost, defined as the amount of money that would be required to purchase and install the system and to prepay all annual operating costs over the system's expected useful lifetime. The MAD program computes the life-cycle cost of each HVAC system from the relationship

$$LCC = IC + P_W(P_O + MC) , \tag{2.2}$$

where

LCC = life-cycle cost of the system, present dollars,
IC = initial or installed cost of the system, present dollars,
P_W = present-worth factor,
P_O = annual power cost, constant dollars,
MC = annual maintenance cost, constant dollars.

The initial cost of each HVAC system is obtained by the MAD program by summing the costs and installation of components of required sizes and capacities for the particular building and climate. The costs of specific components for each system are obtained from arrays of data listing 1979 prices. The annual power requirements of the HVAC systems are computed by the program;

power costs are derived on the basis of the local power rates specified in the input data. Annual maintenance costs are based on an assumed maintenance schedule for each system. The present-worth factor is expressed by the relationship

$$P_W = \sum_{k=1}^{N} (1 + r_t)^{-k} , \tag{2.3}$$

where r_t is the true rate of return available to the homeowner on his best alternative investment opportunity and N is the expected useful lifetime of the HVAC system.

3. METHODS OF LOADS CALCULATION AND SYSTEM DESIGN

3.1 Solar Radiation Intensities

The design of an ACES requires knowledge of the monthly averaged daily total radiation received on tilted surfaces at different localities in the United States. This information is needed for evaluating the performance of the solar collector panel of the system and for determining the effects of insolation on the space-heating and space-cooling requirements of the house for which the ACES is designed. Subroutine SUNLJ of MAD employs the methods of Liu and Jordan[3,4] for calculating the hourly solar radiation impinging on an arbitrarily oriented planar surface. The method uses measured values of the monthly averaged daily total radiation received on a horizontal surface, which are obtainable for numerous locations in the United States.[5] These values, along with empirical relationships between hourly and daily radiation on a horizontal surface, are used to derive the magnitude and angle of incidence of instantaneous solar fluxes received on the solar-collector panel and surfaces of the building. For additional information on the methods of Liu and Jordan, refer to the recent report by Kusuda and Ishii.[6]

3.1.1 Insolation Through Glazed Surfaces

Solar radiation entering the building through windows and glass doors produces heat gains that lower the heating load imposed on the HVAC system in winter and raises the cooling load that must be delivered by the cooling system in summer. Subroutine SUNLJ calculates the incident solar flux striking the windowed areas of the house and integrates the hourly intensities of radiation transmitted through the glass. The hourly intensities of the incident solar radiation are calculated for an average, or typical, day of each month. The fraction of radiation incident upon the outside surface of the glass that is transmitted into the house is calculated by subroutines TRNSMT and GLAZE. (Subroutine GLAZE was written by Kusuda[7] for computing the transmittance and absorptance of single- and double-paned windows of different types of glass.)

3.1.2 Absorption by Opaque Surfaces

The absorption of solar radiation on opaque surfaces of the building causes the temperature of these surfaces to rise, thereby contributing to the overall solar heat gain of the building. The absorbed energy is dissipated by convective heat exchange with the outside air, radiant energy exchange with the sky and outdoor surroundings, and by conductive heat transfer into the building. A heat balance at the outside surface can be written

$$\underbrace{\alpha I_t}_{\text{absorbed solar energy}} = \underbrace{h_o(T_s - T_o)}_{\text{heat dissipated by convection and radiation}} + \underbrace{(T_s - T_i)/R_s}_{\text{heat dissipated by conduction into the building}} , \tag{3.1}$$

where

α = absorptance of the surface for solar radiation,
I_T = total (direct and diffuse) radiation incident on the surface, Btu/h,
h_o = coefficient of heat transfer by radiation and convection at the outer surface, Btu/h·ft^2·°F,
T_o = temperature of outside air, °F,
T_i = temperature of inside surface, °F,
T_s = temperature of the outer surface, °F,
R_s = thermal resistance of the wall or roof slab and its indoor film coefficient, ft^2·h·°F/Btu.

Equation (3.1) can be solved to obtain T_s, the temperature to which the outer surface will rise so that the total heat dissipation by convection, radiation, and conduction into the building will just equal the rate at which it is absorbed on the outer surface. The result is

$$T_s = \frac{\alpha I_t + h_o T_o + T_i / R_s}{h_o + 1/R_s} . \tag{3.2}$$

The rate of heat flow into the house from the surface of area A is given by the relation

$$q/A = (T_s - T_i)/R_s . \tag{3.3}$$

rate of heat gain of a house — rate of heat transfer from outer surface to indoor air mass

Substituting Eq. (3.2) into Eq. (3.3) and rearranging the terms yields

$$q/A = \frac{(T_o - T_i)}{R_s + 1/h_o} + \frac{\alpha I_t}{h_o R_s + 1} . \tag{3.4}$$

In Eq. (3.4), the total rate of heat gain of the house from the outdoor environment is composed of a term that represents heat conduction across the wall or roof and a term that takes into account the effect of absorbed solar radiation on opaque surfaces of the building. The total thermal resistance, which limits heat transfer into the building by conduction, is the sum of the thermal resistances of the wall and the inside and outside boundary films. The heat gain resulting from solar radiation impinging on the outer surface of the house is equal to a fraction $\alpha/(h_o R_s + 1)$ of the total incident radiation. MAD computes monthly solar heat gains from opaque surfaces by integrating the solar opaque gains over all external wall and roof surfaces of the building.

3.1.3 Solar Panel Heat Collection

The solar-collector panel of the ACES consists of an unglazed flat-plate panel mounted in a fixed position selected to provide maximum collection of solar radiation during the winter months. The panel is mounted such that (1) both surfaces are exposed to ambient air and (2) the plane of the collector faces southward, inclined at an angle from the horizontal equal to the latitude plus 20°. The heat collected by the panel is equal to the absorbed solar radiation plus convective gains from the ambient air, less any panel heat losses by long-wave radiation interchange with the surroundings. (See Sect. 3.3.4 for the equation representing a heat balance on an unglazed collector panel through which brine, entering at a temperature of 32°F, is circulated as the heat-transfer fluid.)

The procedures for sizing the solar collector panel for a particular ACES are detailed in Sect. 3.3.4. Here, we note only that panel sizing requires an estimation of the monthly heat-collection capabilities of the panel, which, in turn, depend on the average monthly solar radiation received and absorbed on its surface. In subroutine SUNLJ, the methods of Liu and Jordan (Sect. 3.1) are used for estimating the hourly intensities of solar radiation received by the panel as mounted. Values of average solar heat collected per unit for each month of the year are obtained by integrating over time. Subroutine PANEL uses these values to determine the overall monthly heat-collection capability of the panel from absorption of solar radiation and convective heat collection from the ambient air.

3.2 House Thermal Requirements

The principal objective in ACES design is to size the system capacity to meet the design hourly heating and cooling loads of the building as well as the monthly demands for space heating, water heating, and air conditioning. These thermal loads depend upon the specific design and construction of the building, the climate, and the living habits of the occupants. The following methods estimate the heating and cooling requirement.

3.2.1 Design Hourly Heating Loads

The design hourly heating load represents the rate at which heat must be supplied to the building to maintain a desired indoor temperature on a cold, sunless winter day. The design hourly heating load depends on the air tightness of the building, the amount of thermal insulation of exposed surfaces (walls, windows, floors, and ceilings), and the design-day outdoor temperature of a particular location.

The conduction loss of building is estimated by

$$Q_{CON} = \sum_k A_k U_k \Delta T \,, \tag{3.5}$$

where

Q_{CON} = conduction loss of building, Btu/h,
A_k = area of surface k, ft^2,
U_k = heat-transfer coefficient of surface k, Btu/h·ft^2·°F,
$\Delta T = T_{SW} - T_{DD}$ for above-grade exposure or $T_{SW} - T_G$ for below-grade exposure,
T_{SW} = thermostat winter setting, °F,
T_{DD} = design-day ambient air temperature, °F,
T_G = ground temperature, °F.

The heat loss resulting from infiltration is calculated using the infiltration model developed by Achenbach and Coblentz[8] for an average single-family residence

$$I_{ACH} = N_{ACH}\left(\frac{0.15 + 0.013V_W + 0.005|\Delta T|}{0.695}\right) , \tag{3.6}$$

where

I_{ACH} = infiltration rate in air changes per hour,
V_W = wind speed, mph,
ΔT = temperature difference (°F) between the building's interior and the outside,
N_{ACH} = normalization factor to take into account building airtightness. $N = 1$ is an average house, and $N = 0.75$ might be used if house has certified windows, weather stripping, and no air-breathing equipment, such as a gas furnace.

Using Eq. (3.6), the heat loss resulting from infiltration is

$$Q_{INF} = 1.08 A_{CH} V_H \left(\frac{0.15 + 0.013V_{DW} + 0.005\Delta T}{0.659 \cdot 60.0}\right)(T_{SW} - T_{DD}) \,, \tag{3.7}$$

where

Q_{INF} = infiltration heat loss, Btu/h,
A_{CH} = air changes per hour or normalization factor N,
V_H = heated volume of house, ft^3,
V_{DW} = design-day wind speed, mph.

The design hourly heating load is the sum of conduction loss of the building and infiltration heat loss.

3.2.2 Design Hourly Cooling Loads

The design hourly cooling load is the rate at which heat must be removed from the building under summer design-day conditions to maintain the desired indoor temperature. The cooling load consists of sensible-heat gains resulting from solar radiation, internal heat sources, air infiltration, heat conduction through the building envelope, and the latent-heat gains that result from increases in the moisture content of the air in the building.

The conduction heat gain of the building is estimated by

$$Q_{CON} = \sum_k A_k U_k \Delta T \,, \tag{3.8}$$

where

Q_{CON} = conduction gain of the building, Btu/h,
A_k = area of surface k, ft^2,
U_k = heat-transfer coefficient of surface k, Btu/h·ft^2·°F,
$\Delta T = T_{DD} - T_{SS}$ for above-grade exposure or $T_{SS} - T_G$ for below-grade exposure,
T_{SS} = thermostat summer setting, °F,
T_{DD} = design-day ambient air temperature, °F,
T_G = ground temperature, °F.

The heat loss resulting from infiltration is

$$Q_{INF} = 1.08 A_{CH} V_H \left(\frac{0.15 + 0.013 V_{DW} + 0.005 \Delta T}{0.659 \cdot 60.0} \right) (T_{DD} - T_{SS}) \,, \tag{3.9}$$

where

Q_{INF} = infiltration heat loss, Btu/h,
A_{CH} = air changes per hour,
V_H = cooled volume of house, ft^3,
V_{DW} = design-day wind speed, mph.

The design hourly cooling load, Q_{DC}, is

$$Q_{DC} = (Q_{CON} + Q_{INF} + S_{OP} + S_{HG} + S_O) r_L \,, \tag{3.10}$$

where

S_{OP} = solar gain of opaque surfaces, Btu/h,
S_{HG} = solar gain through glass, Btu/h,
S_O = internal sources, Btu/h,
r_L = ratio of total cooling to sensible-cooling or latent-heat gain multiplier.

3.2.3 Monthly Space-Heating Loads

Space-heating loads are calculated using temperature-bin weather data—tables of outdoor air temperatures and time durations for each month of the year. The time duration of temperatures may be broken down further into daytime and nighttime hours.[9] The tables are compiled by defining consecutive 5°F-wide temperature bins and finding the total elapsed time in each month during which the outdoor air temperature falls within each bin range. The temperature-bin tables preserve the temperature vs time integral needed for calculating steady-state heat losses from the building, but lose the time-sequence information required for calculating transient heat flow. As a result, the temperature-bin method cannot correctly treat the effects of thermal inertia in a building and is limited to use with light residential structures.

Application of the bin method requires detailed information concerning the construction, orientation, location, and intended use schedules of the residential building. Data on the orientation, window area, and location of the building are required for estimating the solar gains of the building. Solar gains through glazed areas are computed using solar radiation intensities obtained by the method of Lui and Jordan.[3] Solar gains resulting from radiation impinging upon opaque areas of the building (roof and walls) are computed by a method that is equivalent to the sol-air temperature technique.[10] The internal heat sources (the rate of sensible- and latent-heat input to the building resulting from the operation of lights and appliances and the presence of people) are estimated from intended-use and occupancy schedules.

The heat-loss coefficient of the building, UA_T, is the rate of heat loss per degree of temperature difference between the interior and exterior of the house. UA_T is expressed in Btu/h·°F by

$$UA_T = C_{INF} + \sum_k U_k A_k \ , \tag{3.11}$$

where

C_{INF} = air-infiltration coefficient, Btu/h·°F,
U_k = heat-transmission coefficient of surface element k, Btu/ft^2·°F,
A_k = area of surface element k, ft^2.

The summation in Eq. (3.11) is taken over all surface elements of the building envelope that are exposed to outside ambient air temperatures.

The rate of heat loss of the building can be used to compute the outdoor balance temperature, T_{BAL}, the temperature at which the heat losses of the house are balanced by heat inputs from internal and solar sources. This condition is expressed in Btu/h by

$$UA_T(T_{SET} - T_{BAL}) = (S_O + S_{OP} + S_{HG}) \ , \tag{3.12}$$

where

T_{SET} = interior room temperature, °F,
S_O = rate of heat input by internal sources, Btu/h,
S_{HG} = solar heat gain through glazed surfaces, Btu/h,
S_{OP} = solar heat gain through opaque surfaces.

Solving Eq. (3.12) for T_{BAL} yields

$$T_{BAL} = T_{SET} - (S_O + S_{OP} + S_{HG}) / UA_T \,. \tag{3.13}$$

The significance of T_{BAL} is that the heating plant must deliver heat to the house only when the outdoor air temperature falls below this value.

The monthly quantity of heat that must be delivered to the building by the heating plant to maintain a desired indoor temperature can be obtained by equating the monthly heat losses of the building to the monthly heat gains. For any given month m, this condition is expressed by

$$Q_H(m) + (S_O + S_{OP} + S_{HG}) \sum_{i=1}^{I} H(m, i) = \sum_{i=1}^{I} UA_T[T_{SET} - T(i)]H(m, i) \,, \tag{3.14}$$

where

$Q_H(m)$ = total space heating load during month m,
m = month index number (1 to 12),
i = temperature-bin index number,
$T(i)$ = mid-temperature of bin i, °F,
$H(m, i)$ = temperature time duration in bin i, for month m, hours,
I = bin index number for which $T(i) = T_{BAL}$.

The bin temperature, $T(i)$, increases with ascending values of the bin index number, i.

The monthly space-heating load is obtained by solving Eq. (3.14) for $Q_H(m)$ and inserting the definition of T_{BAL} given in Eq. (3.13) into the resulting expression. The result obtained, in Btu, is

$$Q_H(m) = UA_T \sum_{i=1}^{I} [T_{BAL} - T(i)]H(m, i) \,. \tag{3.15}$$

This monthly space-heating load is identical in form to the conventional heating degree-day method. In this bin method, however, T_{BAL} is calculated explicitly, whereas in the heating degree-day method it is assumed to be some arbitrary value, usually 65°F, for all buildings and climates. The explicit calculation of T_{BAL} makes it possible to account for differences in life-style (thermostat setting, lights and appliance usage, and occupancy schedules) and for differences in the building construction (location, orientation, window area, thermal insulation level, and air-infiltration control). Furthermore, T_{BAL} is not assumed to be constant, but is calculated each month separately for daytime and nighttime conditions. Thus, the temperature-bin method of calculating thermal loads affords flexibility in modeling specific building designs and uses.

3.2.4 Monthly Space-Cooling Loads

The calculation of monthly space-cooling loads by the temperature-bin method requires separate estimations of the sensible- and latent-heat gains of the building. The sensible-heat gains arise from solar radiation, internal heat sources, infiltration of outdoor air, and heat conduction through the thermal envelope of the building. The balance temperature of the house for cooling, T_{BAL}, is obtained from Eq. (3.13), where T_{SET} is the desired summer indoor air temperature. The cooling plant is activated to remove sensible heat from the building only when the outdoor air temperature rises above T_{BAL}. The monthly sensible-cooling load is obtained from the expression

$$Q_C(m) = UA_T \sum_{i=I}^{IMAX} [T(i) - T_{BAL}]H(m, i) , \tag{3.16}$$

where $IMAX$ is the bin index number of the largest $T(i)$ that exceeds T_{BAL}; the other variables have been defined previously.

The monthly latent-cooling load arises from the need to maintain the relative humidity of the indoor air at a comfortable level. During the summer, the moisture content of the indoor air tends to rise because of moisture introduced by air infiltration, occupant presence, and activities such as cooking and washing. The latent-cooling load caused by air infiltration is based on an estimated air-exchange rate and is calculated from mean coincident wet bulb temperatures that are listed in the temperature-bin data. The latent heat derived from the occupants is about 200 Btu/h per person, and moisture added to the indoor air by cooking, dish washing, laundering, and bathing is estimated to range from 5 to 10 lb of water per day. The total monthly space-cooling load is the sum of sensible- and latent-cooling loads.

3.2.5 Monthly Hot-Water Loads

The calculation of monthly hot water loads assumes a usage rate of about 20 gpd for an adult. The hot water storage temperature for the ACES is 120°F, and the cold water inlet temperature is assumed to be the average monthly ground temperature at a depth just below the frost line.

The standby heat losses from the hot water storage tank, Q_S, and the total hot water load for each month, Q_{HW}, are estimated by Eqs. (3.17) and (3.18), respectively:

$$Q_S = S_T U_T (T_S - 70) , \tag{3.17}$$

in Btu/h, where

S_T = surface area of hot water tank, ft^2
U_T = U-value of hot water tank, Btu/h·ft^2·°F,
T_S = hot water storage temperature, °F;

$$Q_{HW} = H_T[G_d(T_S - T_G)0.348 + Q_S] , \tag{3.18}$$

where

H_T = hours in month, h,
G_d = hot water usage rate, gpd,
T_G = ground water temperature for month, °F,
0.348 = conversion factor of hot water from gallons per day to Btu/h·°F.

3.2.6 Comparison of Calculated and Measured Loads

A verification of the MAD algorithm, a comparison of house loads calculated by MAD and actual loads measured at the Knoxville ACES Demonstration House,[11] is shown in Fig. 3.1 and Table 3.1. The weather data are site-measured data for 1979.

3.3 Sizing of Ice Storage Bin and Solar-Collector Panel

MAD calculates the optimal sizes of an ACES ice storage bin and solar panel to meet the heating, cooling, and hot water demands of a particular building and climate. The algorithm for sizing the ice bin and solar panel can best be understood by considering the monthly heat flows into and out of the ice storage bin. The energy level of the bin varies continuously in response to the heating and cooling demands of the building: each year the ice inventory in the bin grows from zero

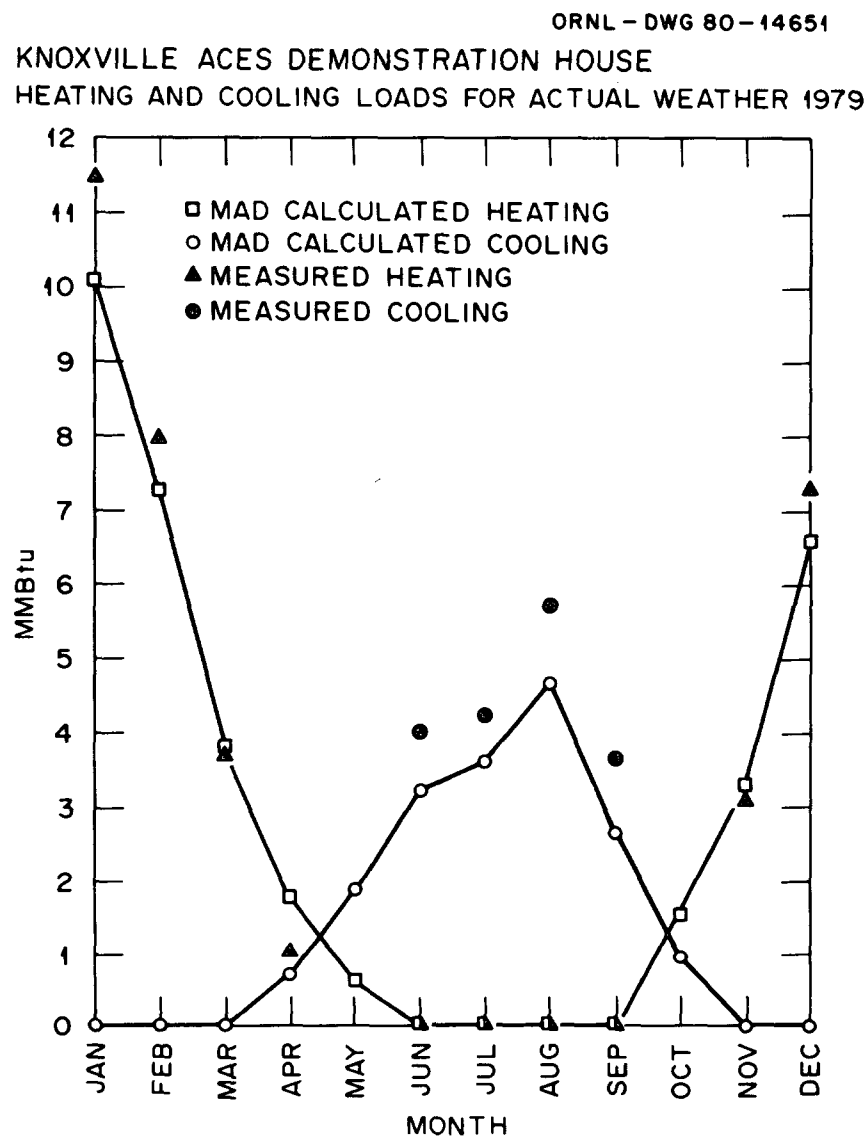

Fig. 3.1. Comparison of MAD vs measured loads.

Table 3.1. Comparison of MAD loads and measured loads for 1979

	Heating loads (MMBtu)		Cooling loads (MMBtu)	
	MAD	Measured	MAD	Measured
January	10.09	11.49	0.0	0.0
February	7.27	7.98	0.0	0.0
March	3.79	3.71	0.0	0.0
April	1.78	1.05	0.72	0.0
May	0.64	0[a]	1.89	0.55[a]
June	0.0	0	3.21	4.02
July	0.0	0	3.61	4.24
August	0.0	0	4.67	5.71
September	0.0	0	2.65	3.66
October	1.54	0.24[a]	0.96	0.12[a]
November	3.29	2.67	0.0	0.0
December	6.58	7.30	0.0	0.0
Total	34.98	34.44	17.71	18.30

[a]Measured data available for only part of the month.

to maximum and back to zero. During the heating season, the heat pump makes monthly withdrawals of energy from the ice bin to supply heat for water and space heating. As the sensible energy of the bin is extracted, the bin temperature declines from 45 to 32°F. Further energy withdrawals result in the formation of ice. Heat leakage into the bin from the surroundings and monthly deliveries of heat from the collector panel partially replenish the bin energy, but continuing heat withdrawals eventually cause the ice inventory to reach the maximum storage capacity of the bin. The environmental heat delivered to the ice bin by the solar-collector panel is regulated so that the bin reaches full ice inventory at the end of the heating season.

At the beginning of the cooling season, the full inventory of winter-formed ice in the bin is available to provide air conditioning to the house. As the cooling season progresses, heat is extracted from the house through an indoor fan coil by the circulating chilled brine that comes from the ice-bin heat exchanger. The heat that is collected is returned to the ice bin. These energy deposits gradually melt all of the ice in the bin and raise the bin temperature to 45°F. For a full ACES in a northern climate, the bin temperature reaches 45°F at the end of the cooling season, at which time the system is ready for the start of a new annual cycle. For a partial or full ACES in a southern climate, supplemental cooling is required because the depletion of winter-formed ice occurs before the end of the cooling season.

Supplemental cooling is provided by operating the heat pump at night during the summer to remove energy from the storage bin. The removal of energy lowers the temperature of the bin and makes air conditioning possible the following day. The energy that is extracted from the storage bin, together with the energy generated by operation of the heat pump, is rejected as waste energy at night to the outdoors.

3.3.1 Principal Heat Flows in the ACES

A quantitative description of ACES operations requires a determination of the principal heat flows that the system must maintain to supply the annual thermal loads of the building.

The nomenclature used to denote the principal monthly heat flows of an ACES is listed here:

$Q_H(m)$ = space-heating load of the building, Btu,
$Q_{HW}(m)$ = heat load for production of hot water, Btu,
$Q_C(m)$ = space-cooling load of the building, Btu,
$Q_L(m)$ = heat leakage into the ice storage bin, Btu,
$Q_{COL}(m)$ = heat collection by solar/convection panel, Btu,
$Q_{BR}(m)$ = bin heat removal for supplemental cooling, Btu,
$Q_E(m)$ = electricity consumption by ACES, Btu,
$Q_{WD}(m)$ = heat withdrawal from the ice storage bin, Btu,
$Q_{DP}(m)$ = heat deposit in the ice storage bin, Btu.

The heat flows $Q_H(m)$ and $Q_{DR}(m)$ are "uphill;" that is the direction of heat flow is from a lower to a higher temperature and requires a driving mechanism—the heat pump—and electrical energy to maintain the flow. The "downhill" heat flows, $Q_C(m)$, $Q_L(m)$, and $Q_{COL}(m)$, occur naturally as a result of the temperature gradient. Because heat flow out of and into the ice storage bin is central to the ACES concept, definition of "bin transfer coefficients" that relate $Q_{WD}(m)$ and $Q_{DP}(m)$ to the delivered heating or cooling loads is useful to ACES design analysis. These coefficients are denoted by $\alpha_P(M)$, where the subscript P refers to the phase of the annual cycle and M is the mode of operation.

The four principal bin transfer coefficients that are essential to an ACES design analysis are:

$\alpha_I(H)$ = the quantity of heat withdrawn from the ice bin for each unit of heat delivered for space or water heating when the system is operating in the winter heating mode;
$\alpha_I(C)$ = the quantity of heat deposited in the ice bin for each unit of heat removed from the building when the system is operating in the ice-melt, space-cooling mode;
$\alpha_S(H)$ = the quantity of heat withdrawn from the ice bin for each unit of heat delivered for space or water heating when the system is operating in the summer heating mode; and
$\alpha_S(C)$ = the quantity of heat deposited in the ice bin for each unit of heat removed from the building when the system is operating in the bin heat-rejection, space-cooling mode.

Expressions for the numerical evaluation of these bin transfer coefficients are provided in Sect. 3.3.2.

The heat flows that occur when the ACES is operating in the *ice phase* of its annual cycle (ice buildup—constant ice inventory—ice decline) are shown in Fig. 3.2.

The ACES heat flows that occur when the system is operating in the *supplemental phase* of its annual cycle are shown in Fig. 3.3. The supplemental phase of operations begins when the ice phase ends and continues throughout the remainder of the cooling season. The supplemental phase ends with the advent of a new heating season. During the supplemental phase, the daily temperature of the ice bin fluctuates between 45°F and a lower temperature that is set by the daily space-cooling needs of the building. Thus, the average temperature of the bin is higher than when the system is operating in the ice phase. This higher average bin temperature reduces heat leakage into the tank from the surroundings and also lowers the cooling-rate capacity of the indoor fan coil because of the higher temperature of the chilled brine that is circulated through it.

3.3.2 Modal Coefficients of Performance

The primary operating parameters required for ACES design analysis include both (1) the coefficients of performance (COPs) and (2) the bin transfer coefficients for each mode of operation.

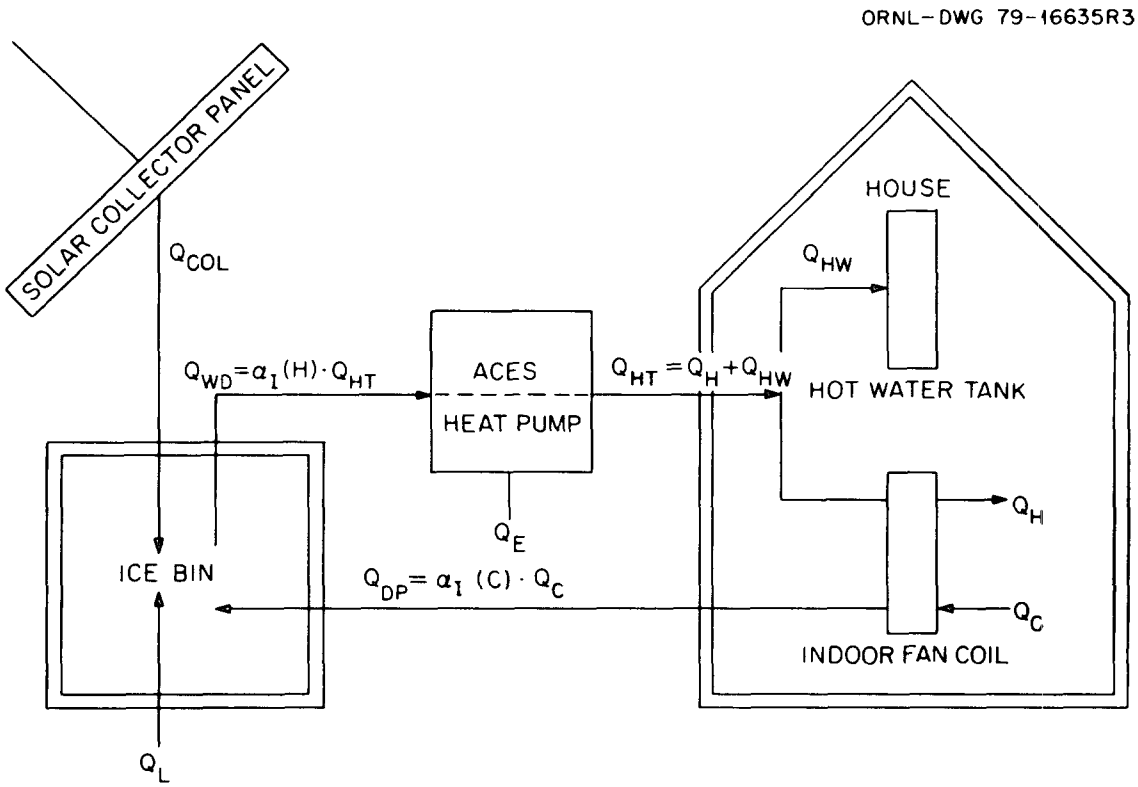

Fig. 3.2. Heat flows during ice phase of ACES operation.

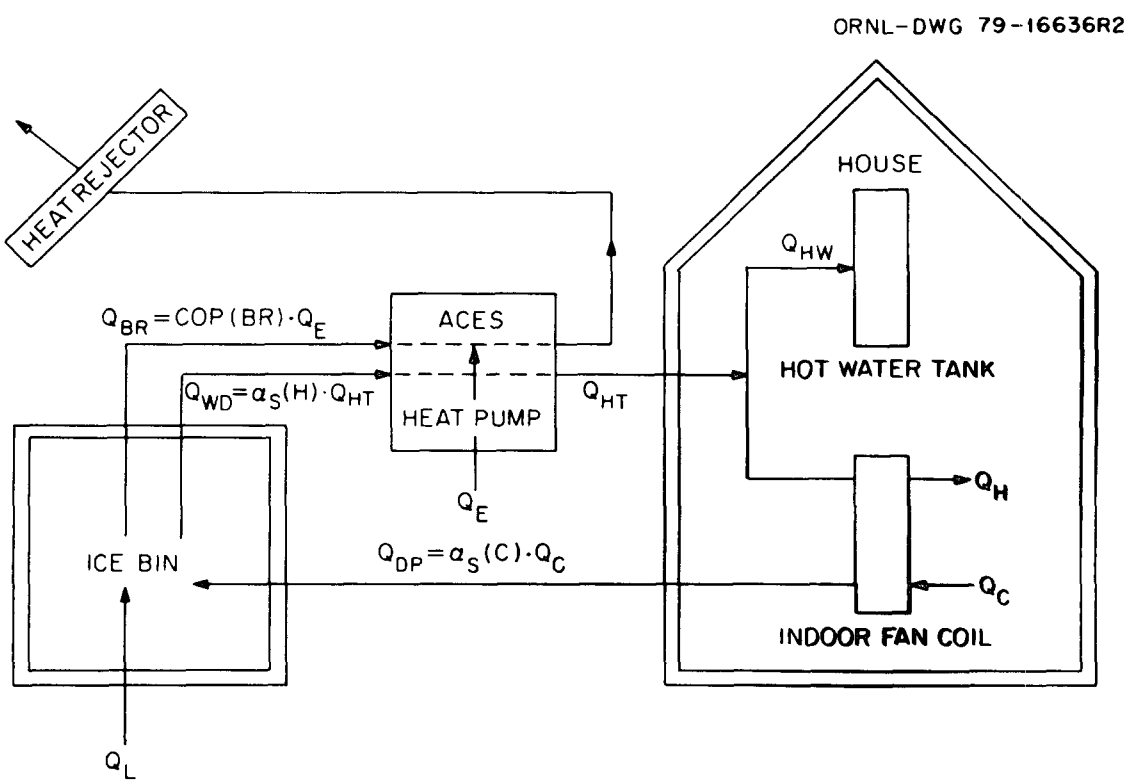

Fig. 3.3. Heat flows during supplemental phase of ACES operation.

The modal COPs are used in computing the monthly and annual electricity consumption and the annual COP of the system. The bin transfer coefficients are used in determining the ice-bin heat flow that results as the system responds to meet the monthly heating and cooling demands of the building. Based upon these ice-bin heat flows, seasonal heat balances can be calculated for the ice bin to determine the amount of heat that must be collected by the solar panel and/or the amount of heat that must be withdrawn from the bin by summertime operation of the heat pump. This information is used to determine supplemental cooling requirements and the size of the solar panel.

In the ACES, a variety of operating modes are established by the control system to meet changing load demands. For example, throughout the annual cycle the system can be called upon to supply space heating, water heating, space and water heating, space cooling, or space cooling and water heating. In each of these operating modes, the system exhibits a specific COP, and the requested house load imposes an ice-bin heat flow according to a specific bin transfer coefficient. The operating parameters and duration times of all of the modes are needed for a full design analysis. In practice, however, space heating and space cooling predominate during the ice phase of operations, and water heating and space cooling predominate during the supplemental phase. In the following analysis, only these four modes of system operation are distinguished.

The nomenclature used to denote system operating variables is defined below:

E_C = draw of heat pump compressor motor, W,
E_F = draw of indoor fan coil motor, W,
E_{HB} = draw of hot brine pump motor, W,
E_{CB} = draw of cold brine pump motor, W,
E_{HW} = draw of hot water pump motor, W,
E_{OF} = draw of outdoor fan coil motor, W,
C_I = compressor-only cooling COP (ice phase),
C_S = compressor-only cooling COP (supplemental phase),
H_I = indoor fan coil cooling rate (32° F ice-phase brine), W,
H_S = indoor fan coil cooling rate (45° F supplemental-phase brine), W.

Ice-Phase Heating Mode. The system COP in the ice-phase heating mode is defined as the ratio of the heat delivered for water heating or space heating to the electrical energy consumed by the system, in consistent units; that is,

$$COP_I(H) = \frac{(1 + C_I)E_C + E_F + E_{HB} + 0.75E_{CB}}{E_C + E_F + E_{HB} + E_{CB}} . \tag{3.19}$$

This expression is based on the assumption that the ACES mechanical package is located indoors and that motor heat losses contribute to the delivered heating load. The compressor-only cooling COP during the ice phase is obtained from the manufacturer's listing of the steady-state rating of the model. The wire-to-water efficiency of the brine-circulating pump is assumed to be 25%.

The bin transfer coefficient, or the fraction of the delivered heat load that is obtained from the ice storage bin, is expressed by

$$\alpha_I(H) = \frac{C_I E_C - 0.25E_{CB}}{(1 + C_I)E_C + E_F + E_{HB} + 0.75E_{CB}} . \tag{3.20}$$

Comparison with Eq. (3.19) shows Eq. (3.20) to be equivalent to

$$\alpha_I(H) = \frac{COP_I(H) - 1}{COP_I(H)} . \tag{3.21}$$

Thus, the monthly heat withdrawal from the ice storage bin to meet house space-heating and water-heating needs when the system is operating in the ice phase of its annual cycle is equal to

$$Q_{WD}(m) = \alpha_I(H)[Q_H(m) + Q_{HW}(m)] . \tag{3.22}$$

Ice-Phase Cooling Mode. The system COP in the ice-phase cooling mode is defined as the ratio of the heat removed from the building (or the space cooling delivered) to the electrical energy consumed by the system, in consistent units; that is,

$$COP_I(C) = \frac{H_I - E_F}{E_F + E_{CB}} . \tag{3.23}$$

The above expression is based on the assumption that, although the ACES mechanical package is located indoors, motor heat losses from the package are vented to the outdoors during cooling-mode operation. The ACES exhibits a very high modal COP when operating in the ice-phase cooling mode because only the indoor fan motor and the cold brine pump motor draw electrical power.

The bin transfer coefficient, or the ratio of heat deposited in the ice bin to the total cooling load delivered, is expressed by

$$\alpha_I(C) = \frac{H_I + 0.25E_{CB}}{H_I - E_F} . \tag{3.24}$$

Thus, the monthly heat deposit in the ice bin that is necessary to meet house space-cooling needs when operating in the ice-phase space-cooling mode is

$$Q_{DP}(m) = \alpha_I(C)Q_C(m) . \tag{3.25}$$

Hot water demands are met by the control system selecting the ice-phase heating mode.

Supplemental-Phase Heating Mode. The delivery of heat to the house during the supplemental phase is principally for the purpose of producing hot water, although some space heating may be required on cool, late-summer nights. The system COP in the supplemental-phase heating mode is defined as the ratio of the heat delivered to the electrical energy consumed by the system, in consistent units; that is,

$$COP_S(H) = \frac{E_C(HC_S)}{E_C + E_{CB} + E_{HW}} . \tag{3.26}$$

The bin transfer coefficient (or the ratio of the heat extracted from the bin to the delivered heating) is expressed by

$$\alpha_S(H) = \frac{C_S E_C - 0.25E_{CB}}{(1 + C_S)E_C} . \tag{3.27}$$

Supplemental-Phase Cooling Mode. The ACES must establish two principal heat flows during the supplemental-phase cooling mode of operation (Fig. 3.3). First, heat must be delivered from the building and deposited in the ice bin to provide space cooling to the building. Second, heat must be extracted from the ice bin and rejected as waste heat to the outdoor environment in order to maintain an ice-bin heat balance. In the following analysis, modal operating parameters are defined separately for the bin heat-deposit and the bin heat-removal systems. These parameters are then combined to yield an overall system COP for the supplemental-phase cooling mode.

The COP of the space-cooling delivery system is defined as the ratio of the heat removed from the building for space cooling to the electrical energy consumed by the delivery system, in consistent units. Using the previously defined nomenclature, the COP of the delivery system for depositing heat in the bin, $COP_S(BD)$, is expressed by

$$COP_S(BD) = \frac{H_S - E_F}{E_F + E_{CB}} . \tag{3.28}$$

This equation is based on the assumption that motor heat losses from the ACES mechanical package are vented to the outdoors during cooling-mode operation.

The bin transfer coefficient (or the ratio of the heat deposited in the ice bin to the total cooling load delivered) is expressed by

$$\alpha_S(C) = \frac{H_S + 0.25E_{CB}}{H_S - E_F} . \tag{3.29}$$

Equations (3.28) and (3.29) are identical to the corresponding expressions for the ice-phase cooling parameters, except that a different value is required for the indoor fan cooling rate. In supplemental-phase cooling, brine at up to 45°F is circulated through the indoor fan coil, whereas in the ice phase the temperature of the brine is near 32°F. The cooling rate of the indoor fan coil is directly proportional to the temperature difference existing between the circulating brine and the indoor air.

