

COMPARISON OF ACTUAL AND SIMULATED
PERFORMANCE OF THE ARLINGTON SOLAR HOUSE SYSTEM

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ABSTRACT

The performance of a solar energy system on a small residential building at Arlington has been monitored by the Solar Energy Laboratory. The house system incorporates Owens-Illinois evacuated tubular collectors with air as the working fluid. A large pebble bed storage unit is used to store off-peak electric auxiliary and solar energy. Auxiliary energy is supplied by the utility only between 10 PM and 8 AM. Domestic hot water is provided by an air-water heat exchanger supplying a preheat tank.

Data for two periods have been analyzed in detail to determine actual system performance. TRNSYS simulations have then been done for the same periods using the measured solar radiation on a horizontal plane and the measured ambient temperature. Leakage and duct losses are found to have a major effect on the results, and these are included in the simulations. Comparisons are made of integrated energy quantities and rock bed temperatures. The data and the simulations agree quite closely for the two data periods simulated.

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TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION	1
CHAPTER I: ARLINGTON HOUSE SYSTEM DESCRIPTION	2
<u>Data Collection System</u>	6
Data Analysis - Removal of Spurious Data Points.	7
<u>Data for Comparison with Simulation.</u>	10
CHAPTER II: COMPONENT MODELS.	14
<u>Collector Model.</u>	14
Introduction	14
Computation of S_{eff}	15
Thermal Performance of Collectors.	20
Leakage Into Collector	21
Capacitance in Collector	23
<u>Controller Model</u>	23
Introduction	23
House Control System	24
Control Strategy	25
<u>Data Reader-Interporator</u>	27
CHAPTER III: SIMULATION	29
<u>Introduction</u>	29
<u>Modeling Decisions</u>	29
Air Leakage.	29

TABLE OF CONTENTS

(Continued)

	<u>Page</u>
Passive Contribution To the Load	30
<u>Simulation Model</u>	33
<u>Simulation Results</u>	37
CONCLUSIONS.	45
REFERENCES	46
APPENDIX A	47
APPENDIX B	50
APPENDIX C	53
APPENDIX D	56
APPENDIX E	75

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1-1	Arlington House System Schematic	3
1-2	Ambient Temperatures vs. Time	8
1-3	Ambient Temperature vs. Time After Removal of Spurious Data Points	9
1-4	Collector System and Associated Energy Flows	12
2-1	Figure Showing Pseudo Incidence Angle Ω	16
2-2	Collector Array Geometry	17
2-3	Collector Efficiency Plot	22
3-1	Schematic of Paths for Duct Leakage	31
3-2	House Temperature vs. Time	32
3-3	Comparison of House Temperature from Simulation and Data	39
3-4	Comparison of Collector Outlet Temperature from Simulation and Data	41

LIST OF TABLES

	<u>Page</u>
Table 1 Control Strategy	4
Table 2 TRNSYS Components Used in the Simulation	34
Table 3 Source of TRNSYS Inputs	35
Table 4 Comparison of Data and Simulation Results	38
Table 5 Effect of Leakage Path on Energy Flows	42

INTRODUCTION

Simulations provide a useful and efficient means of evaluating and comparing the performance of solar heating systems. Models of complex systems are built from separate models for the various components of the system. These component models are developed from detailed studies of the components and many have been well validated by comparison with experimental data. The validity of using component models to simulate an entire system has not been as extensively studied.

This paper compares the measured and simulated performance of the Arlington Solar House. The simulations were done using TRNSYS [1]. The parameters used in the component models have been determined from a combination of experimental and analytical techniques. Weather data taken at the house during the test period were used to drive the simulation. The performance of the system in terms of total energy quantities and the dynamic response of some components are determined and compared to the data.

The comparison of measured and simulated performance establishes the validity of this system simulation. This is a complex system with a large number of components and a complex control strategy; it is clear that such systems can be successfully simulated.

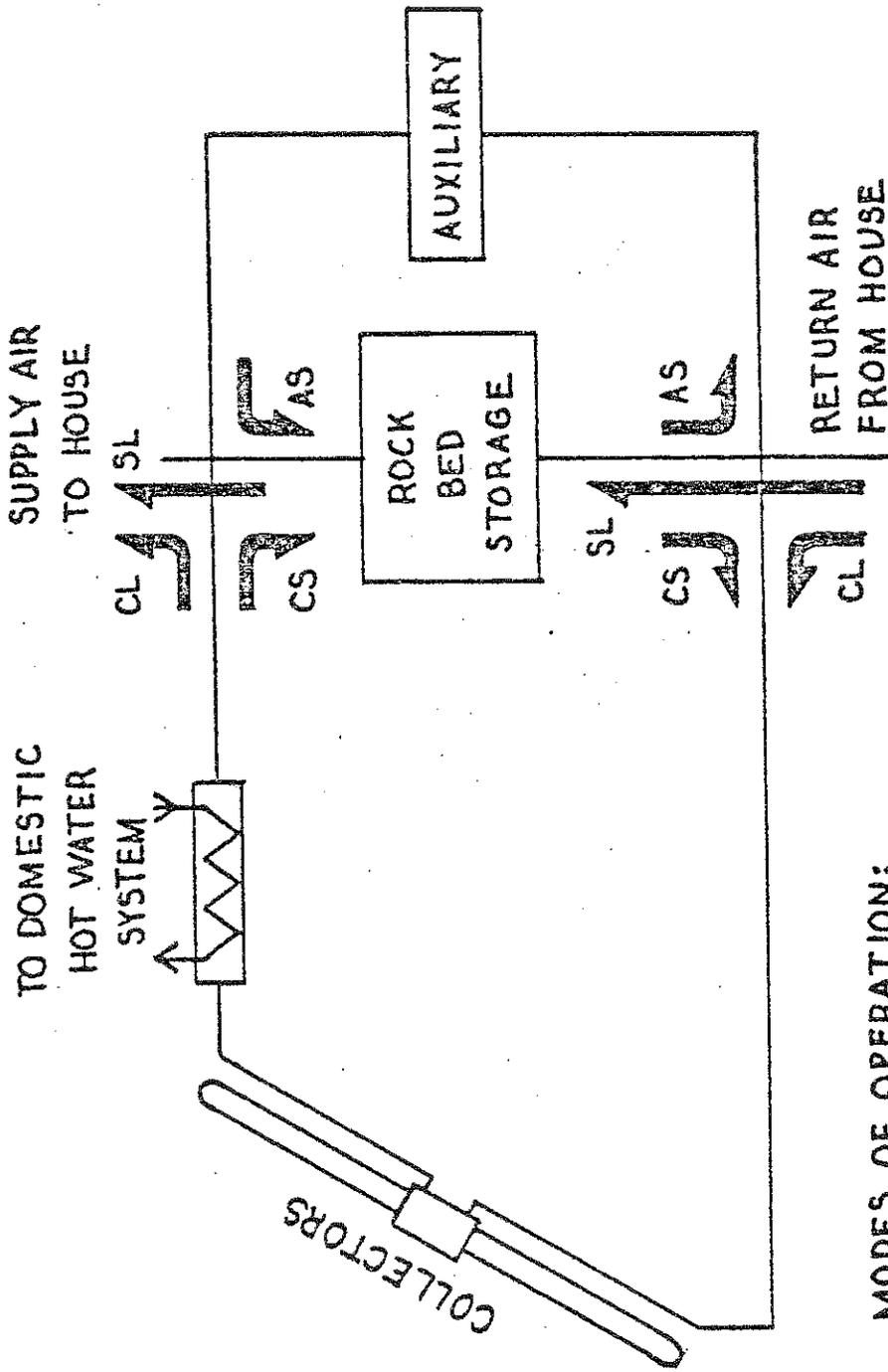
CHAPTER I

ARLINGTON HOUSE SYSTEM DESCRIPTION

The Arlington House is an air-based system as shown schematically in Figure 1.1. The collectors are evacuated tubular collectors with a selective surface on the absorber tube. The rock bed is used as a combined energy storage system for both collected solar energy and auxiliary energy from an electric duct heater. The system is unique in that the auxiliary heater supplies heat directly to the storage and only during the off peak hours of the utility (10 PM to 8 AM). This auxiliary supply does not heat the house directly but is used to ensure that the energy in the rock bed is sufficient to meet the expected demand. Thus, the storage is charged each night with the sufficient energy to provide heat to the house during the next on-peak 16 hour period.

When direct solar is not available to meet the load, the house is heated by using the energy stored in the rock bed. Domestic hot water heating is provided by a heat exchanger in the collector return duct and a preheat-storage tank in combination with a conventional electric water heater. A more detailed description of the system is given by Erdmann [2] Persons [3] and Wallace [4].

The control strategy for the house is given in Table 1. During winter, both house and hot water heating are provided, while hot



MODES OF OPERATION:
 COLLECTOR - TO - STORAGE (CS)
 AUXILIARY - TO - STORAGE (AS)
 STORAGE - TO - LOAD (SL)
 COLLECTOR - TO - LOAD (CL)

Arlington House System Figure 1-1

Table 1

Control Strategy

<u>Input</u>	<u>CL</u>	<u>CS</u>	<u>SL₁</u>	<u>SL₂</u>	<u>AS</u>	<u>CW</u>
Winter	Yes	Yes	Yes	Yes	Yes	No
$T_{\text{house}} < T_{\text{set1}}$	Yes	No	Yes	X	No	X
$T_{\text{house}} < T_{\text{set2}}$	No	X	No	Yes	X	X
Solar Available*	Yes	Yes	No	X	No	Yes
Off Peak Period	X	X	X	X	Yes	X
Charge Store	X	X	X	X	Yes	X

*Solar available if

$$T_{\text{collector}} > T_{\text{supply}} + T_{\text{set1}} \quad (\tau < 5 \text{ min})$$

$$T_{\text{delivery}} > T_{\text{supply}} + T_{\text{set2}} \quad (\tau < 5 \text{ min})$$

Modes:

CL - collector to load

CS - collector to storage

SL₁ - storage to load, first stage heating

SL₂ - storage to load, second stage heating

AS - auxiliary to storage

CW - collector to domestic hot water

water heating only is provided in summer. A two stage thermostat is employed to initiate house heating. First stage heating is provided when the house temperature drops below the first set temperature. Air is circulated through the house directly from the collector if solar energy is available (CL mode), and from the storage if solar energy is not available (SL₁). Second stage heating initiates if the house temperature drops below the second set temperature. In this case air circulates from storage through the house even if solar energy is available (SL₂). During off peak hours, the average rock bed temperature is compared to a set temperature to determine if charging from auxiliary (AS) is required.

There are three differential controllers in the house control system. One of them is used to determine when there is solar energy available for collection during the winter. This controller compares the collector supply temperature at the discharge of the rock bed with the air temperature in the collectors. Air flow through the collectors is initiated when this temperature difference reaches a preset value. The low loss coefficient for the collectors means that this temperature may be high and not reflect the air temperature during solar collection. Accordingly, the controller logic action switches this differential controller's high temperature sensor from the sensor in the collectors to one in the return manifold after the collectors have been operating for five minutes. The second differential

controller is used to determine when solar energy is available for collection during the summer, when the system is used only to heat hot water. It uses the preheat tank temperature instead of the rock bed discharge temperature to determine when the collectors should be turned on. Otherwise its operation is the same as the first differential controller. The final differential controller is used to control the auxiliary furnace. It compares five sensors placed in the rock bed to give an average temperature to the preset value for the minimum storage temperature. If the rock bed temperature is below the set value and it is during the off peak period the auxiliary furnace is turned on to heat the rock bed.

Data Collection System

Data on weather conditions, flow rates, temperatures, electrical power consumption and the mode the house is operating in were recorded at ten minute intervals. The weather data consists of total radiation on the horizontal and 60° planes, ambient temperature, wind speed, and barometric pressure. The water flow rates are measured by turbine flow transducers. The hot water load and the flow rate through the heat exchanger coil are measured.

The air flow rates are measured by multi-point self averaging pitot tube stations with air straighteners. The collector supply, collector return and house supply flow rates are monitored. All temperatures are measured by copper-constantan thermocouples.

The electrical power consumption is measured by watt transducers using Hall Effect multipliers. The furnace, hot water heater, parasitic (including fan, water pump, damper motors, and control box), and domestic power consumption are recorded.

All sixty channels of data and the time they were taken are recorded on magnetic tape for storage. Appendix (A) is a listing of all the channels of data that were recorded.

Data Analysis - Removal of Spurious Data Points

Figure 1-2 is a plot of ambient temperature versus time. The large spikes obviously do not represent the true ambient temperature. Plots like Figure 1-2 were made for all of the data channels. These plots were then used to locate the spurious data points on each channel. Once these points were located they were replaced by the average of the data values for that channel from the time period before and after the spurious points. The causes of the spurious points are not known. Possible explanations are electrical disturbances (lightning) and dust on the magnetic tape used to record the data.