The bin heat-removal system is comprised of the heat pump and an outdoor waste-heat rejector, which may be either a convector panel or an outside air coil. The net amount of bin heat removal any time during the supplemental phase to maintain an ice-bin heat balance is expressed by

$$Q_{BR} = \alpha_S(C)Q_C + Q_L - \alpha_S(H)(Q_H + Q_{HW}) . \tag{3.30}$$

The COP of the heat rejection system is expressed by

$$COP(BR) = \frac{C_S E_C - 0.25E_{CB}}{E_C + E_{CB} + E_{HB} + E_{OF}} . \tag{3.31}$$

This equation is based on the assumption that an outdoor fan coil is used as the waste-heat rejector.

The overall system COP at any time during the supplemental-phase cooling mode, $COP_S(C)$, is defined as the ratio of the delivered space-cooling load to the total purchased energy consumed by the space-cooling delivery system and the bin heat-removal system. This ratio is expressed by

$$COP_S(C) = \frac{Q_C}{Q_C/COP_S(BD) + Q_{BR}/COP_S(BR)} . \tag{3.32}$$

The above expression can be simplified by inserting the definition for Q_{BR} given in Eq. (3.30) and rearranging the terms. The result is

$$COP_S(C) = [COP_S(BD)^{-1} + K_o COP_S(BR)^{-1}]^{-1} , \tag{3.33}$$

where the variable K_o is defined as

$$K_o = \alpha_S(C) + \frac{Q_L}{Q_C} - \alpha_S(H) \frac{Q_H + Q_{HW}}{Q_C} . \tag{3.34}$$

In Eq. (3.34) the value of K_o will be reduced by either a decrease in ground heat leakage into the bin or by an increase in the house demands for space heating and hot water production. Equation (3.33) reveals that both of these changes will act to increase the system COP in the supplemental-phase cooling mode. Equation (3.33) is based on the assumption that, although the ACES mechanical package is located indoors, motor heat losses from the package are vented to the outdoors during summer supplemental cooling operations. This venting of waste heat from system components is essential during summer space-cooling operations to prevent serious degradation of the supplemental-phase cooling-mode COP.

3.3.3 Ice-Bin Heat Balance

Over the period of a year, the heat extracted from the ice bin to meet space-heating, water-heating, and supplemental-cooling demands must be replaced by heat deposits from the collector panel, space cooling, and heat leakage into the ice bin from the surroundings. Furthermore, this ice-bin heat balance must be satisfied separately for both the ice phase and the supplemental phase of the annual cycle.

Ice Phase. Using the previously described notation, the net monthly energy flow into or out of the ice storage bin can be written as

$$Q_{NET}(m) = Q_{COL}(m) + Q_L(m) + \alpha_I(C)Q_C(m) - \alpha_I(H)[Q_H(m) + Q_{HW}(m)] . \tag{3.35}$$

The quantity $Q_{NET}(m)$ represents the net bin heat flow during any particular month and can be either positive (net heat deposit) or negative (net heat withdrawal), depending on the thermal demands of the house. The sum of $Q_{NET}(m)$, however, taken over all the months of ice-phase operation, must be equal to zero. Thus, the ice-bin heat balance condition over this period of time is expressed by

$$\Sigma\, Q_{COL}(m) + \Sigma\, Q_L(m) + \alpha_I(C)\, \Sigma\, Q_C(m) = \alpha_I(H)\, \Sigma\, [Q_H(\mathrm{m}) + Q_{HW}(m)] . \tag{3.36}$$

In Eq. (3.36), $\Sigma\ Q_H$, $\Sigma\ Q_{HW}$, and $\Sigma\ Q_C$ represent the thermal demands of the house during the ice phase of operations. The ice-bin heat leakage, $\Sigma\ Q_L$, is a function of the amount of insulation provided in the bin, the temperature difference between the inner and outer surfaces of the bin, and the heat-transfer areas of the ice bin surfaces. The control variable for satisfying Eq. (3.36) is Q_{COL}, the panel heat collection, which must be varied to match the thermal demands of the house to the ice-bin thermal capacity.

Supplemental Cooling Phase. The net monthly energy flow into or out of the ice bin during the supplemental cooling phase of annual operations is expressed by

$$Q_{NET}(m) = \alpha_S(C)Q_C(m) + Q_L(m) - \alpha_S(H)[Q_H(m) + Q_{HW}(m)] - Q_{BR}(m)\ . \tag{3.37}$$

Here, $Q_{BR}(m)$ represents the amount of heat that must be removed from the bin each month to provide the needed supplemental cooling capacity. The amount of heat removal required is equal to the net heat deposits so that $Q_{NET}(m) = 0$ for each month of supplemental-phase operations. The sum of all the months of supplemental-phase operation is expressed by

$$\Sigma\ Q_{BR}(m) = \alpha_S(C)\ \Sigma\ Q_C(m) + \Sigma\ Q_L(m) - \alpha_S(H)\ \Sigma\ [Q_H(m) + Q_{HW}(m)]\ . \tag{3.38}$$

$\Sigma\ Q_H$, $\Sigma\ Q_{HW}$, and $\Sigma\ Q_C$ represent the thermal demands of the house during the supplemental phase of operation. $\Sigma\ Q_L$ is a function of the ice bin construction and the temperature of its external surroundings. The temperature at the inner surface of the ice bin is assumed to be 45° F during the supplemental phase of annual operation.

Ice-Bin Thermal Capacity. The thermal storage capacity of the ice bin, which determines the amount of beneficial interseasonal energy transfer that can be effected with a given ACES design, is expressed by

$$TCAP = PF \cdot \rho(I) \cdot V[144 + T_{MAX} - 32] + (1 - PF) \cdot \rho(W) \cdot V[T_{MAX} - 32]\ , \tag{3.39}$$

where

$TCAP$ = design thermal capacity of bin, Btu,
PF = ice-packing fraction,
$\rho(I)$ = ice density, 57.0 lb/ft^3,
$\rho(W)$ = water density, 62.4 lb/ft^3,
V = ice-storage-bin wetted volume, ft^3,
T_{MAX} = maximum temperature of ice bin, 45° F,
144 = heat of fusion of water, Btu/lb.

The value of PF in Eq. (3.39) is 0.4 for an ice-maker ACES and 0.8 for a brine-chiller ACES.

For a full ACES, it is possible to select an ice bin size, V, that will result in either $\Sigma\ Q_{COL}$, in Eq. (3.36), or $\Sigma\ Q_{BR}$, in Eq. (3.38), becoming zero. In northern climates, where a surplus of winter ice is produced, the ice bin can be selected to have a thermal capacity great enough to provide for all the summer cooling needs. In this case, the entire annual cycle operates in the ice phase, and panel heat collection is provided to melt excess ice formed during the heating season. In southern climates, the thermal capacity of the ice bin is selected to meet all of the bin heat withdrawals without assistance from solar panel heat collection. Supplemental cooling, however, is required during the summer. For a partial ACES located in either northern or southern climates, both panel heat collection and supplemental cooling must be provided; that is, neither $\Sigma\ Q_{COL}$ nor $\Sigma\ Q_{BR}$ will be zero.

3.3.4 Solar Panel Design

The collection of heat by the solar panel must be regulated to satisfy Eq. (3.36), as described in the preceding section. Thus, the smallest panel is selected that can satisfy the heat balance conditions and prevent full freezing of the bin water at any time during the ice phase. The solar panel gains heat by absorbing solar radiation and heat from the ambient air and loses heat by long-wave radiation to the sky and surroundings. An energy balance on the panel can be written, in Btu/h·ft^2, as

$$C_P = F_r[\alpha \bar{I}_p + 2u(T_a - 32) - R] , \tag{3.40}$$

where

F_r = panel efficiency factor,
α = absorptivity of the panel surface for incident radiation, 0.93,
$\bar{I}_p$ = average daytime intensity of solar radiation on the panel, Btu/h·ft^2,
u = convection coefficient, Btu/h·ft^2·°F,
T_a = temperature of the outside air, °F,
R = heat loss rate by long-wave radiation, Btu/h·ft^2 (R is assigned a value of 15).

In Eq. (3.40), the convection coefficient, u, is doubled because convective heat collection occurs on both sides of the panel surface. An analysis of the performance of an experimental panel tested at the Oak Ridge National Laboratory showed that u, in Btu/h·ft^2·°F, is well represented by

$$u = 0.409S + 0.912 , \tag{3.41}$$

where S is wind speed in miles per hour. Similarly, the panel efficiency factor, F_r, is represented by the correlation

$$F_r = 0.941 - 0.028u . \tag{3.42}$$

The values of $\bar{I}_p$ used in Eq. (3.40) are monthly averaged solar radiation intensities predicted by the method of Liu and Jordan.[3,4] Using Eq. (3.40), the solar panel heat gain per square foot is calculated for each month of the year. Bin tabulations of monthly outdoor air temperatures[9] are used in computing the heat gains from convection. In MAD, the subroutine PANEL calculates the monthly panel heat-collection capacities, and the subroutine DIGEST calculates the size of the panel that will satisfy Eq. (3.36).

4. COMPUTER PROGRAM STRUCTURE

4.1 Main Program and Subroutines

The computer program MAD consists of the twenty-one different subprograms shown in Fig. 4.1. The routine MAIN performs the control function of the program.

Subroutines DATAIN and PRTDAT read and print a description of the building and specifications of the systems to be designed.

MAD then begins a loop that can be repeated for any number of cities. Subroutine BIN reads the bin weather data once for each city in the file, and, at the end of the file, the program ends. After the weather data have been read, subroutine EARTH calculates monthly ground temperatures, and subroutine SUNLJ calculates monthly solar insolation on the house and solar panel. MAIN calculates the solar absorption by opaque surfaces.

After the solar data have been computed, subroutine PANEL calculates the solar panel heat gain per square foot for each month. Using the weather data and solar data, subroutine LOADS calculates the monthly space-heating, space-cooling, and hot-water loads. As LOADS calculates the loads of each temperature bin, it also calculates the energy required by a specific air-to-air heat pump in meeting these thermal loads.

After the monthly thermal loads are known, subroutine DIGEST uses an iterative method to select the ice-bin volume for a full ACES. After this volume is found, DIGEST selects a solar panel area to provide an annual energy balance on the ice bin. DIGEST repeats this process for a minimum ACES.

Subroutine ENERGY models the energy usage of the three conventional HVAC systems. To do this, ENERGY uses the monthly loads and air-to-air heat pump energy usages calculated in LOADS. ENERGY also models the desuperheater hot water heater.

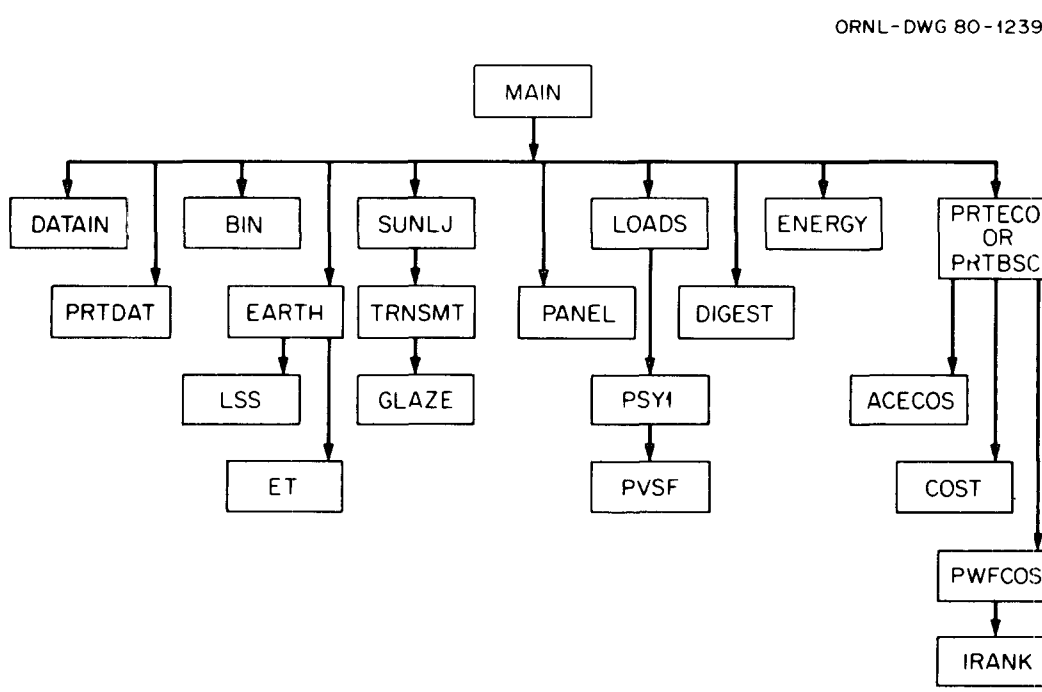

Fig. 4.1. Origins of subroutine calls in the MAD program.

Subroutine PRTECO or PRTBSC is selected as output routine by an option in the house data set. Both PRTECO and PRTBSC call (1) subroutine ACECOS, which calculates costs both for a full and a minimum ACES, and (2) subroutine COST, which calculates the present-worth cost and life-cycle ranking of the five systems. After PRTECO or PRTBSC prints a summary page for the particular city being processed, MAIN writes computed values to unit 8 for use by other programs. MAIN then loops back to subroutine BIN to read a weather data set for each city in the file. After all sets have been read and processed, BIN returns to the end of MAIN.

The next sections provide a detailed description of each subroutine.

4.2 Building Characteristics

4.2.1 Subroutine DATAIN

Subroutine DATAIN reads a description of the building for which an ACES will be designed for one or more locations, or cities, from unit 5.

Subroutine DATAIN reads data describing the hot water tank, the ACES ice storage bin, performance of the mechanical package, and building construction. The building data include the U-value and area of each external surface. Section 5.1.1 describes these input values in detail. The subroutine also calculates representative heat losses through each surface based on a 50°F difference between inside and outside dry bulb temperatures.

4.2.2 Subroutine PRTDAT

Subroutine PRTDAT prints the data read in DATAIN. PRTDAT also prints the heat losses through each surface based on a 50°F difference. These data are independent of location. The output from PRTDAT is detailed in Sect. 6.2.

4.3 Weather Characteristics

4.3.1 Subroutine BIN

Subroutine BIN reads the longitude, latitude, and elevation of the particular location, the design-day temperature for summer and winter, the average monthly insolation, the average monthly wind speed, and the temperature-bin weather data from unit 13. These weather data are described in detail in Sect. 5.1.2.

In subroutine BIN, an end of file on unit 13 causes a return to the end of MAIN. An error in bin weather data will cause a message to be printed and the program to stop.

4.3.2 Subroutine EARTH

Subroutine EARTH estimates the temperature of the earth at various depths by the method based on the relationship between earth temperature oscillations and soil thermal diffusivity, which was described by Lord Kelvin in 1811. Recently, Kusuda and Achenbach[12] have shown that the average annual temperature cycles of outdoor air can be used in the Kelvin relationship with reasonable accuracy to predict ground temperature. The parameters required for estimating soil temperature at a given location are annual average air temperature, A; amplitude of the annual cycle of monthly average outdoor air temperatures, B; and the phase angle of the earth temperature cycle, P.

Subroutine LSS calculates A, B, and P by fitting a least-squares curve to the average monthly air temperatures. Function ET evaluates

$$T_G(\theta, x) = A - |B| \exp(-\sqrt{\pi / D_G T_C}) \cos\left(\frac{2\pi\theta}{T_C} - \sqrt{\frac{\pi}{D_G T_C}} \cdot x - P\right) , \tag{4.1}$$

where

$T_G(\theta, x)$ = ground temperature at time θ and depth x, °F,
x = depth below the surface of the earth, ft,
θ = elapsed time from January 1, h,
T_C = period of the temperature cycle, 8766 h,
D_G = thermal diffusivity of the soil, ft^2/h.

Subroutine EARTH also calculates the inlet water temperature to the house by selecting a depth for water pipes such that inlet water temperature equals or exceeds 36°F. If a depth between 0 and 40 ft fails to meet this condition, a message is printed and the program is stopped.

4.4 Solar Heat Gains

4.4.1 Subroutine SUNLJ

Subroutine SUNLJ estimates the solar heat gain through both glazed and opaque surfaces for each month. The solar gain is used in calculating monthly heating and cooling loads as described in Sects. 3.2.2 and 3.2.3.

Subroutine SUNLJ uses the monthly averaged daily total radiation on a horizontal surface, $\overline{H}$, for a particular location.[5] The total daily extraterrestrial radiation on a horizontal surface, in Btu, at a particular latitude and declination angle, H_o, is calculated according to the expression of Liu and Jordan[3,4] and Kusuda:[6]

$$H_o = \frac{\pi}{24} r I_{SC} (\cos L \cos S \sin W_S + W_S \sin L \sin S) , \tag{4.2}$$

where

r = ratio of solar intensity at normal incidence outside the atmosphere to the solar constant,
I_{SC} = solar constant, 422 $Btu/h \cdot ft^2$,
L = latitude, radians,
S = solar declination angle, radians,
W_S = sunrise hour angle, radians.

The ratio, $\overline{K_T}$, representing the fraction of extraterrestrial radiation that is transmitted through the atmosphere is defined by

$$\overline{K_T} = \overline{H} / H_o . \tag{4.3}$$

Let $\bar{D}$ be the average daily diffuse radiation on a horizontal surface and, using the experimental data of Liu and Jordan,[3,4] calculate the ratio $\bar{D}/\bar{H}$ as a function of $\bar{K}_T$.

To obtain the hourly diffuse radiation and hourly total radiation from daily diffuse radiation and daily total radiation, the ratios r_D and r_T are calculated. The ratio of hourly diffuse radiation to daily diffuse radiation is

$$r_D = \frac{\pi}{24}\left(\frac{\cos W - \cos W_S}{\sin W_S - W_S \cos W_S}\right) , \tag{4.4}$$

where

W = hour angle corresponding to a given hour of the day (solar time), radians.

The ratio of hourly total radiation to daily total radiation, r_T, is obtained using the experimental data of Liu and Jordan.[3]

The hourly direct radiation on a vertical or tilted surface is

$$\bar{I}_{dv} = \frac{\cos \theta_v}{\cos \theta_h} \bar{H}[r_T - r_D(\bar{D}/\bar{H})] \tag{4.5}$$

$$= \frac{\cos \theta_v}{\cos \theta_h} (\bar{H} r_T - r_D \bar{D}) , \tag{4.6}$$

where

θ_v = angle of incidence between the sun's direct beam and a vertical or tilted surface,
θ_h = angle of incidence between the sun's direct beam and a horizontal surface.

The hourly diffuse radiation on a vertical surface is estimated using the relationship

$$\bar{I}_{DV} = \bar{H} r_d \frac{\bar{D}}{2\bar{H}} = r_d \frac{\bar{D}}{2} , \tag{4.7}$$

and the hourly reflective radiation on a vertical or tilted surface is estimated by

$$\bar{I}_{gv} = \rho_g (r_T \cdot \bar{H}/2) , \tag{4.8}$$

where ρ_g = ground reflectance. Thus, the hourly total radiation is

$$\bar{I}_{TV} = \bar{I}_{DV} + \bar{I}_{dv} + \bar{I}_{gv} . \tag{4.9}$$

Subroutine SUNLJ calculates this hourly total radiation for north-, south-, east-, and west-facing walls; for a horizontal roof; and a tilted solar panel. The hourly total radiations are summed for each month to estimate the insolation on the house.

To obtain the solar gain through windows, subroutines TRANSMT and GLAZE provide a transmission factor for direct radiation and a transmission factor for diffuse and reflective radiation. GLAZE was taken from subroutine TAR, an algorithm for calculating transmission, absorption,

and reflection factors for windows in the NBSLD computer code.[7] Subroutine SUNLJ contains arrays of data for daylight hours from 8 to 16.25. In northern latitudes greater than 49°, the hour of sunrise or sunset is reset to these hours and a message is printed.

4.4.2 Subroutine PANEL

Subroutine PANEL calculates the solar panel heat gain per square foot for each month in Btu/h·ft^2 brine temperatures from 32 to 46°F, using Eqs. (3.40), (3.41), and (3.42) for daytime collection and the following for nighttime collection:

$$C_p = F_r[2u(T_a - 32) - R] , \tag{4.10}$$

using the same nomenclature as for Eq. (3.40). Information concerning the panel is detailed in Sect. 3.3.4 and elsewhere.[1,2]

4.5 House Monthly Thermal Requirements

4.5.1 Subroutine LOADS

Subroutine LOADS calculates the monthly heating and cooling loads of the building using temperature-bin weather data as described in Sect. 3.2.2. The monthly hot water loads as described in Sect.3.2.4 are calculated in LOADS. The design hourly loads described in Sect. 3.2.1 are also calculated in LOADS. This subroutine computes both the sensible and latent components of the monthly space-cooling loads. A zero annual heating load would indicate a climate in which an ACES would be inappropriate. If the temperature-bin data is such that the annual heating load is zero, subroutine LOADS will not process the data but will print a message that this condition exists and return to MAIN to process a new weather data set.

Subroutine LOADS also calculates the air-to-air heat pump energy needs.

4.5.2 Latent-Cooling Loads

The monthly latent-cooling load is the cooling necessary to maintain a comfortable indoor relative humidity. The sources that introduce moisture into the building, namely, air infiltration and occupant activities, need to be considered in this calculation.

The nomenclature used to describe the flow of moist air through a residence is:

C_1 = moisture from people, cooking, etc., during daytime, lb H_2O/h,
C_2 = moisture from people, cooking, etc., during nighttime, lb H_2O/h,
A_{INF} = air-introduced infiltration, lb dry air/h,
V_S = specific volume of moist air, ft^3/lb dry air,
W_I = humidity ratio of moist indoor air, lb H_2O/lb dry air,
W_O = humidity ratio of moist outdoor air, lb H_2O/lb dry air,
W_D = design humidity ratio of moist air, lb H_2O/lb dry air,
$\overline{T_a}$ = average monthly outside dry bulb temperature, °F, and
$\overline{V_W}$ = average monthly wind speed, mph.

Subroutine PSYI and function PVSF, excerpted from NBSLD,[7] use the dry bulb and wet bulb temperatures to give the humidity ratio and specific volume of moist air.

Thus, as in Eq. (3.7), the infiltration is calculated using the average monthly wind speed and outdoor air temperature; the specific volume of moist air is used to obtain air introduced by infiltration:

$$A_{INF} = \frac{A_{CH} V_H}{V_S} \left(\frac{0.15 + 0.013 \overline{V}_W + 0.005 | T_a - \overline{T}_{SS} |}{0.695} \right) , \tag{4.11}$$

where T_{SS} = thermostat setting in summer, in °F.

Figure 4.2 is a diagram of the mass flow rate of moisture through the residence, and the balance of these mass flow rates for daytime is

$$A_{INF} \cdot W_I = A_{INF} \cdot W_O + C_1 . \tag{4.12}$$

Subroutine PSY1 gives W_o for each outdoor wet bulb and dry bulb temperature in the temperature-bin weather data. Thus, W_I can be calculated by

$$W_I = W_o + C_1 / A_{INF} . \tag{4.13}$$

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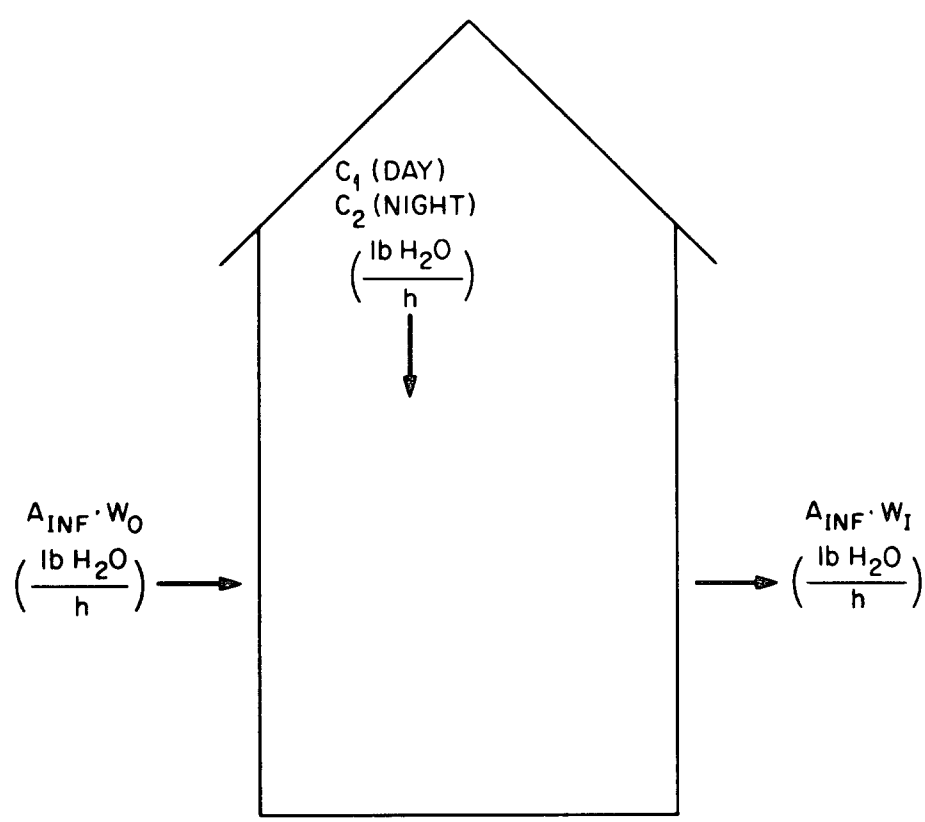

Fig. 4.2. Mass flow rate of moisture.

When W_I is greater than the design humidity ratio, W_D, the latent heat load is calculated by

$$E_S = 0.44T(i) + 1061 \ , \tag{4.14}$$

$$Q_{LAT} = (W_I - W_D)A_{INF}H(m, i)E_S \ , \tag{4.15}$$

where

E_S = specific enthalpy for saturated water vapor, Btu/lb,
Q_{LAT} = latent-heat load, Btu/h,
$H(m, i)$ = the temperature-time duration in bin i and for month m, h,
$T(i)$ = the mid-temperature of bin i, °F.

The latent-heating load, Q_{LAT}, is calculated for both daytime and nighttime and added to the sensible-cooling loads.

4.5.3 Air-to-Air Heat Pump Energy Demands

The performance of the air-to-air heat pump during heating- and cooling-load delivery is determined in subroutine LOADS. The subroutine calculates the energy consumption of the unit for each temperature bin and sums all of the bins of the month. These calculations require data on the heating and cooling capacities and COPs of the specific heat pump as a function of the outdoor air temperature. For each temperature bin, the house heating load is assumed to be supplied to the extent possible with thermodynamically pumped heat, and any remaining demand is assumed to be supplied by auxiliary resistance heating. The pumped heat is delivered at a COP corresponding to a particular outdoor air temperature, and the auxiliary heat is delivered at a COP of unity. The following variables are used in describing the operation of the heat pump for a particular temperature bin:

C_C = constant cooling capacity of the heat pump, Btu/h,
$C_H(T_i)$ = heating capacity of the heat pump, Btu/h,
COP_C = coefficient of performance for cooling,
$COP_H(T_i)$ = coefficient of performance for heating,
$H(m, i)$ = hours at temperature T_i during month m,
$HP_{AUX}(i)$ = auxiliary resistance heating delivered, Btu,
$H_P(i)$ = pumped heating delivered, Btu,
$H_{PMX}(i)$ = maximum pumped heat capacity for bin i, Btu,
$Q_C(m, i)$ = house cooling load for bin i during month m, Btu,
$Q_H(m, i)$ = house heating load for bin i during month m, Btu,
T_i = dry bulb temperature of outdoor air, °F.

Heat Pump Energy Consumption. For a given temperature bin, the maximum amount of pumped heat that can be delivered by the heat pump system is expressed as

$$H_{PMX}(i) = C_H(T_i) \cdot H(m, i) \ . \tag{4.16}$$

The actual amounts of pumped and auxiliary heat delivered to meet the house heating loads are:

$$\text{if } H_{PMX}(i) < Q_H(m, i)\,, \qquad H_P(i) = H_{PMX}(i)\,, \qquad HP_{AUX}(i) = Q_H(m, i) - H_P(i)\,; \tag{4.17}$$

$$\text{if } H_{PMX}(i) \geqslant Q_H(m, i)\,, \qquad H_P(i) = Q_H(m, i)\,, \qquad HP_{AUX}(i) = 0\,. \tag{4.18}$$

The monthly energy consumption of the air-to-air heat pump in supplying the heating and cooling loads of the house is expressed as

$$E_{HT}(m) = \sum_{i=1}^{I} \left[\frac{H_P(i)}{COP_H(T_i)} + HP_{AUX}(i) \right]\,, \tag{4.19}$$

and

$$E_{CL}(m) = \sum_{i=1}^{I} \frac{Q_C(m, i)}{COP_C}\,, \tag{4.20}$$

where

I = number of temperature bins in weather data for month m,
$E_{HT}(m)$ = energy input to heat pump during heating-mode operation,
$E_{CL}(m)$ = energy input to heat pump during cooling-mode operation.

System Performance Factors. Subroutine LOADS uses the computed energy consumptions to calculate seasonal heating and cooling performance factors for the heat pump and an annual performance factor of a system delivering air conditioning, space heating, and hot water to the building. These performance factors are defined as

$$SPF_H = \frac{\sum_{m=1}^{12} Q_H(m)}{\sum_{m=1}^{12} E_{HT}(m)}\,, \tag{4.21}$$

$$SPF_C = COP_C\,, \tag{4.22}$$

$$SPF_A = \frac{\sum_{m=1}^{12} [Q_H(m) + Q_C(m) + Q_{HW}(m)]}{\sum_{m=1}^{12} [E_{HT}(m) + E_{CL}(m) + Q_{HW}(m)]}\,, \tag{4.23}$$

where

SPF_H = seasonal performance factor for heating,
SPF_C = seasonal performance factor for cooling,
SPF_A = annual system performance factor for total energy services, and
$Q_{HW}(m)$ = monthly energy requirements for hot water.

The energy consumption of the air-to-air heat pump is printed by the output subroutines PRTBSC and PRTECO for each month of the year. Subroutine ENERGY uses the monthly energy consumption of the air-to-air heat pump to model three non-ACES systems.

Heat Pump Simulation Model. The data required for simulating the dynamic performance of a selected air-to-air heat pump are its steady-state cooling capacity at an outdoor air temperature of 95° F and its steady-state heating COPs at outdoor air temperatures of 17 and 47° F. These heating COPs are averaged in the program to yield the steady-state heating COP of the selected heat pump at 32° F. The heating COPs of the heat pump at other outdoor air temperatures are obtained from a built-in array, COPH, which is first scaled to yield the desired value of the heating COP at 32° F.

The array COPH in BLOCK DATA lists 76 values of steady-state heating COPs for a standard R-22 heat pump as a function of evaporator temperature. The evaporator temperatures corresponding to the array elements begin with −20° F and increase by 1° increments. The dynamic performance value of the heat pump is obtained by assuming the steady-state heating COP (1) is degraded by 8% at all outdoor air temperatures below 40° F as a result of frosting losses and (2) as a result of cycling losses is degraded by an additional 15% for all outdoor air temperatures for which auxiliary heating is not required. The assumed correlation between evaporator temperature, T_{EVAP}, and outdoor air temperature, T_i (in °F), is

$$T_{EVAP} = 0.7406 T_i - 5.269 \ . \tag{4.24}$$

The value of the steady-state cooling capacity of the selected heat pump at 95° F is used to determine the steady-state heating capacity of the same unit at 32° F. This is accomplished by means of an empirical relationship in which the ratio of heating capacity at 32° F to the cooling capacity at 95° F is given as a function of the average ARI rating of the heat pump performance. The empirical relationship was developed from data for a large number of commercially available heat pumps. The ratio of heating to cooling capacity increases with the quality of the equipment, as reflected in its average ARI rating.

The steady-state heating capacities of the selected heat pump at other outdoor air temperatures are obtained from the program array CAP, which is first scaled to yield the required value of the heating COP at 32° F. This array is specified in a data statement of subroutine LOADS and lists 76 values of the heat pump capacity, in units of 1000 Btu/h, for the same set of heat pump evaporator temperatures described previously. The dynamic heating capacity of the selected heat pump is obtained as a function of outdoor air temperature by assuming that an 8% degradation of the steady-state values at all outdoor air temperatures below 40° F occurs as a result of frosting losses.

The cooling COP of the selected heat pump is assumed to be insensitive to changes in summer outdoor air temperatures. Most cooling needs occur at temperatures very near the rating point of the system. Therefore, a single COP for cooling based on system performance at 95° F is used. The steady-state cooling COP is assumed to be

$$COP_C = (2.4) COP_{H(32)} / 2.88 \ , \tag{4.25}$$

and the dynamic cooling COP of the unit is obtained by assuming that a 15% degradation occurs at all outdoor summer air temperatures as a result of cycling losses.

4.6 ACES Component Sizes: Subroutine DIGEST

Subroutine DIGEST contains the algorithm for sizing both the ice storage bin and the solar panel, as described in Sect. 3.3.

Subroutine DIGEST selects an ice storage bin volume to contain all ice formed by bin heat withdrawals and an ice storage bin volume to provide for all summer cooling needs. The smaller of these two volumes is the full-ACES design (Sect. 3.3).

DIGEST uses an iterative method to select these two volumes. A volume is acceptable when the yearly sum of weekly heat withdrawals and deposits on the ice storage bin is close to the energy capacity of the test-bin volume. In some warm climates, DIGEST may fail to find a volume to provide for all summer cooling, in which cases, the volume found that will contain all the ice formed will be used for the full-ACES design.

Using the full-ACES bin volume selected, the area for a solar panel collector is chosen to make $\Sigma\ Q_{COL}$ satisfy Eq. (3.36). Panel area selected is discussed in Sect. 3.3.4. DIGEST uses an iterative method for selecting the panel area that is satisfied when the lowest energy level of the ice bin is 0.01% of the bin energy capacity. If the iteration fails, DIGEST prints a message and returns to MAIN to process a new weather data set.

When the full-ACES bin volume is chosen to contain all ice formed by bin heat withdrawals (i.e., volume is smaller than needed for summer cooling needs), the panel area is set to zero and supplemental cooling is called for. In this case, DIGEST calculates $\Sigma\ Q_{BR}$ as in Eq. (3.38).

For a minimum ACES, the design bin volume is selected as that which will contain all the ice formed during two weeks of January. DIGEST selects solar panel size and energy required for supplemental cooling based on the bin volume selected.

4.7 Performance of Non-ACES Systems: Subroutine ENERGY

Subroutine ENERGY models energy usage of three non-ACES systems: electric heat with air conditioner and electric water heater, heat pump with electric water heater, and heat pump with desuperheater water heater. See Abbatiello et al.[2] for more information on the desuperheater system.

In subroutine LOADS, the heat pump is modeled by using ARI ratings (Sect. 4.5.3). The energy needed to provide the monthly heating loads for the building, E_{HT}, and the energy needed to provide the monthly cooling loads, E_{CL}, are also calculated by LOADS. Subroutine ENERGY calculates system energy usage each month, m, by the following:

system 1 (electric heat with air conditioner and electric water heater)

$$E_1(m) = Q_H(m) + \frac{Q_C(m)}{COP_C} + Q_{HW}(m)\ ; \tag{4.26}$$

system 2 (heat pump with electric water heater)

$$E_2(m) = E_{CL}(m) + E_{HT}(m) + Q_{HW}(m)\ ; \tag{4.27}$$

system 3 (heat pump with desuperheater water heater)

$$E_3(m) = E_{CL}(m) + E_{HT}(m) + E_W(m) \; ; \tag{4.28}$$

where

$Q_H(m)$ = space-heating load for month m, Btu,
$Q_C(m)$ = space-cooling load for month m, Btu,
$Q_{HW}(m)$ = heat load for production of hot water for month m, Btu,
COP_C = COP of heat pump in cooling mode,
$E_W(m)$ = energy needed by desuperheater water heater, Btu.

E_W is calculated as follows. The energy available from the heat pump for water heating by the desuperheater, E_A, is

$$E_A(m) = 0.15[Q_H(m) + Q_C(m) + E_{CL}(m)] \; . \tag{4.29}$$

During the heating season, the energy can be extracted for water heating at the same seasonal performance factor that applies to space heating, COP_H. Thus, during the heating season

$$E_W(m) = Q_{HW}(m)/COP_H \qquad \text{if } E_A(m) \geqslant Q_{HW}(m) \; , \tag{4.30}$$

$$E_W(m) = E_A(m)/COP_H + [Q_{HW}(m) - E_A(m)] \qquad \text{if } E_A(m) < Q_{HW}(m) \; . \tag{4.31}$$

During the cooling season, however, this energy is available if one purchases only the pumping energy. Thus, during the cooling season

$$E_W(m) = 0.0 \qquad \text{if } E_A(m) \geqslant Q_{HW}(m) \; , \tag{4.32}$$

$$E_W(m) = [Q_{HW}(m) - E_A(m)] \qquad \text{if } E_A(m) < Q_{HW}(m) \; . \tag{4.33}$$

Electrical power consumption of the water pump to circulate water between desuperheater and storage tank is about 5% of the heat energy delivered to the storage tank.

4.8 Systems Economics

4.8.1 Subroutines PRTBSC and PRTECO

MAD produces two types of output to summarize the results for each city. The user may choose the basic output printed by subroutine PRTBSC or the economic output printed by subroutine PRTECO (both types are described in Sect. 6.2). Both subroutines call subroutines ACECOS, COST, and PWFCOS to calculate system costs, present-worth costs, and life-cycle ranking.

Subroutine PRTBSC prints seasonal factors of the systems consisting of air-to-air heat pump with electric water heater and the two ACES. These seasonal performance factors are calculated in subroutine LOADS based on the annual energy needs of the systems.

Subroutine PRTECO prints an annual COP for the five systems in the output. These COPs are based on the annual energy needs calculated by subroutines LOADS and ENERGY.

4.8.2 Subroutine COST

Subroutine COST calculates the cost of three systems sized to meet building demands for heating, cooling, and hot water. These systems are electric heat and air conditioner with electric water heater, heat pump with electric water heater, and heat pump with desuperheater water heater. The capacities and prices of most equipment are based on the values in the Sears catalog for summer 1979. These capacities and prices can be updated by changing a data array. A more detailed discussion of these calculations is presented in another report.[2]

4.8.3 Subroutine ACECOS

Subroutine ACECOS calculates cost of the ACES mechanical package, ice storage bin, coil in the ice storage bin, water heater, other controls, and the installation of ACES for the minimum-ACES design and the full-ACES design. Abbatiello et al. give a more detailed discussion of these costs.[2]

Ice-Bin Heat Exchanger. Subroutine ACECOS also calculates the tubing length for the bin heat-exchanger design. The rate at which heat can be extracted from the ice bin depends on the total length of active tubing in the heat exchanger and the diameter of the ice log that forms around it. To ensure proper ACES operation, the bin heat exchanger must have a total length of active tubing that will enable it to deliver the design heat rating of the heat pump evaporator, H_{EV}, even when the ice logs reach their maximum diameter. If the heat exchanger consists of a number of horizontal tubes, spaced D feet apart in a square lattice and connected by risers to form a serpentine configuration, the maximum attainable diameter of the ice logs is equal to the lattice spacing. The heat-extraction rate that this system can attain can be calculated on the basis of both radial heat conduction through a hollow cylinder and convection at its outer surface.

The system in cross section and a thermal-circuit diagram are shown in Fig. 4.3, where heat flow is assumed to be in a radial direction. The inner and outer diameters of the cylinder are d and D, respectively; h is the heat-transfer coefficient at the water-to-ice interface. The rate at which heat is extracted from the water, also equal to the design heat rating of the evaporator, in Btu/h, is expressed as

$$H_{EV} = \frac{32 - T_B}{\ln(D/d)/2\pi kl + 1/hA_l} \tag{4.34}$$

or

$$H_{EV} = \frac{2\pi kl(32 - T_B)}{\ln(D/d) + 2k/hD}, \tag{4.35}$$

where

H_{EV} = rate of heat extraction from the bin (also equal to the evaporator design heat rating),
k = thermal conductivity of the ice and plastic tube, 1.33 Btu/h·ft^2·°F,
l = total active length of ice-bin heat-exchanger tubing, ft,
T_B = average temperature of brine in the evaporator shell, °F,
d = inner diameter of heat-exchanger tubing, 0.85/12 ft,
D = maximum ice-log diameter (also the lattice spacing), ft,
h = convective heat-transfer coefficient at water-to-ice interface, 15 Btu/h·ft·°F,
A_l = outer surface area of ice log, πDl, ft^2.

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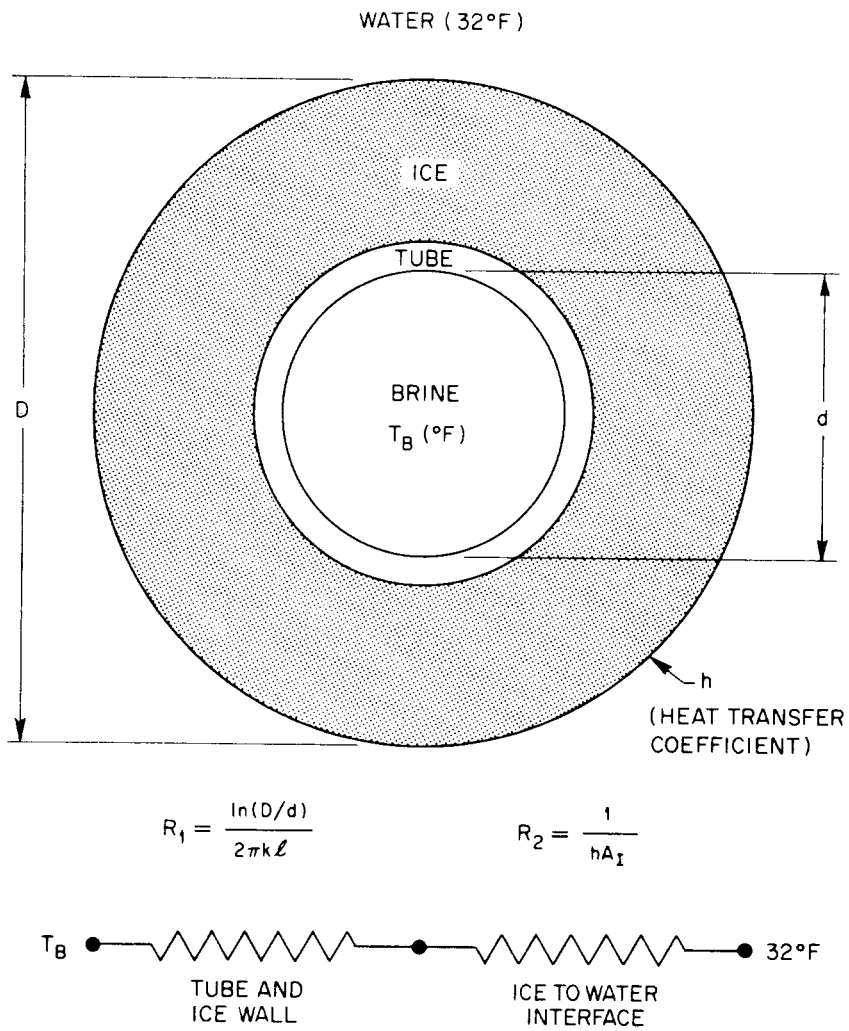

Fig. 4.3. Heat conduction in ice-bin heat exchanger with outer surface convection boundary.

Equation (4.35) can be used to determine the total length of tubing, l, that must be installed in the ice bin at a square-lattice pitch of D inches to ensure that the heat exchanger can deliver the design point heat-flow rating of the evaporator, H_{EV}, at all times. However, a more useful expression for design calculations can be obtained by expressing the variable l in terms of the ice bin volume. If V is the volume of the ice bin, in ft^3,

$$V = D^2 l \,, \tag{4.36}$$

and dividing Eq. (4.35) by Eq. (4.36) yields

$$H_{EV}/V = \frac{2\pi k(32 - T_B)}{[D^2 \ln(D/d)] + 2kD/h} \,, \tag{4.37}$$

in Btu/ft^3.

To determine the lattice spacing D that is required to yield the extraction rate density, Eq. (4.37) is written as a function of D:

$$f(D) = \frac{2\pi k(32 - T_B)}{H_{EV}/V} - [D^2 \ln(D/d)] - \frac{2kD}{h} . \tag{4.38}$$

By the Newton-Raphson iteration method for finding roots,

$$D_{i+1} = D_i - [f(D_i)/f'(D_i)] ; \tag{4.39}$$

thus, the desired D can be found by searching for D_{i+1} and D_i sufficiently close together by using

$$f'(D) = -[2D \ln(D/d) + D] - 2k/h . \tag{4.40}$$

The selection of a brine temperature, T_B, depends on the objectives of the ACES designer. If the residential ACES is to have maximum energy conservation potential, the value $T_B = 28°$ F should be used in the analysis. A heat exchanger that has a shorter length of tubing than is obtained by using a brine temperature of 28°F will require a lower refrigerant evaporation temperature to deliver the heating demand of the building. This will result in a lower COP for the system and, consequently, higher power consumption. Whether or not the dollar savings obtained by using the smaller heat exchanger will outweigh the increased power costs depends on the local rate for electrical power. The MAD program currently is set up to calculate ACES designs assuming that system parameters [ice-phase heating mode, $COP_I(H)$, $\alpha_I(H)$ in Eqs. (3.21) and (3.22); supplemental-phase heating mode, $COP_S(H)$, $\alpha_S(H)$ in Eqs. (3.27) and (3.28)] consistent with the average brine temperature are supplied by the user. Table 4.1 is a guide to optimum brine temperature as a function of electricity costs. If the designer wishes to use brine temperatures other than 15° F, he must supply system parameters consistent with his selected brine temperatures as detailed in Sect. 5.1.1.

Table 4.1. Cost-optimized brine temperatures for heat-exchanger design calculations[a]

Power costs (1978 dollars) (¢/kWh)	Average brine temperature, T_B (°F)
4	15
7	18
10	21
>10	28

[a]Assumes tubing costs of $1.50/ft and a 20-year amortization time.

4.8.4 Subroutine PWFCOS

Subroutine PWFCOS employs two methods of comparing the economics of five HVAC systems (two ACES and three non-ACES systems). The first method, simple payback, requires the selection of a reference system against which to compare initial cost and operating cost of the alternative systems. In

MAD, the electric resistance space- and water-heating system with air conditioner is the reference system. The simple payback periods, PB, of the other systems are determined by

$$PB = \frac{IC - IC_R}{PC_R - PC}, \tag{4.41}$$

where

R = reference system,
IC = initial cost,
PC = power cost for one year.

PWFCOS also gives a ranking of these simple payback periods.

The second comparison made in PWFCOS is life-cycle cost ranking. Life-cycle cost takes into account the full owning and operating cost of the system over its expected lifetime. Included in the operating cost is the present worth of the power cost of the system.

The present worth of the annual costs of power consumed by the ACES over N years is obtained by discounting each annual expenditure and summing the discounted values over each year of the study period. Thus, the present worth of the ACES power costs is expressed by

$$PC = P_0\left[\left(\frac{1 + r_e}{1 + r_d}\right)^1 + \left(\frac{1 + r_e}{1 + r_d}\right)^2 + \left(\frac{1 + r_e}{1 + r_d}\right)^3 + \cdots + \left(\frac{1 + r_e}{1 + r_d}\right)^N\right], \tag{4.42}$$

where

PC = present worth of ACES power costs over a period of N years,
P_0 = annual cost of electricity consumed, at year-zero prices,
r_e = annual price escalation rate of power,
r_d = annual discount rate (cost of capital),
N = number of years (20) in the study period.

The sum of the power series shown in Eq. (4.42) is expressed by the relationship

$$PC = P_0\left(\frac{1 + r_e}{r_d - r_e}\right)\left[1 - \left(\frac{1 + r_e}{1 + r_d}\right)^N\right]. \tag{4.43}$$

Thus, the present worth factor used to evaluate the life-cycle costs of the HVAC systems can be expressed as

$$P_W = \frac{1 + r_e}{r_d - r_e}\left[1 - \left(\frac{1 + r_e}{1 + r_d}\right)^N\right]. \tag{4.44}$$

Subroutine PWFCOS computes the life-cycle costs of the systems using Eq. (2.2) and ranks them.

5. COMPUTER PROGRAM IMPLEMENTATION

5.1 Program Input Data

The MAD program requires two types of input, a data set describing the house and system to be modeled and a data set describing the average weather conditions for the location specified.

5.1.1 House and System Data Set

A description of the card input data is detailed below. Integers must be right adjusted. Real numbers containing decimal points override the format (i.e., 45.66 is read as 45.66 in spite of an F10.0 format).

1. *Card Title*—identification of the house (up to 72 alphanumeric characters)
   Format (18A4)
2. *Card IPRT*—print options
   Format (2I10)
   - IPRT = 0 : print basic output
   - IPRT = 1 : print economic output
   - ISYS = 1 : select brine-chiller ACES
   - ISYS = 2 : select ice-maker ACES
3. *Card HWT*—hot water tank data
   Format (8F10.0)
   - HWT(1) : surface area of the hot water tank, ft^2
   - HWT(2) : U-value of the hot water tank, $Btu/(h \cdot ft^2 \cdot {}^\circ F)$
   - HWT(3) : hot water storage temperature, °F
   - HWT(4) : hot water delivery efficiency (the value 1 denotes 100% efficiency)
4. *Card GAL*—hot water usage
   Format (8F10.0)
   - GAL(I) I = 1,8 : daily hot water usage for month I, gpd
5. *Card GAL*—hot water usage (continued)
   Format (8F10.0)
   - GAL(I) I = 9,12 : daily hot water usage for month I, gpd
6. *Card TICE*—ice storage tank specifications
   Format (8F10.0)
   - TICE(1) : height of ice storage tank, ft
   - TICE(2) : depth of tank top below surface of earth, ft
   - TICE(3) : storage tank top R-value
   - TICE(4) : storage tank side R-value
   - TICE(5) : storage tank bottom R-value
   - TICE(6) : ice packing fraction for brine-chiller system. Use 0.8 if the packing fraction is not known
   - TICE(7) : ice packing fraction for ice-maker system. Use 0.4 if the packing fraction is not known
7. *Card ECONOMIC*—economic parameters
   Format (8F10.0)
   - RATEDC : discount rate, % in decimal form

RATEFL : inflation rate of electricity, % in decimal form

RATEKW : rate of electricity, $/kW. Set RATEKW = 0.0 to use individual city rates contained in weather data set

8. *Card ECONOMIC*—economic parameters

Format (8F10.0)

CSTCOL : unit cost of collector or panel, $/ft^2

CSTINS : unit cost of insulation including installation, $/in.

CSTCOI : unit cost of coil, $/ft

THKSD : thickness of side insulation, in.

THKBTM : thickness of bottom insulation, in.

THKTP : thickness of top insulation, in.

9. *Card COP*

Format (8F10.0)

COPCHT : COP of ACES compressor in heating mode*

COPCBR : COP of ACES compressor in cooling mode*

COPCHW : COP of ACES compressor in hot water mode*

COPHT : COP of ACES system in heating mode at 32°F tank water.* Omit COPHT, and the program will calculate COPHT

COPIM : COP of ACES system in ice-melt cooling mode.* Omit COPIM, and the program will calculate COPIM

COPCW : COP of ACES system in chilled-water cooling mode.* Omit COPCW, and the program will calculate COPCW

COPBR : COP of ACES system for removal of heat from bin at night.* Omit COPBR, and the program will calculate COPBR

COPHW : COP of ACES system during diurnal load management to provide hot water.* Omit COPHW, and the program will calculate COPHW

10. *Card ENERGY*—pump energy

Format (8F10.0)

EC : electrical draw of ACES heat pump compressor motor, W†

EF : electrical draw of ACES indoor fan coil motor, W†

EHB : electrical draw of ACES hot-brine pump motor, W†

ECB : electrical draw of ACES cold-brine pump motor, W†

EOF : electrical draw of ACES outdoor fan motor, W†

EHW : electrical draw of ACES hot water pump, W†

COP47 : COP of air-to-air heat pump at 47°F

COP17 : COP of air-to-air heat pump at 17°F

11. *Card PANEL*

Format (8F10.0)

SUP : suppress or degradation factor of U-value used in describing the house construction. (This is to account for actual differences in dynamic response of house and steady-state calculations method in MAD.) Use 0.95 for frame or brick residential construction.

PSIDES : number of panel sides exposed to ambient air

PDELT : degrees that panel inlet brine temperature exceed 32°F, °F

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*Obtain these COPs from manufacturer's data. Choose COPs consistent with brine temperature desired as explained in Sect. 4.8.3.

†These electrical energies may be input, omit all 5 and the program will calculate them based on design day heating and cooling loads. Choose electrical energies consistent with brine temperature as explained in Sect. 4.8.3.

12. *Card SO*—internal sources
    Format (8F10.0)
    SO(I) I = 1,8 : hourly internal sources during month I, Btu/h assumes 270 Btu/h per person
13. *Card SO*—internal sources (continued)
    Format (8F10.0)
    SO(I) I = 9,12 : hourly internal sources during month I, Btu/h
14. *Card AREA*—wall and window areas
    Format (8F10.0)
    AREA(1) : total area of north-facing windows, ft^2
    AREA(2) : total area of east-facing windows, ft^2
    AREA(3) : total area of south-facing windows, ft^2
    AREA(4) : total area of west-facing windows, ft^2
    AREA(5) : total area of north-facing walls, ft^2
    AREA(6) : total area of east-facing walls, ft^2
    AREA(7) : total area of south-facing walls, ft^2
    AREA(8) : total area of west-facing walls, ft^2
15. *Card SOLAR*
    Format (8F10.0)
    AREA(9) : flat roof area, ft^2
    WAB : wall-surface absorption coefficient
    RAB : roof-surface absorption coefficient
    WR : wall thermal resistance, R-value
    RR : roof thermal resistance, R-value
    HO : outdoor film coefficient of wall and roof
16. *Card WINDOWS*
    Format (8F10.0)
    SF : window-shading coefficient (see Table C5, page 94c of NBSLD Handbook[7])
    GLASS : glass type is a number 1 to 8 as given in Table A-7, page 28A of NBSLD Handbook[7]
    PANES : number of panes; 1 for single glazing and 2 for double glazing
    TSW : house thermostat setting winter, °F
    TSS : house thermostat setting summer, °F
17. *Card HOUSE*
    Format (8F10.0)
    XNS : number of surfaces to describe house. Each type of exterior wall, roof, floor, windows, doors would be included in this number
    ARCHG : air changes per hour. If measured value not available, use 1.0 to 1.5
    VOL : volume of the house, ft^3
18. *Card SURFACE*—description of each surface
    Format (5A4, 5F10.0)
    LABEL(I) I = 1,5—description of surface. Up to 20 alphanumeric characters can be used
    VAR(1) : area of the surface, ft^2
    VAR(2) : inside film coefficient
    VAR(3) : U-value of the slab
    VAR(4) : outside film coefficient
    VAR(5) : fraction of temperature difference to be used. This is 1.0 except for attics. Use 0.96 for attic if unknown

This card is repeated for each surface indicated on Card 17 by XNS. The floor should be the last surface described.

5.1.2 Weather Data Set

The weather data set contains monthly solar insolation, design-day temperatures, monthly wind speeds, and a typical year of dry bulb and wet bulb temperatures in a bin format as presented in *Engineering Weather Data.*[9]

Information concerning the availability of 117 such data sets at ORNL is contained in Appendix A.

A detailed description of the card input is presented below.

1. *Card CITY*—name of city
   Format (10A4, A4, 6X, 2F3.0, 4X, 2F3.0, 4X, F10.0)
   - CITY(I) I = 1,10 : name of city. Up to 40 alphanumeric characters may be used
   - ZONE : National Association of Home Builders climate zone
   - ALAT1 : latitude of city, °
   - ALAT2 : latitude of city, ′
   - ALONG1 : longitude of city, °
   - ALONG2 : longitude of city, ′
   - ELEV : elevation of city, ft
2. *Card DESIGN*—design day
   Format (8F10.0)
   - DD(1) : design-day temperature in winter, °F
   - DD(2) : design-day temperature in summer, °F
   - ELECOS : cost of electricity in the city, $/kWh (January 1979 power costs)
3. *Card HEAD*
   Format (18A4, 6X, I2)
   - HEA(I) I = 1,18 : name of city. Up to 72 alphanumeric characters may be used
   - NSET : number of data set
4. *Card HBR*—solar insolation
   Format (12F5.0)
   - HBR(I) I = 1,12 : monthly solar insolation, langley
5. *Card VAV*—wind speed
   Format (12F5.0)
   - VAV(I) I = 1,12 : average monthly wind speed, mph
6. *Card BINS*—weather data
   Format (7F5.0,35X,12,6X,I2)
   - A(1) : beginning temperature of interval, °F
   - A(2) : ending temperature of interval, °F
   - A(3) : number of observations during the month of this temperature interval between hours 02 to 09
   - A(4) : number of observations during the month of this temperature interval between hours 10 to 17
   - A(5) : number of observations during the month of this temperature interval between hours 18 to 01
   - A(6) : total number of observations during the month of this temperature interval
   - A(7) : mean coincident wet bulb temperature for the month, °F

M : number of month. The data set should begin with January and go through December
NST : number of data set

This card is repeated for the whole year and ends with a card containing M = O.

5.2 Program Output Data

The MAD program prints a listing of the house and system data input. An example is presented in Sect. 6.2.1. On card 2 of the house data set the program asks the user to select whether basic output or economic output is desired. Examples of these two types of output are presented in Sect. 6.2.2 and Sect. 6.2.3. The basic output is in English units of measurement; the economic output, in metric units.

6. SAMPLE PROBLEM

6.1 House Type and Location

As a sample problem the data set describing the ACES demonstration house in Knoxville, Tennessee, and the Knoxville and Minneapolis weather data was run on MAD.

The house is a two-level frame structure having about 1800 ft^2 of living space—three bedrooms, two baths, living-dining room, kitchen, utility room, and entry hall. Figure 6.1 is a diagram of a cross section of the house.

Weather data sets for two different cities were used to illustrate differences in ACES design because of climatic differences.

6.1.1 House Data Set

The data set in Fig. 6.2 provides input for modeling a state-of-the-art ACES and a properly sized and installed air-to-air heat pump.

In modeling a house, surfaces fully or partially exposed to outside air temperature and the floor of the ground level are described by area, U-value, and film coefficient. In the ACES house, because the ceilings of the kitchen-living room and the bedroom have different U-values, they were described separately. In addition, the U-value of the roof above the computer console is different, necessitating the inclusion of three roof descriptions. The insulation of the wall to which the solar collector panel is attached (type 8 wall) is different from the other exterior walls (type 2 walls) and was described

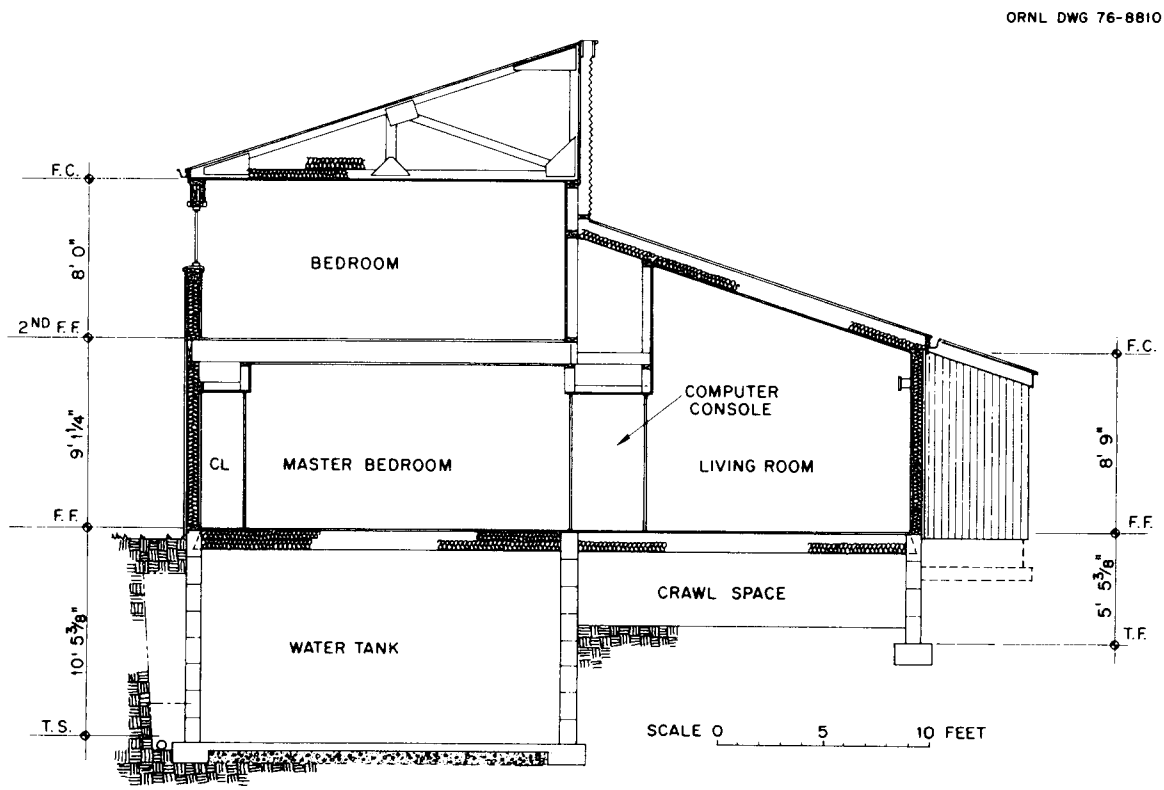

Fig. 6.1. Cross-section view of ACES demonstration house.

```
UT-ACES HOUSE--MODEL TWO-FOR ECONOMIC REPORT
         1          1
        30.       .083       120.        1.
        80.        80.        80.       80.        80.        80.        80.        80.
      80.0       80.0        80.       80.
        8.        1.1       40.0       37.0       37.0        0.8        0.4
     .1024      .0812        .00        20.
       3.0       0.28        1.0        4.0        6.0        6.0
      2.04       2.55       2.01       2.55       12.7        8.9       2.01       2.68
       0.0        0.0        0.0        0.0        0.0        0.0       2.75        1.8
       .95        1.0        0.0
    3547.8     3547.8     3547.8     3547.8     3547.8     3547.8     3547.8     3547.8
    3547.8     3547.8     3547.8     3547.8
       49.        18.       47.5        4.5       709.       466.       657.      479.5
     1155.        .78        .87      20.53        31.        4.0
       .42         1.         1.        70.       78.
       8.0       1.15    16047.9
ROOF KIT                    429.                0.0488                   1.0
TYPE 8 WALL                 483.                0.0862                   1.0
TYPE 2 WALL                1738.5               0.0487                   1.0
DOOR                        20.                   0.25                   1.0
WINDOW                     166.5                 0.580                   1.0
ROOF BEDROOM                594.                 .0252                   .96
ROOF CONSOLE                132.                 .0252                   .78
FLOOR                      1155.                 0.040                  0.17
```

Fig. 6.2. Sample problem: house data set.

separately. Only one floor description can be input. Because inside and outside film coefficients were included in the U-value the spaces for these values were left blank or entered as zero in this sample data set.

VAR(5) on card 18 was set to less than 1.0 for the roof of the bedroom and the roof of the computer console to model the effect of the attic in decreasing the difference between inside and outside temperatures. VAR(5) is not used for the floor because heat loss or gain through the floor is calculated on the basis of the ground temperatures for each month.

6.1.2 Weather Data Set

The weather data for Knoxville is presented in Fig. 6.3 and for Minneapolis in Fig. 6.4.

6.2 Description of Output

6.2.1 Listing of House and System Data

The first page of output from MAD lists the input data for the house and system, independent of location. Figure 6.5 is the output from the sample problem. The following notes apply to Fig. 6.5.

1. specifications concerning domestic hot water tank
2. specifications concerning ACES ice storage bin
3. ice-packing fraction for brine-chiller ACES and ice-maker ACES, respectively
4. economic data for determining the life-cycle of ACES and other systems
5. COPs of components of ACES
6. specifications to model air-to-air heat pump
7. monthly internal sources, Btu/h

```
KNOXVILLE, TENNESSEE                                C        35 49      83 59          980.
        13.        92.     .03036
KNOXVILLE,TN                                                                              201
 131. 186. 285. 420. 446. 488. 474. 484. 383. 288. 202. 154.
   9.   8.  11.   8.   8.   7.   6.   6.   6.   6.   7.   6.
    5    9   0.   3.   0.   3.   8.                                                  1    201
   10   14   3.   7.   0.  10.  12.                                                  1    201
   15   19  12.  20.   2.  34.  16.                                                  1    201
   20   24  14.  43.  18.  75.  20.                                                  1    201
   25   29  26.  33.  15.  74.  25.                                                  1    201
   30   34  40.  43.  33. 116.  29.                                                  1    201
   35   39  62.  57.  34. 153.  34.                                                  1    201
   40   44  51.  26.  66. 143.  37.                                                  1    201
   45   49  15.  11.  31.  57.  42.                                                  1    201
   50   54  12.   3.  27.  42.  44.                                                  1    201
   55   59  13.   2.  17.  32.  47.                                                  1    201
   60   64   0.   0.   4.   4.  49.                                                  1    201
   65   69   0.   0.   1.   1.  51.                                                  1    201
   70   74   0.   0.   0.   0.   0.                                                  1    201
    5    9   5.   1.   0.   6.   7.                                                  2    201
   10   14  11.   5.   8.  24.  10.                                                  2    201
   15   19   0.   3.   6.   9.  15.                                                  2    201
   20   24  10.  10.   3.  23.  20.                                                  2    201
   25   29  17.  12.   4.  33.  26.                                                  2    201
   30   34  33.  14.   6.  53.  30.                                                  2    201
   35   39  42.  20.  24.  86.  33.                                                  2    201
   40   44  44.  32.  29. 105.  39.                                                  2    201
   45   49  29.  47.  40. 116.  43.                                                  2    201
   50   54   9.  27.  44.  80.  46.                                                  2    201
   55   59  10.  25.  20.  55.  50.                                                  2    201
   60   64  14.  18.  27.  59.  54.                                                  2    201
   65   69   0.   6.  11.  17.  59.                                                  2    201
   70   74   0.   4.   2.   6.  61.                                                  2    201
   75   79   0.   0.   0.   0.   0.                                                  2    201
   25   29   9.   1.   0.  10.  25.                                                  3    201
   30   34  40.  16.   0.  56.  30.                                                  3    201
   35   39  62.  36.  17. 115.  33.                                                  3    201
   40   44  58.  46.  45. 149.  37.                                                  3    201
   45   49  38.  47.  46. 131.  41.                                                  3    201
   50   54  21.  35.  55. 111.  45.                                                  3    201
   55   59  15.  33.  36.  84.  51.                                                  3    201
   60   64   5.  17.  25.  47.  51.                                                  3    201
   65   69   0.   9.  12.  21.  54.                                                  3    201
   70   74   0.   7.   7.  14.  56.                                                  3    201
   75   79   0.   1.   5.   6.  59.                                                  3    201
   80   84   0.   0.   0.   0.   0.                                                  3    201
   30   34   4.   0.   0.   4.  32.                                                  4    201
   35   39  15.   4.   2.  21.  36.                                                  4    201
   40   44  22.  10.  11.  43.  39.                                                  4    201
   45   49  34.  18.   6.  58.  44.                                                  4    201
   50   54  39.  24.  22.  85.  47.                                                  4    201
   55   59  50.  33.  30. 113.  51.                                                  4    201
   60   64  41.  34.  50. 125.  56.                                                  4    201
   65   69  29.  45.  38. 112.  57.                                                  4    201
   70   74   6.  36.  42.  84.  58.                                                  4    201
   75   79   0.  30.  26.  56.  61.                                                  4    201
   80   84   0.   6.  13.  19.  62.                                                  4    201
   85   89   0.   0.   0.   0.   0.                                                  4    201
   35   39   3.   0.   0.   3.  39.                                                  5    201
   40   44  13.   4.   2.  19.  41.                                                  5    201
   45   49   0.   6.  14.  20.  45.                                                  5    201
   50   54  14.   2.   0.  16.  50.                                                  5    201
   55   59  41.  15.  10.  66.  54.                                                  5    201
   60   64  85.  29.  31. 145.  60.                                                  5    201
   65   69  77.  35.  34. 146.  62.                                                  5    201
   70   74  15.  49.  43. 107.  64.                                                  5    201
   75   79   0.  63.  54. 117.  66.                                                  5    201
   80   84   0.  38.  46.  84.  67.                                                  5    201
```

Fig. 6.3. Sample problem weather data for Knoxville, Tenn.

85	89	0.	7.	14.	21.	69.	5	201
90	94	0.	0.	0.	0.	0.	5	201
45	49	5.	0.	0.	5.	45.	6	201
50	54	18.	1.	3.	22.	49.	6	201
55	59	16.	10.	9.	35.	52.	6	201
60	64	16.	7.	9.	32.	57.	6	201
65	69	69.	14.	14.	97.	63.	6	201
70	74	106.	32.	46.	184.	67.	6	201
75	79	10.	51.	64.	125.	69.	6	201
80	84	0.	62.	44.	106.	69.	6	201
85	89	0.	54.	41.	95.	71.	6	201
90	94	0.	9.	10.	19.	71.	6	201
95	99	0.	0.	0.	0.	0.	6	201
60	64	2.	0.	0.	2.	62.	7	201
65	69	65.	6.	1.	72.	66.	7	201
70	74	146.	33.	45.	224.	69.	7	201
75	79	33.	62.	67.	162.	71.	7	201
80	84	2.	77.	65.	144.	73.	7	201
85	89	0.	53.	46.	99.	73.	7	201
90	94	0.	17.	23.	40.	73.	7	201
95	99	0.	0.	1.	1.	74.	7	201
100	104	0.	0.	0.	0.	0.	7	201
65	69	73.	5.	2.	80.	67.	8	201
70	74	139.	49.	63.	251.	70.	8	201
75	79	35.	62.	74.	171.	71.	8	201
80	84	1.	68.	53.	122.	72.	8	201
85	89	0.	51.	39.	90.	74.	8	201
90	94	0.	13.	13.	26.	74.	8	201
95	99	0.	0.	4.	4.	73.	8	201
100	104	0.	0.	0.	0.	0.	8	201
45	49	1.	0.	0.	1.	48.	9	201
50	54	16.	1.	0.	17.	51.	9	201
55	59	32.	7.	4.	43.	54.	9	201
60	64	52.	14.	15.	81.	59.	9	201
65	69	88.	34.	45.	167.	63.	9	201
70	74	46.	62.	49.	157.	65.	9	201
75	79	5.	44.	45.	94.	66.	9	201
80	84	0.	55.	40.	95.	67.	9	201
85	89	0.	23.	40.	63.	68.	9	201
90	94	0.	0.	2.	2.	70.	9	201
95	99	0.	0.	0.	0.	0.	9	201
35	39	11.	2.	0.	13.	36.	10	201
40	44	29.	6.	0.	35.	39.	10	201
45	49	42.	12.	9.	63.	44.	10	201
50	54	62.	36.	30.	128.	48.	10	201
55	59	73.	52.	49.	174.	52.	10	201
60	64	20.	35.	46.	101.	54.	10	201
65	69	11.	33.	48.	92.	57.	10	201
70	74	0.	43.	37.	80.	59.	10	201
75	79	0.	28.	24.	52.	61.	10	201
80	84	0.	1.	5.	6.	62.	10	201
85	89	0.	0.	0.	0.	0.	10	201
25	29	12.	2.	0.	14.	27.	11	201
30	34	39.	15.	8.	62.	31.	11	201
35	39	45.	18.	17.	80.	35.	11	201
40	44	46.	31.	24.	101.	39.	11	201
45	49	42.	39.	43.	124.	43.	11	201
50	54	40.	53.	57.	150.	48.	11	201
55	59	5.	35.	48.	88.	50.	11	201
60	64	9.	32.	25.	66.	53.	11	201
65	69	2.	12.	14.	28.	55.	11	201
70	74	0.	3.	4.	7.	58.	11	201
75	79	0.	0.	0.	0.	0.	11	201
15	19	4.	1.	0.	5.	16.	12	201
20	24	37.	9.	4.	50.	21.	12	201
25	29	40.	14.	18.	72.	25.	12	201
30	34	40.	42.	46.	128.	29.	12	201
35	39	53.	51.	47.	151.	34.	12	201

Fig. 6.3 (continued)

```
 40   44  38.  53.  59. 150.  37.                                    12     201
 45   49  13.  37.  33.  83.  41.                                    12     201
 50   54   6.  13.  21.  40.  47.                                    12     201
 55   59   9.   9.  10.  28.  54.                                    12     201
 60   64   8.   7.   6.  21.  57.                                    12     201
 65   69   0.   7.   4.  11.  59.                                    12     201
 70   74   0.   5.   0.   5.  60.                                    12     201
 75   79   0.   0.   0.   0.   0.                                    12     201
                                                                     0     201
```

Fig. 6.3 (continued)

```
MINNEAPOLIS, MINNESOTA                          H        44 53      93 13          834.
      -16.        89.     .04918
MINNEAPOLIS,MINNESOTA                                                                 02
 168. 260. 368. 426. 496. 535. 557. 486. 366. 237. 146. 124.
  11.  11.  12.  13.  12.  11.   9.   9.  10.  11.  12.  11.
   45   49    0    0    0    0   38                                    01     02
   40   44    0    3    0    3   36                                    01     02
   35   39    4   12    6   22   33                                    01     02
   30   34   14   18   15   47   30                                    01     02
   25   29   20   45   31   96   25                                    01     02
   20   24   33   39   42  114   21                                    01     02
   15   19   32   28   32   92   16                                    01     02
   10   14   32   33   31   96   11                                    01     02
    5    9   32   25   30   87    6                                    01     02
    0    4   26   21   22   69    1                                    01     02
   -5   -1   20   12   18   50   -3                                    01     02
  -10   -6   14    8   12   34   -8                                    01     02
  -15  -11   13    3    6   22  -13                                    01     02
  -20  -16    5    1    2    8  -18                                    01     02
  -25  -21    3    0    1    4  -22                                    01     02
  -30  -26    0    0    0    0  -27                                    01     02
   55   59    0    1    0    1   47                                    02     02
   50   54    0    2    0    2   44                                    02     02
   45   49    0    4    1    5   40                                    02     02
   40   44    2   11    4   17   37                                    02     02
   35   39    8   21   14   43   34                                    02     02
   30   34   24   38   36   98   30                                    02     02
   25   29   29   30   30   89   25                                    02     02
   20   24   23   28   23   74   21                                    02     02
   15   19   23   33   35   91   16                                    02     02
   10   14   37   24   30   91   11                                    02     02
    5    9   23   16   22   61    6                                    02     02
    0    4   23    9   16   48    1                                    02     02
   -5   -1   18    4    8   30   -3                                    02     02
  -10   -6    9    2    4   15   -9                                    02     02
  -15  -11    4    1    1    6  -13                                    02     02
  -20  -16    1    0    0    1  -18                                    02     02
  -25  -21    0    0    0    0  -23                                    02     02
  -30  -26    0    0    0    0  -26                                    02     02
   65   69    0    1    0    1   51                                    03     02
   60   64    0    1    0    1   50                                    03     02
   55   59    0    5    1    6   47                                    03     02
   50   54    1   15    4   20   43                                    03     02
   45   49    2   18    9   29   40                                    03     02
   40   44   13   26   22   61   37                                    03     02
   35   39   23   43   36  102   33                                    03     02
   30   34   43   57   58  158   30                                    03     02
   25   29   57   34   47  138   25                                    03     02
   20   24   41   20   31   92   20                                    03     02
   15   19   26   13   16   55   16                                    03     02
   10   14   13    9   11   33   11                                    03     02
    5    9   14    5    7   26    6                                    03     02
    0    4    8    1    3   12    2                                    03     02
   -5   -1    4    0    2    6   -3                                    03     02
```

Fig. 6.4. Sample problem weather data for Minneapolis, Minn.