The data were then replotted to make sure that no spurious points were left uncorrected and to check that none were accidentally introduced during the cleaning up process. Figure 1-3 shows the ambient temperature data in its final state. The spikes still present

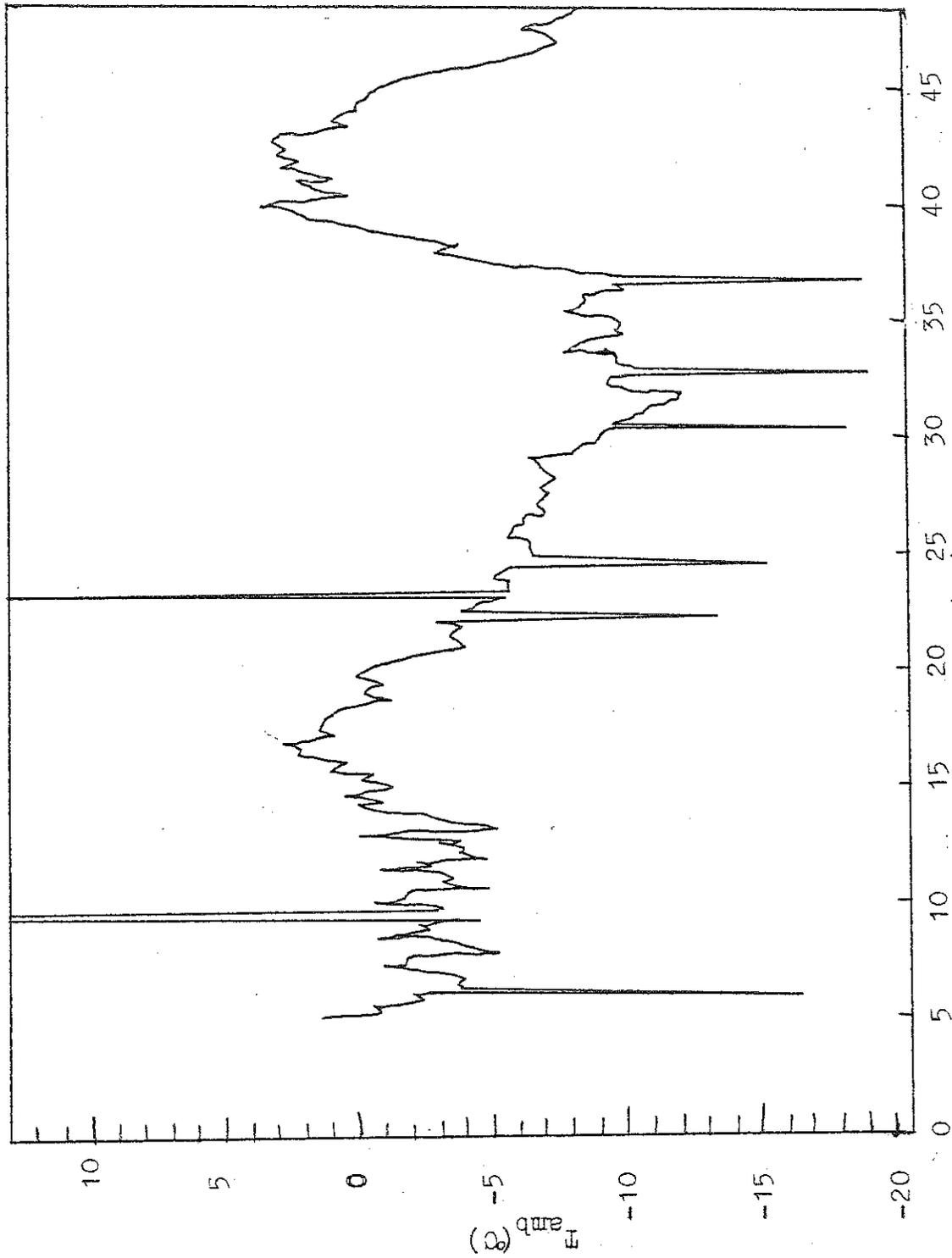


Figure 1-2 T_{amb} as raw data

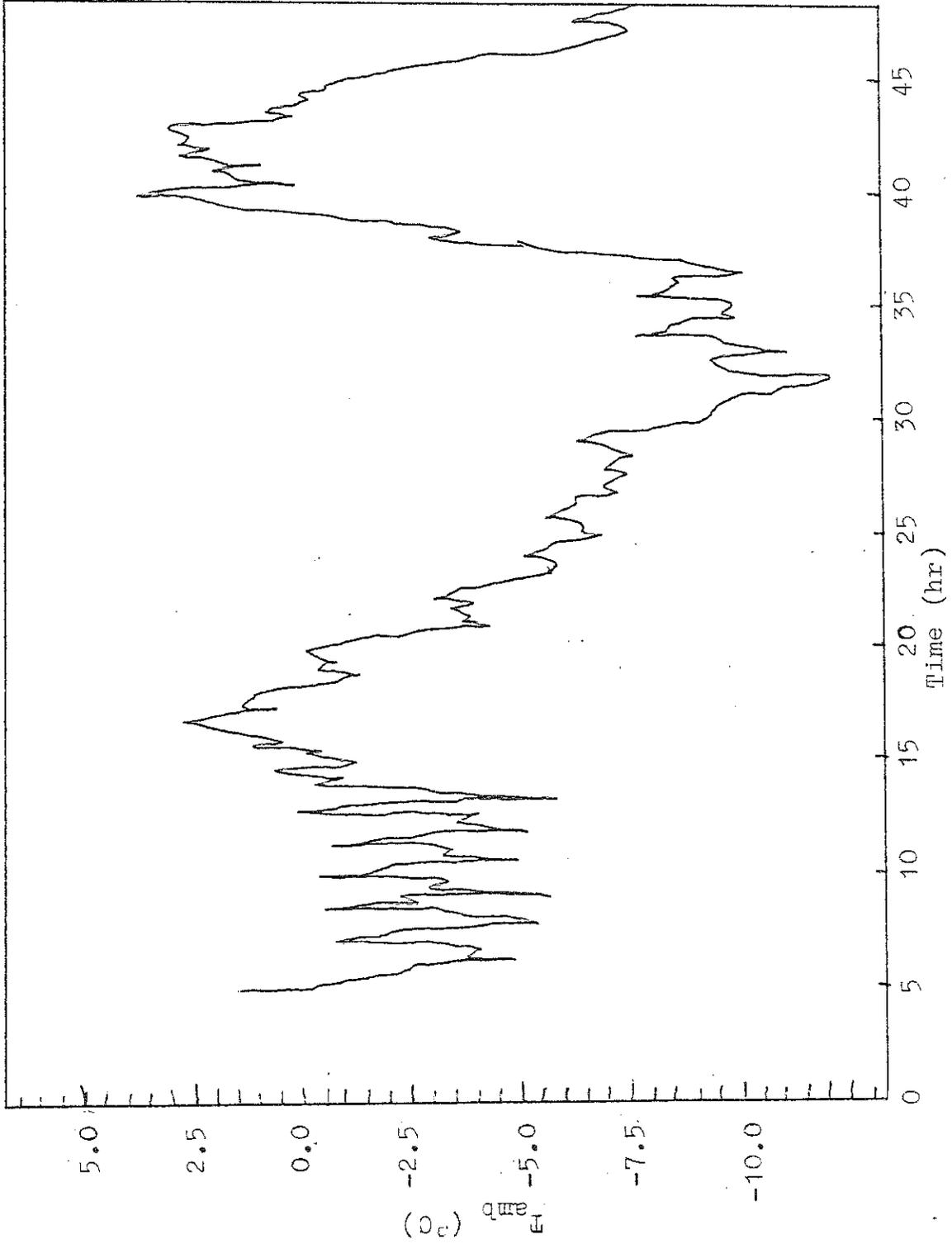


Figure 1-3 T_{amb} after cleaning

in this plot represent atmospheric turbulence.

Data for Comparison with Simulation

The uncertainties and problems encountered with the data measurement and recording have been thoroughly discussed by Erdmann, Persons and Wallace. This section enumerates the data that will be used for comparison with simulation.

The values that will be used for comparison are the totals over the period of:

1. Radiation on 60° plane
2. Auxiliary power consumption
3. Parasitic power consumption
4. Water heater power consumption
5. Useful collected energy

The radiation on the 60° plane is measured by a pyrpnometer mounted on the collector manifold. The auxiliary furnace has its own watt-hour meter. This meter was read daily and these readings were used to determine the furnace power consumption.

The parasitic and waterheater power consumption were measured by watt transducers, whose output was then integrated. The house power meter, which measures the total of domestic, parasitic, and water heater power, was also read daily. By subtracting the parasitic and water heater power from this reading the domestic power consumption was determined.

The useful collected energy is difficult to determine. There is a significant amount of ambient air leakage into the collectors when there is air flow that must be accounted for. The heat loss from the ducts in the attic and the manifolds must also be included. Figure 1-4 shows the collector and these energy flows.

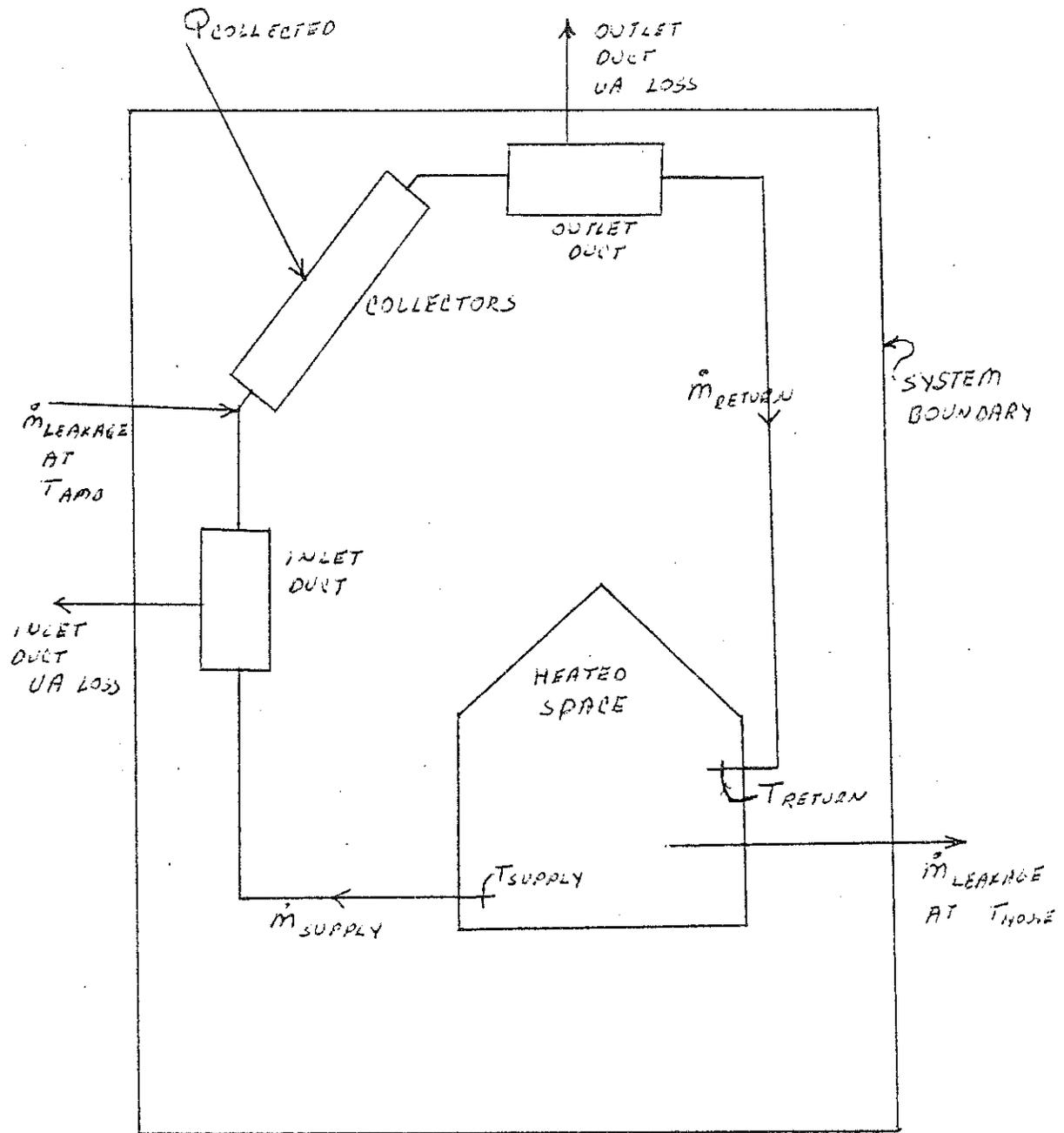
There are three energy terms to be considered in looking at the collectors. The first is the amount of solar energy collected (Q_{COLL} in Figure 3-3). The second is the measured solar energy collected, and the third is the net energy gain to the house from the collectors. If the air leakage and duct UA losses were not included in the analysis, these three terms would be identical.