-10	-6	2	0	1	3	-8	03	02
-15	-11	1	0	0	1	-13	03	02
-20	-16	0	0	0	0	-18	03	02
-25	-21	0	0	0	0	-24	03	02
-30	-26	0	0	0	0	-27	03	02
90	94	0	0	0	0	64	04	02
85	89	0	1	0	1	61	04	02
80	84	0	4	1	5	61	04	02
75	79	0	6	2	8	59	04	02
70	74	0	11	3	14	56	04	02
65	69	2	16	8	26	53	04	02
60	64	5	23	15	43	50	04	02
55	59	11	24	23	58	48	04	02
50	54	21	35	29	85	44	04	02
45	49	31	38	34	103	41	04	02
40	44	41	39	44	124	38	04	02
35	39	53	22	41	116	34	04	02
30	34	39	12	21	72	29	04	02
25	29	22	6	13	41	25	04	02
20	24	11	2	5	18	20	04	02
15	19	2	1	0	3	16	04	02
10	14	1	0	1	2	10	04	02
5	9	1	0	0	1	8	04	02
0	4	0	0	0	0	3	04	02
90	94	0	1	0	1	67	05	02
85	89	0	7	1	8	66	05	02
80	84	0	19	4	23	64	05	02
75	79	2	29	11	42	62	05	02
70	74	7	34	20	61	59	05	02
65	69	18	34	32	84	57	05	02
60	64	35	40	44	119	54	05	02
55	59	48	35	48	131	50	05	02
50	54	46	24	42	112	46	05	02
45	49	43	16	25	84	43	05	02
40	44	29	7	14	50	39	05	02
35	39	14	1	5	20	34	05	02
30	34	5	1	2	8	30	05	02
25	29	1	0	0	1	27	05	02
95	99	0	3	0	3	73	06	02
90	94	0	10	2	12	72	06	02
85	89	0	19	7	26	71	06	02
80	84	4	41	15	60	68	06	02
75	79	14	50	30	94	65	06	02
70	74	33	46	43	122	63	06	02
65	69	48	33	53	134	60	06	02
60	64	59	24	49	132	57	06	02
55	59	41	10	26	77	53	06	02
50	54	28	4	13	45	49	06	02
45	49	11	0	2	13	46	06	02
40	44	2	0	0	2	42	06	02
100	104	0	0	0	0	80	07	02
95	99	0	4	0	4	78	07	02
90	94	0	14	3	17	75	07	02
85	89	1	36	10	47	72	07	02
80	84	6	63	28	97	69	07	02
75	79	22	61	47	130	67	07	02
70	74	55	44	65	164	65	07	02
65	69	76	19	56	151	63	07	02
60	64	56	7	30	93	59	07	02
55	59	25	0	8	33	55	07	02
50	54	6	0	1	7	51	07	02
45	49	1	0	0	1	47	07	02
95	99	0	1	0	1	75	08	02
90	94	0	16	1	17	75	08	02
85	89	0	38	8	46	72	08	02
80	84	5	56	24	85	70	08	02
75	79	20	66	44	130	67	08	02

Fig. 6.4 (continued)

70	74	52	40	69	161	65	08	02
65	69	72	20	60	152	63	08	02
60	64	61	9	29	99	59	08	02
55	59	27	2	10	39	54	08	02
50	54	9	0	3	12	51	08	02
45	49	2	0	0	2	47	08	02
40	44	0	0	0	0	44	08	02
95	99	0	0	0	0	76	09	02
90	94	0	7	0	7	75	09	02
85	89	0	7	2	9	74	09	02
80	84	2	14	6	22	69	09	02
75	79	9	26	11	46	65	09	02
70	74	9	44	16	69	62	09	02
65	69	16	42	31	89	59	09	02
60	64	35	38	46	119	56	09	02
55	59	49	34	50	133	52	09	02
50	54	55	21	41	117	49	09	02
45	49	36	6	27	69	44	09	02
40	44	23	1	8	32	41	09	02
35	39	5	0	2	7	36	09	02
30	34	1	0	0	1	32	09	02
25	29	0	0	0	0	28	09	02
85	89	0	0	0	0	65	10	02
80	84	0	7	0	7	63	10	02
75	79	0	14	2	16	62	10	02
70	74	1	17	6	24	59	10	02
65	69	4	27	14	45	57	10	02
60	64	13	37	23	73	54	10	02
55	59	30	38	36	104	51	10	02
50	54	39	41	46	126	47	10	02
45	49	47	33	44	124	43	10	02
40	44	45	19	39	103	39	10	02
35	39	36	8	23	67	35	10	02
30	34	23	7	11	41	31	10	02
25	29	7	0	3	10	25	10	02
20	24	3	0	1	4	21	10	02
15	19	0	0	0	0	18	10	02
70	74	0	0	0	0	55	10	02
65	69	0	2	0	2	53	11	02
60	64	1	7	1	9	53	11	02
55	59	2	8	6	16	51	11	02
50	54	5	17	8	30	46	11	02
45	49	8	29	16	53	42	11	02
40	44	25	34	28	87	38	11	02
35	39	43	41	46	130	34	11	02
30	34	49	40	48	137	30	11	02
25	29	43	26	35	104	25	11	02
20	24	31	16	25	72	21	11	02
15	19	12	11	14	37	16	11	02
10	14	9	4	8	21	11	11	02
5	9	7	2	2	11	7	11	02
0	4	3	2	2	7	1	11	02
-5	-1	2	1	1	4	-3	11	02
60	64	0	0	0	0	53	12	02
55	59	0	0	1	1	50	12	02
50	54	2	2	1	5	48	12	02
45	49	1	3	3	7	44	12	02
40	44	4	14	4	22	38	12	02
35	39	11	27	21	59	34	12	02
30	34	25	37	37	99	30	12	02
25	29	45	47	41	133	25	12	02
20	24	40	37	34	111	21	12	02
15	19	29	24	29	82	16	12	02
10	14	26	18	22	66	11	12	02
5	9	21	19	21	61	6	12	02
0	4	18	15	18	51	1	12	02
-5	-1	14	4	10	28	-3	12	02
-10	-6	8	1	5	14	-7	12	02
-15	-11	3	0	1	4	-11	12	02
-20	-16	1	0	0	1	-18	12	02
							0	02

Fig. 6.4 (continued)

ORNL-DWG 80-12400

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UT-ACES HOUSE--MODEL TWO-FOR ECONOMIC REPORT

HOT WATER TANK                                   ICE TANK                                          IN-BIN HEAT PUMP

(1)→ WATER TANK SURFACE AREA(FT**2)        30.000   (2) ICE BIN HEIGHT(FT)                  8.000   DISCOUNT RATE (4)                0.102
     WATER TANK U(BTU/HR*FT**2)             0.083   DEPTH BELOW SURFACE(FT)                 1.100   RATE PER KILOWATT-HR             0.0
     WATER STORAGE TEMP (F)               120.000   ICE BIN TOP R VALUE                    40.000   ESCALATION RATE ELEC.            0.081
     WATER DELIVERY EFFICIENCY              1.000   ICE BIN SIDE R VALUE                   37.000   LIFETIME (YRS)                  20.000
                                                    ICE BIN BOT R VALUE                    37.000   UNIT COST PANEL                  3.00
                                                    ICE PACKING FRACTION                0.800 0.400 UNIT COST INSULATION             0.280
                                                                                           (3)      UNIT COST OF COIL                1.000

                                                   (6) HEAT PUMP COP 47F                   2.750
(5)→ COMPRESSOR COP CC(H)                  2.040   HEAT PUMP COP 17F                       1.800
     COMPRESSOR COP CC(BR)                 2.550
     COMPRESSOR COP CC(HW)                 2.010
     ACES HEATING COP(H)                   2.550
     ACES COOLING COP (IM)                12.700
     ACES COOLING COP(CW)                  8.900
     ACES HOT WATER COP(HW)                2.680
     ACES COMPRESSOR MOTOR (BTUH)          0.0
     ACES INDOOR FAN COIL MOTOR (BTUH)     0.0
     ACES HOT BRINE PUMP MOTOR(BTUH)       0.0
     ACES COLD BRINE PUMP MOTOR(BTUH)      0.0
     ACES OUTDOOR FAN MOTOR(BTUH)          0.0
     ACES HOT WATER PUMP(BTUH)             0.0

                          JAN     FEB     MAR     APR     MAY     JUN     JUL     AUG     SEP     OCT     NOV     DEC
(7)→ INTERNAL SOURCES    3548.   3548.   3548.   3548.   3548.   3548.   3548.   3548.   3548.   3548.   3548.   3548.

     DESCRIPTION OF HOUSE
                                        N       E       S       W
     OVERALL WINDOW AREA                49.0    18.0    47.5     4.5
     OVERALL WALL AREA                 709.0   466.0   657.0   479.5
     ROOF AREA              1155.000                WALL ABSORPTANCE                        0.780
     OUTDOOR FILM COEFF        4.000                ROOF ABSORPTANCE                        0.870
     GLASS TYPE                1.000                WALL THERMAL RESISTANCE                20.530
     NO OF PANES               1.000                ROOF THERMAL RESISTANCE                31.000
(8)→ WINDOW SHADING FAC         0.42                U ADJUSTMENT FACTOR                      0.95

     THERMOSTAT SETTING WINTER        70.
     THERMOSTAT SETTING SUMMER        78.
     HOUSE VOLUME (FT**3)          16047.90
     AIR CHANGES PER HOUR              1.15

(9)→ SOLAR PANEL:  SIDES(CONVECTION)          1.     EXCHANGER DELTA T (F)        0.

     BUILDING HEAT          AREA    H-INSIDE   U(SLAB) H-OUTSIDE  UTOTAL)   DELTA T  HEAT LOSS
     TRANSFER SURFACES     (SQFT)  **********(BTU/HR/SQFT/DEG-F)**********  (DEG-F)  (BTU/HR)

     ROOF KIT              429.00    0.0     0.04880    0.0      0.04880    50.00   1046.76
     TYPE 8 WALL           483.00    0.0     0.08620    0.0      0.08620    50.00   2081.73
     TYPE 2 WALL          1738.50    0.0     0.04870    0.0      0.04870    50.00   4233.25
(10)→ DOOR                  20.00    0.0     0.25000    0.0      0.25000    50.00    250.00
     WINDOW                166.50    0.0     0.58000    0.0      0.58000    50.00   4828.50
     ROOF BEDROOM          594.00    0.0     0.02520    0.0      0.02520    48.00    718.50
     ROOF CONSOLE          132.00    0.0     0.02520    0.0      0.02520    39.00    129.73
                                                                            SUM =   13288.46

     FLOOR                1155.00    0.0     0.04000    0.0      0.04000

       UA(FLOOR)        46.20
```

Fig. 6.5. First page of MAD program output.

8. specifications concerning windows and walls of house, thermostat settings, °F, house volume, and air changes per hour
9. data concerning solar panel
10. description of each heat-transfer surface of house and heat loss based on a temperature difference of 50°F

6.2.2 Option 1—Basic Output

Figure 6.6 is the printed output for the basic output option. This output gives information only on thermal loads for the house, the ACES, and the air-to-air heat pump system. Units are English, and the output is repeated for each weather data set included in the computer run. The following notes apply to Fig. 6.6.

1. location of weather data, latitude, elevation, and electrical cost
2. house identifier
3. house thermostat settings

MINNEAPOLIS, MINNESOTA LATITUDE = 44.88 ELEVATION= 834. ELEC.COST= 0.0492
UT-ACES HOUSE--MODEL TWO-FOR ECONOMIC REPORT
TSETW(F) = 70. TDDW(F) = -16. DDHL(BTUH) = 55295. BCAP(CFM) = 2050. COOL(T/S) = 1.1327 COPHT= 2.55 COPIM= 12.70
TSETS(F) = 78. TDDS(F) = 89. DDCL(BTUH) = 18396. PAN (NHR) = 369. COPCW= 8.90 COPBR= 2.01

CLIMATIC PARAMETERS:	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
AVERAGE WIND SPEED (MPH)	11.00	11.00	12.00	13.00	12.00	11.00	9.00	9.00	10.00	11.00	12.00	11.00	11.00
AVERAGE OUTDOOR AIR TEMP (F)	13.53	18.93	28.90	45.12	58.69	68.31	72.56	71.91	60.59	50.88	33.13	20.70	45.27
TEMP AT BIN TOP (1.) (F)	20.17	20.66	27.69	39.17	52.67	63.80	70.22	69.70	62.73	50.78	37.72	26.33	
TEMP AT BIN BOT (9.) (F)	41.33	37.61	35.54	36.12	39.21	43.81	48.96	53.08	55.01	54.34	51.29	46.50	
TEMP AT BIN SIDE (5.) (F)	32.93	29.71	30.29	34.82	42.34	50.41	57.33	60.90	60.22	55.44	48.11	39.78	
WATER INLET TEMP (10.) (F)	41.93	38.26	36.07	36.39	39.14	43.44	48.37	52.43	54.48	54.08	51.35	46.89	
BIN TOP-BOT LK32F(MBTU/SQFT)	-0.032	-0.089	-0.009	0.209	0.529	0.802	1.052	1.125	1.001	0.798	0.478	0.186	
BIN SIDE LEAK 32F(MBTU/SQFT)	0.019	-0.042	-0.034	0.055	0.208	0.358	0.509	0.581	0.549	0.471	0.313	0.156	
INFILTRATION COEFF. (BTUH/F)	275.01	262.09	244.49	211.94	173.28	144.08	133.75	132.17	156.32	185.73	234.37	257.86	
PANEL HEAT COEF 32F(MBTU/SQ)	4.29	12.77	32.80	71.15	113.19	133.90	138.56	137.41	106.35	79.65	27.59	9.46	
BUILDING LOADS:													
SPACE HEAT (MMBTU)	18.72	14.26	11.27	5.32	1.90	0.0	0.0	0.0	1.30	3.51	9.75	15.51	81.55
WATER HEAT (MMBTU)	1.71	1.61	1.83	1.76	1.77	1.62	1.57	1.49	1.40	1.46	1.46	1.61	19.29
SPACE COOL (MMBTU)	0.0	0.0	0.0	0.0	1.19	2.63	4.08	3.93	1.46	0.0	0.0	0.0	13.30
HEAT PUMP COST AND PERFORMANCE:													
HEAT PUMP ENERGY USE (KWH)	4652.80	3332.24	2246.24	904.94	480.82	526.80	745.18	722.23	441.35	597.25	1820.40	3526.43	19997.
STRIP HEAT (KWH)	3160.92	1992.08	875.85	72.68	0.28	0.0	0.0	0.0	0.0	9.66	541.81	2011.24	8665.

SYSTEM COSTS	2985.29	COOLING COP	1.63
FUEL PRESENT WORTH	20705.53	HEATING COP	1.36
MAINT. PRESENT WORTH	2009.66	ANNUAL COP	1.30

PRESENT WORTH = 25700.47

ACES DESIGN, COST, AND PERFORMANCE: BRINE CHILL

BIN HEAT LEAKAGE (MMBTU)	0.00	-0.03	-0.02	0.06	0.18	0.30	0.41	0.45	0.27	0.14	0.02	0.05	1.84
PANEL HEAT COLLECTION(MMBTU)	4.34	9.68	7.98	4.25	0.72	0.0	0.0	0.0	0.0	3.14	7.40	8.16	45.66
PANEL HEAT COEFF.(MBTU/SQFT)	4.29	12.77	32.80	71.15	113.19	133.90	138.56	137.41	80.87	46.09	11.65	7.88	
BIN ICE/WATER TEMPERATURE(F)	32.00	32.00	32.00	32.00	32.00	32.00	32.00	32.00	41.39	45.00	45.00	35.25	
ICE INVENTORY (FT**3)	1148.07	1148.07	1148.07	1148.07	1148.07	875.17	389.25	0.0	0.0	0.0	0.0	163.87	

BIN VOLUME (FT**3) =	1435.08	AUX. COST =	790.00	INSTALLATION COST=	518.00	MAINT. P.WORTH=	1929.49	
PANEL AREA (FT**2) =	1012.28	PANEL COST =	4344.21	DUCTS COST =	1287.50	PRESENT WORTH =	24485.61	
COIL LENGTH (FT) =	821.94	MECH COST =	3350.00	SYSTEM COST =	13143.84			
ENERGY USE (KWH) =	11660.02	BIN COST =	2854.14	FUEL PRESENT WORTH	9412.28	ECON COEFF. =	1.05	
ANNUAL COP =	2.87							

BIN HEAT LEAKAGE (MMBTU)	0.00	-0.02	-0.01	0.04	0.13	0.22	0.30	0.22	0.16	0.11	0.02	0.04	1.22
PANEL HEAT COLLECTION(MMBTU)	6.81	9.67	7.98	4.26	0.77	0.0	0.0	0.0	0.0	3.18	7.40	9.28	49.35
PANEL HEAT COEFF.(MBTU/SQFT)	4.29	12.77	32.80	71.15	113.19	133.90	138.56	109.65	70.21	46.09	11.65	7.88	
BIN ICE/WATER TEMPERATURE(F)	32.00	32.00	32.00	32.00	32.00	32.00	32.00	41.75	45.00	45.00	45.00	35.25	
ICE INVENTORY (FT**3)	756.51	756.51	756.51	756.51	756.51	493.12	20.04	0.0	0.0	0.0	0.0	73.34	

BIN VOLUME (FT**3) =	945.64	AUX. COST =	790.00	INSTALLATION COST=	518.00	MAINT. P.WORTH=	1929.49	
PANEL AREA (FT**2) =	1588.71	PANEL COST =	6419.34	DUCTS COST =	1287.50	PRESENT WORTH =	26424.84	
COIL LENGTH (FT) =	780.15	MECH COST =	3350.00	SYSTEM COST =	14711.88			
ENERGY USE (KWH) =	12119.86	BIN COST =	2347.04	FUEL PRESENT WORTH	9783.47	ECON COEFF. =	0.97	
ANNUAL COP =	2.76							

Fig. 6.6. MAD program basic output.

```
(1)  KNOXVILLE, TENNESSEE                    LATITUDE  =   35.82  ELEVATION=    980.  ELEC.COST= 0.0304
(2)  UT-ACES HOUSE--MODEL TWO-FOR ECONOMIC REPORT
(3)  TSETW(F) =      70.  TDDW(F) =      13.  DDHL(BTUH) =  32516.  BCAP(CFM) =   1200.  COOL(T/S) = 1.2596  COPHT=   2.55  COPIM=  12.70
     TSETS(F) =      78.  TDDS(F) =      92.  DDCL(BTUH) =  23145.  PAN (NHR) =    217.                     COPCW=   8.90  COPBR=   2.01
                                              (4)        (5)                    (6)                  (7)                  (8)          (9)
     CLIMATIC PARAMETERS:                     JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG      SEP      OCT      NOV      DEC    ANNUAL

(10) AVERAGE WIND SPEED        (MPH)        9.00     8.00    11.00     8.00     8.00     7.00     6.00     6.00     6.00     6.00     7.00     6.00     7.33
(11) AVERAGE OUTDOOR AIR TEMP  (F)         35.95    43.37    47.15    60.39    68.07    74.22    77.62    76.90    71.65    59.37    48.17    39.10    58.49
     TEMP AT BIN TOP   ( 1.)  (F)         40.65    41.52    46.95    55.28    64.74    72.27    76.26    75.32    69.95    61.29    52.14    44.45
(12) TEMP AT BIN BOT   ( 9.)  (F)         55.34    52.85    51.60    52.22    54.57    57.89    61.47    64.23    65.39    64.70    62.38    58.94
     TEMP AT BIN SIDE  ( 5.)  (F)         49.40    47.44    48.20    51.66    57.10    62.75    67.40    69.59    68.76    65.11    59.82    54.00
(13) WATER INLET TEMP  ( 2.)  (F)         41.62    42.05    46.87    54.62    63.67    71.08    75.27    74.81    70.04    61.97    53.22    45.64
(14) BIN TOP-BOT LK32F(MBTU/SQFT)          0.630    0.539    0.672    0.812    1.063    1.229    1.416    1.454    1.333    1.202    0.954    0.773
     BIN SIDE LEAK 32F(MBTU/SQFT)          0.350    0.280    0.326    0.383    0.505    0.598    0.712    0.756    0.715    0.666    0.541    0.442
(15) INFILTRATION COEFF. (BTUH/F)        208.99   185.05   194.64   144.41   126.02   125.27   127.18   125.47   112.93   134.39   167.37   182.83
(16) PANEL HEAT COEF 32F(MBTU/SQ)         21.14    39.12    65.66    93.68   113.73   117.19   118.99   122.22   105.56    79.92    53.91    31.25

     BUILDING LOADS:

(17) SPACE HEAT            (MMBTU)         8.60     5.07     4.37     1.16     0.0      0.0      0.0      0.0      0.0      1.13     3.47     6.72    30.51
     WATER HEAT            (MMBTU)         1.71     1.54     1.61     1.40     1.26     1.07     1.02     1.03     1.09     1.29     1.43     1.63    16.07
     SPACE COOL            (MMBTU)         0.0      0.0      0.0      1.02     2.42     4.26     5.80     5.82     3.14     0.86     0.0      0.0     23.32

     HEAT PUMP COST AND PERFORMANCE:

(18) HEAT PUMP ENERGY USE    (KWH)      1473.34   871.43   674.06   347.58   483.49   784.44  1042.72  1047.04   576.63   309.49   535.36  1096.80    9242.
(19) STRIP HEAT              (KWH)       247.19   144.10     3.51     0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0     81.65     476.
     SYSTEM COSTS          2885.29   (21) COOLING COP      1.63
(20) FUEL PRESENT WORTH    6952.80        HEATING COP      1.77
     MAINT. PRESENT WORTH  2009.66        ANNUAL  COP      1.47
                                                                                                                  PRESENT WORTH = 11847.75

(22) ACES DESIGN, COST, AND PERFORMANCE:  BRINE CHILL

(23) BIN HEAT LEAKAGE        (MMBTU)       0.42     0.35     0.42     0.50     0.66     0.77     0.90     0.88     0.56     0.48     0.51     0.52     6.95
     PANEL HEAT COLLECTION(MMBTU)          0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0      0.0
(24) PANEL HEAT COEFF.(MBTU/SQFT)         21.14    39.12    65.66    93.68   113.73   117.19   118.99   117.98    78.89    53.72    42.41    31.25
(25) BIN ICE/WATER TEMPERATURE(F)         32.00    32.00    32.00    32.00    32.00    32.00    32.00    34.10    45.00    44.59    37.57    32.00
     ICE INVENTORY         (FT**3)    1357.61  1804.64  2196.31  2186.05  1871.53  1279.46   459.48     0.0      0.0      0.0     89.84   644.95
(26) BIN VOLUME (FT**3) =   2701.20     AUX. COST  =   720.00     INSTALLATION COST=   434.00     MAINT. P.WORTH=  1929.49
(27) PANEL AREA (FT**2) =      0.0      PANEL COST =     0.0      DUCTS COST        =   888.89     PRESENT WORTH = 13453.33 (31)
     COIL LENGTH    (FT) =   529.07     MECH COST  =  2650.00     SYSTEM COST       =  8315.96
(28) ENERGY USE    (KWH) =  6437.40     BIN COST   =  3623.07     FUEL PRESENT WORTH  3207.88     ECON COEFF.    =     0.88 (32)
(29) ANNUAL COP          =     3.18                        (30)

     BIN HEAT LEAKAGE      (MMBTU)       0.12     0.10     0.12     0.14     0.19     0.17     0.17     0.18     0.16     0.14     0.10     0.13     1.73
     PANEL HEAT COLLECTION(MMBTU)          3.33     3.91     3.51     0.27     0.0      0.0      0.0      0.0      0.0      0.51     3.14     4.38    19.06
     PANEL HEAT COEFF.(MBTU/SQFT)         21.14    39.12    65.66    93.68   113.73   101.30    91.42    94.65    78.89    53.72    31.30    27.41
     BIN ICE/WATER TEMPERATURE(F)         32.00    32.00    32.00    32.00    32.00    39.03    45.00    45.00    45.00    45.00    45.00    35.25
     ICE INVENTORY         (FT**3)      381.83   381.83   381.83   381.83   124.27     0.0      0.0      0.0      0.0      0.0      0.0     38.86
     BIN VOLUME (FT**3) =    477.29     AUX. COST  =   720.00     INSTALLATION COST=   434.00     MAINT. P.WORTH=  1929.49
     PANEL AREA (FT**2) =    157.44     PANEL COST =  1266.78     DUCTS COST        =   888.89     PRESENT WORTH = 13655.82
     COIL LENGTH    (FT) =   428.68     MECH COST  =  2650.00     SYSTEM COST       =  7442.24
     ENERGY USE    (KWH) =  8597.10     BIN COST   =  1482.58     FUEL PRESENT WORTH  4284.09     ECON COEFF.    =     0.87
     ANNUAL COP          =     2.38
```

Fig. 6.6 (continued)

4. design-day temperatures
5. design-day loads
6. blower capacity and area of panel for night heat rejection
7. ratio of total yearly cooling load to yearly sensible-cooling load
8. ACES COP for heating and cooling in chilled-water phase
9. ACES COP for cooling in ice-melt phase and ACES COP for supplementary cooling by bin heat removal
10. monthly average wind speeds as contained in weather data
11. average outdoor air temperature calculated from temperature-bin data
12. temperature of earth at depths of ice storage bin top, side, and bottom
13. temperature of inlet water for hot water tank
14. heat leakage from the ice storage bin to surrounding earth assuming a temperature of 32°F for ice or water in storage bin
15. coefficient of heat loss by infiltration
16. coefficient of heat gain by the solar panel assuming temperature of 32°F (MBtu/ft^2)
17. monthly and annual thermal loads of the building
18. energy used by air-to-air heat pump in providing heating and cooling (kWh)
19. energy used by auxiliary strip heat to supplement heat pump (kWh)
20. cost of air-to-air heat pump
21. COPs of air-to-air heat pump and electric hot water
22. ACES design, cost, and performance data for brine-chiller ACES in the example. This information is given first for full ACES and, then, a minimum ACES
23. bin heat leakage as calculated with bin temperature rising to maximum of 45°F in summer
24. panel heat collection as calculated using area in 27
25. panel heat-gain coefficient using calculated bin temperatures
26. volume of solid ice in ice storage bin. Note: multiply by ice-packing fraction to obtain the volume this ice occupies
27. ice bin volume and solar panel area. If area of panel exceeds one-half of home floor area it is considered impractical; an alternative heat source must be used
28. annual COP for this ACES
29. cost of this ACES
30. present worth of ACES and fuel needed
31. ratio of present worth of an air-to-air heat pump to present worth of this ACES design

6.2.3 Option 2—Economic Output

Figure 6.7 is the printed output for the economic output option. This data is MAD-generated information on the five HVAC systems. Units are metric, and the output is repeated for each weather data set included in the computer run. The following notes apply to Fig. 6.7.

1. conduction loss coefficient is the sum over all external building surfaces of U-value times area
2. ratio of total yearly cooling load to yearly sensible-cooling load
3. design blower capacity
4. conduction-loss coefficient plus the monthly infiltration coefficient
5. system 1—electric heat with air conditioner and electric water heater
6. system 2—heat pump with electric water heater
7. system 3—heat pump with desuperheater water heater

ORNL-DWG 80-12399R

KNOXVILLE, TENNESSEE

167 SQ M HOME, WELL INSULATED
POWER COSTS ($/KWH) = 0.0304
PRESENT WORTH FACTOR= 16.41

DESIGN DAY LOADS (WATTS)
HEATING = 9529.
COOLING = 6783.

COND. LOSS COEF. (W/C) = 158. (1)
COOLING (TOTAL/SEN.) = 1.26 (2)
BLOWER CAPACITY (M3/H) = 2038. (3)

AIR TEMP:	OUTDOOR	INDOOR
WINTER =	-10 C	21 C
SUMMER =	33 C	26 C

DESIGN AND PERFORMANCE

MONTH	WEATHER DATA: AVE AIR TEMP C	WEATHER DATA: AVE WIND SPEED KM/H	WEATHER DATA: INLET WATER TEMP C (0.5M)	BUILDING PARAMETERS AND LOADS: HEAT LOSS COEF. W/C (4)	BUILDING PARAMETERS AND LOADS: WATER HEAT MJ	BUILDING PARAMETERS AND LOADS: SPACE HEAT MJ	BUILDING PARAMETERS AND LOADS: SPACE COOL MJ	SYSTEM ENERGY CONSUMPTION, KWH: (1) ELEC. A/C I2R (5)	(2) HEAT PUMP I2R (6)	(3) HEAT PUMP D.S. (7)	(4) MIN. ACES BR.CHILL (8)	(5) FULL ACES BR.CHILL (9)
JAN	2.20	14.48	5.34	267.81	1808.	9071.	0.	3022.	1976.	1819.	1220.	1185.
FEB	6.32	12.87	5.59	255.18	1625.	5345.	0.	1936.	1323.	1230.	801.	759.
MAR	8.42	17.70	8.26	260.24	1694.	4612.	0.	1752.	1145.	1064.	716.	687.
APR	15.76	12.87	12.57	233.74	1475.	1220.	1079.	933.	757.	706.	312.	309.
MAY	20.04	12.87	17.59	224.04	1327.	0.	2552.	804.	852.	689.	193.	193.
JUN	23.45	11.26	21.71	223.64	1128.	0.	4498.	1080.	1098.	810.	677.	215.
JUL	25.34	9.65	24.04	224.65	1074.	0.	6120.	1341.	1341.	1063.	1125.	245.
AUG	24.94	9.65	23.78	223.75	1084.	0.	6145.	1348.	1348.	1068.	1130.	469.
SEP	22.03	9.65	21.13	217.13	1150.	0.	3309.	883.	896.	685.	616.	619.
OCT	15.20	9.65	16.65	228.46	1364.	1192.	903.	864.	688.	643.	281.	273.
NOV	8.98	11.26	11.79	245.95	1505.	3658.	0.	1434.	953.	890.	541.	521.
DEC	3.94	9.65	7.58	254.01	1721.	7092.	0.	2448.	1575.	1452.	985.	960.
ANNUAL	14.72	11.80	14.67		16955.	32190.	24605.	17845.	13953.	12119.	8597.	6437.
ANNUAL COP								1.15	1.47	1.69	2.38	3.18

SYSTEMS FIRST COSTS

NO.	CONVENTIONAL SYSTEMS	COST, $: FAN UNIT	A/C, H.P.	CONTROL	AUXILIARY	W. HEATER	DUCTS	INSTALN.	SYSTEM
1	ELECTRIC HEAT, A/C, AND HOT WATER	250.	970.	40.	160.	200.	759.	434.	2813.
2	HEAT PUMP WITH ELECTRIC HOT WATER	250.	1080.	29.	178.	200.	714.	434.	2885.
3	HEAT PUMP WITH DESUPERHEATER HOT WATER	250.	1080.	29.	578.	240.	714.	534.	3425.
	ACES SYSTEMS, INTEGRATED CONSTRUCTION	MECH. P.	ICE BIN	PANEL	AUXILIARY	W. HEATER	DUCTS	INSTALN.	SYSTEM
4	MIN., BR.CHILL, BIN(M3)= 14 P(M2)= 15	2650.	1483.	1267.	480.	240.	889.	434.	7442.
5	FULL.BR.CHILL, BIN(M3)= 76 P(M2)= 0	2650.	3623.	0.	480.	240.	889.	434.	8316.

COMPARATIVE SYSTEMS COSTS

NO.	NEW CONSTRUCTION ALTERNATIVES: SYSTEMS	MAINT. PRESENT WORTH $	1ST YEAR POWER COST $	1ST YEAR POWER SAVING $	SIMPLE PAYBACK PERIOD YEARS	SIMPLE PAYBACK RANKING	POWER PRESENT WORTH $	LIFE CYCLE COST $	LIFE CYCLE RANKING
1	ELECTRIC HEAT, A/C, AND HOT WATER	776.	541.78	REF.	REF.	REF.	8893.	12482.	3
2	HEAT PUMP WITH ELECTRIC HOT WATER	2010.	423.60	118.18	0.6	1	6953.	11848.	2
3	HEAT PUMP WITH DESUPERHEATER HOT WATER	2257.	367.93	173.85	3.5	2	6039.	11721.	1
4	MIN. ACES, BR.CHILL, BIN (M3)= 14	1929.	261.01	280.77	16.5	4	4284.	13656.	5
5	FULL ACES, BR.CHILL, BIN (M3)= 76	1929.	195.44	346.34	15.9	3	3208.	13453.	4

Fig. 6.7. MAD program economic output.

MINNEAPOLIS, MINNESOTA

167 SQ M HOME, WELL INSULATED	DESIGN DAY LOADS (WATTS)	COND. LOSS COEF. (W/C) = 158.	AIR TEMP:	OUTDOOR	INDOOR
POWER COSTS ($/KWH) = 0.0492	HEATING = 16205.	COOLING (TOTAL/SEN.) = 1.13	WINTER =	-26 C	21 C
PRESENT WORTH FACTOR= 16.41	COOLING = 5391.	BLOWER CAPACITY (M3/H) = 3481.	SUMMER =	32 C	26 C

DESIGN AND PERFORMANCE

	WEATHER DATA		BUILDING PARAMETERS AND LOADS					SYSTEM ENERGY CONSUMPTION, KWH				
MONTH	AVE AIR TEMP C	AVE WIND SPEED KM/H	INLET WATER TEMP C (2.9M)	HEAT LOSS COEF. W/C	WATER HEAT MJ	SPACE HEAT MJ	SPACE COOL MJ	(1) ELEC. A/C I2R	(2) HEAT PUMP I2R	(3) HEAT PUMP D.S.	(4) MIN. ACES BR.CHILL	(5) FULL ACES BR.CHILL
JAN	-10.26	17.70	5.52	302.64	1802.	19753.	0.	5988.	5153.	4983.	2359.	2359.
FEB	-7.26	17.70	3.48	295.82	1700.	15044.	0.	4651.	3804.	3637.	1837.	1844.
MAR	-1.72	19.31	2.26	286.54	1929.	11892.	0.	3840.	2782.	2598.	1515.	1520.
APR	7.29	20.92	2.44	269.36	1860.	5614.	0.	2077.	1422.	1332.	819.	821.
MAY	14.83	19.31	3.97	248.97	1862.	2004.	1256.	1288.	998.	936.	450.	450.
JUN	20.17	17.70	6.36	233.57	1712.	0.	2778.	949.	1002.	825.	238.	238.
JUL	22.54	14.48	9.09	228.12	1661.	0.	4305.	1195.	1207.	932.	266.	266.
AUG	22.17	14.48	11.35	227.29	1572.	0.	4150.	1144.	1159.	894.	774.	254.
SEP	15.88	16.09	12.49	240.02	1478.	1375.	1543.	1056.	852.	699.	302.	321.
OCT	10.49	17.70	12.27	255.54	1536.	3698.	0.	1454.	1024.	963.	499.	502.
NOV	0.63	19.31	10.75	281.20	1544.	10289.	0.	3287.	2249.	2090.	1139.	1155.
DEC	-6.28	17.70	8.27	293.59	1693.	16365.	0.	5017.	3997.	3833.	1922.	1929.
ANNUAL	7.37	17.70	7.35		20352.	86035.	14031.	31945.	25650.	23721.	12120.	11660.
ANNUAL COP								1.05	1.30	1.41	2.76	2.87

SYSTEMS FIRST COSTS

NO.	CONVENTIONAL SYSTEMS	COST, $ FAN UNIT	A/C, H.P.	CONTROL	AUXILIARY	W. HEATER	DUCTS	INSTALN.	SYSTEM
1	ELECTRIC HEAT, A/C, AND HOT WATER	310.	930.	40.	213.	200.	688.	392.	2773.
2	HEAT PUMP WITH ELECTRIC HOT WATER	310.	1080.	58.	231.	200.	714.	392.	2985.
3	HEAT PUMP WITH DESUPERHEATER HOT WATER	310.	1080.	58.	631.	240.	714.	492.	3525.
	ACES SYSTEMS, INTEGRATED CONSTRUCTION	MECH. P.	ICE BIN	PANEL	AUXILIARY	W. HEATER	DUCTS	INSTALN.	SYSTEM
4	MIN., BR.CHILL, BIN(M3)= 27 P(M2)= 148*	3350.	2347.	6419.	550.	240.	1288.	518.	14712.*
5	FULL, BR.CHILL, BIN(M3)= 41 P(M2)= 94*	3350.	2854.	4344.	550.	240.	1288.	518.	13144.*

COMPARATIVE SYSTEMS COSTS

NO.	NEW CONSTRUCTION ALTERNATIVES SYSTEMS	MAINT. PRESENT WORTH $	1ST YEAR POWER COST $	1ST YEAR POWER SAVING $	SIMPLE PAYBACK PERIOD YEARS	SIMPLE PAYBACK RANKING	POWER PRESENT WORTH $	LIFE CYCLE COST $	LIFE CYCLE RANKING
1	ELECTRIC HEAT, A/C, AND HOT WATER	776.	1571.07	REF.	REF.	REF.	25787.	29335.	5
2	HEAT PUMP WITH ELECTRIC HOT WATER	2010.	1261.49	309.58	0.7	1	20706.	25700.	3
3	HEAT PUMP WITH DESUPERHEATER HOT WATER	2257.	1166.61	404.46	1.9	2	19148.	24931.	2
4	MIN. ACES, BR.CHILL, BIN (M3)= 27	1929.	596.06	975.01	12.2	4	9783.	26425.*	4
5	FULL ACES, BR.CHILL, BIN (M3)= 41	1929.	573.44	997.62	10.4	3	9412.	24486.*	1

*UNGLAZED PANEL EXCEEDS A PRACTICAL SIZE, AN ALTERNATIVE SUPPLEMENTARY HEAT SOURCE SHOULD BE USED IN THIS DESIGN.

Fig. 6.7 (continued)

8. system 4—minimum ACES
9. system 5—full ACES
10. volume of ice storage bin for ACES
11. area of solar panel for ACES
12. cost of air conditioner or heat pump
13. cost of ice storage bin, including installation and excavation
14. cost of solar panel, including installation

6.3 ORNL Job Control Language

MAD runs on the ORNL IBM-360 system. Figure 6.8 is the JCL for the sample program. The MAD program had been precompiled and stored on disk in two parts—MAD and SUNLJ. The Q-compiler was used for its greater efficiency, but the H-compiler is also suitable.

Data is saved on units 8 and 10 to be used by other programs. Unit 13 contains the weather data sets, which reside on the private disk UTACE1. A complete list of these data sets is presented in Appendix A. Any number of weather data sets may be concatenated on unit 13. Unit 5 contains the house data set as card images from PDP-10 in this sample problem. Actual cards can be used in place of the reference to the PDP-10 file UTACE.ECO. The first card read on unit 5 indicates that data set on unit 8 is new (i.e., 0) or old (i.e., 1) and gives number of data set. The ENDINPUT is required only for use by PDP-10 Submit program.