The amount of solar energy collected is the amount of energy transferred to the air in the collectors while they are operating (see Figure 1-4).

The measured solar energy collected is computed as:

$$Q_{\text{measured}} = \dot{M}_{\text{RETURN}} C_p (T_{\text{RETURN}} - T_{\text{SUPPLY}}). \quad (1-1)$$

Q_{measured} is less than $Q_{\text{collected}}$ for two reasons. The first is the UA losses in the supply and return ducts. The second reason is the air leaking into the collectors. When computing Q_{measured} the temperature difference used is $T_{\text{RETURN}} - T_{\text{SUPPLY}}$ (equation 3-1) due to air leakage into the supply duct downstream from the location of the thermocouple measuring T_{SUPPLY} . The actual collector inlet temperature is lower than T_{SUPPLY} . It was decided that the collectors



$$\dot{m}_{RETURN} = \dot{m}_{SUPPLY} + \dot{m}_{LEAKAGE}$$

Figure 1-4
Collector Energy Flows

should be charged for this air leakage and not the house. It should be stressed that Q_{measured} is the only one of the three collector energy terms that can be computed directly from the data.

The final term is the actual gain in energy of the house due to the collector. This is computed as follows:

$$Q_{\text{NET}} = Q_{\text{measured}} - \dot{M}_{\text{LEAK}} C_p (T_{\text{HOUSE}} - T_{\text{AMB}}) \quad (1-2)$$

The air that leaked into the system at the collector inlet must leak out of the system somewhere (mass balance). From the position of the air flow monitor stations it was determined that this air leaked out of the ducts into the house and then from the house to the atmosphere. The amount of energy associated with this air flow leaving the house is the $\dot{M}_{\text{LEAK}} C_p (T_{\text{HOUSE}} - T_{\text{AMB}})$ term in equation (1-2). Q_{NET} then represents the actual energy gain to the house from the solar system.

The actual solar collected and the net energy collected are not measured by the data acquisition system. Thus, Q_{measured} must be used for comparison with the simulation. All three terms will be computed by the simulation. Then Q_{measured} from the simulation and the data will be compared. The simulation can then be used to determine Q_{COLL} and Q_{NET} and thus enable one to analyze the system performance in greater detail than the data alone can provide.

CHAPTER II

COMPONENT MODELS

Collector Model

Introduction

The collector model written for this simulation is based on Eberline [5]. Eberline developed a comprehensive program to predict the performance of the evacuated tubular collectors using air as the working fluid. He then used this program to develop several simplified methods for predicting collector performance. One of these, a graph of collector efficiency versus $T_{IN}^3(T_{IN} - T_{AMB})/S_{eff}$ was used as the basis for this model.

If the instantaneous efficiency of a collector array is defined as the ratio of useful energy output of the collector to the total solar radiation intercepted by the backing surface area, it will vary as the sun's position in the sky changes during the day. This is because as the sun's position changes the amount of energy reflected off the backing surface to the tubes will vary.

Eberline, however, defines efficiency as the ratio of useful energy output to the radiation incident on the tubes, not the radiation incident on the backing surface. Using this definition, one can separate the effects of the relative positions of the sun and the

collector array, which determines the amount of radiation that strikes a tube, from the thermal performance of the tube array.

Computation of S_{eff}

Eberline defines S_{eff} as the effective solar radiation incident on a single collector tube. It is a function of the solar radiation, the collector array geometry, and the collector array orientation.

To determine S_{eff} one must first define a special incidence angle Ω . This angle includes the effects of latitude, slope of collector array, hour angle, declination, and rotation of the collector tubes from the north-south meridian.

Looking at Figure 2.1 one can see that Ω is the projection of beam radiation measured from vertical in a plane normal to the collector axis.

For an orientation of the tube axis along the north-south axis, as we have at the Arlington House, Ω becomes:

$$\Omega = \text{TAN}^{-1} \left(\frac{\cos \delta \cdot \sin W}{\cos(\phi-S) \cos \delta \cos W + \sin(\phi-S) \sin \delta} \right) \quad (2-1)$$

This angle determines the location of the illuminated window on the backing surface (Figure 2-2) which is needed to determine S_{eff} .

The beam and diffuse radiation reflected off the backing surface onto the tubes can be a significant portion of the radiation incident on the tubes. For this reason, it is necessary to consider four components of the solar radiation striking the tubes:

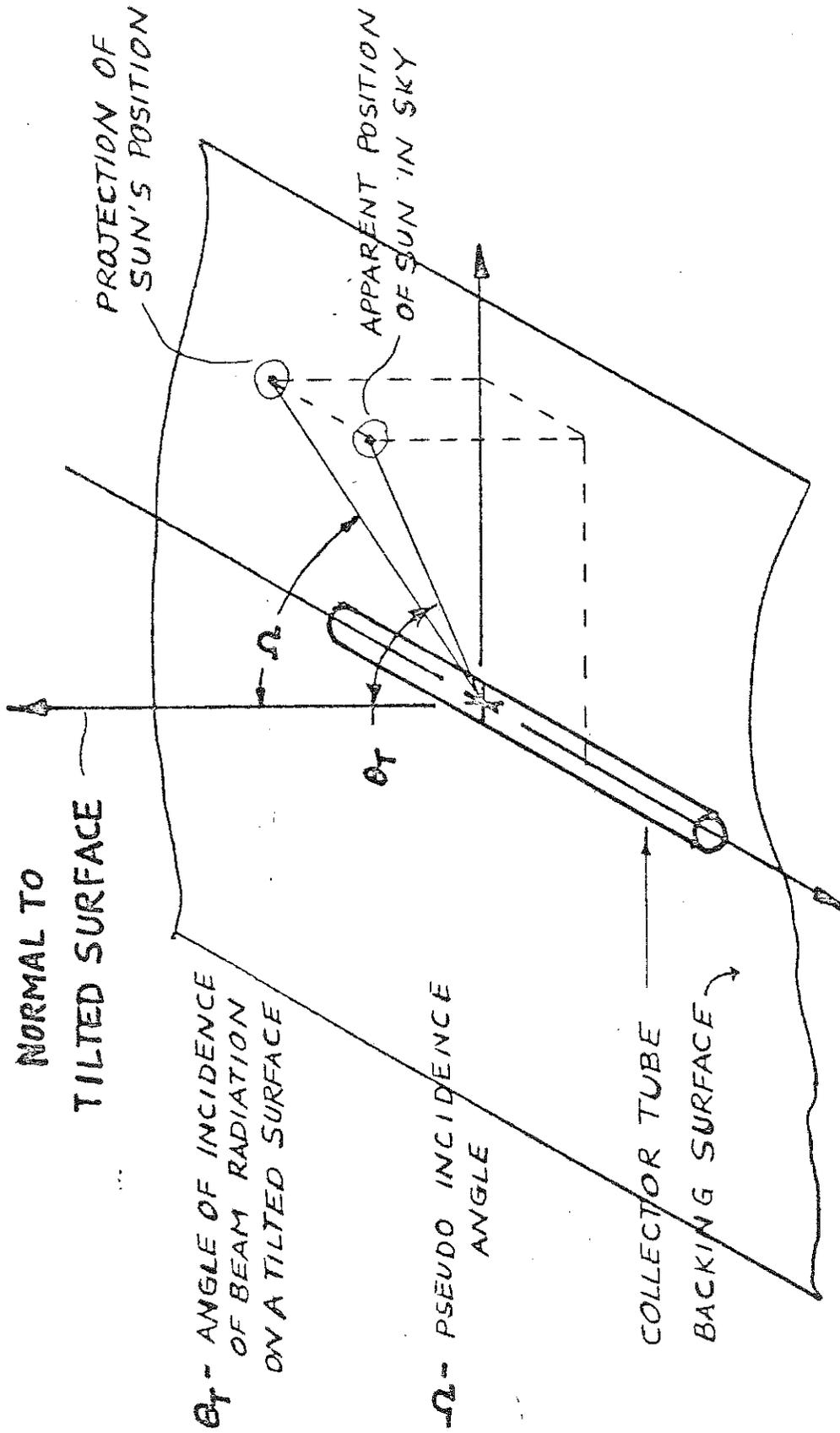


Figure 2-1

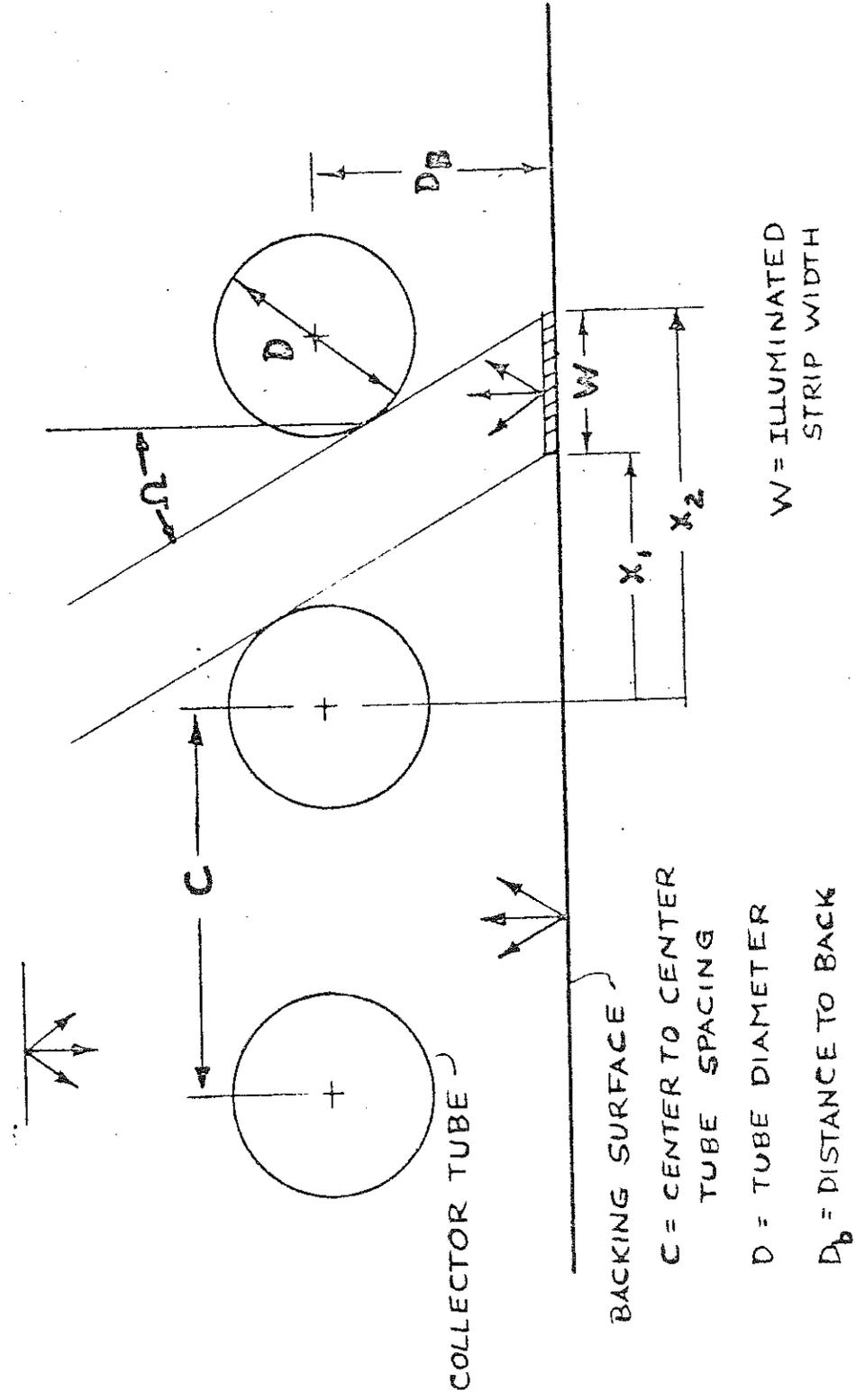


Figure 2-2

W = ILLUMINATED STRIP WIDTH

C = CENTER TO CENTER TUBE SPACING
D = TUBE DIAMETER
D_b = DISTANCE TO BACK

1. Beam radiation directly intercepted by tubes.
2. Beam radiation reflected off backing surface to the tubes.
3. Diffuse radiation directly intercepted by the tubes.
4. Diffuse radiation reflected off the backing surface to the tubes.

Looking at Figure 2-2 it is apparent that the circular absorber tube presents a constant intercept area for solar radiation until shading of a tube by the adjacent tube occurs. The directly intercepted beam radiation is then equal to:

$$S_B \text{DNL} - \text{no shading} \quad (2-2a)$$

$$S_B \text{CNL} \cos \Omega - \text{shading} \quad (2-2b)$$

Where S_B is a solar flux in the same plane as angle Ω that gives the correct beam radiation intensity received by the collector array.

$$S_B = \frac{H_B R_B}{\cos \Omega} \quad (2-3)$$

The beam radiation reflected off the backing surface is:

$$S_B \cos \Omega \text{WLN} S_B F_{W-T} \quad (2-4)$$

where F_{W-T} is the view factor from the illuminated strip, W, to all of the tubes, and all reflections are treated as diffuse reflections.

The diffuse radiation directly intercepted by the tubes is

$$S_D A_S F_{S-T} \quad (2-5)$$

Where S_D is the intensity of diffuse radiation (assumed uniform across the sky).

By reciprocity $A_S F_{S-T} = A_T F_{T-S}$ so the directly intercepted diffuse radiation can be written as:

$$S_D \pi \text{ DNL } F_{T-S} \quad (2-6)$$

Where: $\pi \text{ DNL}$ = tube area

The diffuse radiation reaching on incremental area on the backing surface is:

$$S_D A_S F_{S-dA} \quad (2-7)$$

By reciprocity $A_S F_{S-dA} = dA F_{dA-S}$. Because the incremental area sees only the sky and the tubes $1 - F_{dA-S} = F_{dA-T}$. Thus the total diffuse reflected to the tubes is then

$$S_D \int_{\text{Backing Surface}} F_{dA-S} (1 - F_{dA-S}) dA \quad (2-8)$$

We are now ready to determine S_{eff} . It is convenient to define the following two ratios:

R_B' = Beam radiation incident on tube
Beam radiation incident on a flat plate having the same orientation as collector array.

R_D' = Diffuse radiation incident on tube
Diffuse radiation incident on a flat plate having the same orientation as the collector array.

Combining equations 2-2, 2-4, 2-6, and 2-8 we have:

$$R_B' = \frac{D + \rho_B \cos \Omega \cdot W_{FW-T}}{c \cos \Omega} \quad \text{no shading} \quad (2-9a)$$

$$R_B' = 1 \quad \text{shading} \quad (2-9b)$$

$$R_D' = \frac{\pi B F_{T-S} + \rho_B \int_0^C F_{dA-S} (1 - F_{dA-S}) dx}{C} \quad (2-10)$$

Eberline shows that when either $Db/D \geq 1.5$ and $C/D \leq 2.0$ or $Db/D \geq .75$ and $C/D > 2.0$ these equations can be simplified to:

$$R_B' = \rho_B F_{P-T} \left[1 - \frac{D}{c \cos \Omega} \right] + \frac{D}{c \cos \Omega} \quad (2-11)$$

$$R_D' = F_{P-T} [1 - \rho_B (1 - F_{P-T})] \quad (2-12)$$

where F_{P-T} = view factor from the whole backing surface to the tubes.

The total radiation received by all of the collector tubes is then:

$$S_T = [H_B R_B R_B' + H_D R_D R_D'] CNL \quad (2-13)$$

If it is assumed that the solar radiation incident on a single tube is uniformly distributed around the tube perimeter the effective solar radiation is then:

$$S_{\text{eff}} = [H_B R_B R_B' + H_D R_D R_D'] \frac{C}{\pi D} \quad (2-14)$$

Thermal Performance of Collectors

Eberline found in his model that if collector efficiency were plotted against the variable $T_{IN}^3 (T_{IN} - T_{AMB}) / S_{\text{eff}} \times 10^{-7}$ that a

straight line was obtained (Figure 2-3). The slope of the line is a function of F_R , the collector heat removal factor, and collector properties. The slope was found to be fairly constant by Eberline for various flow rates.

The intercept is also a function of F_R and the collector properties. This graph was used to determine the collector efficiency in the model. Eberline determined that for these evacuated tubular collectors the slope of the line on the efficiency plot was relatively insensitive to variations in mass flow rate. The difficulty comes in trying to determine the correct intercept value for the plot to accurately predict the performance of the collector at the Arlington House. This will be discussed later.

Quantitatively the graph predicts:

1. as inlet temperature increases, the efficiency decreases
2. as ambient temperature decreases, the efficiency decreases
3. as incident solar radiation decreases, the efficiency decreases

Leakage Into Collector

Erdman determined experimentally that the collector outlet mass flow rate was approximately 15% greater than the inlet flow rate. This air leaked into the collector array from the atmosphere. In the model used in this simulation the leakage was treated in the following way. The efficiency was computed using the temperature of the inlet

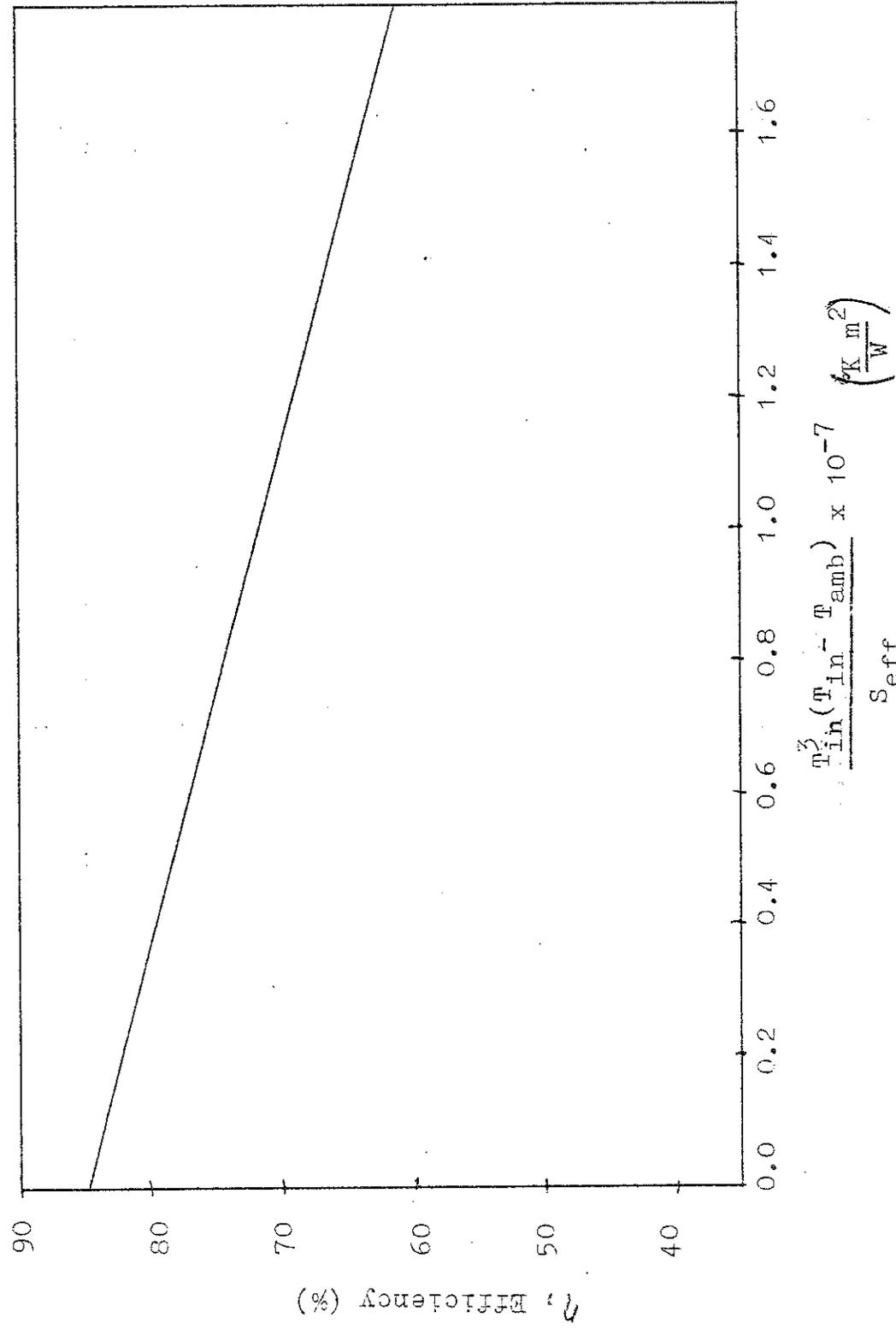


Figure 2-3 Collector Efficiency

air without mixing it with ambient air, this gives a conservative value for the efficiency. Then the actual inlet temperature was computed as the mass averages of the inlet and ambient air temperatures. The outlet temperature was then computed as:

$$T_{OUT} = \bar{T}_{IN} + QU/M \text{ CP} \quad (2-15)$$

where $QU = (S_{eff})(\eta)(\text{Backing Area}) \quad (2-16)$

Physically this means that all of the leakage was assumed to occur at the collector inlet.

Capacitance in Collector

Capacitance was not included in the collector model for reasons of computational simplicity. Grunes [6] determined that the response time for both heating and cooling of the collector assembly was on the order of thirty minutes. It was assumed that the delay in heating and cooling would, on the average, cancel out.

Controller Model

Introduction

The controller model is not a standard TRNSYS component. It was written specifically to model the Arlington House controller. There are some slight differences between the controller model and the

actual house control strategy. These will be discussed after the house control system has been explained.

House Control System

The control box at the Arlington House contains three differential temperature controllers, a digital logic section, and the necessary electronics to interface with the house thermostat and heating system.

The first differential controller determines if there is solar energy available for collection. It compares the temperature of the bottom node of the rock bed to the collector plate temperature when the collectors are off and determines when they should be turned on. After the collectors have been on for approximately five minutes it switches sensors and compares the bottom node of the rock bed to the air temperature in the return manifold to determine when the collectors should be shut off.

The second differential controller is used only during the summer when the rock bed is by-passed and the system is used only to heat hot water. Its operation is identical to the first controller except its low temperature sensor is located at the bottom of the pre-heat tank.

The third controller is used to indicate when the rock bed is below its set temperature. One input is from five sensors spaced vertically in the bed to give the average temperature. The other

input is from a potentiometer calibrated with a temperature scale. The potentiometer is used to adjust the rock bed set temperature.

There are three inputs to the controller from the room thermostat. A first stage heating command is output when the room temperature falls below the first stage set temperature. If the room temperature continues to fall and reaches the second stage set temperature, a second stage heating command is output.

This will happen when the system responds to the first stage command with the collector to load mode and there is not enough collected energy to meet the load. The third output is from a manual winter/summer switch. This tells the system to supply space and water heating (winter) or only water heating (summer).

To avoid overheating the water in the pre-heat tank a sensor is located near the top of the tank to indicate if the tank is over the hot water set temperature. If it is the pump to the heat-exchanger is shut off.

The controller also contains a clock to determine when the electric auxiliary will be allowed to turn on. The off-peak window is manually set on the controller.

Control Strategy

The following section describes how the controller model determines which mode the house will operate in.

Keeping the house warm is understandably assigned the top priority. When the house temperature falls below the first stage set temperature the controller first checks to see if there is solar energy directly available to meet the load. If there is, the system goes into collector to load mode. If there is not any solar available or if the house temperature drops below the second stage set point the system goes into storage to load mode.

If the house does not need heat, the controller checks to see if there is any solar available for collection. If there is, it goes into collector to storage mode. In either collector mode the pump to pump water from the pre-heat tank through the heat exchanger in the return duct is always on until the pre-heat tank reaches the hot water set temperature.

If there is no solar to collect, the controller then checks to see if the rock bed is below its minimum set temperature. If the bed is below its minimum set temperature and the time is during the off-peak window the auxiliary furnace is turned on to heat the rock bed. If it is not off-peak hours or if the rock bed is above its set temperature the house goes into the idle mode. The auxiliary furnace cannot directly heat the house, it can only charge the rock bed.

Differences Between Simulation Controller and House Controller

A few additional comments need to be made about the controller used in the simulation. First, since the collector model does not have capacitance built into it, there is no collector plate temperature. For control purposes if the collector is off, the collector model computes what its outlet temperature would be if it were on. This temperature is used as the collector plate temperature in the simulation.

The fastest the simulation can respond to a change of inputs is one timestep (10 minutes). So control is switched from the collector plate temperature to the return air temperature after one timestep. (This is to be compared with five minutes in the actual controller).

Finally, once the house temperature drops below the stage one set temperature the house is heated until it reaches a temperature higher than the stage one set temperature before the heat is turned off. This is done to prevent the system from oscillating around the stage one set temperature and corresponds to the dead band present in the actual house and control system.

Data Reader-Interporator

The standard simulation data reader is set up to read data only if it is given at equal time increments. The data from the Arlington House are taken at ten minute intervals and at all mode changes. Of

course, these mode changes can happen at any time so the Arlington data is not at equal time increments.

This component simply uses linear interpolation to supply the needed data to the simulation at the proper ten minute simulation timestep. The data used to drive the simulation are the total horizontal radiation and the ambient temperature.