```
//MLBSAM JOB (15929),'BALLOU 9102-1'
/*ROUTE  PRINT LOCAL
//*CLASS CPU91=100S,IO=6.0,SPECIAL=DISK
// EXEC FORTQLG,PARM.GO='DUMP=I',REGION.GO=270K
//LKED.MAD DD DSN=T.MLB05929.MADQ,DISP=SHR
//LKED.SUNLJ DD DSN=T.MLB05929.SUNLJQ,DISP=SHR
//LKED.SYSIN DD *
 INCLUDE MAD
 INCLUDE SUNLJ
/*
//GO.FT10F001 DD SYSOUT=(J,,RM05)
//GO.FT08F001 DD UNIT=SPDA,DSN=T.MLB05929.MAD230,SPACE=(TRK,(20,2)),
//  DISP=(NEW,CATLG),DCB=(RECFM=FB,LRECL=485,BLKSIZE=12837)
//*GO.FT08F001 DD DSN=T.MLB05929.MAD230,DISP=(OLD,KEEP)
//GO.FT13F001 DD UNIT=2314,VOL=SER=UTACE1,DSN=MAD.CITY.DATA(CITY201),
//    DISP=SHR,LABEL=(,,,IN)
//   DD UNIT=2314,VOL=SER=UTACE1,DSN=MAD.CITY.DATA(CITY02),
//    DISP=SHR,LABEL=(,,,IN)
//GO.FT05F001 DD *
        0      230.
=UTACES.ECO
/*
//
ENDINPUT
```

Fig. 6.8. ORNL JCL for sample problem.

7. REFERENCES

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APPENDIX A
WEATHER DATA BASE

A.1 List of Cities in Weather Data Base

Weather data for 117 cities of the United States, obtained from *Engineering Weather Data,*[9] are stored as a partitioned data set on the private disk UTACE1 at the Oak Ridge National Laboratory. The cities and their data set numbers are:

City	Data set No.	City	Data set No.
AL, Birmingham	51	NV, Las Vegas	42
AL, Montgomery	76	NV, Winnemucca	109
AZ, Phoenix	53	NJ, Trenton	07
AZ, Tucson	52	NM, Albuquerque	43
AZ, Yuma	78	NM, Roswell	06
AR, Little Rock	30	NY, Albany	65
CA, Los Angeles	31	NY, Binghamton	66
CA, Merced	17	NY, Niagara Falls	110
CA, Oakland	133	NY, Syracuse	111
CA, San Diego	81	NY, Westhampton Beach	135
CO, Colorado Springs	82	NC, Greensboro	14
CO, Denver	83	NC, New Bern	67
CO, Grand Junction	32	ND, Bismarck	44
DC, Washington	58	ND, Grand	98
FL, Appalachicola	55	ND, Williston	112
FL, Jacksonville	85	OH, Akron	05
FL, Miami	57	OH, Columbus	45
FL, Orlando	134	OH, Dayton	04
FL, Tampa	56	OH, Toledo	113
GA, Atlanta	59	OK, Altus	03
GA, Augusta	92	OK, Oklahoma City	68
GA, Macon	16	OK, Tulsa	114
ID, Boise	33	OR, Astoria	46
ID, Idaho Falls	15	OR, Medford	47
IL, Chicago	88	OR, Portland	115
IL, East St. Louis	214	PA, Middletown	102
IL, Urbana	87	PA, Philadelphia	202
IN, Ft. Wayne	89	PA, Pittsburgh	116
IN, Indianapolis	34	PA, Wilkes-Barre	117
IN, South Bend	93	SC, Charleston	48
IA, Des Moines	90	SC, Greenville	101
IA, Sioux City	91	SC, Sumter	84
KS, Dodge City	35	SD, Huron	80
KS, Topeka	13	SD, Rapid City	70
KY, Louisville	95	TN, Bristol	18
LA, Lake Charles	36	TN, Knoxville	201
LA, New Orleans	97	TN, Memphis	21
LA, Shreveport	96	TN, Nashville	22
ME, Portland	37	TX, El Paso	71
MA, Falmouth	60	TX, Fort Worth	72
MI, Battle Creek	12	TX, Houston	23
MI, Detroit	99	TX, San Antonio	79
MI, Sault Ste. Marie	61	UT, Salt Lake City	73
MN, Duluth	01	VT, Burlington	77
MN, International Falls	94	VA, Norfolk	25
MN, Minneapolis	02	VA, Richmond	24
MS, Biloxi	10	VA, Roanoke	26
MS, Columbus	11	WA, Moses Lake	86
MS, Jackson	103	WA, Seattle	74
MO, Columbia	38	WA, Spokane	75
MO, Kansas City	104	WV, Charleston	27
MO, Springfield	105	WV, Elkins	28
MT, Billings	106	WI, Green Bay	29
MT, Great Falls	40	WI, Madison	50
MT, Missoula	09	WY, Casper	20
NB, Grand Island	08	WY, Cheyenne	130
NB, Lincoln	63	WY, Lander	131
NB, North Platte	108	WY, Sheridan	132
NV, Ely	41		

A.2 ORNL JCL for Using Weather Data Base

The program MAD reads the weather data on unit 13. The data set on the ORNL computer system for each individual city is a member of the partitioned data set MAD.CITY.DATA on the private disk UTACE1. The name of an individual city, or member of MAD.CITY.DATA, is determined by its data set number (Sect. A.1). For example, CITY51 denotes Birmingham, Alabama. An arbitrary number of members of MAD.CITY.DATA may be concatenated in the following manner:

```
// GO.FT13F001 DD UNIT=2314,VOL=SER=UTACE1,
// DSN=MAD.CITY.DATA(CITY51),DISP=SHR,LABEL=(,,,IN)
// DD UNIT=2314,VOL=SER=UTACE1,
// DSN=MAD.CITY.DATA(CITY76),DISP=SHR,LABEL=(,,,IN)
// DD UNIT=2314,VOL=SER=UTACE1,
// DSN=MAD.CITY.DATA(CITY52),DISP=SHR,LABEL=(,,,IN)
```

The program MAD stops when an end of file is read on unit 13.

APPENDIX B
LISTING OF PROGRAM

```
C
C     PROGRAM FOR MONTHLY ACES DESIGN--MAD
C
C                  WRITTEN BY
C                  M.L. BALLOU
C                      AND
C                  E.A. NEPHEW
C           OAK RIDGE NATIONAL LABORATORY
C                OAK RIDGE,TENNESSEE
C
      COMMON/HPUMP/COPH(76),AUX(12),ENGHP(12),CCOP,HCOP,SCOP
      LOGICAL OPT1,OPT2
      COMMON/DAT/HWT(4),TICE(7),AREA(9),RAB,WAB,RR,WR,HO,SF,GLASS,
     >       PANES,SUP,PSIDES,PDELT,TILT,TSW,TSS,GAL(12),COPCHT,
     >       COPCBR,COPCHW,COPHT,COPIM,COPCW,COPBR,COPHW,EC,EF,EHB,
     >       ECB,EOF,EHW,OPT1,OPT2,COP47,COP17,IPRT
      COMMON/BINS/CITY(10),ZONE,DD(2),ALAT,NINV(12),T(12,40),
     >       H(12,40,2),HBR(12),VAV(12),TAV(12),WB(12,40),
     >       ALONG,ELEV,ELECOS
      COMMON/DIG/TVOL(5),PAREA(5),SYSKW(5),BTEMP(12,5),BLEAK(12,5),
     >       PCOL(12,5),BICE(12,5),IRUN,TBLEAK(12),SILEAK(12)
      COMMON/HOUS/LABEL(50,5),XNS,ARCHG,VOL,VAR(50,5),U(50),DT(50),
     >       HL(50),SM,UA,UFLOOR,DCOOL,DHEAT,BCAP,PAN(12,15)
      COMMON/QLOAD/SOL(12,10),SHG(12),QH(12),QC(12),QW(12),
     >       TITLE(18),SOP(12),MON(12),XNFIL(12),SO(12),TH(12),
     >       TG(12,7),DTH(7),HRSPAN(12),HFLOOR(12),CFLOOR(12)
      COMMON/RICE/ISYS,RATEDC,RATEFL,RATEKW,KWFLAG,YRS,CSTCOL,CSTINS,
     >       CSTCOI,THKSD,THKBTM,THKTP
      DIMENSION HEAD(18)
      COMMON/FILE8/POINT(120,9),SAVREC(65),NREC,CASENO
C
C  THE FILE ON UNIT 8 WILL SAVE DATA FROM MAD RUNS TO BE
C  MAPPED LATER.  THE STRUCTURE OF THE FILE IS AS FOLLOWS:
C
C  RECORD 1  LAST RECORD NO. USED, CASE NO. CONTAINED IN SET
C  RECORD 2-31 CITY NAME, FIRST RECORD NO. REPEATED 4 TIMES PER
C              RECORD
C  RECORD 32 POINTER, CITY NAME(8A4), LATITUDE, LONGITUDE,
C            RATIO OF TOTAL COOLING TO SENSIBLE COOLING,
C            RATE OF ELECTRICITY, ISYS,
C            VOLUME OF MIN. ACES BIN,
C            VOLUME OF FULL ACES BIN, FLAG ON VOLUME,
C            PANEL AREA OF MIN. ACES,
C            PANEL AREA OF FULL ACES, FLAG ON PANEL,
C            ANNUAL COP OF 5 SYSTEMS,
C            ANNUAL ENERGY OF 5 SYSTEMS(KWH),
C            SYSTEM COST OF 5 SYSTEMS,
C            TOTAL PRESENT WORTH OF 5 SYSTEMS,
C            SIMPLE PAYBACK PERIOD OF 5 SYSTEMS,
C            SIMPLE  PAYBACK RANK OF 5 SYSTEMS,
C            1ST YEAR FUEL COST OF 5 SYSTEMS,
C            FUEL SAVINGS OF 5 SYSTEMS,
C            AND LIFE CYCLE RANKING OF 5 SYSTEMS
C            ( THE 5 SYSTEMS ARE I2R, HEAT PUMP/I2R,
C            HEAT PUMP/DESUPER, MIN. ACES, AND FULL ACES)
```

```
C
C  REST OF THE RECORDS ARE REPEATS OF RECORD 31 ABOVE.
C
C  JCL FOR GO STEP IS
C  //GO.FT08F001 DD UNIT=SPDA,DSN=T.MLB05929.MADXX,SPACE=(TRK,(20,2)),
C  //  DISP=(NEW,CATLG),DCB=(RECFM=FB,LRECL=485,BLKSIZE=12837)
C                OR
C  //GO.FT08F001 DD DSN=T.MLB05929.MADXX,DISP=(OLD,KEEP)
C
      DEFINE FILE 8(600,485,E,NREC)
C
C  IFILE8=0 MEANS FILE 8 NOT USED BEFORE
C
      READ(5,450) IFILE8, CASENO
      IF (IFILE8.EQ.0) GO TO 20
C
C  READ IN POINTER TABLE
C
      J1=1
      J2=4
      DO 10 I=2,31
      READ(8'I,500) ((POINT(J,K),K=1,9),J=J1,J2)
      J1=J1+4
      J2=J2+4
10    CONTINUE
C
C  READ LAST RECORD NO. USED AND INITIALIZE NREC
C
      READ(8'1,550) RLAST
      NREC=INT(RLAST)+1
      GO TO 40
C
C  FIRST TIME FILE USED--INITIALIZE POINTER TABLE AND NREC.
C
20    DO 30 J=1,120
      DO 30 K=1,9
      POINT(J,K)=0.
30    CONTINUE
      NREC=32
C
C  READ IN DATA ABOUT HOUSE AND ICE TANK
C
40    CALL DATAIN
      CALL PRTDAT
      NCITY=0
C
C     READ MONTHLY TEMPERATURE, WIND SPEED, AND INSOLATION DATA
C
C     M       = MONTH INDEX
C     I       = BIN INDEX
C     T(M,I)  = TEMPERATURE MIDPOINT OF BIN
C     H(M,I,1)= BIN DAYLIGHT HOURS
C     H(M,I,2)= BIN NIGHT HOURS
C     WB(M,I) = WET BULB AVERAGE
C     TAV(M)  = AVERAGE OUTDOOR TEMPERATURE (F)
```

```
C     VAV(M)  = AVERAGE WIND SPEED (MILES PER HOUR)
C     HBR(M)  = MONTHY INSOLATION
C
C
50      CALL BIN(HEAD,&5000)
C
C  CALCULATE EARTH TEMPERATURE
C  TG(M,1) = GROUND TEMPERATURE FOR TANK TOP
C  TG(M,2) = GROUND TEMPERATURE FOR TANK BOTTOM
C  TG(M,3) = AVERAGE GROUND TEMPERATURE FOR TANK SIDES
C  TG(M,4) = INLET WATER TEMPERATURE
C  TG(M,5) = GROUND TEMPERATURE (5 FT)
C
        CALL EARTH(TAV)
C
C     COMPUTE INSOLATION ON SURFACES
C
        CALL SUNLJ
C
C
C     SOL(M,1) = SOLAR HEAT GAIN THROUGH NORTH WINDOW (BTU/DAY*SQFT)
C     SOL(M,2) = SOLAR HEAT GAIN THROUGH EAST  WINDOW (BTU/DAY*SQFT)
C     SOL(M,3) = SOLAR HEAT GAIN THROUGH SOUTH WINDOW (BTU/DAY-SQFT)
C     SOL(M,4) = SOLAR HEAT GAIN THROUGH WEST  WINDOW (BTU/DAY-SQFT)
C     SOL(M,5) = INCIDENT SOLAR FLUX ON NORTH FACING WALL(BTU/DAY-FT**2)
C     SOL(M,6) = INCIDENT SOLAR FLUX ON EAST FACING WALL (BTU/DAY-FT**2)
C     SOL(M,7) = INCIDENT SOLAR FLUX ON SOUTH FACING WALL(BTU/DAY-FT**2)
C     SOL(M,8) = INCIDENT SOLAR FLUX ON WEST FACING WALL (BTU/DAY-FT**2)
C     SOL(M,9) = INCIDENT SOLAR FLUX ON ROOF (BTU/DAY-FT**2)
C     SOL(M,10) = SOLAR FLUX ON RADIANT/CONVECTOR PANEL  (BTU/DAY-FT**2)
C
C
        DO 80 M=1,12
        SHG(M)= 0.0
        SOP(M)=AREA(9)*SOL(M,9)*RAB/((RR*HO+1.0)*8.0)
        DO 80 J=1,4
        SHG(M)=SHG(M)+AREA(J)*SOL(M,J)*SF/8.0
        SOP(M)=SOP(M)+AREA(J+4)*SOL(M,J+4)*WAB/((WR*HO+1.0)*8.0)
80      CONTINUE
C
C  PANEL CALCULATES SOLAR PANEL HEAT PICKUP
C
        CALL PANEL
C
C  LOADS USES UA OF THE HOUSE TO CALCULATE MONTHLY HEATING,
C  COOLING, AND HOT WATER LOADS.  LOADS ALSO CALCULATES
C  DESIGN DAY HEATING AND COOLING LOADS.
C
        CALL LOADS(&50)
C
C  DIGEST CALCULATES BIN SIZE, PANEL SIZE, AND ENERGY CONSUMPTION
C
        CALL DIGEST(&50)
C
C  ENERGY CALCULATES ENERGY CONSUMPTION OF NON-ACES SYSTEMS
```

```
C
        CALL ENERGY
        IF(IPRT.EQ.0) CALL PRTBSC(HEAD)
        IF(IPRT.EQ.1) CALL PRTECO(HEAD)
C
C  WRITE CITY DATA INTO FILE8
C
        NCITY=NCITY+1
        WRITE(8'NREC,300) (SAVREC(J),J=1,65)
300     FORMAT(F5.0,8A4,16F8.2,15F8.0,5F8.2,20F8.0)
        NWRT=NREC-1
C
C  UPDATE POINTERS
C
        DO 90 J=1,120
        IN=J
        IF(HEAD(1).NE.POINT(J,1)) GO TO 90
        IF(HEAD(2).NE.POINT(J,2)) GO TO 90
        IF(HEAD(3).NE.POINT(J,3)) GO TO 90
        IF(HEAD(4).NE.POINT(J,4)) GO TO 90
        IF(HEAD(5).NE.POINT(J,5)) GO TO 90
        IF(HEAD(6).NE.POINT(J,6)) GO TO 90
        IF(HEAD(7).NE.POINT(J,7)) GO TO 90
        IF(HEAD(8).EQ.POINT(J,8)) GO TO 110
90      CONTINUE
        DO 100 I=1,8
        POINT(NCITY,I)=HEAD(I)
100     CONTINUE
        POINT(NCITY,9)=FLOAT(NREC-1)
        GO TO 140
C
C  CITY ALREADY IN POINTER TABLE--UPDATE POINTERS IN PREVIOUS RECORDS
C
110     PT1=POINT(IN,9)
120     IP=INT(PT1)
        READ(8'IP,350) PT2
350     FORMAT(F5.0)
C
C  FIND LAST POINTER
C
        IF(PT2.EQ.9999.) GO TO 130
        PT1=PT2
        GO TO 120
C
C  NWRT IS NUMBER OF RECORD JUST WRITTEN
C
130     PT=FLOAT(NWRT)
        READ(8'IP,300) SAVREC
        SAVREC(1)=PT
        WRITE(8'IP,300) SAVREC
        PT=9999.
        READ(8'NWRT,300) SAVREC
        SAVREC(1)=PT
        WRITE(8'NWRT,300) SAVREC
140     CONTINUE
```

```
      GO TO 50
C
C  WRITE RECORD 1 AND POINTER TABLE IN RECORD 2-30
C
5000      RLAST=FLOAT(NREC-1)
      WRITE(8'1,400) RLAST,CASENO
400   FORMAT(36F10.0)
      J1=1
      J2=4
      DO 150 I=2,31
      WRITE(8'I,500) ((POINT(J,K),K=1,9),J=J1,J2)
      J1=J1+4
      J2=J2+4
150   CONTINUE
      STOP
450   FORMAT(I10,F10.0)
500   FORMAT(4(8A4,F10.0))
550   FORMAT(F10.0)
      END
      BLOCK DATA
      COMMON/HPUMP/COPH(76),AUX(12),ENGHP(12),CCOP,HCOP,SCOP
      COMMON/QLOAD/SOL(12,10),SHG(12),QH(12),QC(12),QW(12),
     >      TITLE(18),SOP(12),MON(12),XNFIL(12),SO(12),TH(12),
     >      TG(12,7),DTH(7),HRSPAN(12),HFLOOR(12),CFLOOR(12)
      DATA COPH/3*1.28,5*1.36,5*1.50,5*1.68,5*1.92,5*2.18,5*2.42,
     >         5*2.67,5*2.88,5*3.04,5*3.21,5*3.34,5*3.43,5*3.50,
     >         5*3.56,3*3.60/
      DATA MON/'JAN ','FEB ','MAR ','APR ','MAY ','JUN ','JUL ',
     >        'AUG ','SEP ','OCT ','NOV ','DEC '/
      DATA TH/744.,672.,744.,720.,744.,720.,744.,744.,
     >        720.,744.,720.,744./
      END
      SUBROUTINE ACECOS
C
C  THIS SUBROUTINE CALCULATES COST OF ACES WITH I2R HOT WATER HEATER
C
      COMMON/HPUMP/COPH(76),AUX(12),ENGHP(12),CCOP,HCOP,SCOP
      LOGICAL OPT1,OPT2
      COMMON/DAT/HWT(4),TICE(7),AREA(9),RAB,WAB,RR,WR,HO,SF,GLASS,
     >      PANES,SUP,PSIDES,PDELT,TILT,TSW,TSS,GAL(12),COPCHT,
     >      COPCBR,COPCHW,COPHT,COPIM,COPCW,COPBR,COPHW,EC,EF,EHB,
     >      ECB,EOF,EHW,OPT1,OPT2,COP47,COP17,IPRT
      COMMON/DIG/TVOL(5),PAREA(5),SYSKW(5),BTEMP(12,5),BLEAK(12,5),
     >      PCOL(12,5),BICE(12,5),IRUN,TBLEAK(12),SILEAK(12)
      COMMON/RICE/ISYS,RATEDC,RATEFL,RATEKW,KWFLAG,YRS,CSTCOL,CSTINS,
     >      CSTCOI,THKSD,THKBTM,THKTP
      REAL*4 INSCOS,MECCOS
      COMMON/COSDAT/FANCOS(5),CNTCOS(5),AHPCOS(5),AUXCOS(5),
     >              HWTCOS(5),DUCCOS(5),INSCOS(5),SYSCOS(5),
     >              MECCOS(2),BINCOS(2),PANCOS(2),COILFT(2)
      COMMON/HOUS/LABEL(50,5),XNS,ARCHG,VOL,VAR(50,5),U(50),DT(50),
     >      HL(50),SM,UA,UFLOOR,DCOOL,DHEAT,BCAP,PAN(12,15)
      DIMENSION AMECHP(2,6),DUCTS(2,9),C(11),CBIN(7)
      DATA DUCTS/10000.,435.,
     >           12500.,500.,
```

```
     >              26500.,750.,
     >              40000.,1000.,
     >              53500.,1200.,
     >              66500.,1375.,
     >              80000.,1500.,
     >              100000.,1650.,
     >              115000.,1688./
        DATA AMECHP/24500.,2500.,
     >              34000.,2650.,
     >              45000.,2950.,
     >              60000.,3350.,
     >              75000.,3750.,
     >              115000.,4750./
        F(D)=CON-D*D*ALOG(D/(0.85/12.))-2.0*1.33*D/15.
        DF(D)=-(2*D*ALOG(D/(0.85/12.))+D)-2.0*1.33/15.
C
C
C  ACES COST
C
C
        DO 200 IK=1,2
        IF(IK.EQ.1) K=2
        IF(IK.EQ.2) K=1
        DO 130 J=1,6
        IF(DHEAT.LE.AMECHP(1,J)) GO TO 140
130     CONTINUE
        PRINT 1600, DHEAT
1600    FORMAT('0EXCEEDED CAPACITY ON ACES MECH. PACKAGE IN',
     >          ' SUBROUTINE COST, DHEAT =',F10.0)
C
C  COST OF MECHNICAL PACKAGE
C
140     MECCOS(IK)=AMECHP(2,J)
        DCAP=AMECHP(1,J)
C
C  ADD TO COST IF HIGH EFFICIENCY HEAT PUMP
C
        IF(COPHT.GE.5.0) MECCOS(IK)=MECCOS(IK)+1200.
C
C  ICE STORAGE BIN COST
C  TAKEN FROM R.S. SNOW CONSTRUCTION COST ESTIMATION
C
C  C(1) = LINER MATERIAL AND INSTALLATION
C  C(2) = FLOOR SLAB MATERIAL AND INSTALLATION
C  C(3) = FLOOR INSULATION MATERIAL AND INSTALLATION
C  C(4) = TOP SLAB MATERIAL AND INSTALLATION
C  C(5) = TOP INSULATION MATERIAL AND INSTALLATION
C  C(6) = FOAM FORM WALL (MATERIAL AND INSTALLATION)
C  C(7) = FOAM FORM SUPPLEMENTAL INSULATION (MAT. + INSTALL.)
C  C(8) = BAR BLOCK UPGRADE TO FOAM FORM LEVEL
C  C(9) = FOOTERS, MATERIALS AND INSTALLATION
C  C(10) = EXCAVATION COST
C  C(11) = COIL COSTS
C
C  T=1 DENOTES FREE STANDING BIN CONSTRUCTION
```

```
C  T=0 DENOTES INTEGRATED TANK CONSTRUCTION
C
        T=0.
C
C  CBIN(1) = LINER COST
C  CBIN(2) = FLOOR COST
C  CBIN(3) = TOP COST
C  CBIN(4) = WALLS COST
C  CBIN(5) = FOOTERS COST
C  CBIN(6) = EXCAVATION COST
C  CBIN(7) = COIL COST
        C(1)=.45
        C(2)=.97
        C(3)=CSTINS*THKBTM
        C(4)=0.0
        C(5)=CSTINS*THKTP
        C(6)=2.11
        C(7)=CSTINS*THKSD
        C(8)=.29
        C(9)=1.73
        C(10)=.0925
        C(11)=CSTCOI
        HT=TICE(1)
        W=SQRT(TVOL(K)/HT)
        ABTM=TVOL(K)/HT
        CBIN(1)=C(1)*(HT+HT+W)**2
        CBIN(2)=ABTM*(C(2)*T+C(3))
        CBIN(3)=ABTM*(C(4)*T+C(5))
        CBIN(4)=2.*HT*W*((C(6)+C(7))*(T+1.)-(C(7)+C(8))*(T-1.))
        CBIN(5)=2.*W*C(9)*(T+1.)
        CBIN(6)=C(10)*TVOL(K)*T
        CBIN(7)=0.0
        IF(ISYS.NE.1) GO TO 170
C
C  COIL COST
C
        ECAP=DHEAT*(COPH(43)-1)/COPH(43)
        ED=ECAP/TVOL(K)
C
C  CALCULATE BRINE TEMPERATURE AS A FUNCTION OF COST OF POWER
C
        IF(RATEKW.LE.0.04) TB=15.0
        IF(RATEKW.GE.0.17) TB=28.0
        IF(RATEKW.LT.0.17.AND.RATEKW.GT.0.04) TB=(RATEKW-0.04)/.01+15.0
C
C  CALCULATE LENGTH OF COIL IN BIN
C
        CON=(2.0*3.1416*1.33*(32.0-TB))/ED
        D1=4./12.
        DO 150 KK=1,100
        D2=D1-F(D1)/DF(D1)
        IF(ABS(D1-D2).LE.0.001) GO TO 160
        D1=D2
150     CONTINUE
160     COILFT(K)=TVOL(K)/(D2*D2)
```

```
      CBIN(7)=CSTCOI*COILFT(K)
170   BINCOS(IK)=CBIN(1)+CBIN(2)+CBIN(3)+CBIN(4)+CBIN(5)+
     >            CBIN(6)+CBIN(7)
C
C  COST OF SOLAR PANEL
C
      PANCOS(IK)=PAREA(K)*CSTCOL
      IF(PAREA(K).GT.0.0) PANCOS(IK)=PANCOS(+IK)+700.+
     >                     PAREA(K)*.6
C
C  COST OF AUXILIARIES
C
      AUXCOS(3+IK)=320.+100.
      IF(DHEAT.GT.45500.) AUXCOS(3+IK)=AUXCOS(3+IK)+20.
      IF(DHEAT.LE.35000.) AUXCOS(3+IK)=AUXCOS(3+IK)+60.
      IF(DHEAT.GT.35000.0.AND.DHEAT.LE.60000.0) AUXCOS(3+IK)=
     >  AUXCOS(3+IK)+110.
      IF(DHEAT.GT.60000.0.AND.DHEAT.LE.115000.0) AUXCOS(3+IK)=
     >     AUXCOS(3+IK)+180.
C
C  COST OF HOT WATER HEAT-82 GALLONS CAPACITY
C
      HWTCOS(3+IK)=240.
C
C  COST OF DUCTS
C
      DO 180 J=1,9
      IF(DCAP.LE.DUCTS(1,J)) GO TO 185
180   CONTINUE
      PRINT 1200,DCAP
1200  FORMAT('0CAPACITY ON DUCTS EXCEEDED IN SUBROUTINE',
     >         'ACECOS, DCAP=',F10.0)
185   IF(J.EQ.1) DUCCOS(3+IK)=DUCTS(2,J)
      IF(J.EQ.1) GO TO 190
C
C  INTERPOLATE TO FIND COST
C
      DUCCOS(3+IK)=DUCTS(2,J-1)+(DCAP-DUCTS(1,J-1))/
     >         (DUCTS(1,J)-DUCTS(1,J-1))*(DUCTS(2,J)-DUCTS(2,J-1))
C
C  INSTALLATION COST
C
190   INSCOS(3+IK)=140.
      IF(DHEAT.LE.24500.) INSCOS(3+IK)=INSCOS(3+IK)+252.
      IF(DHEAT.GT.24500.0.AND.DHEAT.LE.34500.) INSCOS(3+IK)=
     >  INSCOS(3+IK)+294.
      IF(DHEAT.GT.34500.) INSCOS(3+IK)=INSCOS(3+IK)+378.
      SYSCOS(3+IK)=MECCOS(IK)+BINCOS(IK)+PANCOS(IK)+AUXCOS(3+IK)+
     >              HWTCOS(3+IK)+DUCCOS(3+IK)+INSCOS(3+IK)
200   CONTINUE
      RETURN
      END
      SUBROUTINE BIN(HEAD,*)
      COMMON/BINS/CITY(10),ZONE,DD(2),ALAT,NINV(12),T(12,40),
     >       H(12,40,2),HBR(12),VAV(12),TAV(12),WB(12,40),
```

```
     >        ALONG,ELEV,ELECOS
         DIMENSION A(7),TH(12),HEAD(18),HMON(12)
         DATA HMON/744.,672.,744.,720.,744.,720.,744.,744.,
     >      720.,744.,720.,744./
C
C  THIS SUBROUTINE READS THE BIN WEATHER DATA
C
C
C  ALAT = LATITUDE
C  ALONG = LONGITUDE
C  ELEV = ELEVATION
C
         READ(13,4,END=700) CITY,ZONE,ALAT1,ALAT2,ALONG1,ALONG2,ELEV
         ALAT=ALAT1+ALAT2/60.0
         ALONG=ALONG1+ALONG2/60.0
C
C  READ IN DESIGN DAY INFORMATION
C  DD(1) = DESIGN DAY TEMPERATURE WINTER(F)
C  DD(2) = DESIGN DAY TEMPERATURE SUMMER(F)
C  ELECOS = COST OF ELECTRICITY IN THE CITY
C
         READ(13,5) DD,ELECOS
C
C  T(M,I)--AVERAGE TEMPERATURE
C  H(M,I,1)--DAY HOURS  H(M,I,2)--NIGHT HOURS
C  HBR(M)--MONTHLY INSOLATION
C  VAV(M)--AVERAGE WIND SPEED (MPH)
C  WB(M,I)--AVERAGE WET BULB
C
         DO 10 M=1,12
         NINV(M)=0
         TAV(M)=0.0
         TH(M)=0.0
         DO 10 I=1,40
         T(M,I)=0.
         WB(M,I)=0.
         DO 10 J=1,2
10       H(M,I,J)=0.
         READ(13,1)  HEAD,NSET
         READ(13,2) HBR,VAV
C
C  CHANGE LANGLEY TO BTU/SQ FT
C
         DO 20 M=1,12
20       HBR(M)=HBR(M)*3.687
C
C  READ IN BIN DATA
C
30       READ(13,3) (A(J),J=1,7),M,NST
         IF(M.EQ.0) GO TO 40
         NINV(M)=NINV(M)+1
         I=NINV(M)
         T(M,I)=(A(1)+A(2))/2.0
         H(M,I,1)=A(4)
         H(M,I,2)=A(6)-A(4)
```

```
      TEST=A(3)+A(4)+A(5)
      IF(TEST.NE.A(6)) GO TO 599
      TAV(M)=TAV(M)+T(M,I)*A(6)
      WB(M,I)=A(7)
      IF (WB(M,I) .GT. T(M,I)-1.) WB(M,I)=T(M,I)-1.
      TH(M)=TH(M)+A(6)
      GO TO 30
C
C  CALCULATE AVERAGE MONTHLY DRY BULB
C
40    DO 50 M=1,12
      IF(TH(M).NE.HMON(M)) GO TO 599
50    TAV(M)=TAV(M)/TH(M)
C
C  SORT INTO DECREASING ORDER
      DO 100 M=1,12
      N2=NINV(M)-1
      DO 70 K=1,N2
      N1=N2-(K-1)
      DO 60 I=1,N1
      IF(T(M,I).LT.T(M,I+1)) GO TO 60
      SAV=T(M,I)
      T(M,I)=T(M,I+1)
      T(M,I+1)=SAV
      SAV=WB(M,I)
      WB(M,I)=WB(M,I+1)
      WB(M,I+1)=SAV
      DO 60 J=1,2
      SAV=H(M,I,J)
      H(M,I,J)=H(M,I+1,J)
      H(M,I+1,J)=SAV
60    CONTINUE
70    CONTINUE
C
C  INSERT BIN OF ZERO AT BEG AND END OF MONTH
C
      IF(H(M,1,1).EQ.0.0.AND.H(M,1,2).EQ.0.0) GO TO 90
      TOP=T(M,1)-5.
      N=NINV(M)
      DO 80 J=1,N
      I=N-(J-1)
      T(M,I+1)=T(M,I)
      H(M,I+1,1)=H(M,I,1)
      H(M,I+1,2)=H(M,I,2)
      WB(M,I+1)=WB(M,I)
80    CONTINUE
      NINV(M)=NINV(M)+1
      T(M,1)=TOP
      WB(M,1)=TOP-1.
      H(M,1,1)=0.
      H(M,1,2)=0.
90    IF(H(M,NINV(M),1).EQ.0.0.AND.H(M,NINV(M),2).EQ.0.0) GO TO 100
      NINV(M)=NINV(M)+1
      T(M,NINV(M))=T(M,NINV(M)-1)+5.
      WB(M,NINV(M))=T(M,NINV(M))-1.
```