CHAPTER III

SIMULATION

Introduction

The house was simulated using TRNSYS, a transient simulation program developed by the Solar Energy Laboratory at the University of Wisconsin. Using the components described in the previous chapter and the standard components available in TRNSYS a system to simulate the house was developed. The values of all of the parameters in the simulation are contained in the listing of the TRNSYS deck in Appendix (C).

Modeling Decisions

Air Leakage

A major source of uncertainty in the modeling concerned the location of air leakage into and out of the solar-house system. In experiments, Erdmann [2] determined that the mass flowrate out of the collector was 15% larger than that into the collector. Ambient air was found to be leaking into the collectors and manifolds. In the simulations leakage was all assumed to occur at the collector inlet as indicated in Figure 3-1. The collector inlet temperature was then

determined by a mass weighted average of the supply air at its temperature and the leakage air at ambient temperature. It was more difficult to determine the path the leakage air took when it left the system. Various alternatives are shown in Figure 3-1. Path (a) was the route assumed in the simulation. The leakage flowrate at the return temperature transferred energy into the heated space. Then the leakage flowrate at the house temperature was transferred to ambient as an energy loss from the heated space. The three other possible paths for the leakage (b, c, and d) were investigated and these will be discussed later.

Passive Contribution To the Load

There is no direct way to determine from the data the passive contribution to meeting the load. Looking at Figure 3-2, a plot of room temperature versus time, there are periods of several hours during the day the system never went into collector to load or storage to load modes. The house temperature did not oscillate as it does when the load is being met by the system cycling on and off. The energy to meet the load during these periods is not being provided by the house heating system. The passive gain through the south facing windows and the uncontrolled gain due to the air leakage when the house is running in storage to load mode. To determine the amount of the passive gain, the south facing windows were modeled using standard TRNSYS components.

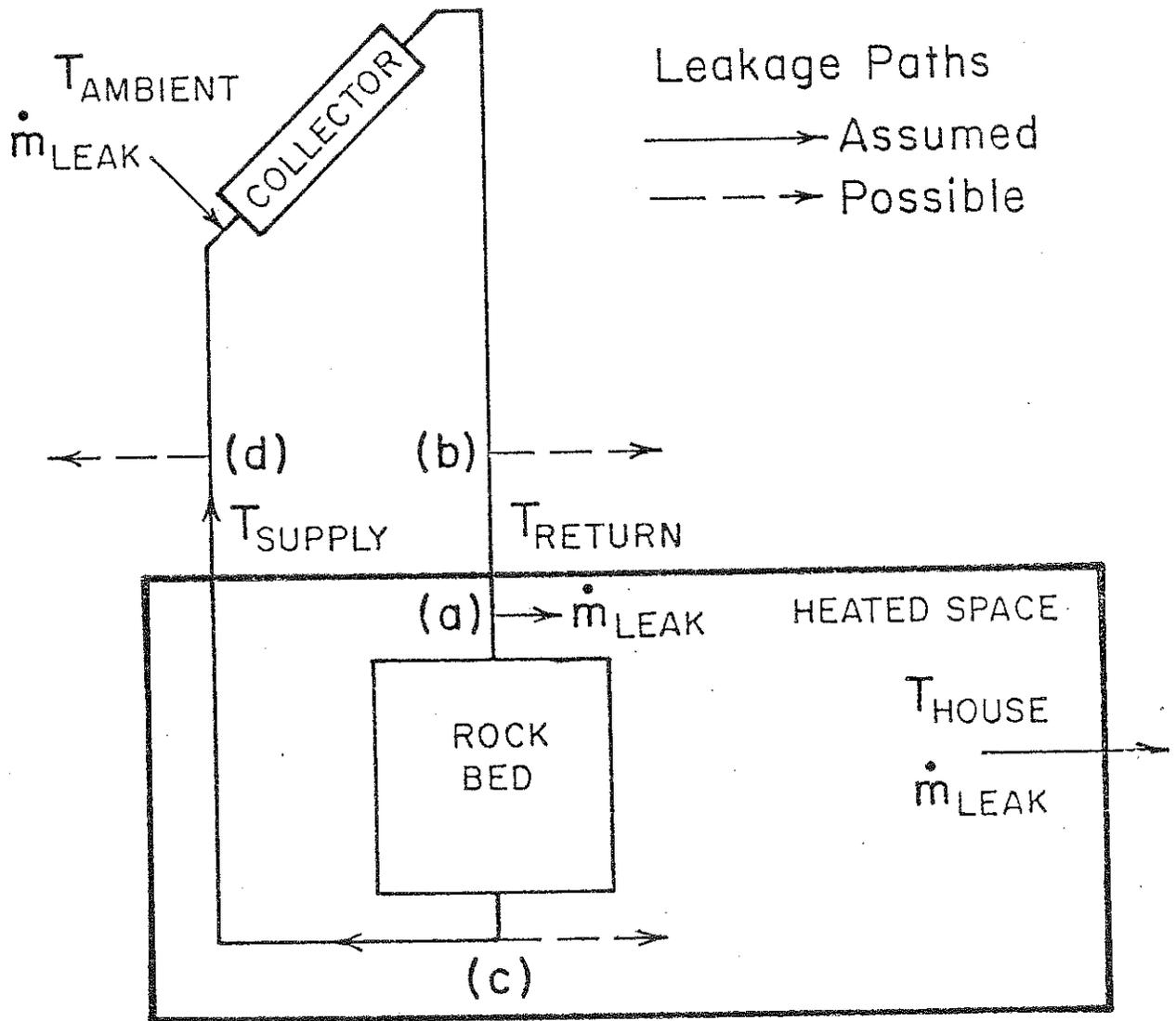


Figure 3-1

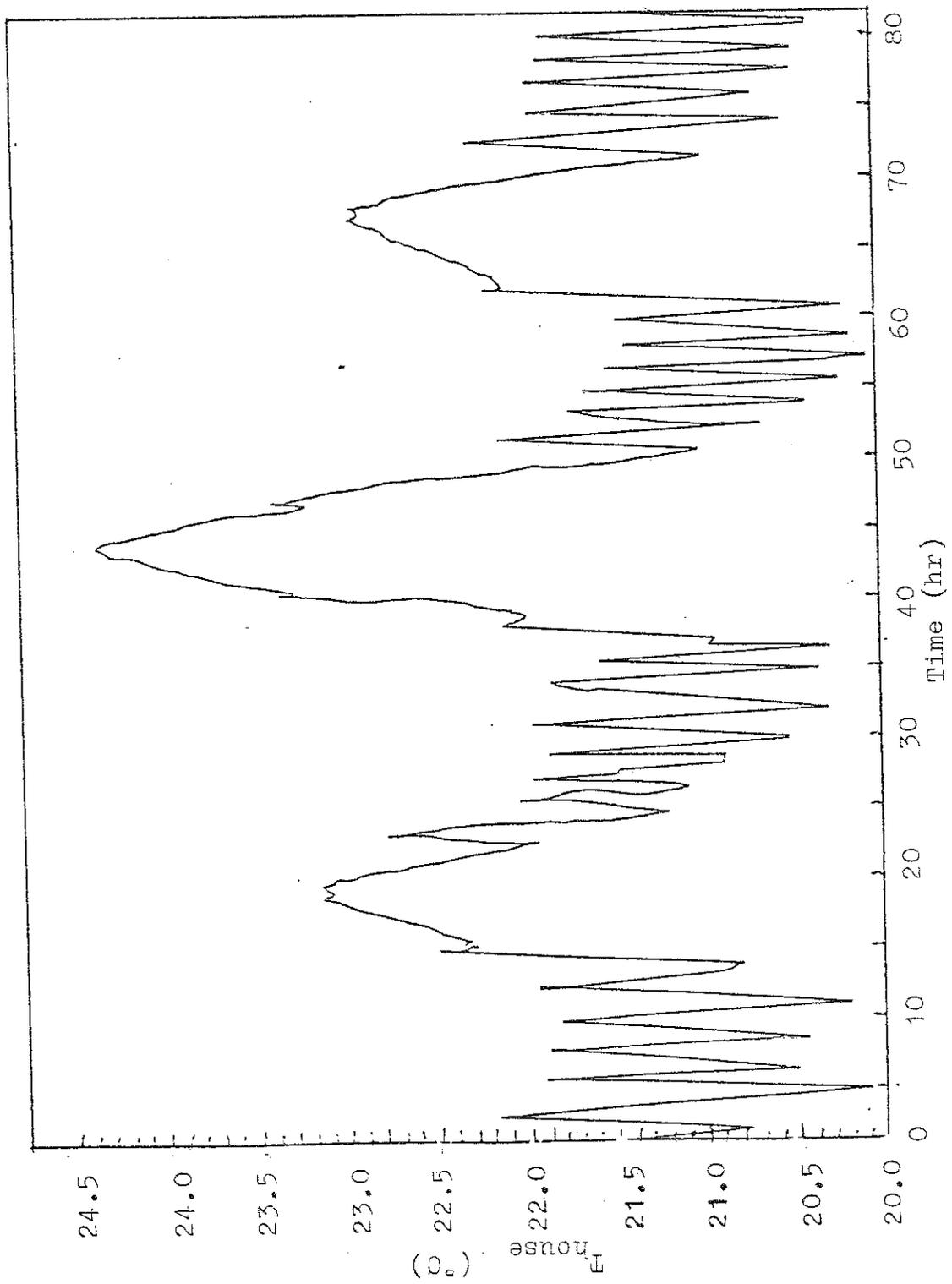


Figure 3-2 House Temperature

Simulation Model

The Arlington House heating system was modeled and simulated using TRNSYS [1]. Special component models were written to simulate the collectors and control system. The rest of the system, including the house load, rock bed, pre-heat tank, electric duct heater, electric water heater, windows for passive gain, pump, fan, heat exchanger, dampers, and ducts were modeled using standard TRNSYS components. Table 2 presents the components used. In order to accurately model this system many more components are required than for typical simulation studies. The source of inputs and parameters for the simulations are listed in Table 3. Where available, values were taken directly from manufacturers specifications.

Values for four of the system parameters were not directly available. These parameters are the house loss coefficient UA, the intercept of the collector efficiency plot, the rock bed set temperature, and the temperature differential required to turn the collector on. Since the exact value of these four parameters could not be directly determined, it was necessary to use the simulation to determine their values. This was done by using two separate data periods. First, estimates were made for each of the four parameters. The simulation was then run on the first data period and the values of the four parameters were adjusted until the simulation results

Table 2
TRNSYS Components Used in the Simulation

Standard Components

<u>Name</u>	<u>Type</u>	<u>Quantity Used</u>
Radiation Processor	16	3
Rock*Bed	10	1
One-Node House	12	1
Window	35	1
Overhang	34	1
Heat Exchanger	5	1
Preheat Tank	4	1
Water Heater	4	1
On/Off Auxiliary Heater	6	1
Fan	3	1
Damper	11	3
Tee Piece	11	3
Duct	31	2
Pump	3	1
Forcing Functions	14	1

Nonstandard Components

Collector	-	1
Controller	-	1

Table 3
Source of TRNSYS Inputs

Forcing Functions:

- Weather
- Domestic Power Consumption
- Hot Water Loads

Previous Steady State Experiments:

- Rock Bed UA and Parameters (Persons [2])
- Water Heater Parameters (Manufacturer Specs)
- Heat Exchanger Effectiveness (Manufacturer Specs)
- Flow Rates (Measured)
- Duct Heater Power Consumption (Manufacturer Specs)

Building Plans:

- Overhang Dimensions
- Window Dimensions

Engineering Calculations:

- Inlet and Outlet Duct UA
- Pre-heat Tank UA

Dynamic Calibration Experiments:

- House UA
- Collector Efficiency Plot Intercept Value
- Rock Bed Set Temperature
- Temperature Differential Required to Turn Collector on

agreed with the data. The values determined in this way were close to the estimates made earlier. Then the simulation program, using the same values for all parameters, was run for the second data period.

In the case of house loss coefficient, a design value was available and this was used as a base. It was modified to take into account the differences between design and construction. Adequate modeling information was not available on the collector performance to allow the data to give the daily performance. These data provided initial estimates for use with the model developed by Eberlein [5].

In the initial simulations, the minimum rock bed temperature for control was assumed to be 35C as set on the controller. It became apparent that the actual set temperature was higher than this. The actual temperature was based on the average of five temperatures located in the rock bed. However, as shown by Persons [3], these sensors were located in a region of low air flow and did not accurately represent the rock bed energy. It was found that a value of 52C more accurately represented the actual controlled temperature.

The collector model used in the simulations did not include thermal capacitance. The actual collectors and the sensors have appreciable capacitance which creates a significant delay on the time at which the collectors are turned on. This effect is modeled by increasing the collector turn on temperature so that the turn on

times for the actual operation and simulations agree.

Simulation Results

The data and simulation results for the two periods are compared in Table 4. As stated earlier, four parameters were adjusted to achieve the agreement shown for period 1. The test is, then, the agreement between the two results for period 2. The agreement between simulation and measured for collected energy, auxiliary supplied, and water heating auxiliary is within 6% of the input energy. This agreement establishes confidence in the system model and the choice of parameters.

As another evaluation of the simulation predictions, some dynamic outputs from the simulation were examined and compared to data. Figure 3-3 is a plot of house temperature as a function of time. The relatively smooth periods with peaks and without the oscillations represent day time during which the load is being met by the passive solar contribution. The regular oscillations represent night time when energy is supplied from storage. The frequency of the oscillations in the simulations is lower than that of the data, indicating that the actual lumped house capacitance is smaller than the value used in the simulation. The temperature from the simulation represents the average temperature of the entire house. The temperature plotted as data represents the south half of the house where essentially all of the passive contribution enters

Table 4
 Period 1
 13 Noon-Noon Days
 February 25 - March 10, 1978

	<u>Data</u>	<u>Simulation</u>	Difference Based on $Q_{\text{collector}}$
$Q_{\text{collector}}$	4.04 GJ	3.99 GJ	1.3
Q_{aux}	2.91 GJ	2.93 GJ	0.5
$Q_{\text{water aux}}$	0.19 GJ	0.19 GJ	--

Period 2
 12 Noon-Noon Days
 March 11 - March 23, 1978

	<u>Data</u>	<u>Simulation</u>	Difference Based on $Q_{\text{collector}}$
$Q_{\text{collector}}$	2.55 GJ	2.61 GJ	2.4
Q_{aux}	1.59 GJ	1.43 GJ	6.2
$Q_{\text{water aux}}$	0.19 GJ	0.20 GJ	0.4

(see appendix E for daily totals)

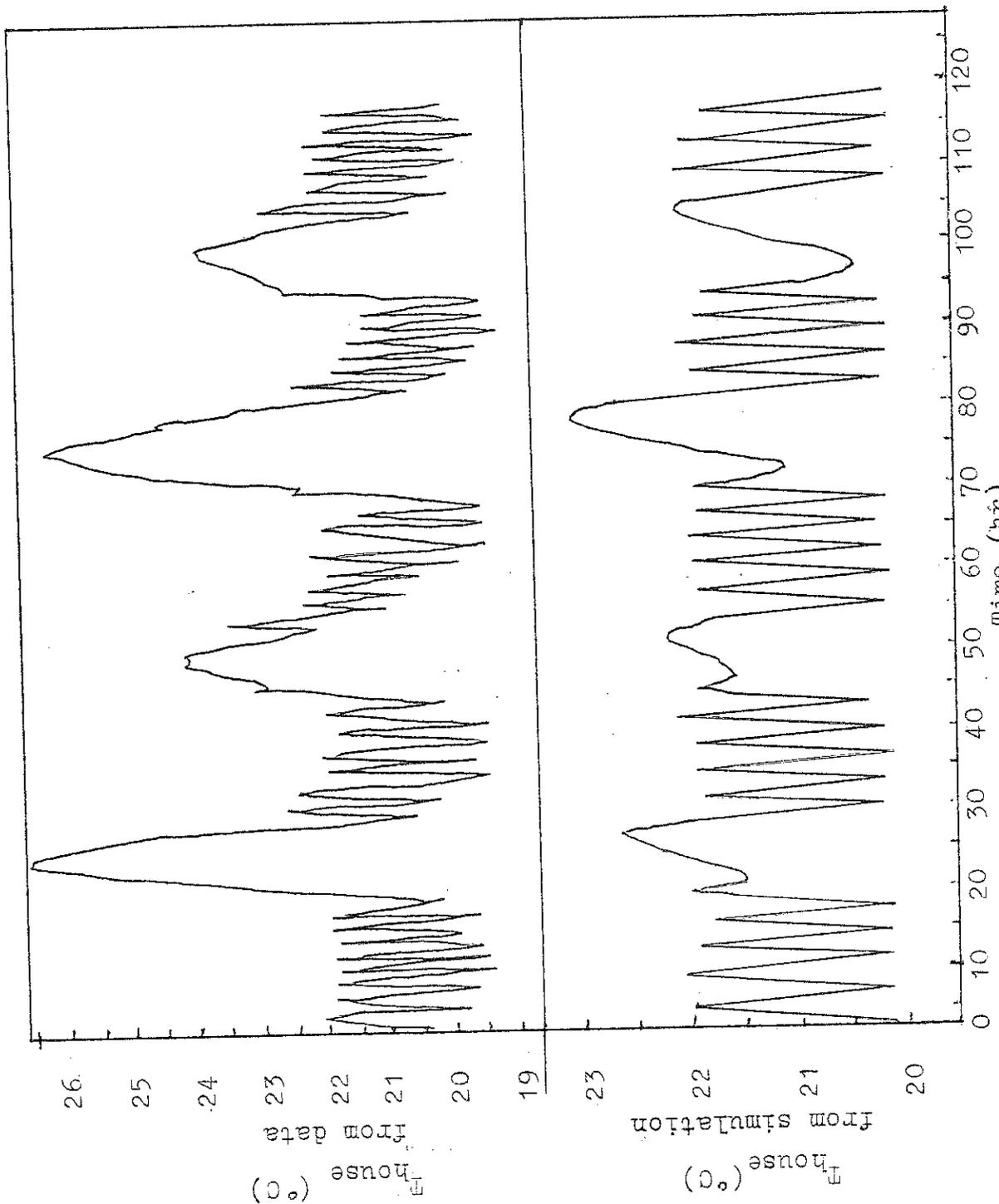


Figure 3-3 House Temperature March 6-9, 1978

through the south facing windows. Thus the temperature increases in the data are larger than those in the simulation. Nevertheless, the model is able to accurately represent the history of the room temperature.

Figure 3-4 shows the measured and simulated collector outlet temperature as a function of time. The temperatures from the simulation are larger than those from the data. For several reasons these temperatures are not directly comparable. This plot is presented to show that the dynamic response of the simulation is comparable to the actual dynamic response of the collector system. Reasons that the temperature values differ are:

1. The difficulty of measuring an average duct temperature with one thermocouple.
2. Leakage from ducts and dampers that could not be modeled.
3. Physically the temperature plotted as data was located further downstream than the value plotted from the simulation, meaning more duct losses.
4. The difficulty of measuring the flowrate of the system in different modes, which would affect the temperature in the simulation.

The oscillations in the data at night are due to the heating system cycling on and off during the night. The leaky dampers allow warm air to enter the collectors in some of the modes of operation.

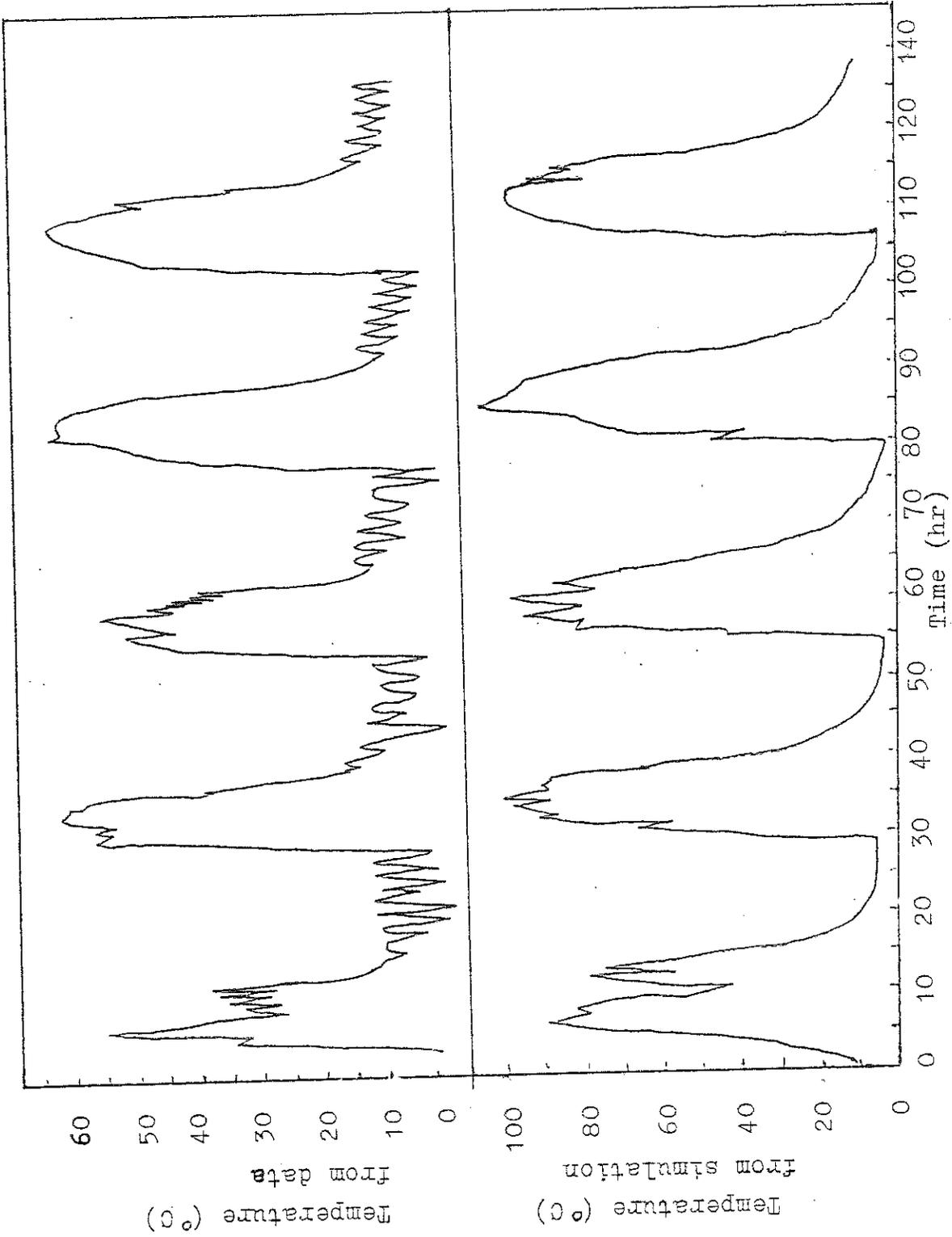


Figure 3-4 Collector outlet temp. March 5-9, 1978

Simulations were performed to determine the effects of air leaks out of the house by paths b, c, and d as shown in Figure 3-1. Table 5 presents the effect the path has on system performance. By dumping all of the leakage air directly to the outside ambient before the rock bed as in path b, the net gain from the collectors is considerably reduced. To meet the load, the auxiliary power then increases as shown. If air leaks occur after the entire flowrate has passed through the bed as in paths c and d, much less energy is lost from the systems. Since the air leaving the bottom of the rock bed is at a temperature near room temperature, there is virtually no change in performance between leakage via paths c and d. These results demonstrate the need to accurately determine leakage routes in actual systems.

Table 5
Effect of Leakage Path on Energy Flows

Leakage Path	$Q_{\text{collector}}$	Q_{aux}	Percent Difference from Path (a)	
			$Q_{\text{collector}}$	Q_{aux}
(a)	2.26 GJ	2.94 GJ	-	-
(b)	1.76 GJ	3.37 GJ	-22	+15
(c)	2.51 GJ	2.87 GJ	+11	-2
(d)	2.52 GJ	3.07 GJ	+12	+4

The passive gain through the south facing windows was modeled by the simulation. In the first data period the passive gain was 0.70GJ. The total solar contribution for this period was 4.69 GJ. The passive gain was 15 percent of the total gain. In the second period the passive gain was 0.59 GJ, which was 18 percent of the total gain for that period. This gain was entirely from the windows and demonstrates the need to model the passive contribution in simulations.

The time step size used in the simulations was ten minutes. Two additional simulations were run with time steps of one-half and one hour to determine the effect of time step size on simulation results. Table 6 presents the results of these simulations. The larger timesteps save on computer time but give less accurate results. The one hour time step simulation only required one-half of the computer time that the ten minute time step simulation did.

Table 6

<u>Time step size</u>	<u>Q_{coll}</u>	<u>Q_{aux}</u>	<u>Q_{wat aux}</u>
10 min	3.99 GJ	2.93 GJ	0.19 GJ
30 min	3.76 GJ	3.18 GJ	0.19 GJ
60 min	3.74 GJ	3.37 GJ	0.19 GJ
percent difference from 10 minute			
30 min	-6	+9	--
60 min	-6	+15	--

CONCLUSIONS

The Arlington House system has been modeled using standard and non-standard components. The system is quite complex and requires a large number of components and parameter values. Previous steady state experiments are used to provide values for most of the parameters. Air leakage is found to have a significant effect on the results, and the location of leaks must be determined accurately. Dynamic experiments are used to determine values of four critical parameters. Simulations using weather data that does not include the parameter evaluation periods are found to yield performance results in good agreement with that measured. This produces confidence in the system model, and in the use of simulations to evaluate systems.