```
100     CONTINUE
        RETURN
599     PRINT 600,M,TEST,TH(M),(A(J), J=1,7)
        STOP
700     RETURN1
C  FORMATS
1       FORMAT(18A4,6X,I2)
2       FORMAT(12F5.0)
3       FORMAT(7F5.0,35X,I2,6X,I2)
4       FORMAT(10A4,A4,6X,2F3.0,4X,2F3.0,4X,F10.0)
5       FORMAT(8F10.0)
600     FORMAT('0MISTAKE IN BINS MONTH = ',I5,2F12.6/' ',7F10.2)
        END
        SUBROUTINE COST
C
C  THIS SUBROUTINE CALCULATES COST OF AN I2R SYSTEM, HEAT PUMP
C  WITH I2R HOT WATER HEATER, AND HEAT PUMP WITH DESUPER
C  HOT WATER HEATER.
C
        COMMON/HPUMP/COPH(76),AUX(12),ENGHP(12),CCOP,HCOP,SCOP
        LOGICAL OPT1,OPT2
        COMMON/DAT/HWT(4),TICE(7),AREA(9),RAB,WAB,RR,WR,HO,SF,GLASS,
     >        PANES,SUP,PSIDES,PDELT,TILT,TSW,TSS,GAL(12),COPCHT,
     >        COPCBR,COPCHW,COPHT,COPIM,COPCW,COPBR,COPHW,EC,EF,EHB,
     >        ECB,EOF,EHW,OPT1,OPT2,COP47,COP17,IPRT
        COMMON/DIG/TVOL(5),PAREA(5),SYSKW(5),BTEMP(12,5),BLEAK(12,5),
     >        PCOL(12,5),BICE(12,5),IRUN,TBLEAK(12),SILEAK(12)
        COMMON/RICE/ISYS,RATEDC,RATEFL,RATEKW,KWFLAG,YRS,CSTCOL,CSTINS,
     >        CSTCOI,THKSD,THKBTM,THKTP
        COMMON/HOUS/LABEL(50,5),XNS,ARCHG,VOL,VAR(50,5),U(50),DT(50),
     >        HL(50),SM,UA,UFLOOR,DCOOL,DHEAT,BCAP,PAN(12,15)
        REAL*4 INSCOS,MECCOS
        COMMON/COSDAT/FANCOS(5),CNTCOS(5),AHPCOS(5),AUXCOS(5),
     >                HWTCOS(5),DUCCOS(5),INSCOS(5),SYSCOS(5),
     >                MECCOS(2),BINCOS(2),PANCOS(2),COILFT(2)
        COMMON/PWFDAT/ANZCOS(5),FFCOS(5),PAYPER(5),FFSAV(5),IPAYRK(5),
     >         FUELPW(5),TOTPW(5),LIFCYC(5),ANTOT(12)
        DIMENSION FAN(2,6),ELECMP(6),AIRCND(2,6),DUCTS(2,9),HEATP(2,6)
C
C  FAN UNIT COST BASED ON SEARS CATALOG-SUMMER 79
C
        DATA FAN/35260.,250.,
     >          52600.,280.,
     >          69760.,310.,
     >          84235.,350.,
     >          96775.,380.,
     >          115905.,410./
C
C  ELECTRICAL SERVICE COMPONENTS BASED ON SEARS CATALOG-SUMMER 79
C
        DATA ELECMP/59.,72.,112.,180.,180.,180./
C
C  AIR CONDITIONER COST BASED ON SEARS CATALOG-SUMMER 79
C
        DATA AIRCND/23000.,930.,
```

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     >              27000.,970.,
     >              33500.,1050.,
     >              41000.,1080.,
     >              46000.,1130.,
     >              60000.,1170./
C
C  DUCT SYSTEM COST DEVELOPED FROM R.S. MEANS DATA
C
        DATA DUCTS/10000.,435.,
     >             12500.,500.,
     >             26500.,750.,
     >             40000.,1000.,
     >             53500.,1200.,
     >             66500.,1375.,
     >             80000.,1500.,
     >             100000.,1650.,
     >             115000.,1688./
C
C  HEAT PUMP COST FROM SEARS CATALOG-SUMMER 79
C
        DATA HEATP/24500.,1080.,
     >             29000.,1180.,
     >             34500.,1280.,
     >             40000.,1410.,
     >             48000.,1640.,
     >             58000.,1980./
C
C
C  COST OF I2R SYSTEM
C
C
        DO 20 J=1,6
        JELE=J
        IF(DHEAT.LE.FAN(1,J)) GO TO 30
20      CONTINUE
        PRINT 1000,DHEAT
1000    FORMAT('0EXCEEDED CAPACITY OF FAN UNIT IN SUBROUTINE',
     >         'COST, DHEAT=',F10.0)
C
C  COST OF FAN UNIT AND CONTROLS
C
30      FANCOS(1)=FAN(2,J)
        CNTCOS(1)=40.
        DO 40 J=1,6
        IF(DCOOL.LE.AIRCND(1,J)) GO TO 50
40      CONTINUE
        PRINT 1100, DCOOL
1100    FORMAT('0EXCEEDED CAPACITY OF AIR CONDITION UNIT IN SUBROUTINE',
     >         'COST, DCOOL=',F10.0)
C
C  COST OF AIR CONDITIONING UNIT
C
50      AHPCOS(1)=AIRCND(2,J)
        DCAP=AIRCND(1,J)
C
```

```
C  COST OF AUXILLARIES
C  BASED ON SEARS CATALOG-SUMMER 79
        IF(DCOOL.LT.40000.) AUXCOS(1)=101.
        IF(DCOOL.GE.40000.0.AND.DCOOL.LE.56000.) AUXCOS(1)=119.
        IF(DCOOL.GT.56000.) PRINT 1400, DCOOL
1400    FORMAT('0CAPACITY ON AUXILIARY EXCEEDED, DCOOL=',F10.0)
        AUXCOS(1)=AUXCOS(1)+ELECMP(JELE)
C
C  COST OF HOT WATER HEATER-52 GALLON CAPACITY
C  BASED ON SEARS CATALOG-SUMMER 79
C
        HWTCOS(1)=200.
C
C  COST OF DUCTS
C
        DO 60 J=1,9
        IF(DCAP.LE.DUCTS(1,J)) GO TO 70
60      CONTINUE
        PRINT 1200,DCAP
1200    FORMAT('0CAPACITY ON DUCTS EXCEEDED IN SUBROUTINE',
     >          'COST, DCAP=',F10.0)
70      IF(J.EQ.1) DUCCOS(1)=DUCTS(2,J)
        IF(J.EQ.1) GO TO 80
C
C  INTERPOLATE TO FIND COST
C
        DUCCOS(1)=DUCTS(2,J-1)+(DCAP-DUCTS(1,J-1))/
     >          (DUCTS(1,J)-DUCTS(1,J-1))*(DUCTS(2,J)-DUCTS(2,J-1))
C
C  INSTALLATION COST
C  $140 FOR HOT WATER HEATER FROM  R.S.MEANS DATA
C  FAN AND AIR CONDITIONER COST FROM KHASHAB
C
80      INSCOS(1)=140.
        IF(DCOOL.LE.21700.0) FAC=252.
        IF(DCOOL.GT.21700.0.AND.DCOOL.LE.33500.) FAC=294.
        IF(DCOOL.GT.33500.0.AND.DCOOL.LE.55000.) FAC=378.
        IF(DCOOL.GT.55000.) PRINT 1300, DCOOL
1300    FORMAT('0EXCEEDED CAPACITY ON INSTALLATION IN SUBROUTINE',
     >          'COST, DCOOL=',F10.0)
        INSCOS(1)=INSCOS(1)+FAC
        SYSCOS(1)=FANCOS(1)+AHPCOS(1)+CNTCOS(1)+AUXCOS(1)+HWTCOS(1)+
     >             DUCCOS(1)+INSCOS(1)
C
C
C  HEAT PUMP WITH I2R HOT WATER
C
C
        DO 90 J=1,6
        JELE=J
        IF(DHEAT.LE.FAN(1,J)) GO TO 100
90      CONTINUE
        PRINT 1000, DHEAT
C
C  FAN COST
```

```
100     FANCOS(2)=FAN(2,J)
        DO 110 J=1,6
        IF(DCOOL.LE.HEATP(1,J)) GO TO 120
110     CONTINUE
        PRINT 1500,DCOOL
1500    FORMAT('0CAPACITY EXCEEDED ON HEAT PUMP IN SUBROUTINE',
     >          'COST, DCOOL=',F10.0)
C
C  HEAT PUMP COST
C
120     AHPCOS(2)=HEATP(2,J)
        DCAP=HEATP(1,J)
C
C  ADD TO COST IF HIGH EFFICIENCY HEAT PUMP
C
        IF(COP47.GE.3.1.AND.COP47.LE.3.8) AHPCOS(2)=AHPCOS(2)+460.
        IF(COP47.GT.3.8.AND.COP47.LE.4.4) AHPCOS(2)=AHPCOS(2)+800.
        IF(COP47.GT.4.4) AHPCOS(2)=AHPCOS(2)+1200.
C
C  CONTROL COSTS
C
        CNTCOS(2)=29.
        IF(DHEAT.GT.35260.0.AND.DHEAT.LE.69760.) CNTCOS(2)=CNTCOS(2)+29.
        IF(DHEAT.GT.69760.0.AND.DHEAT.LE.115905.)CNTCOS(2)=CNTCOS(2)+58.
C
C  AUXILIARY COSTS
C
        IF(DCOOL.LT.34500.0) AUXCOS(2)=119.
        IF(DCOOL.GT.34500.0.AND.DCOOL.LE.58000.) AUXCOS(2)=148.
        AUXCOS(2)=AUXCOS(2)+ELECMP(JELE)
C
C  COST OF HOT WATER HEATER-52 GALLON CAPACITY
C
        HWTCOS(2)=200.
C
C  COST OF DUCTS
C
        DO 130 J=1,9
        IF(DCAP.LE.DUCTS(1,J)) GO TO 140
130     CONTINUE
        PRINT 1200,DCAP
140     IF(J.EQ.1) DUCCOS(2)=DUCTS(2,J)
        IF(J.EQ.1) GO TO 150
C
C  INTERPOLATE TO FIND COST
C
        DUCCOS(2)=DUCTS(2,J-1)+(DCAP-DUCTS(1,J-1))/
     >          (DUCTS(1,J)-DUCTS(1,J-1))*(DUCTS(2,J)-DUCTS(2,J-1))
C
C  INSTALLATION COST
C
150     INSCOS(2)=INSCOS(1)
        SYSCOS(2)=FANCOS(2)+AHPCOS(2)+CNTCOS(2)+AUXCOS(2)+HWTCOS(2)+
     >            DUCCOS(2)+INSCOS(2)
C
```

```
C
C  HEAT PUMP WITH DESUPER HOT WATER HEATER
C
C
C  FAN COST
C
      FANCOS(3)=FANCOS(2)
C
C  COST OF HEAT PUMP
      AHPCOS(3)=AHPCOS(2)
C
C  COST OF CONTROLS
C
      CNTCOS(3)=CNTCOS(2)
C
C  AUXILIARY COSTS
C  $400 COST ON DESUPER HEATER PACKAGE BASED ON INDEPENDENT
C  MANUFACTOR SELLING PRICE.
C
      AUXCOS(3)=AUXCOS(2)+400.
C
C  COST OF HOT WATER HEATER-82 GALLON CAPACITY
C
      HWTCOS(3)=240.
C
C  COST OF DUCTS
C
      DUCCOS(3)=DUCCOS(2)
C
C  INSTALLATION COST
C  $100 COST ON DESUPER HEATER PACKAGE BASED ON CONTRACTORS ESTIMATE
C
      INSCOS(3)=INSCOS(2)+100.
      SYSCOS(3)=FANCOS(3)+AHPCOS(3)+CNTCOS(3)+AUXCOS(3)+HWTCOS(3)+
     >          DUCCOS(3)+INSCOS(3)
      RETURN
      END
      SUBROUTINE DATAIN
      LOGICAL OPT1,OPT2
      COMMON/DAT/HWT(4),TICE(7),AREA(9),RAB,WAB,RR,WR,HO,SF,GLASS,
     >       PANES,SUP,PSIDES,PDELT,TILT,TSW,TSS,GAL(12),COPCHT,
     >       COPCBR,COPCHW,COPHT,COPIM,COPCW,COPBR,COPHW,EC,EF,EHB,
     >       ECB,EOF,EHW,OPT1,OPT2,COP47,COP17,IPRT
      COMMON/BINS/CITY(10),ZONE,DD(2),ALAT,NINV(12),T(12,40),
     >       H(12,40,2),HBR(12),VAV(12),TAV(12),WB(12,40),
     >       ALONG,ELEV,ELECOS
      COMMON/HOUS/LABEL(50,5),XNS,ARCHG,VOL,VAR(50,5),U(50),DT(50),
     >       HL(50),SM,UA,UFLOOR,DCOOL,DHEAT,BCAP,PAN(12,15)
      COMMON/QLOAD/SOL(12,10),SHG(12),QH(12),QC(12),QW(12),
     >       TITLE(18),SOP(12),MON(12),XNFIL(12),SO(12),TH(12),
     >       TG(12,7),DTH(7),HRSPAN(12),HFLOOR(12),CFLOOR(12)
      COMMON/RICE/ISYS,RATEDC,RATEFL,RATEKW,KWFLAG,YRS,CSTCOL,CSTINS,
     >       CSTCOI,THKSD,THKBTM,THKTP
C
C  INPUT DATA
```

```
C
C     DD(1) = DESIGN DAY TEMPERATURE WINTER  (F)
C     DD(2) = DESIGN DAY TEMPERATURE SUMMER (F)
C     DHEAT = DESIGN DAY HEAT LOSS WINTER  (BTUH/HR)
C     SUP = SUPPRESSION FACTOR FOR UA
C     PSIDES = NUMBER OF SIDES PANEL FOR CONVECTION
C     PDELT = SOLAR PENEL EXCHANGER DELTA TEMPERATURE (F)
C     TSW = HOUSE TEMPERATURE SETTING WINTER (F)
C     TSS = HOUSE TEMPERATURE SETTING SUMMER (F)
C     AREA(1) = NORTH FACING WINDOW AREA (FT**2)
C     AREA(2) = EAST FACING WINDOW AREA (FT**2)
C     AREA(3) = SOUTH FACING WINDOW AREA (FT**2)
C     AREA(4) = WEST FACING WINDOW AREA (FT**2)
C     AREA(5) = NORTH FACING WALL AREA (FT**2)
C     AREA(6) = EAST FACING WALL AREA (FT**2)
C     AREA(7) = SOUTH FACING WALL AREA (FT**2)
C     AREA(8) = WEST FACING WALL AREA (FT**2)
C     AREA(9) = EQUIVALENT FLAT ROOF AREA (FT**2)
C     SF = WINDOW SHADING FACTOR (CURTAINS, BLINDS, ETC.)
C     WAB = WALL SURFACE ABSORPTANCE
C     RAB = ROOF SURFACE ABSORPTANCE
C     TICE(1) = ICE STORAGE TANK HEIGHT (FT)
C     TICE(2) = DEPTH BELOW GROUND SURFACE (FT)
C     TICE(3) = TES TANK TOP R-VALUE
C     TICE(4) = TES TANK SIDES R-VALUE
C     TICE(5) = TES TANK BOTTOM R-VALUE
C     TICE(6) = ICE PACKING FRACTION FOR BRINE CHILLER
C     TICE(7) = ICE PACKING FRACTION FOR ICE MAKER
C     GLASS = GLASS TYPE
C     PANES = NO. OF PANES (SINGLE OR DOUBLE GLAZING)
C     HO = OUTDOOR FILM COEFFICIENT
C     RR = ROOF THERMAL RESISTANCE (FOR INSOLATION CALC.)
C     WR = WALL THERMAL RESISTANCE (FOR INSOLATION CALC.)
C     HWT(1) = HOT WATER TANK AREA (FT**2)
C     HWT(2) = HOT WATER TANK U(BTU/HR*FT**2-F)
C     HWT(3) = HOT WATER STORAGE TEMPERATURE (F)
C     HWT(4)= HOT WATER DELIVERY EFFICIENCY
C     IPRT = 0 GIVES BASIC OUTPUT
C     IPRT = 1 GIVES ECONOMIC OUTPUT
C     ISYS = 1 FOR BRINE CHILLER SYSTEM
C     ISYS = 2 FOR ICE MAKER SYSTEM
C     RATED = DISCOUNT RATE
C     RATEFL = ESCALATION RATE OF ELEC.
C     RATEKW = RATE PER KILOWATT-HR OF ELEC.(INPUT 0
C              TO PICK UP RATES FOR EACH CITY)

C     YRS = LIFETIME OF THE SYSTEM (YRS)
C     CSTCOL = UNIT COST OF COLLECTOR
C     CSTINS = UNIT COST OF INSULATION
C     CSTCOI = UNIT COST OF COIL
C     THKSD = SIDE INSULATION THICKNESS (IN)
C     THBTM = BOTTOM INSULATION THICKNESS (IN)
C     THKTP = TOP INSULATION THICKNESS (IN)
C     COPHT = ACES HEATING COP AT 32 F TANK
C     COPIM = ACES COOLING COP IN ICE MELT PHASE
```

```
C      COPCW = ACES COOLING COP IN CHILLED WATER PHASE
C      COPHW = ACES COP FOR HOT WATER ONLY
C      COPCHT = ACES COMPRESSOR COP HEATING PHASE
C      COPCBR = ACES COMPRESSOR COP COOLING PHASE
C      COPCHW = ACES COPRESSOR COP HOT WATER PHASE
C      COPBR = ACES COP FOR REMOVAL OF BIN HEAT AT NIGHT
C      EC = ACES HEAT PUMP COMPRESSOR MOTOR (WATTS)
C      EF = ACES INDOOR FAN COIL MOTOR (WATTS)
C      EHB = ACES HOT BRINE PUMP MOTOR (WATTS)
C      ECB = ACES COLD BRINE PUMP MOTOR (WATTS)
C      EOF = ACES OUTDOOR FAN MOTOR (WATTS)
C      EHW = HOT WATER CIRCULATING PUMP (WATTS)
C      COP47 = COP FOR HEAT PUMP AT 47F
C      COP17 = COP FOR HEAT PUMP AT 17F
C
        READ(5,190) TITLE
190     FORMAT(18A4)
        READ(5,180) IPRT,ISYS
180     FORMAT(2I10)
C
C  READ HOT WATER TANK DATA
C
        READ(5,200) HWT
200     FORMAT(8F10.0)
        READ(5,200) GAL
C
C  READ ICE TANK DATA
C
        READ(5,200) TICE
C
C  READ ECONOMIC DATA
C
        READ(5,200) RATEDC,RATEFL,RATEKW,YRS
        IF(RATEKW.EQ.0.0) KWFLAG=0
        IF(RATEKW.NE.0.0) KWFLAG=1
        READ(5,200) CSTCOL,CSTINS,CSTCOI,THKSD,THKBTM,THKTP
C
C  READ ACES COPS AND PUMP ENERGIES AND
C    COPS FOR HEAT PUMP
C
        READ(5,200) COPCHT,COPCBR,COPCHW,COPHT,COPIM,COPCW,COPBR,COPHW
        READ(5,200) EC,EF,EHB,ECB,EOF,EHW,COP47,COP17
        OPT1=.FALSE.
        IF(COPHT.NE.0.0.AND.COPIM.NE.0.0) OPT1=.TRUE.
        OPT2=.FALSE.
        IF(EC.NE.0.0.AND.EF.NE.0.0.AND.EHB.NE.0.0.AND.ECB.NE.0.0)
     >     OPT2=.TRUE.
        EC=EC*3412.
        EF=EF*3412.
        EHB=EHB*3412.
        ECB=ECB*3412.
        EOF=EOF*3412.
        EHW=EHW*3412.
C
C  READ SUPPRESS FACTOR, NUMBER OF PANEL SIDES, AND PANEL EXCHANGER
```

```
C   DELTA T.
C
        READ(5,200) SUP,PSIDES,PDELT
C
C  READ INTERNAL SOURCES
C
        READ(5,200) SO
C
C  READ DATA ABOUT HOUSE CONSTRUCTION
C
        READ(5,200) (AREA(I),I=1,8)
        READ(5,200) AREA(9),WAB,RAB,WR,RR,HO
        READ(5,200) SF,GLASS,PANES,TSW,TSS
        READ(5,200) XNS,ARCHG,VOL
        NS=XNS
        DO 10 J=1,NS
        READ(5,220) (LABEL(J,I),I=1,5),(VAR(J,I),I=1,5)
220     FORMAT(5A4,5F10.2)
10      CONTINUE
C
C  CALCULATE HEAT LOSS (BTU/HR) BASED ON 50 DEGREE TEMPERATURE DIFFERENCE
C
        SM=0.0
        DO 40 J=1,NS
        JAY=J
        UR=0.0
        DO 20 K=2,4
        IF(VAR(J,K).NE.0.0) UR=UR+1./VAR(J,K)
20      CONTINUE
        U(J)=1./UR
        IF(JAY.EQ.NS) GO TO 30
        DT(J)=VAR(J,5)*50.
        HL(J)=U(J)*VAR(J,1)*DT(J)
        SM=SM+HL(J)
30      IF(JAY.EQ.NS) UFLOOR=U(J)*VAR(J,1)
40      CONTINUE
        RETURN
        END
        SUBROUTINE DIGEST(*)
        DIMENSION VOLM(2),ENSUP(5),COPFAC(76)
        COMMON/EDIG/ACESEU(12,2)
        COMMON/HPUMP/COPH(76),AUX(12),ENGHP(12),CCOP,HCOP,SCOP
        LOGICAL OPT1,OPT2
        COMMON/DAT/HWT(4),TICE(7),AREA(9),RAB,WAB,RR,WR,HO,SF,GLASS,
     >        PANES,SUP,PSIDES,PDELT,TILT,TSW,TSS,GAL(12),COPCHT,
     >        COPCBR,COPCHW,COPHT,COPIM,COPCW,COPBR,COPHW,EC,EF,EHB,
     >        ECB,EOF,EHW,OPT1,OPT2,COP47,COP17,IPRT
        COMMON/BINS/CITY(10),ZONE,DD(2),ALAT,NINV(12),T(12,40),
     >        H(12,40,2),HBR(12),VAV(12),TAV(12),WB(12,40),
     >        ALONG,ELEV,ELECOS
        COMMON/DIG/TVOL(5),PAREA(5),SYSKW(5),BTEMP(12,5),BLEAK(12,5),
     >        PCOL(12,5),BICE(12,5),IRUN,TBLEAK(12),SILEAK(12)
        COMMON/HOUS/LABEL(50,5),XNS,ARCHG,VOL,VAR(50,5),U(50),DT(50),
     >        HL(50),SM,UA,UFLOOR,DCOOL,DHEAT,BCAP,PAN(12,15)
        COMMON/QLOAD/SOL(12,10),SHG(12),QH(12),QC(12),QW(12),
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     >        TITLE(18),SOP(12),MON(12),XNFIL(12),SO(12),TH(12),
     >        TG(12,7),DTH(7),HRSPAN(12),HFLOOR(12),CFLOOR(12)
      COMMON/RICE/ISYS,RATEDC,RATEFL,RATEKW,KWFLAG,YRS,CSTCOL,CSTINS,
     >        CSTCOI,THKSD,THKBTM,THKTP
C
C  THIS SUBROUTINE CALCULATES BIN SIZE, PANEL AREA, AND
C  ENERGY CONSUMPTION FOR ACES
C
C  TCAP = LATENT AND SENSIBLE ENERGY CAPACITY OF BIN
C  QBIN = INSTANTOUS ENERGY CONTENT OF BIN
C  QLK = BIN ENERGY LEAKAGE
C  BIN = CHANGE IN ENERGY CONTENT IN ONE TIME INCREMENT
C
C  SYSKW = TOTAL ACES ENERGY IN BTU
C  ENSUP = SUPPLEMENTAL COOLING ENERGY IN BTU
C  PAREA = PANEL AREA
C  TVOL = BIN VOLUME
C  ACESEU = MONTHLY ACES ENERGY IN BTU
C  BTEMP = MONTHLY AVERAGE BIN TEMPERATURE
C  BLEAK = MONTHLY BIN LEAKAGE IN BTU
C  PCOL = MONTHLY PANEL COLLECTION IN BTU
C
      RT= TICE(3)
      RS= TICE(4)
      RB= TICE(5)
      HT= TICE(1)
C
C  ISYS=1 MEANS BRINE CHILLER   ISYS=2 MEANS ICE MAKER
C
      IF(ISYS.EQ.1) PF= TICE(6)
      IF(ISYS.EQ.2) PF=TICE(7)
      TMX = 45.0
      ALPCW=1.0871
      ALPHW=0.663
      IF(OPT1) GO TO 20
      IF(OPT2) GO TO 10
C
C  CALCULATE EC,EF,EHB,ECB
C
      EC=0.3333*DHEAT
      EF=0.06*DHEAT
      ECB=0.018*DHEAT
      EHB=0.025*DHEAT
      EOF=0.0436*DHEAT
      EHW=0.01*DHEAT
      ALPCW=(0.754*DHEAT+0.25*ECB)/(0.754*DHEAT-EF)
      ALPHW=(COPCHW*EC-0.25*ECB)/(EC*(1.+COPCHW))
C
C  CALCULATE COPS FROM MOTOR ENERGIES
C
10    COPHT=((1.+COPCHT)*EC+EF+EHB+0.75*ECB)/(EC+EF+EHB+ECB)
      COPIM=(1.051*DHEAT-EF)/(EF+ECB)
      COPCW=(0.754*DHEAT-EF)/(EF+ECB)
      COPHW=EC*(1.+COPCHW)/(EC+ECB+EHW)
      COPBR=(COPCBR*EC-0.25*ECB)/(EC+ECB+EHB+EOF)
```

```
C
C  CALCULATE ACES COP ADJUSTMENT FACTOR FROM COPHT
C
20      J=32.0+11.5
        ACOPF=COPHT/COPH(J)
        DO 30 J=1,76
        COPFAC(J)=COPH(J)*ACOPF
30      CONTINUE
C
C  VMIN = VOLUME OF ICE FORMED IN 2 WEEKS IN JAN.
C
        VMIN= (QH(1)+QW(1))*.5*(COPFAC(43)-1.)/
     >        COPFAC(43)/(57.0*PF*144.)
C
        IRUN=0
        NTIME=4
C
C     ------------------------------------------------------------------
C     VOLM(1)= NEEDED ICE VOLUME,  VOLM(2)= FORMABLE ICE VOLUME
C     ------------------------------------------------------------------
C
C
        DO 100 J=1,2
        VOLM(J)=1.0
        DO 90 ITER=1,500
        VTES=VOLM(J)
        TP=VTES/HT
        SD=4.0*SQRT(VTES*HT)
        TEM= 32.0
        TCAP= 57.0*PF*VTES*(144.0+TMX-32.0)+(1.-PF)*VTES*62.4*(TMX-32.)
        TCAPL=57.0*PF*VTES*144.0
        QBIN=TCAP
        DO 40 I=1,12
        M=I
        IF(J.EQ.2) M=8-I
        IF(M.LE.0) M=M+12
        DO 40 JJ=1,NTIME
        NT= TEM+11.5
        TCF= (TG(M,1)-TEM)/RT
        BCF= (TG(M,2)-TEM)/RB
        SCF= (TG(M,3)-TEM)/RS
        QLK= (TP*(TCF+BCF)+SD*SCF)*TH(M)
        BIN= QLK+(QH(M)+QW(M))*(1.-COPFAC(NT))/COPFAC(NT)+QC(M)*
     >      (COPCW+1.)/COPCW
        BIN=BIN/NTIME
        IF(J.EQ.2) BIN=-BIN
        IF(BIN.LE.0.0) GO TO 40
        QBIN= QBIN-BIN
        TEM=32.0+(QBIN-TCAPL)/(TCAP-TCAPL)*(TMX-32.0)
        IF(QBIN.LE.TCAPL) TEM=32.0
        IF(TEM.GT.45.0) TEM= 45.0
        IF(TEM.LT.32.0) TEM= 32.0
40      CONTINUE
C  FIRST ITERATION
        IF(VTES.GT.1.0) GO TO 50
```

```
      VOLM(J)=VOLM(J)+100.
      GO TO 90
C  CONTINUE TO MAKE VOLUME LARGER IF QBIN IMPROVING
50    IF(QBIN.GT.0.0) GO TO 60
      VOLM(J)=VOLM(J)+100.
      GO TO 90
C  CHANGE IN SIGN OF QBIN-USE BISECTION TO FIND ROOT
60    VL=VTES-100
      VR=VTES
70    VTES=(VL+VR)*0.5
      VOLM(J)=VTES
      TP=VTES/HT
      SD=4.0*SQRT(VTES*HT)
      TEM= 32.0
      TCAP= 57.0*PF*VTES*(144.0+TMX-32.0)+(1.-PF)*VTES*62.4*(TMX-32.)
      TCAPL=57.0*PF*144.0*VTES
      QBIN=TCAP
      DO 80 I=1,12
      M=I
      IF(J.EQ.2) M=8-I
      IF(M.LE.0) M=M+12
      DO 80 JJ=1,NTIME
      NT= TEM+11.5
      TCF= (TG(M,1)-TEM)/RT
      BCF= (TG(M,2)-TEM)/RB
      SCF= (TG(M,3)-TEM)/RS
      QLK= (TP*(TCF+BCF)+SD*SCF)*TH(M)
      BIN= QLK+(QH(M)+QW(M))*(1.-COPFAC(NT))/COPFAC(NT)+QC(M)*
     >       (COPCW+1.)/COPCW
      BIN=BIN/NTIME
      IF(J.EQ.2) BIN=-BIN
      IF(BIN.LE.0.0) GO TO 80
      QBIN= QBIN-BIN
      TEM=32.0+(QBIN-TCAPL)/(TCAP-TCAPL)*(TMX-32.0)
      IF(QBIN.LE.TCAPL) TEM=32.0
      IF(TEM.GT.45.0) TEM= 45.0
      IF(TEM.LT.32.0) TEM= 32.0
80    CONTINUE
      IF(VTES-VL.LE.VTES*.0001) GO TO 100
      IF(QBIN.LE.0.0) VL=VTES
      IF(QBIN.GT.0.0) VR=VTES
      GO TO 70
90    CONTINUE
100   CONTINUE
      VLM= VOLM(2)
      IF(VOLM(1).LT.VOLM(2)) VLM= VOLM(1)
C
C     ------------------------------------------------------------------
C     SOLAR PANEL OPERATION BEGINS AT MONTH  (MM+1)
C     ------------------------------------------------------------------
C
110   TP= VLM/HT
      SD= 4.0*SQRT(VLM*HT)
      TCAP= 57.0*PF*VLM*(144.+TMX-32.)+(1.-PF)*VLM*62.4*(TMX-32.)
      TCAPL=57.0*PF*144.0*VLM
```

```
      NTMX= TMX+11.5
C
      MM=0
      DO 120 M=1,12
      TCF= (TG(M,1)-TMX )/RT
      BCF= (TG(M,2)-TMX )/RB
      SCF= (TG(M,3)-TMX )/RS
      QLK= (TP*(TCF+BCF)+SD*SCF)*TH(M)
      BIN= QLK+(QH(M)+QW(M))*(1.-COPFAC(NTMX))/COPFAC(NTMX)+QC(M)*
     >     (COPCW+1.)/COPCW
      IF(BIN.GT.0.0) MM=M
120   CONTINUE
C
C     ------------------------------------------------------------------
C     SIZE SOLAR PANEL AND COMPUTE ENERGY CONSUMPTION
C     ------------------------------------------------------------------
C
      ARE= 0.0
      IRUN=IRUN+1
      NTIME=4
C
      DO 150 ITER=1,100
      ETOT= 0.0
      ESUP= 0.0
      TEM= TMX
      QBIN=TCAP
      QMIN=TCAP
      FULPAN=0.0
C
      DO 140 I=1,12
      M= MM+I
      IF(M.GT.12)M=M-12
      BTEMP(M,IRUN)=0.0
      BLEAK(M,IRUN)=0.0
      PCOL(M,IRUN)=0.0
      BICE(M,IRUN)=0.0
      ACESEU(M,IRUN)=0.0
      DO 140 JJ=1,NTIME
      NT= TEM+11.5
      MT=TEM-30.5
      TCF= (TG(M,1)-TEM)/RT
      BCF= (TG(M,2)-TEM)/RB
      SCF= (TG(M,3)-TEM)/RS
      QLK= (TP*(TCF+BCF)+SD*SCF)*TH(M)/NTIME
      BIN = QLK+(QH(M)+QW(M))/NTIME*(1.-COPFAC(NT))/COPFAC(NT)+
     >      QC(M)/NTIME*(COPCW+1.)/COPCW
      CMX= ARE*PAN(M,MT)/NTIME
      COL=0.0
      IF(BIN.LT.0.0) COL=AMIN1(CMX,-BIN)
      IF(COL.EQ.CMX) FULPAN=FULPAN+PAN(M,MT)/NTIME
      QBIN= QBIN+BIN+COL
      IF(QBIN.LT.QMIN) QMIN=QBIN
      ECOL=0.0
      IF(CMX.NE.0.0)  ECOL=COL/CMX*(HRSPAN(M)/NTIME*.021*
     >                (AMAX1(DCOOL,DHEAT)))
```

```
      IF(QW(M).LT.QH(M)) ENERGY= (QH(M)+QW(M))/(NTIME*COPFAC(NT))+
     >                          QC(M)/(NTIME*COPIM)+ECOL
      IF(QW(M).GE.QH(M)) ENERGY=QH(M)/(NTIME*COPFAC(NT))+
     >                QW(M)/(NTIME*COPHW)+ QC(M)/(NTIME*COPIM)+ECOL
      IF(QBIN.LT.TCAP.OR.QC(M).LE.0.0)  GO TO 130
C
C  SUPPLEMENTAL COOLING MODE
C
      QBIN=TCAP
      IF(1.EQ.0) QC(M)=1.0
C  THE ABOVE STATEMENT KEEPS OPTIMIZING COMPLIER FROM CALCULATING
C  TERMK TO SOON AND GETTING DIVIDE BY ZERO
      TERMK=ALPCW+QLK/QC(M)/NTIME-ALPHW*((QH(M)+QW(M))/QC(M))
      COPSC=(COPCW**(-1)+TERMK*COPBR**(-1))**(-1)
      ENERGY=QH(M)/(NTIME*COPFAC(NT))+QW(M)/(NTIME*COPHW)+
     >      ECOL+QC(M)/(NTIME*COPSC)
      ESUP= ESUP+QC(M)/(NTIME*COPSC)
130   ETOT= ETOT+ENERGY
      ACESEU(M,IRUN)=ACESEU(M,IRUN)+ENERGY
      BTEMP(M,IRUN)= TEM/NTIME+BTEMP(M,IRUN)
      BLEAK(M,IRUN)= QLK+BLEAK(M,IRUN)
      PCOL(M,IRUN)= COL+PCOL(M,IRUN)
      IF(QBIN.GT.TCAPL) BICE(M,IRUN)=0.0
      IF(QBIN.LE.TCAPL) BICE(M,IRUN)=(TCAPL-QBIN)/(144.0*57.0)
      TEM=32.0+(QBIN-TCAPL)/(TCAP-TCAPL)*(TMX-32.0)
      IF(QBIN.LE.TCAPL) TEM=32.0
      IF(TEM.GT.45.) TEM=45.
      IF(TEM.LT.32.) TEM=32.
140   CONTINUE
C
      IF(ABS(QMIN/TCAP).LT.0.0001) GO TO 160
      IF(VLM.EQ.VOLM(2)) GO TO 160
      IF(FULPAN.EQ.0.0) GO TO 180
      ARE=ARE-QMIN/FULPAN
150   CONTINUE
C
160   SYSKW(IRUN)= ETOT
      ENSUP(IRUN)= ESUP
      PAREA(IRUN)= ARE
      IF(PAREA(IRUN).LT.10.0) PAREA(IRUN)=0.0
      TVOL(IRUN)=VLM
C  CALCULATE HEAT LEAKAGE COEFFICIENTS AT 32 DEG TANK TEMP
      DO 170 M=1,12
      SILEAK(M)=((TG(M,3)-32.0)/RS)*TH(M)
      TBLEAK(M)=((TG(M,1)-32.0)/RT+(TG(M,2)-32.0)/RB)*TH(M)
      SILEAK(M)=SILEAK(M)/1000.
      TBLEAK(M)=TBLEAK(M)/1000.
170   CONTINUE
      IF(IRUN .EQ. 1) VLM =VMIN
      IF(IRUN .EQ. 2) GO TO 190
      GO TO 110
180   PRINT 310, CITY
310   FORMAT('1',10A4,'FULL PANEL = 0')
      RETURN1
190     RETURN
```

```
      END
      SUBROUTINE EARTH(T)
C
C  PROGRAM TO CALCULATE EARTH TEMPERATURE FROM AIR TEMPERATURE
C  ADAPTED FROM 'EARTH TEMPERATURE AND THERMAL DIFFUSIVITY AT SELECTED
C  STATTIONS IN THE UNITED STATES' BY T. KUSUDA AND P.R.ACHENBACH
C
      LOGICAL OPT1,OPT2
      COMMON/DAT/HWT(4),TICE(7),AREA(9),RAB,WAB,RR,WR,HO,SF,GLASS,
     >       PANES,SUP,PSIDES,PDELT,TILT,TSW,TSS,GAL(12),COPCHT,
     >       COPCBR,COPCHW,COPHT,COPIM,COPCW,COPBR,COPHW,EC,EF,EHB,
     >       ECB,EOF,EHW,OPT1,OPT2,COP47,COP17,IPRT
      COMMON/QLOAD/SOL(12,10),SHG(12),QH(12),QC(12),QW(12),
     >       TITLE(18),SOP(12),MON(12),XNFIL(12),SO(12),TH(12),
     >       TG(12,7),DTH(7),HRSPAN(12),HFLOOR(12),CFLOOR(12)
      COMMON/LEAST/A,B,P
      COMMON/EQU/DT
      DIMENSION T(12),MHR(12)
      DATA MHR/744,672,744,720,744,720,744,744,720,744,720,744/
      PI=3.141593
      D=0.025
C
C  LEAST SQUARE ANALYSIS FOR A,B,P
C
      CALL LSS(T)
      DT=SQRT(PI/(D*8766.))
C
C  PICK A DEPTH FOR INLET WATER SO THAT GROUND TEMPERATURE
C  IS 36 OR ABOVE.
C
      X=1.0
10    THR=0.0
      X=X+.5
      IF(X.GT.40.0) GO TO 70
      DO 20 K=1,12
      THR=THR+MHR(K)
      TG(K,4)=ET(THR,X)
      IF(TG(K,4).LT.36.0) GO TO 10
20    CONTINUE
      DTH(4)=X
      NDTH=5
      DTH(1)=TICE(2)
      DTH(2)=TICE(2)+TICE(1)
      DTH(3)=TICE(2)+TICE(1)/2.0
      DTH(5)=5.0
C
C  CALCULATE EARTH TEMPERATURES AT DESIRED DEPTHS
C
      DO 60 I=1,NDTH
      THR=0.0
      DO 50 K=1,12
      THR=THR+MHR(K)
      TG(K,I)=ET(THR,DTH(I))
50    CONTINUE
60    CONTINUE
```

```
      RETURN
70    PRINT 100
100   FORMAT('0FAILED TO FIND DEPTH FOR INLET',
     >        ' WATER IN SUBROUTINE EARTH')
      STOP
      END
      SUBROUTINE ENERGY
      COMMON/FRACS/ANHEAT,ANCOOL,ANWATR,ANLATN,RATIO
      COMMON/HPUMP/COPH(76),AUX(12),ENGHP(12),CCOP,HCOP,SCOP
      COMMON/ENG/ENGDS,ENGHPP,ENGEL,DSHPEU(12),HPEU(12),ELEU(12)
      COMMON/QLOAD/SOL(12,10),SHG(12),QH(12),QC(12),QW(12),
     >       TITLE(18),SOP(12),MON(12),XNFIL(12),SO(12),TH(12),
     >       TG(12,7),DTH(7),HRSPAN(12),HFLOOR(12),CFLOOR(12)
      COMMON/ELOAD/HPEUH(12),HPEUC(12)
      DIMENSION HPEUW(12)
C
C  THIS SUBROUTINE CALCULATES THE ENERGY USED IN A NON-ACES SYSTEM
C
C  ENGDS=YEARLY ENERGY USED BY HEAT PUMP WITH DESUPER WATER HEATER  (BTU)
C  ENGHPP=YEARLY ENERGY USED BY HEAT PUMP WITH I2R HOT WATER HEATER(BTU)
C  ENGEL=YEARLY ENERGY USED BY ELECTRIC HEAT AND AIR COND. (BTU)
C
C  HEAT PUMP WITH DESUPER WATER HEATER
      ENGDS=0.0
      TAUX=0.0
      THPEUH=0.0
      DO 20 M=1,12
      TAUX=TAUX+AUX(M)
      THPEUH=THPEUH+HPEUH(M)
20    CONTINUE
      HPCOP=(ANHEAT-TAUX)/(THPEUH-TAUX)
      DO 50 M=1,12
      DSHE=0.15*(QH(M)+QC(M)+HPEUC(M))
      HPEUW(M)=0.0
      IF(QC(M).GE.QH(M)) GO TO 30
C
C  HEATING SEASON
C
      IF(DSHE.GE.QW(M).AND.HPCOP.NE.0.0) HPEUW(M)=QW(M)/HPCOP
      IF(DSHE.LT.QW(M).AND.HPCOP.NE.0.0) HPEUW(M)=DSHE/HPCOP+
     >                          (QW(M)-DSHE)
      GO TO 40
C
C  COOLING SEASON
C
30    IF(DSHE.LT.QW(M)) HPEUW(M)=(QW(M)-DSHE)
C
C  MONTH AND YEARLY ENERGY FOR DESUPER HEATER SYSTEM
C
40    HPEUW(M)=HPEUW(M)+DSHE/20.
      DSHPEU(M)=HPEUC(M)+HPEUW(M)+HPEUH(M)
      ENGDS=ENGDS+DSHPEU(M)
50    CONTINUE
C
C  HEAT PUMP WITH I2R HOT WATER HEATER
```

```
C
        ENGHPP=0.0
        DO 60 M=1,12
        HPEU(M)=HPEUC(M)+HPEUH(M)+QW(M)
        ENGHPP=ENGHPP+HPEU(M)
60      CONTINUE
C
C  ELECTRIC HEAT WITH AIR CONDITIONER
C
        ENGEL=0.0
        DO 70 M=1,12
        ELEU(M)=QH(M)+QC(M)/CCOP+QW(M)
        ENGEL=ENGEL+ELEU(M)
70      CONTINUE
        RETURN
        END
        SUBROUTINE GLAZE(IGLASS,T,A,TD,AO,AI)
C
C  THIS SUBROUTINE IS CALLED BY TRNSMT
C
        DIMENSION T(6),A(6),TD(6),AO(6),AI(6),A1(48),T2(48),AO3(48),
     >            AI4(48),T5(48)
      DATA A1/0.01154,0.77674,-3.94657,8.57881,-8.38135,3.01188,0.01636,
     11.40783,-6.79030,14.37378,-13.83357,4.92439,0.01837,1.92497,
     2-8.89134,18.40197,-17.48648,6.17544,0.01902,2.35417,-10.47151,
     321.24322,-19.95978,6.99964,0.01712,3.50839,-13.86390,26.34330,
     4-23.84846,8.17372,0.01406,4.15958,-15.06279,27.18492,-23.88518,
     58.03650,0.01153,4.55946,-15.43294,26.70568,-22.87993,7.57795,
     60.00962,4.81911,-15.47137,25.86516,-21.69106,7.08714/
        DATA T2/-0.00885,2.71235,-0.62062,-7.07329,9.75995,-3.89922,
     1-0.01114,2.39371,0.42978,-8.98262,11.51798,-4.52064,-0.01200,
     22.13036,1.13833,-10.07925,12.44161,-4.83285,-0.01218,1.90950,
     31.61391,-10.64872,12.83698,-4.95199,-0.01056,1.29711,2.28615,
     4-10.37132,11.95884,-4.54880,-0.00835,0.92766,2.15721,-8.71429,
     59.87152,-3.73328,-0.00646,0.68256,1.82449,-6.95325,7.80647,
     6-2.94454,-0.00496,0.51403,1.47607,-5.41985,6.05546,-2.28162/
        DATA AO3/0.01407,1.06226,-5.59131,12.15034,-11.78092,4.20070,
     10.01819,1.86277,-9.24831,19.49443,-18.56094,6.53940,0.01905,
     22.47900,-11.74226,24.14037,-22.64299,7.89954,0.01862,2.96400,
     3-13.48701,27.13020,-25.11877,8.68895,0.01423,4.14384,-16.66709,
     431.30484,-27.81955,9.36959,0.01056,4.71447,-17.33454,30.91781,
     5-26.63898,8.79495,0.00819,5.01768,-17.21228,29.46388,-24.76915,
     68.05040,0.00670,5.18781,-16.84820,27.90292,-22.99619,7.38140/
        DATA AI4/0.00228,0.34559,-1.19908,2.22366,-2.05287,0.72376,
     10.00123,0.29788,-0.92256,1.58171,-1.40040,0.48316,0.00067,
     20.26017,-0.72713,1.14950,-0.97138,0.32705,0.00035,0.22974,
     3-0.58381,0.84626,-0.67666,0.22102,-0.00009,0.15049,-0.27590,
     40.25618,-0.12919,0.02859,-0.00016,0.10579,-0.15035,0.06487,
     50.02759,-0.02317,-0.00015,0.07717,-0.09059,0.00050,0.06711,
     6-0.03394,-0.00012,0.05746,-0.05878,-0.01855,0.06837,-0.03191/
        DATA T5/-0.00401,0.74050,7.20350,-20.11763,19.68824,-6.74585,
     1-0.00438,0.57818,7.42065,-20.26848,19.79706,-6.79619,-0.00428,
     20.45797,7.41367,-19.92004,19.40969,-6.66603,-0.00401,0.36698,
     37.27324,-19.29364,18.75408,-6.43968,-0.00279,0.16468,6.17715,
     4-15.84811,15.28302,-5.23666,-0.00192,0.08180,4.94753,-12.43481,
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     511.92495,-4.07787,-0.00136,0.04419,3.87529,-9.59069,9.16022,
     6-3.12776,-0.00098,0.02576,3.00400,-7.33834,6.98747,-2.38328/
        L=IGLASS*6
        K=L-5
        DO 100 M=1,6
        N=M-1
        A(M)=A1(K+N)
        T(M)=T2(K+N)
        AO(M)=AO3(K+N)
        AI(M)=AI4(K+N)
        TD(M)=T5(K+N)
100     CONTINUE
        RETURN
        END
         SUBROUTINE LOADS(*)
        COMMON/ELOAD/HPEUH(12),HPEUC(12)
        COMMON/HPUMP/COPH(76),AUX(12),ENGHP(12),CCOP,HCOP,SCOP
        COMMON/FRACS/ANHEAT,ANCOOL,ANWATR,ANLATN,RATIO
        LOGICAL OPT1,OPT2
        COMMON/DAT/HWT(4),TICE(7),AREA(9),RAB,WAB,RR,WR,HO,SF,GLASS,
     >        PANES,SUP,PSIDES,PDELT,TILT,TSW,TSS,GAL(12),COPCHT,
     >        COPCBR,COPCHW,COPHT,COPIM,COPCW,COPBR,COPHW,EC,EF,EHB,
     >        ECB,EOF,EHW,OPT1,OPT2,COP47,COP17,IPRT
        COMMON/BINS/CITY(10),ZONE,DD(2),ALAT,NINV(12),T(12,40),
     >        H(12,40,2),HBR(12),VAV(12),TAV(12),WB(12,40),
     >        ALONG,ELEV,ELECOS
        COMMON/DIG/TVOL(5),PAREA(5),SYSKW(5),BTEMP(12,5),BLEAK(12,5),
     >        PCOL(12,5),BICE(12,5),IRUN,TBLEAK(12),SILEAK(12)
        COMMON/HOUS/LABEL(50,5),XNS,ARCHG,VOL,VAR(50,5),U(50),DT(50),
     >        HL(50),SM,UA,UFLOOR,DCOOL,DHEAT,BCAP,PAN(12,15)
        COMMON/QLOAD/SOL(12,10),SHG(12),QH(12),QC(12),QW(12),
     >        TITLE(18),SOP(12),MON(12),XNFIL(12),SO(12),TH(12),
     >        TG(12,7),DTH(7),HRSPAN(12),HFLOOR(12),CFLOOR(12)
        DIMENSION CAP(76),QBINH(2),QBINC(2)
        DATA CAP/3*10.0,5*10.5,5*12.5,5*14.6,5*17.5,5*21.0,5*24.0,
     >           5*27.5,5*30.5,5*34.0,5*37.0,5*40.5,5*43.5,5*45.7,
     >           5*47.6,3*49.5/
C
C  THIS SUBROUTINE CALCULATES MONTHLY HOT WATER, HEATING,
C  AND COOLING LOADS USING BIN WEATHER DATA.
C
C
C
C
C     C1 = (3 PEOPLE * 200 BTU/PERSON/HR / 1094 BTU/# OF WATER) * 0.5
C     C2 = (3 PEOPLE * 200 BTU/PERSON/HR / 1094 BTU/# OF WATER) * 0.75
C     WD = DESIGN HUMIDITY RATIO
C     WI = INDOOR HUMIDITY RATIO
C     WO = OUTDOOR HUMIDITY RATIO
C     XNFIL = MONTHLY INFILTRATION
C     QH = MONTHLY HEATING LOAD
C     QC = MONTHLY COOLING LOAD
C     QW = MONTHLY HOT WATER LOAD
C     ANHEAT = ANNUAL HEATING LOAD
C     ANCOOL = ANNUAL COOLING LOAD
```

```
C     ANLATN = ANNUAL LATENT COOLING LOAD
C     ANWATR = ANNUAL HOT WATER LOAD
C     ANPWHR = ANNUAL POWER FOR AIR TO AIR HEAT PUMP
C     CCOP = ANNUAL COOLING COP FOR AIR TO AIR HEAT PUMP
C     HCOP = ANNUAL HEATING COP FOR AIR TO AIR HEAT PUMP
C     SCOP = ANNUAL COP FOR AIR TO AIR HEAT PUMP
C     HPCAPF = HEAT PUMP CAPACITY ADJUSTMENT FACTOR
C     HPCOPF = HEAT PUMP COP ADJUSTMENT FACTOR
C
C     DD(1) = DESIGN DAY TEMPERATURE, WINTER
C     DD(2) = DESIGN DAY TEMPERATURE, SUMMER
C     DHEAT = DESIGN DAY HEATING LOAD
C     DCOOL = DESIGN DAY COOLING LOAD
C     SUP = SUPPRESSION FACTOR
C     TSS = HOUSE TEMPERATURE SETTING,SUMMER
C     TSW = HOUSE TEMPERATURE SETTING, WINTER
C     UFLOOR = UA (FLOOR)
C     UA = UA (WALLS,WINDOWS,DOORS AND CEILINGS)
C     BCAP = BLOWER CAPACITY (CFM)
C     ARCHG = NUMBER OF AIR CHANGES PER HOUR
C     VOL = NUMBER OF CUBIC FEET PER AIR CHANGE
C     HPEUH(M) = HEAT PUMP ENERGY FOR HEATING AND AUXILIARY ENERGY
C     HPEUC(M) = HEAT PUMP ENERGY FOR COOLING
C     AUX(M) = AUXILIARY ENERGY FOR HEATING
C
C
      C1=(3.*200./1094.)*0.5+5./24.
      C2=(3.*200./1094.)*0.75+5./24.
      PB=29.92
      C=ARCHG*VOL/.695
      CALL PSY1(TSS,66.,PB,WD,V)
C
C
C
      CONST=(1.08*ARCHG*VOL)/(.695*60.)
C
C
C  CALCULATE UA AND DESIGN DAY LOADS
C
      UA=(SM/50.)*SUP
      WINF=CONST*(.15+.013*15.0+.005*(TSW-DD(1)))
      SINF=CONST*(.15+.013*7.5+.005*(DD(2)-TSS))
      DHEAT=(UA+WINF)*(TSW-DD(1))+UFLOOR*(TSW-TG(1,5))
      DCOOL=(UA+SINF)*(DD(2)-TSS)-UFLOOR*(TSS-TG(8,5))+SOP(8)+
     >      SHG(8)+SO(8)
      DCOOL=1.3*DCOOL
C
C  ESTIMATE REQUIRED BLOWER CAPACITY                        (CFM)
C
      CAPH= DHEAT/(1.08*(95.0-TSW))
      CAPC= DCOOL/(1.08*(TSS-50.0))
      IF(CAPC.GT.CAPH) CAPH=CAPC
      M= (CAPH+25.0)/50.0
      BCAP= 50*M
C
```

```
C  ADJUST COOLING COP TO MODEL HEAT PUMP SPECIFIED BY USER
C  WITH 14% CYCLING LOSS AS CONSTANT.
C  2.88 IS COP OF ARRAY COPH AT 32 DEGREES.
C
   COPBAR=(COP17+COP47)/2.
        CCOP=2.4*0.86*COPBAR/2.88
        ANPWHP=0.0
        ANWATR=0.0
        ANHEAT=0.0
        ANCOOL=0.0
        ANLATN=0.0
        DO 100 M=1,12
C
C  CALCULATE MONTHLY INFILTRATION COEFFICIENT   (BTUH/F)
C
        XNFIL(M)= CONST*(.15+.013*VAV(M)+.005*ABS(TAV(M)-TSW))
        IF(XNFIL(M).EQ.0.0) GO TO 10
        TGRND= TG(M,5)
        HFLOOR(M)= UFLOOR*((TGRND+TSW)/2.0-TSW)
        CFLOOR(M)= UFLOOR*((TGRND+TSS)/2.0-TSS)
10      UAT= UA+XNFIL(M)
C
C  CALCULATE BALANCE TEMPERATURES
C
        TBALHD=TSW-(SOP(M)+SHG(M)+SO(M)+HFLOOR(M))/UAT
        TBALHN=TSW-(SO(M)+HFLOOR(M))/UAT
        TBALCD=TSS-(SOP(M)+SHG(M)+SO(M)+CFLOOR(M))/UAT
        TBALCN=TSS-(SO(M)+CFLOOR(M))/UAT
        IF(TBALCD.LT.65.) TBALCD=65.0
        IF(TBALCN.LT.65.) TBALCN=65.0
C
        AIRFLO=C*(.15+.013*VAV(M)+.005*ABS(TAV(M)-TSS))
        AUX(M)=0.0
        HPEUH(M)=0.0
        HPEUC(M)=0.0
        QH(M)=0.0
        QC(M)=0.0
        QW(M)=0.0
        SLATD=0.0
        SLATN=0.0
        SIZE=6000.*INT((DCOOL+6000.)/6000.)
        IEND=NINV(M)
        DO 80 I=1,IEND
        CALL PSY1(T(M,I),WB(M,I),PB,WO,V)
        AIRFLW=AIRFLO/V
        SATVH=.444*T(M,I)+1061.
C
C  CALCULATE HEATING LOAD FOR EACH TEMPERTURE BIN
C
        DO 20 J=1,2
        QBINH(J)=0.0
        QBINC(J)=0.0
20      CONTINUE
        IF(T(M,I).GT.TBALHD) GO TO 30
        QBINH(1)=(UAT*(TSW-T(M,I))-(SOP(M)+SHG(M)+SO(M)+HFLOOR(M)))
```

```
     >          *H(M,I,1)
30      IF(T(M,I).GT.TBALHN) GO TO 40
        QBINH(2)=(UAT*(TSW-T(M,I))-(SO(M)+HFLOOR(M)))*H(M,I,2)
C
C  CALCULATE COOLING LOADS AND LATENT COOLING LOAD
C  OF EACH TEMPERATURE BIN
C
40      IF(T(M,I).LT.TBALCD) GO TO 50
        QBINC(1)=(UAT*(T(M,I)-TSS)+SOP(M)+SHG(M)+SO(M)+CFLOOR(M))
     >          *H(M,I,1)
        WI=WO+C1/AIRFLW
        IF (WI .LE. WD) GO TO 50
        WLBHD=(WI-WD)*AIRFLW
        SLATD=SLATD+WLBHD*H(M,I,1)*SATVH
        QBINC(1)=QBINC(1)+WLBHD*H(M,I,1)*SATVH
50      IF(T(M,I).LT.TBALCN) GO TO 60
        QBINC(2)=(UAT*(T(M,I)-TSS)+SO(M)+CFLOOR(M))*H(M,I,2)
        WI=WO+C2/AIRFLW
        IF (WI .LE. WD) GO TO 60
        WLBHN=(WI-WD)*AIRFLW
        SLATN=SLATN+WLBHN*H(M,I,2)*SATVH
        QBINC(2)=QBINC(2)+WLBHN*H(M,I,2)*SATVH
60      QH(M)=QH(M)+QBINH(1)+QBINH(2)
C       PRINT 600, M,QH(M),QBINH
600     FORMAT('0',I5,3F15.2)
        QC(M)=QC(M)+QBINC(1)+QBINC(2)
C
C  CALCULATE AIR TO AIR HEAT PUMP ENERGY NEEDED
C
        NT=0.7406*T(M,I)-5.269+21.
        IF(NT.LT.1) NT=1
        IF(NT.GT.76) NT=76
C
C  CALCULATE CAPACITY ADJUSTMENT FACTOR FOR USER SPECIFIED
C  AIR-TO-AIR HEAT PUMP.  IF TEMPERATURE LESS THAN 40F,
C  8% LOSS DUE TO FROSTING IS APPLIED.
C
        HPCAPF=1.0-EXP(-1.2*(COPBAR-1.2))
   IF(T(M,I).LT.40.0) HPCAPF=HPCAPF*0.92
        HPCAP=(SIZE/30500.)*CAP(NT)
        HP=HPCAP*(H(M,I,1)+H(M,I,2))*1000.*HPCAPF
        AUXX=QBINH(1)+QBINH(2)-HP
C
C  ADJUST HEATING COP TO MODEL HEAT PUMP SPECIFIED BY USER.
C  FROSTING LOSS IS 8% WHEN TEMPERATURE IS BELOW 40F.
C  WHEN NO AUXILLARY HEATING IS NEEDED AN ADDITIONAL 15%
C  IS LOST DUE TO CYCLING.
C
   HPCOPF=COPBAR/2.88
   IF(T(M,I).LT.40.0) HPCOPF=HPCOPF*0.92
        IF(AUXX.GT.0) GO TO 70
        HP=QBINH(1)+QBINH(2)
        AUXX=0.0
   HPCOPF=HPCOPF*0.85
70      AUX(M)=AUX(M)+AUXX
```

```
      HPEUH(M)=HPEUH(M)+(HP/(COPH(NT)*HPCOPF))+AUXX
      HPEUC(M)=HPEUC(M)+((QBINC(1)+QBINC(2))/CCOP)
      ENGHP(M)=HPEUC(M)+HPEUH(M)
80    CONTINUE
C
C  ZERO SMALL LOADS
C
      IF(QC(M).EQ.0.0) GO TO 90
      IF(QH(M)/QC(M).LE.0.2) QH(M)=0.0
      IF(QH(M).EQ.0.0) GO TO 90
      IF(QC(M)/QH(M).LE.0.2) QC(M)=0.0
C
C  MONTHLY HOT WATER LOAD
C
C     HWT(1) = HOT WATER TANK SURFACE AREA
C     HWT(2) = U-VALUE OF HOT WATER TANK INSULATION
C     HWT(3) = HOT WATER STORAGE TEMPERATURE
C     HWT(4) = HOT WATER DELIVERY EFFICIENCY
C
C
90    CON=231.*62.4/(24.*1728.)
      QS=HWT(1)*HWT(2)*(HWT(3)-70.0)
      QW(M)=TH(M)*(GAL(M)*((HWT(3)-TG(M,4))*CON)+QS)/HWT(4)
C
      IF (M .EQ. 8) DLT=SLATD+SLATN
C
C  ANNUAL SUMS
C
      ANPWHP=ANPWHP+HPEUH(M)+HPEUC(M)
      ANHEAT=ANHEAT+QH(M)
      ANCOOL=ANCOOL+QC(M)
      ANWATR=ANWATR+QW(M)
      ANLATN=ANLATN+SLATD+SLATN
100   CONTINUE
      IF(ANHEAT.EQ.0.0) GO TO 110
      HCOP=ANHEAT/(ANPWHP-ANCOOL/CCOP)
      SCOP=(ANHEAT+ANCOOL+ANWATR)/(ANPWHP+ANWATR)
C  CORRECT DCOOL TO ACCOUNT FOR ACTUAL LATENT COOLING NEEDS
      IF(QC(8).NE.0.0) DCOOL=QC(8)*DCOOL/(1.3*(QC(8)-DLT))
      RATIO=ANCOOL/(ANCOOL-ANLATN)
      RETURN
110   PRINT 500, CITY
500   FORMAT('1',10A4,'  HEATING LOADS ARE ZERO')
      RETURN1
      END
      SUBROUTINE LSS(T)
C
C  SUBROUTINE TO DO LEAST SQUARE FIT ON T TO GET A,B,P
C  THIS IS USED IN COMBINATION WITH SUBROUTINE EARTH
C
      COMMON/LEAST/A,B,P
      DIMENSION T(12)
      PI=3.141593
      TERM1=0.0
      SUM=0.0
```

```
      TERM2=0.0
      DO 20 K=1,12
      SUM =SUM+T(K)
      WTH=PI*(K)/6.
      TERM1=T(K)*COS(WTH)+TERM1
      TERM2=T(K)*SIN(WTH)+TERM2
20    CONTINUE
      A=SUM/12.
      B=-2/12.*SQRT(TERM1*TERM1+TERM2*TERM2)
      ARG=TERM2/TERM1
      P=ATAN(ARG)
      RETURN
      END
      SUBROUTINE PANEL
      LOGICAL OPT1,OPT2
      COMMON/DAT/HWT(4),TICE(7),AREA(9),RAB,WAB,RR,WR,HO,SF,GLASS,
     >       PANES,SUP,PSIDES,PDELT,TILT,TSW,TSS,GAL(12),COPCHT,
     >       COPCBR,COPCHW,COPHT,COPIM,COPCW,COPBR,COPHW,EC,EF,EHB,
     >       ECB,EOF,EHW,OPT1,OPT2,COP47,COP17,IPRT
      COMMON/BINS/CITY(10),ZONE,DD(2),ALAT,NINV(12),T(12,40),
     >       H(12,40,2),HBR(12),VAV(12),TAV(12),WB(12,40),
     >       ALONG,ELEV,ELECOS
      COMMON/QLOAD/SOL(12,10),SHG(12),QH(12),QC(12),QW(12),
     >       TITLE(18),SOP(12),MON(12),XNFIL(12),SO(12),TH(12),
     >       TG(12,7),DTH(7),HRSPAN(12),HFLOOR(12),CFLOOR(12)
      COMMON/HOUS/LABEL(50,5),XNS,ARCHG,VOL,VAR(50,5),U(50),DT(50),
     >       HL(50),SM,UA,UFLOOR,DCOOL,DHEAT,BCAP,PAN(12,15)
C
C  THIS SUBROUTINE CALCULATES SOLAR PANEL HEAT PICKUP
C
C  PDELT = PANEL DELTA TEMPERATURE
C  PSIDES = NUMBER OF PANEL SIDES CONVECTIVE
C  VAV(M) = WIND SPEED FOR MONTH M
C  T(M,I) = TEMPERATURE FOR MONTH M AND BIN I
C  H(M,I,1) = BIN DAYLIGHT HOURS
C  H(M,I,2) = BIN NIGHT HOURS
C
      DO 100 NT=1,15
      DO 100 M=1,12
      PAN(M,NT)=0.
      TNXT=NT+31+PDELT
      UU = 0.912+0.409*VAV(M)
      FR= 0.941-0.028*UU
      HRSPAN(M)=0.0
      DO 100 I=1,40
      IF(T(M,I).LT.32.0) GO TO 100
     DY= FR*(.93*SOL(M,10)/8.0+PSIDES*UU*(T(M,I)-TNXT)-15.0)*H(M,I,1)
      IF(DY.LT.0.0) DY=0.0
      IF(DY.GT.0.0) HRSPAN(M)=HRSPAN(M)+H(M,I,1)
      DK= FR*(PSIDES*UU*(T(M,I)-TNXT)-15.0)*H(M,I,2)
      IF(DK.LT.0.0) DK=0.0
      IF(DK.GT.0.0) HRSPAN(M)=HRSPAN(M)+H(M,I,2)
      PAN(M,NT)= PAN(M,NT)+DY+DK
100   CONTINUE
C
```

```
      RETURN
      END
      SUBROUTINE PRTDAT
C
C  OUTPUTS INPUT DATA
C
      LOGICAL OPT1,OPT2
      COMMON/DAT/HWT(4),TICE(7),AREA(9),RAB,WAB,RR,WR,HO,SF,GLASS,
     >       PANES,SUP,PSIDES,PDELT,TILT,TSW,TSS,GAL(12),COPCHT,
     >       COPCBR,COPCHW,COPHT,COPIM,COPCW,COPBR,COPHW,EC,EF,EHB,
     >       ECB,EOF,EHW,OPT1,OPT2,COP47,COP17,IPRT
      COMMON/HOUS/LABEL(50,5),XNS,ARCHG,VOL,VAR(50,5),U(50),DT(50),
     >       HL(50),SM,UA,UFLOOR,DCOOL,DHEAT,BCAP,PAN(12,15)
      COMMON/QLOAD/SOL(12,10),SHG(12),QH(12),QC(12),QW(12),
     >       TITLE(18),SOP(12),MON(12),XNFIL(12),SO(12),TH(12),
     >       TG(12,7),DTH(7),HRSPAN(12),HFLOOR(12),CFLOOR(12)
      COMMON/RICE/ISYS,RATEDC,RATEFL,RATEKW,KWFLAG,YRS,CSTCOL,CSTINS,
     >       CSTCOI,THKSD,THKBTM,THKTP
C  WATER TANK AND ICE TANK AND ECONOMIC DATA
C
      PRINT 300, TITLE
      IF(ISYS.EQ.1) PRINT 310
      IF(ISYS.EQ.2) PRINT 320
      PRINT 330,HWT(1),TICE(1),RATEDC,HWT(2),TICE(2),RATEKW,HWT(3),
     >          TICE(3),RATEFL,HWT(4),TICE(4),YRS,TICE(5),CSTCOL,
     >          TICE(6),TICE(7),CSTINS,CSTCOI
C
C  COPS AND PUMP ENERGIES
C
      PRINT 340, COPCHT,COP47,COPCBR,COP17,COPCHW,COPHT,
     >           COPIM,COPCW,COPHW,EC,EF,EHB,ECB,EOF,EHW
C
C  INTERNAL SOURCES
C
      PRINT 350, MON,SO
C
C  DESCRIPTION OF HOUSE
C
      PRINT 360, (AREA(I),I=1,9),WAB,HO,RAB,GLASS,WR,
     >           PANES,RR,SF,SUP
      PRINT 370, TSW,TSS,VOL,ARCHG
      PRINT 380, PSIDES,PDELT
C
C  PRINT SURFACES OF THE HOUSE
C
      NS=XNS
      IF(NS.EQ.0) GO TO 80
      PRINT 390
      NS1=NS-1
      DO 40 J=1,NS1
      PRINT 400, (LABEL(J,I),I=1,5),(VAR(J,I),I=1,4),U(J),DT(J),
     >           HL(J)
40    CONTINUE
      PRINT 410, SM
      PRINT 420, (LABEL(NS,I),I=1,5),(VAR(NS,I),I=1,4),U(NS)
```

```
      PRINT 430, UFLOOR
80    RETURN
300   FORMAT(1H1,18A4)
310   FORMAT('0HOT WATER TANK',T50,'ICE TANK',T95,'IN-BIN HEAT PUMP'/)
320   FORMAT('0HOT WATER TANK',T50,'ICE TANK',T95,
     >        'ICE MAKER HEAT PUMP'/)
330   FORMAT('0WATER TANK SURFACE AREA(FT**2)',T35,F10.3,T50,
     >        'ICE BIN HEIGHT(FT)',T80,F10.3,
     >        T95,'DISCOUNT RATE',T120,F10.3/
     >       ' WATER TANK U(BTU/HR*FT**2)',T35,F10.3,T50,
     >       'DEPTH BELOW SURFACE(FT)',
     >       T80,F10.3,T95,'RATE PER KILOWATT-HR',T120,F10.3/
     >       ' WATER STORAGE TEMP (F)',T35,F10.3,T50,
     >       'ICE BIN TOP R VALUE',T80,
     >       F10.3,T95,'ESCALATION RATE ELEC.',T120,F10.3/
     >       ' WATER DELIVERY EFFICIENCY',T35,F10.3,
     >       T50,'ICE BIN SIDE R VALUE',T80,
     >       F10.3,T95,'LIFETIME (YRS)',T120,F10.3/
     >       1X,T50,'ICE BIN BOT R VALUE',T80,F10.3,
     >       T95,'UNIT COST PANEL',
     >       T120,F10.2/
     >       1X,T50,'ICE PACKING FRACTION',T80,F7.3,F7.3,T95,
     >       'UNIT COST INSULATION',T120,F10.3/
     >       1X,T95,'UNIT COST OF COIL',T120,F10.3/)
340   FORMAT('0COMPRESSOR COP CC(H)',T35,F10.3,T50,
     >       'HEAT PUMP COP 47F',T80,F10.3/
     >       ' COMPRESSOR COP CC(BR)',T35,F10.3,T50,
     >       'HEAT PUMP COP 17F',T80,F10.3/
     >       ' COMPRESSOR COP CC(HW)',T35,F10.3/
     >       ' ACES HEATING COP(H)',T35,F10.3/
     >       ' ACES COOLING COP (IM)',T35,F10.3/
     >       ' ACES COOLING COP(CW)',T35,F10.3/
     >       ' ACES HOT WATER COP(HW)',T35,F10.3/
     >       ' ACES COMPRESSOR MOTOR (BTUH)',T35,F10.3/
     >       ' ACES INDOOR FAN COIL MOTOR (BTUH)',T35,F10.3/
     >       ' ACES HOT BRINE PUMP MOTOR(BTUH)',T35,F10.3/
     >       ' ACES COLD BRINE PUMP MOTOR(BTUH)',T35,F10.3/
     >       ' ACES OUTDOOR FAN MOTOR(BTUH)',T35,F10.3/
     >      ' ACES HOT WATER PUMP(BTUH)',T35,F10.3/)
350   FORMAT('0',T23,A4,11(5X,A4)/' INTERNAL SOURCES',12F9.0//)
360   FORMAT('0DESCRIPTION OF HOUSE'/' ',T30,6X,'N',9X,'E',9X,
     >       'S',9X,'W'/
     >       ' OVERALL WINDOW AREA',T30,4F10.1/
     >       ' OVERALL WALL AREA',T30,4F10.1/
     >       ' ROOF AREA',T20,F10.3,T50,'WALL ABSORPTANCE',T80,F10.3/
     >       ' OUTDOOR FILM COEFF',T20,F10.3,T50,'ROOF ABSORPTANCE',
     >       T80,F10.3/
     >       ' GLASS TYPE',T20,F10.3,T50,'WALL THERMAL RESISTANCE',
     >       T80,F10.3/
     >       ' NO OF PANES',T20,F10.3,T50,'ROOF THERMAL RESISTANCE',
     >       T80,F10.3/
     >       ' WINDOW SHADING FACTOR',T20,F10.2,T50,
     >       'U ADJUSTMENT FACTOR',T80,F10.2//)
370   FORMAT(' THERMOSTAT SETTING WINTER',F10.0/
     >       ' THERMOSTAT SETTING SUMMER',F10.0/
```