REFERENCES

1. Solar Energy Laboratory, University of Wisconsin, TRNSYS - A Transient Simulation Program, Engineering Experiment Station Report 38, (1979).
2. D. R. Erdmann, "Thermal Performance of the Arlington House," M. S. Thesis, University of Wisconsin (1979).
3. R. W. Persons, "Rock Bed Storage Performance, Arlington Solar House," M. S. Thesis, University of Wisconsin (1978).
4. L. Wallace, "Description, Problems, and Performance Data of the Arlington Solar House," M. S. Thesis, University of Wisconsin (1979).
5. M. B. Eberlein, "Analysis and Performance Predictions of Evacuated Tubular Solar Collectors Using Air as the Working Fluid," M. S. Thesis, University of Wisconsin (1976).

APPENDIX A

Arlington House Instrumentation

(November 4, 1977 - December 31, 1978)

<u>Channel No.</u>	<u>Function</u>	<u>Comments</u>
0	Integrated Total Radiation on 60° Plane	Eppley Precision Pyronometer
1	Integrated Diffuse Radiation on Horizontal Plane	Eppley B&W Pyronometer in use after Feb. 15
2	Integrated Total Radiation on Horizontal Plane	Spectrolab Pyronometer
3	Integrated DHW Coil Flowrate	
4	Integrated DHW Load Flowrate	
5	Integrated Furnace Power	
6	Integrated Water Heater Power	
7	Integrated Domestic Power	
8	Integrated Parasitic Power	
9		
10	Collector Outlet Plenum Temp	Measured in Attic
11	Collector Inlet Plenum Temp	Measured in Attic
12	Pressure Transducer #1	Air Flow to Collectors
13	Pressure Transducer #2	Air Flow from Collectors
14	Pressure Transducer #3	Air Flow to/from House
15	Outside Dry Bulb Temperature	
16	Wind Velocity	
17	Wind Direction	

<u>Channel No.</u>	<u>Function</u>	<u>Comments</u>
18	Barometer	
19	House Supply Temp before Humidification	
20	Ground Water Supply Temp	
21	Preheat Tank Node 1 Temp	Top
22	Preheat Tank Node 4 Temp	
23	Preheat Tank Node 6 Temp	Bottom
24	DHW Supply Temperature	Good only after January 5, 1978
25	Living Room Temp	
26	Air Temperature above DHW Coil	
27	Air Temperature below DHW Coil	
28	Air Temperature at Top of Storage	
30	Rock Bed Node 1 Temperature	Top Rock Node
31	Rock Bed Node 2 Temperature	
32	Rock Bed Node 3 Temperature	
33	Rock Bed Node 4 Temperature	
34	Rock Bed Node 5 Temperature	Bottom Rock Node
35	Collector Plate Temperature	
36	Temperature in Thermostat	
37	Instantaneous Total Radiation on 60° Plane	Eppley Precision Pyranometer
38	Instantaneous Diffuse Radiation on Horizontal Plane	Eppley B&W Pyranometer
39	Instantaneous Total Radiation on Horizontal Plane	Spectrolab Pyranometer

<u>Channel No.</u>	<u>Function</u>	<u>Comments</u>
40	Mode	0 = CS, 1 = CL, 2 = AS, 3 = CW, 4 = SL, 5 = IDLE
41	House Supply Air Temperature	
42	DHW Coil Water Inlet Temperature	
43	DHW Coil Water Outlet Temperature	
44	Preheat Tank Temperature at Inlet from DHW Coil	
45	Preheat Tank Temperature at Exit to DHW Coil	
46	Manifold 6 Inlet Air Temp	West End
47	Manifold 6 Outlet Air Temp	
48	Manifold 7 Outlet Air Temp	East End
49	Manifold 7 Inlet Air Temp	
50	Manifold 1 Inlet Air Temp	West End
51	Manifold 1 Outlet Air Temp	
52	Manifold 2 Inlet Air Temp	
53	Manifold 2 Outlet Air Temp	
54	Manifold 3 Inlet Air Temp	
55	Manifold 3 Outlet Air Temp	
56	Manifold 4 Inlet Air Temp	
57	Manifold 4 Outlet Air Temp	
58	Manifold 5 Inlet Air Temp	East End
59	Manifold 5 Outlet Air Temp	

Appendix B
Specifications-Arlington solar system

HOUSE

Floor Area	106 m ²
Walls	.027 m gypsum board .038 by .089 m studs .406 m center to center 2.44 m high .089 m fiberglass insulation .1 mm polyethelene vapor barrier .025 m thick insulation sheathing .019 m thick bevel siding
Windows	glass area
south wall	6.509 m ²
west wall	1.486 m ²
north wall	1.434 m ²
east wall	1.399 m ²
basement	1.534 m ²
Doors	
main entrance(north facing)	.813 by 2.032 by .0445 m solid wood door with half wood half glass storm door
front door (south facing)	same as main entrance
outside entrance to basement	two 1.016m by 2.032 m by .0445 m thick flush doors

Ceiling

.0127 gypsum board
 .1 mm polyethelene vapor barrier
 .038 m by .235 m studs
 .610 m center to center
 .235 m fiberglass insulation
 .019 m plywood

Basement walls

.229 m thick poured concrete
 2.37 m tall
 19.9 m² is exposed to ambient
 air on the outside

HEATING SYSTEM

Collectors

solar absorptance 0.86
 infrared emmitance 0.07
 .0254 m outside diameter on
 glass delivery tube
 manifolds - .178 by .102 m
 supply and return ducts
 manifold insulation
 .076 m polyurethane
 number of tubes 380
 exposed length of tubes 1.054 m
 cover tube outer diameter 53 mm
 absorber tube outer diameter 43 mm
 tube spacing .102m centers

Rock Bed

flow area 12.2 m²
 flow length 1.57 m
 volume 19.2 m³

void fraction 0.428
 solid volume 11.0 m^3
 specific gravity of solid 2.73
 effective density 1560 Kg/m^3
 rock mean diameter 2.9 cm
 area to volume ratio $117 \text{ m}^2/\text{m}^3$
 top plenum height 0.43 m
 bottom plenum height 0.28 m

Furnace

45 kw 240 volt duct heater
 5 heating stages, 4 on at any
 one time
 maximum temperature 118 C

Air Handler

1 hp motor custom made

Heat Exchanger

type: air to water fin and tube
 effectiveness .265

Pre Heat Tank

volume $.454 \text{ m}^3$
 diameter .610 m
 height 1.829 m
 insulation .10 m fiberglass
 note: a 1/20 hp pump circulates
 water between pre-heat tank and
 heat exchanger

Electric Water Heater

conventional $.303 \text{ m}^3$ (80 gallon)
 electric water heater

Appendix C TRNSYS DECK

```

888216518MARK(1).R2(5)
1      SIMULTAION 0.0 288.0 0.16666667
2      TOLERANCES .000005 .000005
3      LIMITS 35 3 20
4      UNIT 17 TYPE 14 TIME FUNCTION FOR ELECTRIC OFF PEAK
5      PARAMETERS 12
6      0.0,1 7.8333,1 7.8333,0 22.1667,0 22.1667,1 24.0,1
7      UNIT 18 TYPE 30 DATA READER - INTERPOLATOR
8      UNIT 28 TYPE 16 RAD PROS--USED FOR W ONLY
9      PARAMETERS 5
10     1 71 43. 4871. 0.
11     INPUTS 4
12     18,5 18,19 18,20 0,0 0,0 0,0
13     0. 0. .16 .7 60. 0.
14     UNIT 27 TYPE 29 RAD PROCESSOR
15     PARAMETERS 8
16     1 71 43. 4871. 0.7 0. 60. 0.
17     INPUTS 1
18     18,5
19     0.
20     UNIT 36 TYPE 29 RAD PROCESSOR--USED FOR WINDOW
21     PARAMETERS 8
22     1 71 43. 4871. 0.7 0. 90. 0.
23     INPUTS 1
24     18,5
25     0.
26     UNIT 1 TYPE 32 CONTROLER
27     PARAMETERS 7
28     3 21.5 20.5 23.5 10.0 9.0 50.0
29     INPUTS 9
30     8,1 14,1 30,1 14,8 0,0 13,4 11,3 1,7 17,1
31     40.0 20.0 35.0 40.0 52.5 22.0 60.0 5. 1.
32     UNIT 2 TYPE 3 FAN
33     PARAMETERS 1
34     2100.
35     INPUTS 3
36     14,1 14,2 1,5
37     20.0 0.0 0
38     UNIT 3 TYPE 11 DAMPER 1
39     PARAMETERS 1
40     2
41     INPUTS 3
42     2,1 2,2 1,1
43     20.0 0.0 1
44     UNIT 4 TYPE 11 DAMPER 2
45     PARAMETERS 1
46     2
47     INPUTS 3
48     14,1 14,2 1,2
49     20.0 0.0 1
50     UNIT 5 TYPE 11 DAMPER 3
51     PARAMETERS 1
52     2
53     INPUTS 3
54     32,1 32,2 1,3
55     20.0 0.0 1
56     UNIT 6 TYPE 4 UNCT HEATER
57     PARAMETERS 3
58     129600.0 130.0 1.012
59     INPUTS 3
60     3,3 3,4 1,4
61     20.0 0.0 1

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62      UNIT 31 TYPE 2 FLOW DUMP BEFORE ROCK BED
63      INPUTS 5
64      6,1 6,2 13,4 1,7 18,3
65      0. 0. 20. 1 0.
66      UNIT 7 TYPE 11 TEE PIECE 1
67      PARAMETERS 1
68      1
69      INPUTS 4
70      5,1 5,2 4,1 4,2
71      20.0 0.0 20.0 0.0
72      UNIT 29 TYPE 31 INLET DUCT
73      PARAMETERS 4
74      15. 36.61 1.012 0.
75      INPUTS 3
76      7,1 7,2 18,3
77      0. 0. 0.
78      UNIT 8 TYPE 1 COLLECTOR
79      PARAMETERS 7
80      43. 60. .85 .65 .043 .106 1.012
81      INPUTS 8
82      29,1 29,2 27,2 27,3 27,20 28,1 18,3 14,1
83      20. 0. 0. 0. 1. 0. 0. 20.
84      UNIT 30 TYPE 31 OUTLET DUCT
85      PARAMETERS 4
86      15. 36.61 1.012 0.
87      INPUTS 3
88      8,1 8,2 18,3
89      0. 0. 0.
90      UNIT 9 TYPE 3 PUMP
91      PARAMETERS 1
92      200.0
93      INPUTS 3
94      11,1 11,2 1,6
95      10.0 0.0 0.0
96      UNIT 10 TYPE 5 HEAT EXCHANGER
97      PARAMETERS 4
98      3 1000.0 1.012 4.19
99      INPUTS 4
100     30,1 30,2 9,1 9,2
101     20.0 0.0 20.0 0.0
102     UNIT 11 TYPE 4 PRE HEAT TANK
103     PARAMETERS 5
104     0.454 1.829 4.19 1000.0 3.0
105     INPUTS 5
106     10,3 10,4 0.0 0.0 13,4
107     20.0 0.0 4.0 8.78 20.0
108     DERIVATIVES 2
109     40.0 20.0
110     UNIT 12 TYPE 4 WATER HEATER
111     PARAMETERS 9
112     0.15 1.4 4.19 1000.0 8.00 20000. 1 1 50.0
113     INPUTS 3
114     0,0 0,0 11,3 11,4 13,4
115     20.0 0.0 20.0 0.0 20.0
116     DERIVATIVES 1
117     45.0
118     UNIT 38 TYPE 34 OVERHANG
119     PARAMETERS 15
120     1.448 0.499 .914 .229 .914 .914 .0635 .0127 .299 .299 .0635
121     .0127 .299 .299 0.
122     INPUTS 6
123     28,2 28,3 36,4 36,6 36,2 0,0
124     0.0 0.0 0.0 0.0 0.0 0.7
125     UNIT 37 TYPE 35 WINDOW
126     PARAMETERS 3
127     2 6.509 3 0.05 1.526