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     >        ' HOUSE VOLUME (FT**3)',6X,F10.2/
     >        ' AIR CHANGES PER HOUR',6X,F10.2/)
380     FORMAT('0SOLAR PANEL:  SIDES(CONVECTION)',3X,F10.0,5X,
     >        'EXCHANGER DELTA T (F)',F10.0/)
390     FORMAT(' BUILDING HEAT',9X,'AREA    H-INSIDE   U(SLAB)',
     >        ' H-OUTSIDE',2X,'UTOTAL)   DELTA T  HEAT LOSS'/
     >        ' TRANSFER SURFACES    (SQFT)',
     >        '  **********(BTU/HR/SQFT/DEG-F)**********  (DEG-F)',2X,
     >        '(BTU/HR)'/2H0 )
400     FORMAT(' ',5A4,F8.2,2X,4(F8.5,2X),F8.2,F10.2)
410     FORMAT(3X/74X,'SUM =',F10.2)
420     FORMAT('0',5A4,F8.2,2X,4(F8.5,2X))
430     FORMAT('0  UA(FLOOR)  ',F10.2)
        END
        SUBROUTINE PRTBSC(HEAD)
C
C  PRINTS THE SUMMARY PAGE FOR EACH CITY
C
        COMMON/ENG/ENGDS,ENGHPP,ENGEL,DSHPEU(12),HPEU(12),ELEU(12)
        COMMON/PWFDAT/ANZCOS(5),FFCOS(5),PAYPER(5),FFSAV(5),IPAYRK(5),
     >         FUELPW(5),TOTPW(5),LIFCYC(5),ANTOT(12)
        REAL*4 INSCOS,MECCOS
        COMMON/COSDAT/FANCOS(5),CNTCOS(5),AHPCOS(5),AUXCOS(5),
     >                HWTCOS(5),DUCCOS(5),INSCOS(5),SYSCOS(5),
     >                MECCOS(2),BINCOS(2),PANCOS(2),COILFT(2)
        COMMON/EDIG/ACESEU(12,2)
        COMMON/ELOAD/HPEUH(12),HPEUC(12)
        COMMON/HPUMP/COPH(76),AUX(12),ENGHP(12),CCOP,HCOP,SCOP
        COMMON/FRACS/ANHEAT,ANCOOL,ANWATR,ANLATN,RATIO
        LOGICAL OPT1,OPT2
        COMMON/DAT/HWT(4),TICE(7),AREA(9),RAB,WAB,RR,WR,HO,SF,GLASS,
     >        PANES,SUP,PSIDES,PDELT,TILT,TSW,TSS,GAL(12),COPCHT,
     >        COPCBR,COPCHW,COPHT,COPIM,COPCW,COPBR,COPHW,EC,EF,EHB,
     >        ECB,EOF,EHW,OPT1,OPT2,COP47,COP17,IPRT
        COMMON/BINS/CITY(10),ZONE,DD(2),ALAT,NINV(12),T(12,40),
     >        H(12,40,2),HBR(12),VAV(12),TAV(12),WB(12,40),
     >        ALONG,ELEV,ELECOS
        COMMON/DIG/TVOL(5),PAREA(5),SYSKW(5),BTEMP(12,5),BLEAK(12,5),
     >        PCOL(12,5),BICE(12,5),IRUN,TBLEAK(12),SILEAK(12)
        COMMON/HOUS/LABEL(50,5),XNS,ARCHG,VOL,VAR(50,5),U(50),DT(50),
     >        HL(50),SM,UA,UFLOOR,DCOOL,DHEAT,BCAP,PAN(12,15)
        COMMON/QLOAD/SOL(12,10),SHG(12),QH(12),QC(12),QW(12),
     >        TITLE(18),SOP(12),MON(12),XNFIL(12),SO(12),TH(12),
     >        TG(12,7),DTH(7),HRSPAN(12),HFLOOR(12),CFLOOR(12)
        COMMON/RICE/ISYS,RATEDC,RATEFL,RATEKW,KWFLAG,YRS,CSTCOL,CSTINS,
     >        CSTCOI,THKSD,THKBTM,THKTP
        COMMON/FILE8/POINT(120,9),SAVREC(41),NREC,CASENO
        DIMENSION ANNUAL(3,5),TOTAL(7),PCOEF(12),HEAD(18),QHMM(12),
     >           QWMM(12),QCMM(12),TYPE(6)
        DATA TYPE/'BRIN','E CH','ILL ','ICE ','MAKE','R   '/
C
        DO 10 L=1,3
        DO 10 J=1,IRUN
        ANNUAL(L,J)=0.0
10      CONTINUE
```

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      IF(KWFLAG.EQ.0) RATEKW=ELECOS
      ALAT=ALAT*180./3.1415927
      WRITE(6,300) (CITY(I),I=1,9),ALAT,ELEV,RATEKW,TITLE
300   FORMAT('1',9A4,1X,'LATITUDE  =',F8.2,2X,
     >        'ELEVATION=',F8.0,2X,'ELEC.COST=',F7.4/1X,18A4)
C
C  PRINT TEMPERATURE SETTINGS AND DESIGN DAY INFORMATION
C
      PANNHR=DHEAT/150.
      WRITE(6,310) TSW,DD(1),DHEAT,BCAP,RATIO,COPHT,COPIM,TSS,DD(2),
     >             DCOOL,PANNHR,COPCW,COPBR
310   FORMAT(' TSETW(F)=',F8.0,2X,'TDDW(F)=',F8.0,2X,'DDHL(BTUH)=',
     >       F8.0,2X,'BCAP(CFM)=',F8.0,2X,'COOL(T/S)=',F7.4,2X,
     >       'COPHT=',F7.2,2X,'COPIM=',F7.2/
     >       ' TSETS(F)=',F8.0,2X,'TDDS(F)=',F8.0,2X,'DDCL(BTUH)=',
     >       F8.0,2X,'PAN (NHR)=',F8.0,21X,'COPCW=',F7.2,2X,
     >       'COPBR=',F7.2)
      WRITE(6,320) MON
320   FORMAT('0CLIMATIC PARAMETERS:',T31,12(2X,A4,2X),1X,'ANNUAL'/)
C
C  WRITE CLIMATIC PARAMETERS AND BUILDING LOADS
C
      DO 20 K=1,7
      TOTAL(K)=0.0
20    CONTINUE
      DO 30 M=1,12
      TOTAL(1)=TOTAL(1)+VAV(M)
      TOTAL(2)=TOTAL(2)+TAV(M)
30    CONTINUE
      TOTAL(1)=TOTAL(1)/12.0
      TOTAL(2)=TOTAL(2)/12.0
      DO 40 JK=1,12
      IT=32.-30.5
      PCOEF(JK)=PAN(JK,IT)/1000.
40    CONTINUE
      WRITE(6,330) VAV,TOTAL(1),TAV,TOTAL(2),
     >             (DTH(I),(TG(M,I),M=1,12),I=1,4),TBLEAK,SILEAK,
     >             XNFIL,PCOEF
330   FORMAT('0AVERAGE WIND SPEED     (MPH)',13F8.2,/,
     >       ' AVERAGE OUTDOOR AIR TEMP (F)',13F8.2,/,
     >       ' TEMP AT BIN TOP  (',F4.0,')  (F)',12F8.2,/,
     >       ' TEMP AT BIN BOT  (',F4.0,')  (F)',12F8.2,/,
     >       ' TEMP AT BIN SIDE (',F4.0,')  (F)',12F8.2,/,
     >       ' WATER INLET TEMP (',F4.0,')  (F)',12F8.2,/,
     >       ' BIN TOP-BOT LK32F(MBTU/SQFT)',12F8.3,/,
     >       ' BIN SIDE LEAK 32F(MBTU/SQFT)',12F8.3,/,
     >       ' INFILTRATION COEFF. (BTUH/F)',12F8.2/,
     >       ' PANEL HEAT COEF 32F(MBTU/SQ)',12F8.2)
C
C  WRITE PANEL HEAT PICKUP COEFFICENT TO UNIT 10
C
      IF(ISYS.EQ.1) WRITE(10,340) HEAD
340   FORMAT(18A4)
      IF(ISYS.EQ.1) WRITE(10,350) PCOEF
350   FORMAT(12F6.2)
```

```
      DO 50 M=1,12
      TOTAL(5)=TOTAL(5)+QH(M)
      TOTAL(6)=TOTAL(6)+QW(M)
      TOTAL(7)=TOTAL(7)+QC(M)
      QHMM(M)=QH(M)/1.0E6
      QWMM(M)=QW(M)/1.0E6
      QCMM(M)=QC(M)/1.0E6
50    CONTINUE
      DO 60 JK=5,7
      TOTAL(JK)=TOTAL(JK)/1.0E6
60    CONTINUE
      WRITE(6,360) QHMM,TOTAL(5),QWMM,
     > TOTAL(6),QCMM,TOTAL(7)
360   FORMAT('0BUILDING LOADS:'/,
     >        '0SPACE HEAT            (MMBTU)',13F8.2/,
     >        ' WATER HEAT            (MMBTU)',13F8.2/,
     >        ' SPACE COOL            (MMBTU)',13F8.2)
C
C  ECONOMIC CALCULATIONS
C
C  PRESENT WORTH FACTOR
C
      DC=1+RATEDC
      FL=1.+RATEFL
      PWF=FL/(RATEDC-RATEFL)*(1.-(FL/DC)**YRS)
      IF(RATEDC.EQ.RATEFL) PWF=YRS
      DO 62 M=8,12
      ANTOT(M)=0.0
62    CONTINUE
      DO 65 M=1,12
      ANTOT(8)=ANTOT(8)+ELEU(M)/3412.
      ANTOT(9)=ANTOT(9)+HPEU(M)/3412.
      ANTOT(10)=ANTOT(10)+DSHPEU(M)/3412.
      ANTOT(12)=ANTOT(12)+ACESEU(M,1)/3412.
      ANTOT(11)=ANTOT(11)+ACESEU(M,2)/3412.
65    CONTINUE
      CALL COST
      CALL ACECOS
      CALL PWFCOS(PWF)
      TENGHP=0.0
      TOTAUX=0.0
      DO 70 M=1,12
      AUX(M)=AUX(M)/3412.
      ENGHP(M)=ENGHP(M)/3412.
      TOTAUX=TOTAUX+AUX(M)
      TENGHP=ENGHP(M)+TENGHP
70    CONTINUE
C
C  PRINT AIR TO AIR HEAT PUMP COST AND PERFORMANCE
C
      WRITE(6,370) ENGHP,TENGHP,AUX,TOTAUX,SYSCOS(2),CCOP,FUELPW(2),
     >             HCOP,ANZCOS(2),SCOP,TOTPW(2)
370   FORMAT('0HEAT PUMP COST AND PERFORMANCE:',/,
     >        '0HEAT PUMP ENERGY USE   (KWH)',12F8.2,F8.0,/,
     >        ' STRIP HEAT             (KWH)',12F8.2,F8.0,/,
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```
     >         ' SYSTEM COSTS          ',F8.2,5X,'COOLING COP ',F8.2,/,
     >         ' FUEL PRESENT WORTH    ',F8.2,5X,'HEATING COP ',F8.2,/,
     >         ' MAINT. PRESENT WORTH ',F8.2,5X,'ANNUAL  COP ',F8.2/
     >        ' ',T92,'PRESENT WORTH = ',F8.2)
      IS=ISYS*ISYS
      IE=IS+2
      WRITE(6,380)(TYPE(I),I=IS,IE)
380   FORMAT('0ACES DESIGN, COST, AND PERFORMANCE:',2X,3A4)
      DO 100 J=1,IRUN
      IF(J.EQ.1) K=2
      IF(J.EQ.2) K=1
      DO 80 M=1,12
      BLEAK(M,J)=BLEAK(M,J)/1.0E6
      PCOL(M,J)=PCOL(M,J)/1.0E6
      ANNUAL(1,J)=ANNUAL(1,J)+BLEAK(M,J)
      ANNUAL(2,J)=ANNUAL(2,J)+PCOL(M,J)
80    CONTINUE
      YCOP=(TOTAL(5)+TOTAL(6)+TOTAL(7))*1.0E6/SYSKW(J)
      COEF=TOTPW(2)/TOTPW(3+K)
      SYSKW(J)=SYSKW(J)/3412.
      AUXHWT=AUXCOS(3+K)+HWTCOS(3+K)
C
C  CALCULATE PANEL HEAT PICKUP COEFF
C
      DO 90 M=1,12
      MT=BTEMP(M,J)-30.5
      PCOEF(M)=PAN(M,MT)/1000.
90    CONTINUE
C
C  PRINT ACES DESIGN PARAMETERS
C
      WRITE(6,390) (BLEAK(M,J),M=1,12),ANNUAL(1,J),
     >             (PCOL(M,J),M=1,12),ANNUAL(2,J),
     >             (PCOEF(M),M=1,12),(BTEMP(M,J),M=1,12),
     >             (BICE(M,J),M=1,12),TVOL(J),AUXHWT,INSCOS(3+K),
     >             ANZCOS(3+K),PAREA(J),PANCOS(K),DUCCOS(3+K),
     >             TOTPW(K+3),COILFT(J),MECCOS(K),SYSCOS(3+K),
     >             SYSKW(J),BINCOS(K),FUELPW(3+K),COEF,YCOP
390   FORMAT('0BIN HEAT LEAKAGE     (MMBTU)',13F8.2,/,
     >        ' PANEL HEAT COLLECTION(MMBTU)',13F8.2,/,
     >        ' PANEL HEAT COEFF.(MBTU/SQFT)',12F8.2/,
     >        ' BIN ICE/WATER TEMPERATURE(F)',12F8.2,/,
     >        ' ICE INVENTORY        (FT**3)',12F8.2,/,
     >        ' BIN VOLUME (FT**3) = ',F8.2,5X,'AUX. COST  = ',F8.2,5X,
     >        'INSTALLATION COST= ',F8.2,5X,'MAINT. P.WORTH= ',F8.2,/,
     >        ' PANEL AREA (FT**2) = ',F8.2,5X,'PANEL COST = ',F8.2,5X,
     >        'DUCTS COST       = ',F8.2,5X,'PRESENT WORTH = ',F8.2,/
     >        ' COIL LENGTH   (FT) = ',F8.2,5X,'MECH COST  = ',F8.2,5X,
     >        'SYSTEM COST      = ',F8.2/
     >        ' ENERGY USE   (KWH) = ',F8.2,5X,'BIN COST   = ',F8.2,5X,
     >        'FUEL PRESENT WORTH ',F8.2,5X,'ECON COEFF.   = ',F8.2/
     >        ' ANNUAL COP         =',F8.2)
100   CONTINUE
      SAVREC(1)=9999.
      DO 110 K=1,8
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      J=K+1
      SAVREC(J)=HEAD(K)
110   CONTINUE
      SAVREC(10)=ALAT
      SAVREC(11)=ALONG
      SAVREC(12)=RATIO
      RETURN
      END
      SUBROUTINE PRTECO(HEAD)
C
C  PRINTS A SUMMARY PAGE FOR EACH CITY
C
      COMMON/PWFDAT/ANZCOS(5),FFCOS(5),PAYPER(5),FFSAV(5),IPAYRK(5),
     >        FUELPW(5),TOTPW(5),LIFCYC(5),ANTOT(12)
      REAL*4 INSCOS,MECCOS
      COMMON/COSDAT/FANCOS(5),CNTCOS(5),AHPCOS(5),AUXCOS(5),
     >              HWTCOS(5),DUCCOS(5),INSCOS(5),SYSCOS(5),
     >              MECCOS(2),BINCOS(2),PANCOS(2),COILFT(2)
      COMMON/DIG/TVOL(5),PAREA(5),SYSKW(5),BTEMP(12,5),BLEAK(12,5),
     >       PCOL(12,5),BICE(12,5),IRUN,TBLEAK(12),SILEAK(12)
      LOGICAL OPT1,OPT2
      COMMON/DAT/HWT(4),TICE(7),AREA(9),RAB,WAB,RR,WR,HO,SF,GLASS,
     >       PANES,SUP,PSIDES,PDELT,TILT,TSW,TSS,GAL(12),COPCHT,
     >       COPCBR,COPCHW,COPHT,COPIM,COPCW,COPBR,COPHW,EC,EF,EHB,
     >       ECB,EOF,EHW,OPT1,OPT2,COP47,COP17,IPRT
      COMMON/HOUS/LABEL(50,5),XNS,ARCHG,VOL,VAR(50,5),U(50),DT(50),
     >       HL(50),SM,UA,UFLOOR,DCOOL,DHEAT,BCAP,PAN(12,15)
      COMMON/FRACS/ANHEAT,ANCOOL,ANWATR,ANLATN,RATIO
      COMMON/EDIG/ACESEU(12,2)
      COMMON/ENG/ENGDS,ENGHPP,ENGEL,DSHPEU(12),HPEU(12),ELEU(12)
      COMMON/ELOAD/HPEUH(12),HPEUC(12)
      COMMON/BINS/CITY(10),ZONE,DD(2),ALAT,NINV(12),T(12,40),
     >       H(12,40,2),HBR(12),VAV(12),TAV(12),WB(12,40),
     >       ALONG,ELEV,ELECOS
      COMMON/RICE/ISYS,RATEDC,RATEFL,RATEKW,KWFLAG,YRS,CSTCOL,CSTINS,
     >       CSTCOI,THKSD,THKBTM,THKTP
      COMMON/QLOAD/SOL(12,10),SHG(12),QH(12),QC(12),QW(12),
     >       TITLE(18),SOP(12),MON(12),XNFIL(12),SO(12),TH(12),
     >       TG(12,7),DTH(7),HRSPAN(12),HFLOOR(12),CFLOOR(12)
      COMMON/FILE8/POINT(120,9),SAVREC(65),NREC,CASENO
      DIMENSION HLOSS(12),IBVOL(2),IPAREA(2),TYPE(2),
     >          ANCOP(5),SKIND(2,2),XMAK(2),HEAD(18)
      DATA SKIND/'BR.C','ICE ','HILL','MAKE'/
      DATA BLANK/'    '/,STAR/'*   '/
      TYPE(1)=SKIND(ISYS,1)
      TYPE(2)=SKIND(ISYS,2)
C
C  IF KWFLAG=0 USE POWER COST OF PARTICULAR CITY
C
      IF(KWFLAG.EQ.0) RATEKW=ELECOS
C
C  CALCULATE COST OF SYSTEMS
C
      CALL COST
      CALL ACECOS
```

```
C
C  TEMPERATURES CONVERTED TO METRIC
        IDD1=(DD(1)-32.)/1.8+0.5
        IDD2=(DD(2)-32.)/1.8+0.5
        ITSW=(TSW-32.)/1.8+0.5
        ITSS=(TSS-32.)/1.8+0.5
C
C  CONDUCTION HEAT LOSS COEFFICIENT
C
        CONCOF=UA+UFLOOR
        DO 10 M=1,12
        HLOSS(M)=CONCOF+XNFIL(M)
10      CONTINUE
C
C  PRESENT WORTH FACTOR
C
        DC=1.+RATEDC
        FL=1.+RATEFL
        PWF=FL/(RATEDC-RATEFL)*(1.-(FL/DC)**YRS)
        IF(RATEDC.EQ.RATEFL) PWF=YRS
C
C  ANNUAL TOTALS AND CONVERT TO METRIC
C
        DO 30 M=1,12
        ANTOT(M)=0.0
        TAV(M)=(TAV(M)-32.)/1.8
        VAV(M)=VAV(M)*1.609
        TG(M,4)=(TG(M,4)-32.)/1.8
        HLOSS(M)=HLOSS(M)*.29307*1.8
        QW(M)=QW(M)*1.055/1000.
        QH(M)=QH(M)*1.055/1000.
        QC(M)=QC(M)*1.055/1000.
        ELEU(M)=ELEU(M)/3412.
        HPEU(M)=HPEU(M)/3412.
        DSHPEU(M)=DSHPEU(M)/3412.
        ACESEU(M,1)=ACESEU(M,1)/3412.
        ACESEU(M,2)=ACESEU(M,2)/3412.
30      CONTINUE
        DO 40 M=1,12
        ANTOT(1)=ANTOT(1)+TAV(M)
        ANTOT(2)=ANTOT(2)+VAV(M)
        ANTOT(3)=ANTOT(3)+TG(M,4)
        ANTOT(4)=BLANK
        ANTOT(5)=ANTOT(5)+QW(M)
        ANTOT(6)=ANTOT(6)+QH(M)
        ANTOT(7)=ANTOT(7)+QC(M)
        ANTOT(8)=ANTOT(8)+ELEU(M)
        ANTOT(9)=ANTOT(9)+HPEU(M)
        ANTOT(10)=ANTOT(10)+DSHPEU(M)
        ANTOT(11)=ANTOT(11)+ACESEU(M,2)
        ANTOT(12)=ANTOT(12)+ACESEU(M,1)
40      CONTINUE
        CONCOF=CONCOF*.29307*1.8
        DTH(4)=DTH(4)*.3048
        ANTOT(1)=ANTOT(1)/12.
```

```
      ANTOT(2)=ANTOT(2)/12.
      ANTOT(3)=ANTOT(3)/12.
      DHEAT=DHEAT*.29307
      DCOOL=DCOOL*.29307
      BCAP=BCAP*.0283*60.
      DO 50 I=1,2
      IBVOL(I)=TVOL(I)*.0283+0.5
      IPAREA(I)=PAREA(I)*.0929+0.5
      IF(IPAREA(I).GT.84) XMAK(I)=STAR
      IF(IPAREA(I).LE.84) XMAK(I)=BLANK
      NOTE=0
      IF(IPAREA(I).GT.84) NOTE=1
50    CONTINUE
C
C  CALCULATE ANNUAL COPS
C
      ANCOP(1)=1000.*(ANTOT(5)+ANTOT(6)+ANTOT(7))/(ANTOT(8)*1.055*
     >            3412.)
      ANCOP(2)=1000.*(ANTOT(5)+ANTOT(6)+ANTOT(7))/(ANTOT(9)*1.055*
     >          3412.)
      ANCOP(3)=1000.*(ANTOT(5)+ANTOT(6)+ANTOT(7))/(ANTOT(10)*1.055*
     >          3412.)
      ANCOP(4)=1000.*(ANTOT(5)+ANTOT(6)+ANTOT(7))/(ANTOT(11)*1.055*
     >          3412.)
      ANCOP(5)=1000.*(ANTOT(5)+ANTOT(6)+ANTOT(7))/(ANTOT(12)*1.055*
     >          3412.)
C
C  PRINT TABLE
C
      PRINT 1000, (CITY(J),J=1,8),CONCOF,RATEKW,DHEAT,RATIO,IDD1,ITSW,
     >            PWF,DCOOL,BCAP,IDD2,ITSS
C
C  DESIGN AND PERFORMANCE
C
      PRINT 1010,DTH(4),TYPE,TYPE
      DO 200 M=1,12
      PRINT 1020, MON(M),TAV(M),VAV(M),TG(M,4),HLOSS(M),QW(M),QH(M),
     >             QC(M),ELEU(M),HPEU(M),DSHPEU(M),ACESEU(M,2),
     >             ACESEU(M,1)
      IF(M.EQ.3.OR.M.EQ.6.OR.M.EQ.9.OR.M.EQ.12) PRINT 1030
200   CONTINUE
      PRINT 1040, ANTOT,ANCOP
C
C  CHECK IF FULL ACES IS A VALID DESIGN (BIGGER THAN MIN. ACES)
C
C  IF NOT-SET FULL ACES TO MIN. ACES DESIGN
C
      IF(IBVOL(1).GE.IBVOL(2)) GO TO 210
      IBVOL(1)=IBVOL(2)
      IPAREA(1)=IPAREA(2)
      XMAK(1)=XMAK(2)
      MECCOS(2)=MECCOS(1)
      BINCOS(2)=BINCOS(1)
      PANCOS(2)=PANCOS(1)
      AUXCOS(5)=AUXCOS(4)
```

```
      HWTCOS(5)=HWTCOS(4)
      DUCCOS(5)=DUCCOS(4)
      INSCOS(5)=INSCOS(4)
      SYSCOS(5)=SYSCOS(4)
      ANTOT(12)=ANTOT(11)
C
C  SYSTEM COST
C
210   PRINT 1050
      PRINT 1060
      PRINT 1070, FANCOS(1),AHPCOS(1),CNTCOS(1),AUXCOS(1),HWTCOS(1),
     >            DUCCOS(1),INSCOS(1),SYSCOS(1),BLANK
      PRINT 1080
      PRINT 1070, FANCOS(2),AHPCOS(2),CNTCOS(2),AUXCOS(2),HWTCOS(2),
     >           DUCCOS(2),INSCOS(2),SYSCOS(2),BLANK
      PRINT 1090
      PRINT 1070, FANCOS(3),AHPCOS(3),CNTCOS(3),AUXCOS(3),HWTCOS(3),
     >           DUCCOS(3),INSCOS(3),SYSCOS(3),BLANK
      PRINT 1030
      PRINT 1100, TYPE,IBVOL(2),IPAREA(2),XMAK(2)
      PRINT 1070, MECCOS(1),BINCOS(1),PANCOS(1),AUXCOS(4),HWTCOS(4),
     >            DUCCOS(4),INSCOS(4),SYSCOS(4),XMAK(2)
      PRINT 1110, TYPE,IBVOL(1),IPAREA(1),XMAK(1)
      PRINT 1070, MECCOS(2),BINCOS(2),PANCOS(2),AUXCOS(5),HWTCOS(5),
     >            DUCCOS(5),INSCOS(5),SYSCOS(5),XMAK(1)
      PRINT 1030
C
C  COMPARATIVE OWNING COST
C
      CALL PWFCOS(PWF)
      PRINT 1120
      PRINT 1060
      PRINT 1170, ANZCOS(1),FFCOS(1),FUELPW(1),TOTPW(1),
     >            LIFCYC(1)
      PRINT 1080
      PRINT 1140, ANZCOS(2),FFCOS(2),FFSAV(2),PAYPER(2),IPAYRK(2),
     >           FUELPW(2),TOTPW(2),BLANK,LIFCYC(2)
      PRINT 1090
      PRINT 1140, ANZCOS(3),FFCOS(3),FFSAV(3),PAYPER(3),IPAYRK(3),
     >            FUELPW(3),TOTPW(3),BLANK,LIFCYC(3)
      PRINT 1150, TYPE,IBVOL(2)
      PRINT 1140, ANZCOS(4),FFCOS(4),FFSAV(4),PAYPER(4),IPAYRK(4),
     >            FUELPW(4),TOTPW(4),XMAK(2),LIFCYC(4)
      PRINT 1160, TYPE,IBVOL(1)
      PRINT 1140, ANZCOS(5),FFCOS(5),FFSAV(5),PAYPER(5),IPAYRK(5),
     >            FUELPW(5),TOTPW(5),XMAK(2),LIFCYC(5)
      PRINT 1030
      IF(NOTE.EQ.1) PRINT 1180
C
C  SAVE DATA TO WRITE ON UNIT 8 FOR LATER MAP WORK.
C
      SAVREC(1)=9999.
      DO 220 K=1,8
      J=K+1
      SAVREC(J)=HEAD(K)
```

```
220     CONTINUE
        ALAT=ALAT*180./3.145927
        SAVREC(10)=ALAT
        SAVREC(11)=ALONG
        SAVREC(12)=RATIO
        SAVREC(13)=RATEKW
        SAVREC(14)=FLOAT(ISYS)
        SAVREC(15)=FLOAT(IBVOL(2))
        SAVREC(16)=FLOAT(IBVOL(1))
        SAVREC(17)=1111.
        SAVREC(18)=FLOAT(IPAREA(2))
        SAVREC(19)=FLOAT(IPAREA(1))
        SAVREC(20)=1111.
        IF(XMAK(2).EQ.STAR) SAVREC(17)=9999.
        IF(XMAK(1).EQ.STAR) SAVREC(20)=9999.
        DO 230 K=1,5
        SAVREC(20+K)=ANCOP(K)
        SAVREC(25+K)=ANTOT(7+K)
        SAVREC(30+K)=SYSCOS(K)
        SAVREC(35+K)=TOTPW(K)
        SAVREC(40+K)=PAYPER(K)
        SAVREC(45+K)=FLOAT(IPAYRK(K))
        SAVREC(50+K)=FFCOS(K)
        SAVREC(55+K)=FFSAV(K)
        SAVREC(60+K)=FLOAT(LIFCYC(K))
230     CONTINUE
        RETURN
C
C  FORMAT STATEMENTS
C
1000    FORMAT(1H1//'0',T49,8A4/
     >       '0    167 SQ M HOME, WELL INSULATED',T40,
     >       'DESIGN DAY LOADS (WATTS)',T69,
     >       'COND. LOSS COEF. (W/C) = ',F5.0,T104,
     >       'AIR TEMP: OUTDOOR  INDOOR'/
     >       5X,'POWER COSTS ($/KWH) =',F7.4,T40,'HEATING  =',F9.0,T69,
     >       'COOLING (TOTAL/SEN.)   =',F6.2,T104,'WINTER =',I6,' C',I7,
     >       ' C'/
     >       5X,'PRESENT WORTH FACTOR=',F7.2,T40,'COOLING  =',F9.0,T69,
     >       'BLOWER CAPACITY (M3/H) =',F6.0,T104,'SUMMER =',I6,' C',I7,
     >       ' C')
1010    FORMAT(/'0',T50,'DESIGN AND PERFORMANCE'/'+',4X,126(' ')/
     >        '    ^',7X,'^',6X,'WEATHER DATA',9X,
     >        '^ BUILDING PARAMETERS AND LOADS',T81,
     >        '^  SYSTEM ENERGY CONSUMPTION, KWH',T131,'^'/
     >        '+',T13,118(' ')/
     >       4X,'^',7X,'^AVE AIR ^AVE WIND^  INLET  ^  HEAT   ^  WATER',
     >        T61,'^  SPACE  ^  SPACE  ^   (1)   ^   (2)   ^   (3)   ^',
     >        '   (4)   ^   (5)   ^'/
     >       4X,'^ MONTH ^  TEMP  ^ SPEED  ^  WATER  ^  LOSS   ^  HEAT',
     >        T61,'^  HEAT   ^  COOL   ^  ELEC.  ^  HEAT   ^  HEAT   ^',
     >        '  MIN.   ^  FULL   ^'/
     >        4X,'^',7X,'^',T22,'^',T31,'^  TEMP   ^  COEF.  ^',T61,'^',
     >       T71,'^',T81,'^   A/C   ^',2('  PUMP   ^'),2('  ACES   ^')/
     >       4X,'^',7X,'^   C    ^ KM/H   ^ C (',F3.1,'M)^   W/C   ^',
```

Note: ^ prints as on IBM computers.

```
     >        3('   MJ    ^'),2('   I2R   ^'),'  D.S.   ^',
     >        2(1X,2A4,'^')/'+',3X,127(' '))
1020    FORMAT(4X,'^',2X,A4,' ^',2(F7.2,' ^'),2(F8.2,' ^'),3(F8.0,' ^'),
     >        5(F8.0,' ^'))
1030    FORMAT('+',3X,127(' '))
1040    FORMAT('     ^ ANNUAL^',2(F7.2,' ^'),F8.2,' ^',A4,4X,' ^',
     >         3(F8.0,' ^'),5(F8.0,' ^')/'+',3X,127(' ')/
     >        '     ^ ANNUAL COP',T81,'^',5(F8.2,' ^')/'+',3X,127(' '))
1050    FORMAT('0',T50,'SYSTEMS FIRST COSTS'/'+',3X,127(' ')/
     >        '     ^     ^',T51
     >        ,'^',T82,'COST,$',T131,'^'/'+',T52,79(' ')/
     >        4X,'^ NO.^    CONVENTIONAL SYSTEMS',T51,'^FAN UNIT ^',
     >         'A/C, H.P.^ CONTROL ^AUXILIARY^W. HEATER^  DUCTS  ^',
     >        ' INSTALN.^ SYSTEM  ^'/'+',3X,127(' '))
1060    FORMAT('     ^  1 ^ ELECTRIC HEAT, A/C, AND HOT WATER',T51,'^')
1070    FORMAT('+',T52,7(F8.0,' ^'),F8.0,A1,'^')
1080    FORMAT('     ^  2 ^ HEAT PUMP WITH ELECTRIC HOT WATER',T51,'^')
1090    FORMAT('     ^  3 ^ HEAT PUMP WITH DESUPERHEATER HOT WATER ^')
1100    FORMAT('     ^     ^    ACES SYSTEMS,INTEGRATED CONSTRUCTION',
     >        T51,'^ MECH. P.^ ICE BIN ^',
     >      '  PANEL  ^AUXILIARY^W. HEATER^  DUCTS  ^ INSTALN.^ SYSTEM',
     >        '  ^'/'+',3X,127(' ')/
     >      '     ^  4 ^ MIN.,',2A4,', BIN(M3)=',I4,' P(M2)=',I4,A1,'^')
1110    FORMAT('     ^  5 ^ FULL,',2A4,', BIN(M3)=',I4,
     >         ' P(M2)=',I4,A1,'^')
1120    FORMAT(/'0',T51,'COMPARATIVE SYSTEMS COSTS'/'+',3X,127(' ')/
     >         4X,'^     ^',T51,'^  MAINT. ^ 1ST YEAR^ 1ST YEAR^ SIMP',
     >        'LE  ^ SIMPLE  ^  POWER  ^   LIFE  ^  LIFE   ^'/
     >        4X,'^     ^   NEW CONSTRUCTION ALTERNATIVES',T51,
     >       '^ PRESENT ^',2('  POWER  ^'),
     >        2(' PAYBACK ^'),' PRESENT ^',2('  CYCLE  ^')/
     >        4X,'^     ^',T51,'^  WORTH  ^  COST   ^ SAVING  ^ PER',
     >        'IOD  ^ RANKING ^  WORTH  ^   COST  ^ RANKING ^'/
     >        '     ^ NO.^',T17,'SYSTEMS',T51,3('^     $     '),
     >        '^  YEARS  ^',T101,'^',2(4X,'$',4X,'^'),T131,
     >        '^',/'+',3X,127(' '))
1140    FORMAT('+',T52,F8.0,' ^',2(F8.2,' ^'),F8.1,' ^'3X,I2,4X,'^',
     >         F8.0,' ^',F8.0,A1,'^',3X,I2,4X,'^')
1150    FORMAT('     ^  4 ^ MIN. ACES, ',2A4,', BIN (M3)=',I5,T51,'^')
1160    FORMAT('     ^  5 ^ FULL ACES, ',2A4,', BIN (M3)=',I5,T51,'^')
1170    FORMAT('+',T52,F8.0,' ^',F8.2,' ^',3('  REF.   ^'),
     >         2(F8.0,' ^'),3X,I2,4X,'^')
1180    FORMAT('0*UNGLAZED PANEL EXCEEDS A PRACTICAL SIZE, AN',
     >         ' ALTERNATIVE SUPPLEMENTARY HEAT SOURCE SHOULD BE USED',
     >         ' IN THIS DESIGN.')
        END
        SUBROUTINE PSY1 (DB,WB,PB,W,V)
C
C     ****************************************************************
C
C  THIS SUBROUTINE WAS TAKEN FROM NBSLD BY T. KUSUDA.
C  IT GENERATES DEWPOINT TEMPERATURE,VAPOR PRESSURE, HUMIDITY RATIO,
C  ENTHALPHY, SPECIFIC VOLUME, AND RELATIVE HUMIDITY.
C
        PVP=PVSF(WB)
```

Note. ^ prints as on IBM computers

```
      IF (DB.LE.WB) GO TO 30
      WSTAR=0.622*PVP/(PB-PVP)
      IF (WB.GT.32.0) GO TO 40
      PV=PVP-5.704E-4*PB*(DB-WB)/1.8
      GO TO 50
C
30    PV=PVP
      GO TO 50
C
40    CDB=(DB-32.)/1.8
      CWB=(WB-32.)/1.8
      HL=597.31+0.4409*CDB-CWB
      CH=0.2402+0.4409*WSTAR
      EX=(WSTAR-CH*(CDB-CWB)/HL)/0.622
      PV=PB*EX/(1.+EX)
50    W=0.622*PV/(PB-PV)
      V=0.754*(DB+459.7)*(1+7000*W/4360)/PB
      H=0.24*DB+(1061+0.444*DB)*W
      IF (PV.LE.0) RETURN
      IF (DB.NE.WB) GO TO 60
      DP=DB
      RH=1.
      RETURN
C
60    CONTINUE
C    DP=DPF(PV)
      RH=PV/PVSF(DB)
      RETURN
C
      END
      SUBROUTINE PWFCOS(PWF)
C
C  THIS SUBROUTINE CALCULATES PRESENT WORTH AND LIFE CYCLE RANKING
C  OF THE SYSTEMS
C
      REAL*4 INSCOS,MECCOS
      COMMON/COSDAT/FANCOS(5),CNTCOS(5),AHPCOS(5),AUXCOS(5),
     >              HWTCOS(5),DUCCOS(5),INSCOS(5),SYSCOS(5),
     >              MECCOS(2),BINCOS(2),PANCOS(2),COILFT(2)
      COMMON/PWFDAT/ANZCOS(5),FFCOS(5),PAYPER(5),FFSAV(5),IPAYRK(5),
     >        FUELPW(5),TOTPW(5),LIFCYC(5),ANTOT(12)
      COMMON/RICE/ISYS,RATEDC,RATEFL,RATEKW,KWFLAG,YRS,CSTCOL,CSTINS,
     >       CSTCOI,THKSD,THKBTM,THKTP
      DIMENSION DUM(5)
C
C  ANNUALIZED MAINTENCE COSTS
C
      ANZCOS(1)=775.89
      ANZCOS(2)=2009.66
      ANZCOS(3)=2257.20
      ANZCOS(4)=1929.49
      ANZCOS(5)=1929.49
C
C  1ST YEAR FUEL COST
C
```

```
      DO 20 K=1,5
      FFCOS(K)=ANTOT(7+K)*RATEKW
20    CONTINUE
C
C  1ST YEAR FUEL SAVINGS
C
      DO 30 K=1,5
      FFSAV(K)=FFCOS(1)-FFCOS(K)
30    CONTINUE
C
C  SIMPLE PAYBACK PERIOD
C
      PAYPER(1)=0.0
      DO 40 K=2,5
      PAYPER(K)=(SYSCOS(K)-SYSCOS(1))/FFSAV(K)
40    CONTINUE
C
C  PAYBACK RANKING
C
      DO 50 K=1,5
      DUM(K)=PAYPER(K)
50    CONTINUE
      DUM(1)=1000.
      DO 60 M=1,4
      J=IRANK(DUM)
      IPAYRK(J)=M
      DUM(J)=1000.
60    CONTINUE
      IPAYRK(1)=5
C
C  FUEL PRESENT WORTH
C
      DO 70 K=1,5
      FUELPW(K)=FFCOS(K)*PWF
70    CONTINUE
C
C  TOTAL PRESENT WORTH
C
      DO 80 K=1,5
      TOTPW(K)=FUELPW(K)+SYSCOS(K)+ANZCOS(K)
80    CONTINUE
C
C  LIFE CYCLE RANKING
C
      DO 90 K=1,5
      DUM(K)=TOTPW(K)
90    CONTINUE
      DO 100 M=1,5
      J=IRANK(DUM)
      LIFCYC(J)=M
      DUM(J)=2.0E6
100   CONTINUE
      RETURN
      END
      SUBROUTINE SUNLJ
```

```
C
C     LIU-JORDAN SUN DATA TABLE GENERATOR
C
C  HOO    = DAILY TOTAL EXTRATERRESTRIAL RADIATION ON A HORIZONTAL
C           SURFACE FOR A GIVEN LATITUDE AND DECLINATION ANGLE
C  ALAT   = LATITUDE
C  DEC    = SOLAR DECLINATION ANGLE, RADIANS
C  HALF   = SUNRISE HOUR ANGLE, RADIANS
C  RDV    = RATIO OF AVERAGE INTENSITY OF DIFFUSE RADIATION TO
C           DAILY DIFFUSE RADIATION
C  RTV    = RATIO OF AVERAGE INTENSITY OF TOTAL RADIATION TO
C           DAILY TOTAL RADIATION
C  TLTCOS = COS OF INCIDENT ANGLE OF TILTED SOLAR PANEL
C  THCOS  = COS OF INCIDENT ANGLE ON HORIZONTAL SURFACE
C  SCOSV  = COS OF INCIDENT ANGLE ON SOUTH WALL
C  SWCOSV = COS OF INCIDENT ANGLE ON EAST OR WEST WALL
C
      DIMENSION ANG(12),RTV(7),RDV(7),GHOUR(18),GRT(7,18),RO(12)
C
      LOGICAL OPT1,OPT2
      COMMON/DAT/HWT(4),TICE(7),AREA(9),RAB,WAB,RR,WR,HO,SF,GLASS,
     >       PANES,SUP,PSIDES,PDELT,TILT,TSW,TSS,GAL(12),COPCHT,
     >       COPCBR,COPCHW,COPHT,COPIM,COPCW,COPBR,COPHW,EC,EF,EHB,
     >       ECB,EOF,EHW,OPT1,OPT2,COP47,COP17,IPRT
      COMMON/BINS/CITY(10),ZONE,DD(2),ALAT,NINV(12),T(12,40),
     >       H(12,40,2),HBR(12),VAV(12),TAV(12),WB(12,40),
     >       ALONG,ELEV,ELECOS
      COMMON/QLOAD/SOL(12,10),SHG(12),QH(12),QC(12),QW(12),
     >       TITLE(18),SOP(12),MON(12),XNFIL(12),SO(12),TH(12),
     >       TG(12,7),DTH(7),HRSPAN(12),HFLOOR(12),CFLOOR(12)
      DATA GHOUR/8.0,8.5,9.0,9.5,10.0,10.5,11.0,11.5,12.0,12.5,13.0,
     >        13.5,14.0,14.5,15.0,15.5,16.0,16.25/
      DATA GRT/
     1   0.197  ,  0.164  ,  0.103  ,  0.034  ,  0.0    ,  0.0    ,0.0
     2,  0.188  ,  0.160  ,  0.105  ,  0.044  ,  0.0    ,  0.0    ,0.0
     3,  0.180  ,  0.155  ,  0.108  ,  0.052  ,  0.0    ,  0.0    ,0.0
     4,  0.171  ,  0.150  ,  0.109  ,  0.059  ,  0.011  ,  0.0    ,0.0
     5,  0.165  ,  0.145  ,  0.110  ,  0.065  ,  0.020  ,  0.0    ,0.0
     6,  0.158  ,  0.140  ,  0.109  ,  0.068  ,  0.026  ,  0.002  ,0.0
     7,  0.152  ,  0.135  ,  0.108  ,  0.072  ,  0.032  ,  0.005  ,0.0
     8,  0.147  ,  0.131  ,  0.106  ,  0.074  ,  0.036  ,  0.007  ,0.0
     9,  0.142  ,  0.128  ,  0.105  ,  0.076  ,  0.040  ,  0.011  ,0.0
     1,  0.137  ,  0.124  ,  0.103  ,  0.077  ,  0.045  ,  0.015  ,0.0
     2,  0.133  ,  0.121  ,  0.101  ,  0.078  ,  0.048  ,  0.019,0.003
     3,  0.128  ,  0.118  ,  0.100  ,  0.078  ,  0.050  ,  0.022,0.005
     4,  0.124  ,  0.114  ,  0.099  ,  0.078  ,  0.052  ,  0.026,0.008
     5,  0.120  ,  0.111  ,  0.097  ,  0.078  ,  0.054  ,  0.029,0.010
     6,  0.117  ,  0.109  ,  0.096  ,  0.078  ,  0.055  ,  0.032,0.013
     7,  0.112  ,  0.105  ,  0.095  ,  0.077  ,  0.057  ,  0.035,0.015
     8,  0.109  ,  0.103  ,  0.093  ,  0.077  ,  0.058  ,  0.038,0.018
     9,  0.107  ,  0.101  ,  0.092  ,  0.077  ,  0.058  ,  0.039,.019/
      DATA RO/1.0315,1.0235,1.0103,0.9913,0.9757,0.9680,0.9680,0.9757,
     >          0.9898,1.0087,1.0238,1.0318/
      DATA ANG/-21.25,-12.92,-2.42,9.5,18.68,23.28,21.65,14.28,3.32,
     >        -8.25,-18.3,-23.23/
```

```
C
      PI=3.1415927
      IGLASS=GLASS
      ITYPE=PANES
      TILT=(ALAT+20.0)*PI/180.0
      ALAT=ALAT*PI/180.0
C
C
      DO 1000 M=1,12
      DO 10 K=1,10
      SOL(M,K)=0.0
10    CONTINUE
      HBAR=HBR(M)
      DEC=ANG(M)*PI/180.0
C
      AB=-TAN(ALAT)*TAN(DEC)
      HALF=ARCOS(AB)
      HOO=24.0*442.0*RO(M)/PI
      HOO=(COS(ALAT)*COS(DEC)*SIN(HALF)+HALF*SIN(ALAT)*SIN(DEC))*HOO
      HOUR=24.0*HALF/PI
      IF(HOUR.LT.8.0.OR.HOUR.GE.16.25) PRINT 500
500   FORMAT('1 IN SUBROUTINE SUNLJ, THE HOUR OF SUNRISE',
     >        ' OR SUNSET EXCEEDS THE LIMITS OF PROGRAM BECAUSE'/
     >        '  THE LATITUDE IS GREATER THAN 49.  THE HOUR IS'
     >        ' BEING RESET.')
      IF(HOUR.LT.8.0) HOUR=8.0
      IF(HOUR.GE.16.25) HOUR=16.2
C
      SUM1=0.0
      SUM2=0.0
      DO 20 I=1,18
      I2=I
      I1=I-1
      IF(GHOUR(I).GT.HOUR) GO TO 30
20    CONTINUE
C
30    DO 40 J=1,7
      W=(2*J-1)*PI/24.0
      IF(W.GT.0.95*HALF) GO TO 50
      JAY=J
      X=(GHOUR(I2)-HOUR)/(GHOUR(I2)-GHOUR(I1))
      RTV(J)=GRT(J,I2)-(GRT(J,I2)-GRT(J,I1))*X
      RDV(J)=(PI/24.)*(COS(W)-COS(HALF))/(SIN(HALF)-HALF*COS(HALF))
      IF (RDV(J) .LT. 0.0)  RDV(J)=0.0
      SUM1=SUM1+RTV(J)
      SUM2=SUM2+RDV(J)
40    CONTINUE
C
50    DO 60 J=1,JAY
      RTV(J)=0.5*RTV(J)/SUM1
      IF(RTV(J).LT.0.0) RTV(J)=0.0
      RDV(J)=0.5*RDV(J)/SUM2
60    CONTINUE
C
      AKBAR=HBAR/HOO
```

```
      IF(AKBAR.GT.0.75) DH=0.167
      IF(AKBAR.GT.0.75) GO TO 70
      DH=.41717143-1.2034286*AKBAR
      IF(DH.LT.0.0) DH=0.0
      DH=DH+.78842857-.82857143*AKBAR
      IF(DH.GT.1.0) DH=1.0
C
70    RHO=0.2
      DO 200 J=1,JAY
      W=(2*J-1)*PI/24.0
      THCOS=COS(ALAT)*COS(DEC)*COS(W)+SIN(ALAT)*SIN(DEC)
      BETA=ARSIN(THCOS)
      PHISIN=COS(DEC)*SIN(W)/COS(BETA)
      PHI=ARSIN(PHISIN)
      TEST=COS(W)-TAN(DEC)/TAN(ALAT)
      IF(TEST.LE.0.0) PHI=PI-PHI
      SCOSV=0.0
      IF(PHI.LE.1.57079) SCOSV=COS(BETA)*COS(PHI)
      GAM=ABS(PHI-1.570796)
      EWCOSV=COS(BETA)*COS(GAM)
      TLTCOS=COS(ALAT-TILT)*COS(DEC)*COS(W)+SIN(ALAT-TILT)*SIN(DEC)
      IF(TLTCOS.LT.0.0)  TLTCOS=0.0
C
      TERM=RTV(J)-RDV(J)*DH
      IF(DH.GT.0.98.OR.TERM.LT.0.0) TERM=0.0
C
C  CALCULATE THE HOURLY DIRECT, DIFFUSE, REFLECTIVE, AND TOTAL
C   RADIATION ON SURFACES
C
      EDIR=(EWCOSV/THCOS)*HBAR*TERM
      EDIF=HBAR*RDV(J)*DH/2.0
      EREF=HBAR*RTV(J)*RHO/2.0
      EDRF=EDIF+EREF
      SDIR=(SCOSV/THCOS)*HBAR*TERM
      HDIR=HBAR*TERM
      HDRF=HBAR*(RDV(J)*DH)
      PDIR=(TLTCOS/THCOS)*HBAR*TERM
      PDIF=HBAR*RDV(J)*DH*(1.0+COS(TILT))/2.0
      PREF=HBAR*RTV(J)*RHO*(1.0-COS(TILT))/2.0
      SOL(M,10)=SOL(M,10)+2.0*(PDIR+PDIF+PREF)
      SOL(M,9)=SOL(M,9)+2.0*(HDIR+HDRF)
      SOL(M,5)=SOL(M,5)+2.0*EDRF
      SOL(M,6)=SOL(M,6)+EDIR+2.0*EDRF
      SOL(M,7)=SOL(M,7)+2.0*(SDIR+EDRF)
      CALL TRNSMT(SCOSV,IGLASS,ITYPE,TDR,TDF)
      SOL(M,1)=SOL(M,1)+2.0*EDRF*TDF
      SOL(M,3)=SOL(M,3)+2.0*(TDR*SDIR+TDF*EDRF)
      CALL TRNSMT (EWCOSV,IGLASS,ITYPE,TDR,TDF)
      SOL(M,2)=SOL(M,2)+TDR*EDIR+TDF*EDRF*2.0
200   CONTINUE
C
C
      SOL(M,4)=SOL(M,2)
      SOL(M,8)=SOL(M,6)
1000  CONTINUE
```

```
C
        RETURN
        END
        SUBROUTINE TRNSMT(X,IGLASS,ITYPE,TDR,TDF)
        DIMENSION D(4),T(6),A(6),TD(6),AO(6),AI(6),C(10)
        REAL NO,NI
C     ITYPE=NUMBER OF PANES,1-SINGLE GLAZING AND 2-DOUBLE GLAZING
C     IGLASS IS AN INTEGER FROM 1 TO 8 WHICH REPRESENTS ONE TYPE OF
C     GLASS GIVEN IN TABLE A-7, PAGE 28A OF NBSLD HANDBOOK.
C     1--- K*L=0.05 (1/8 IN SHEET)
C     2--- K*L=0.10
C     3--- K*L=0.1  (1/4 IN REG. PLATE)
C     4--- K*L=0.20
C     5--- K*L=0.40
C     6--- K*L=0.60
C     7--- K*L=0.80 (K/% TRANS. H.A. PLATE)
C     8--- K*L=1.0
C     D(1)=TDR FOR SINGLE GLAZING
C     D(2)=TDF FOR SINGLE GLAZING
C     D(3)=TDR FOR DOUBLE GLAZING
C     D(4)=TDF FOR DOUBLE GLAZING
C
C     C(1)=TRANSMISSIVITY OF A SINGLE PANE FOR DIRECT RADIATION
C     C(2)=TRANSMISSIVITY OF A SINGLE PANE FOR DIFFUSE RADIATION
C     C(3)=ABSORPTIVITY OF A SINGLE PANE FOR DIRECT RADIATION
C     C(4)=ABSORPTIVITY OF A SINGLE PANE FOR DIFFUSE RADIATION
C     C(5)=TRANSMISSIVITY OF A DOUBLE PANE FOR DIRECT RADIATION
C     C(6)=TRANSMISSIVITY OF A DOUBLE PANE FOR DIFFUSE RADIATION
C     C(7)=ABSORPTIVITY OF INNER PANE FOR DIRECT RADIATION
C     C(8)=ABSORPTIVITY OF OUTER PANE FOR DIRECT RADIATION
C     C(9)=ABSORPTIVITY OF INNER PANE FOR DIFFUSE RADIATION
C     C(10)=ABSORPTIVITY OF OUTER PANE FOR DIFFUSE RADIATION
C
C     RI,RO,RA=THERMAL RESISTANCE(INSIDE,OUTSIDE,AND AIRSPACE)
        RI=0.70
        RO=0.25
        RA=1.0
        CALL GLAZE(IGLASS,T,A,TD,AO,AI)
        DO 10 K=1,10
10      C(K)=0.0
        DO 100 J=2,6
        ETA=X**(J-1)
        C(1)=C(1)+T(J)*ETA
        C(2)=C(2)+T(J)/(J+1)
        C(3)=C(3)+A(J)*ETA
        C(4)=C(4)+A(J)/(J+1)
        C(5)=C(5)+TD(J)*ETA
        C(6)=C(6)+TD(J)/(J+1)
        C(7)=C(7)+AI(J)*ETA
        C(8)=C(8)+AO(J)*ETA
        C(9)=C(9)+AI(J)/(J+1)
        C(10)=C(10)+AO(J)/(J+1)
100     CONTINUE
        C(1)=C(1)+T(1)
        C(2)=(C(2)+T(1)/2.0)*2.0
```

```
      C(3)=C(3)+A(1)
      C(4)=(C(4)+A(1)/2.0)*2.0
      C(5)=C(5)+TD(1)
      C(6)=(C(6)+TD(1)/2.0)*2.0
      C(7)=C(7)+AI(1)
      C(8)=C(8)+AO(1)
      C(9)=(C(9)+AI(1)/2.0)*2.0
      C(10)=(C(10)+AO(1)/2.0)*2.0
C
C     DOUBLE-GLAZING
      NI=(RO+RA)/(RO+RA+RI)
      NO=RO/(RO+RI+RA)
      D(3)=C(5)+NO*C(8)+NI*C(7)
      D(4)=C(6)+NO*C(10)+NI*C(9)
C
C     SINGLE-GLAZING
      NO=RO/(RO+RI)
      D(1)=C(1)+NO*C(3)
      D(2)=C(2)+NO*C(4)
      IF(ITYPE.EQ.2)GOTO 200
      TDR=D(1)
      TDF=D(2)
      GOTO 300
200   TDR=D(3)
      TDF=D(4)
300   CONTINUE
      RETURN
      END
      FUNCTION ET(TH,X)
C
C  TH IS THE SUM OF DAYS SINCE JANUARY AND X IS THE DEPTH IN FEET.
C  THIS FUNCTION IS USED IN COMBINATION WITH SUBROUTINE EARTH.
C
      COMMON/EQU/DT
      COMMON/LEAST/A,B,P
      PI=3.141593
      E1=EXP(-1*DT*X)
      ARG=2.*PI*(TH/8766.)-DT*X-P
      ET=A-ABS(B)*E1*COS(ARG)
      RETURN
      END
      FUNCTION IRANK(A)
C
C  USED BY SUBROUTINE PWFCOS
C
      DIMENSION A(5)
      X=AMIN1(A(1),A(2),A(3),A(4),A(5))
      DO 40 K=1,5
      IF(A(K).EQ.X) GO TO 50
40    CONTINUE
50    IRANK=K
      RETURN
      END
      FUNCTION PVSF (X)
C
```

```
C     ******************************************************************
C
C  THIS FUNCTION WAS TAKEN FROM NBSLD BY T.KUSUDA
C
C  IT GIVES THE PARTICAL PRESSURE OF WATER VAPOR IN MOISTURE
C   SATURATED AIR, IN HG.
C
        DIMENSION A(6),B(4),P(4)
        DATA A/-7.90298,5.02808,-1.3816E-7,11.344,8.1328E-3,-3.49149/
        DATA B/-9.09718,-3.56654,0.876793,0.0060273/
        T=(X+459.688)/1.8
        IF (T.LT.273.16) GO TO 10
        Z=373.16/T
        P(1)=A(1)*(Z-1.0)
        P(2)=A(2)*ALOG10(Z)
        Z1=A(4)*(1.0-1.0/Z)
        P(3)=A(3)*(10.0**Z1-1.0)
        Z1=A(6)*(Z-1.0)
        P(4)=A(5)*(10.0**Z1-1.0)
        GO TO 20
C
10      Z=273.16/T
        P(1)=B(1)*(Z-1.0)
        P(2)=B(2)*ALOG10(Z)
        P(3)=B(3)*(1.0-1.0/Z)
        P(4)=ALOG10(B(4))
20      SUM=0
        DO 30 I=1,4
30      SUM=SUM+P(I)
        PVSF=29.921*10.0**SUM
        RETURN
C
        END
```

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