```

```

128     INPUTS 6
129     13,4 18,3 0,0 38,1 38,2 36,7
130     20, 0, 0, 0, 0, 0.
131     UNIT 13 TYPE 12 HOUSE
132     PARAMETERS 8
133     4.905.0 25000.0 8432.69 1.012 1.0 1619.20 3219.
134     INPUTS 5
135     3,1 3,2 18,3 33,1 0,0
136     20,0 0,0 -10,0 0,0 0,0
137     DERIVATIVES 1
138     20,0
139     UNIT 32 TYPE 8 HOUSE FLOW DUMP
140     INPUTS 4
141     13,1 13,2 18,3 1,7
142     20, 0, 0, 1.
143     UNIT 14 TYPE 10 ROCK BED THERMAL STORAGE
144     PARAMETERS 8
145     1,01 1,57 12,2 14,0 0,82 1560,0 1,26 0,45
146     INPUTS 5
147     31,1 31,2 5,3 5,4 13,4
148     20,0 0,0 20,0 0,0 20,0
149     DERIVATIVES 5
150     65,2 58,7 50,0 40,8 34,9
151     UNIT 33 TYPE 38 SUM FOR Q ADDED TO HOUSE
152     INPUTS 5
153     14,7 31,3 11,5 12,5 37,1
154     0,0 0,0 0,0 0,0 0,0
155     UNIT 15 TYPE 11 TEE-PIECE 2
156     PARAMETERS 1
157     1
158     INPUTS 4
159     14,3 14,4 4,3 4,4
160     20,0 0,0 20,0 0,0
161     UNIT 16 TYPE 11 TEE-PIECE 3
162     PARAMETERS 1
163     1
164     INPUTS 4
165     10,1 10,2 15,1 15,2
166     20,0 0,0 20,0 0,0
167     UNIT 34 TYPE 24 INTEGRATOR
168     INPUTS 10
169     8,3 29,3 30,3 10,5 11,5 11,6 12,5 13,5 14,7 12,6
170     0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0
171     UNIT 22 TYPE 25 PRINTER
172     PARAMETERS 4
173     12,0 12, 288,0 0.
174     INPUTS 10
175     34,1 34,2 34,3 34,4 34,5 34,6 34,7 34,8 34,9 34,10
176     SEFF QINDU QOTDU QHEEX QPHENV QPHLD QWHENV QHSTRN QBDENV WMLoad
177     UNIT 23 TYPE 24 INTEGRATOR
178     INPUTS 10
179     8,6 8,7 6,3 13,3 33,1 32,3 31,3 31,4 12,8 37,1
180     0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0 0,0
181     UNIT 24 TYPE 25 PRINTER
182     PARAMETERS 4
183     12, 12, 288, 0.
184     INPUTS 10
185     23,1 23,2 23,3 23,4 23,5 23,6 23,7 23,8 23,9 23,10
186     QCOL QACT QAUX QLOAD QADD QMLOSS QDUMP QGLOSS QWAUX WINDOW
187     UNIT 40 TYPE 25 PRINTER
188     PARAMETERS 4
189     12, 12, 288, 0.
190     INPUTS 1
191     14,8
192     TAUBED
193     END

```

Appendix D Program Listings

```

(886216518*P(1).C2(19)
  1      SUBROUTINE TYPE1(TIME,XIN,OUT,T,DTOT,PAR,INFO)
  2      DIMENSION XIN(20),OUT(20),PAR(20),INFO(9)
  3      IF(INFO(7).GE.0) GO TO 5
  4      INFO(6)=8
  5      INFO(9)=1
  6      CALL TYPECK(1,INFO,8,7,0)
  7      5  LAT=PAR(1)*3.1416/180.
  8      SLOPE=PAR(2)*3.1416/180.
  9      RHOB=PAR(3)
 10      FPT=PAR(4)
 11      D=PAR(5)
 12      C=PAR(6)
 13      CP=PAR(7)
 14      DIF=LAT-SLOPE
 15      TIN=XIN(1)
 16      TINC=TIN+273.
 17      XMDOT=XIN(2)
 18      HB=XIN(3)
 19      HD=XIN(4)
 20      DECL=XIN(5)*3.1416/180.
 21      W=-XIN(6)*3.1416/180.
 22      TAMB=XIN(7)
 23      TAMB=TAMB+273.
 24      TINC=XIN(8)+273.
 25      IF(XMDOT.LE.0.) GO TO 10
 26      XOUTMD=XMDOT*1.1494253
 27      XMLEAK=XOUTMD-XMDOT
 28      TINACT=(TIN*XMDOT+TAMB*XMLEAK)/XOUTMD
 29      10  X=COS(DECL)*SIN(W)
 30      Y=COS(DIF)*COS(DECL)*COS(W)+SIN(DIF)*SIN(DECL)
 31      OMEGA=ATAN(X/Y)
 32      RBPRM=RHOB*FPT*(1.-D/(C*COS(OMEGA)))+D/(C*COS(OMEGA))
 33      RDPRM=FPT*(1.+RHOB*(1.-FPT))
 34      SEFF=(HB*RBPRM+HD*RDPRM)*C/D/3.1416
 35      IF(SEFF.LT.0.001) GO TO 25
 36      XX=TIN**3.*(TIN-TAMB)/SEFF*10E-7
 37      C  SET UP TO USE GRAPH OF PERFORMANCE AS GIVEN BY EBERLINE
 38      EFF=.85-.12*XX
 39      QU=SEFF*EFF*41.
 40      IF(XMDOT.LE.0.) GO TO 20
 41      TOUT=TINACT+QU/CP/1600.
 42      QUACT=(TOUT-TIN)*CP*1600.
 43      GO TO 60
 44      20  TOUT=TINC+QU/CP/1600.
 45      XOUTMD=XMDOT
 46      GO TO 60
 47      25  EFF=0.
 48      XOUTMD=XMDOT
 49      QU=0.
 50      QUACT=0.
 51      TOUT=TIN
 52      60  OUT(1)=TOUT-273.
 53      OUT(2)=XOUTMD
 54      OUT(3)=SEFF
 55      OUT(4)=XX
 56      OUT(5)=EFF
 57      IF(XMDOT.LT.100.) GO TO 200
 58      OUT(6)=QU
 59      OUT(7)=QUACT
 60      GO TO 300

```

```
61      200 OUT(6)=0.  
62      OUT(7)=0.  
63      300 OUT(8)=RDPRM  
64      350 RETURN  
65      END  
----->EXIT PRT
```

ROL MODE

(78 P.TYPE3
PUR 27R3A05 L36 SLIB12 03/02/80 13:30:16

```

5216518*P(1).TYPE3(8)
  1      SUBROUTINE TYPE3(TIME,XIN,OUT,T,DTDT,PAR,INFO)
  2      DIMENSION XIN(20),OUT(20),T(5),DTDT(5),PAR(20),INFO(10)
  3      INFO(6)=3
  4      INFO(9)=1
  5      CALL TYPECK(1,INFO,4,0,0)
  6      QDUMP=0.0
  7      TIN=XIN(1)
  8      XMASS=XIN(2)
  9      TAMB=XIN(3)
 10      MODE=XIN(4)+0.1
 11      IF(MODE.NE.2) GO TO 50
 12      XLOSS=0.13*XMASS
 13      XMASS=XMASS-XLOSS
 14      QDUMP=XLOSS*1.012*(TIN-TAMB)
 15      50  OUT(1)=TIN
 16          OUT(2)=XMASS
 17          OUT(3)=QDUMP
 18          RETURN
 19          END
--->EXIT PRT

```

F,S P.TYPE2

```

5216518*P(1).TYPE2(9)
  1      SUBROUTINE TYPE2(TIME,XIN,OUT,T,DTDT,PAR,INFO)
  2      DIMENSION XIN(20),OUT(20),T(5),DTDT(5),PAR(20),INFO(10)
  3      INFO(6)=4
  4      INFO(9)=1
  5      CALL TYPECK(1,INFO,5,0,0)
  6      QDUMP=0.0
  7      TIN=XIN(1)
  8      XMASS=XIN(2)
  9      THSE=XIN(3)
 10      MODE=XIN(4)+0.1
 11      TAMB=XIN(5)
 12      IF(MODE.NE.1) GO TO 50
 13      XLOSS=0.13*XMASS
 14      XMASS=XMASS-XLOSS
 15      QDUMP=XLOSS*1.012*(TIN-THSE)
 16      QLOSS=XLOSS*1.012*(THSE-TAMB)
 17      50  OUT(1)=TIN
 18          OUT(2)=XMASS
 19          OUT(3)=QDUMP
 20          OUT(4)=QLOSS
 21          RETURN
 22          END
--->EXIT PRT

```

*,S P.TYPE36

```
.216518*P(1).TYPE36(2)
1      SUBROUTINE TYPE36(TIME,XIN,OUT,T,DTDT,PAR,INFO)
2      DIMENSION XIN(20),OUT(20),PAR(20),INFO(20)
3      INFO(6)=1
4      INFO(9)=1
5      CALL TYPECK(1,INFO,5,0,0)
6      QENV=XIN(1)
7      QDUMP=XIN(2)
8      QPREH=XIN(3)
9      QWAT=XIN(4)
10     QWIND=XIN(5)
11     OUT(1)=QENV+QDUMP+QPREH+QWAT+QWIND
12     RETURN
13     END
--->EXIT PRT
```

*,S P.TYPE13

```
.216518*P(1).TYPE13(1)
1      SUBROUTINE TYPE13(TIME,XIN,OUT,T,DTDT,PAR,INFO)
2      DIMENSION XIN(20),OUT(20),PAR(10),INFO(10)
3      INFO(9)=1
4      TOUT=XIN(1)
5      TIN=XIN(3)
6      XMDOT=XIN(2)
7      Q=(TOUT-TIN)*XMDOT*4.19
8      OUT(1)=Q
9      RETURN
10     END
--->EXIT PRT
```

FREE F.
 EASY
 PRT,3 P,TYPE16
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586216518*P(1),TYPE16(5)
1   SUBROUTINE TYPE16(TIME,XIN,OUT,DUM1,DUM2,PAR,INFO)
2   DIMENSION XIN(16),OUT(20),PAR(6),INFO(10),NPAR(5)
3   C   THIS ROUTINE FINDS THE POSITION OF THE SUN IN THE SKY AND
4   C   ESTIMATES THE RADIATION INCIDENT ON UP TO SIX SURFACES OF
5   C   ANY ORIENTATION.
6   COMMON /SIM/ TIME0,TFINAL,DELTA
7   COMMON /STORE/ NSTORE,IAV,S(200)
8   COMMON /LUNITS/ LUR,LUW,IFORM
9   DATA IUNIT/0/,RDCONV/0.0174533/,DCCONV/57.2958/,PI/3.1415927/
10  DATA NPAR/5,5,6,5,5/
11  C   STATEMENT FUNCTIONS TO CALCULATE SOLAR TIME AND HOUR
12  C   ANGLES. THE EQUATION OF TIME IS FROM D.L. SIEBERS, TECH.
13  C   REPORT ME-HTL-75-2, PURDUE UNIVERSITY, LAFAYETTE, INDIANA
14  EDOT(XX) = -(0.1236*SIN(XX) - 0.004289*ICOS(XX) + 0.1539*SIN(2.*XX))
15  + 0.06078*ICOS(2.*XX)
16  ANGLE(TT) = ((AMOD(TT+ET,24.)-12.)*15.0 + SHFT)*RDCONV
17  C
18  IF (INFO(1) .EQ. IUNIT) GO TO 10
19  MODE = INT(PAR(1) + .2)
20  DAY1 = PAR(2)
21  ALAT = PAR(3)*RDCONV
22  SC = PAR(4)
23  SHFT = PAR(5)
24  ALT = PAR(6)
25  NP = NPAR(MODE)
26  IE = SIGN(1.,PAR(NP+1))
27  SINLAT = SIN(ALAT)
28  COSLAT = COS(ALAT)
29  TANLAT = SINLAT/COSLAT
30  ID = INFO(10)
31  NRAD = 1
32  IF (MODE .GT. 3) NRAD = 2
33  IF (INFO(7) .GT. -1) GO TO 10
34  IF (MODE .LT. 1 .OR. MODE .GT. 5) CALL TYPECK(4,INFO,0,0,0)
35  NS = MINO((INFO(3)-NRAD-3)/2,6)
36  IF (NS .LT. 0) NS = 0
37  NI = NRAD + 3 + NS*2
38  IF (INFO(4) .EQ. NP+1) NP = NP+1
39  INFO(10) = 6
40  CALL TYPECK(1,INFO,NI,NP,0)
41  INFO(6) = 5 + MINO(NS,1)*5 + MAXO(NS-1,0)*2
42  ID = INFO(10)
43  S(ID+5) = 0.
44  C   STORE INITIAL RADIATION DATA
45  S(ID) = TIME0
46  S(ID+1) = XIN(1)
47  S(ID+2) = XIN(1)
48  S(ID+3) = XIN(2)
49  S(ID+4) = XIN(2)
50  P12365 = PI*2./365.242
51  ADAY = TIME - 1.
52  HDDELTA = DELTA/2.
53  CDDELTA = DELTA*0.01
54  C
55  C   CALCULATE DECLINATION AND OTHER DAY DEPENDENT QUANTITIES.
56  C   THESE CALCULATIONS ARE DONE ONCE PER DAY.
57  10  IF (TIME .LE. ADAY) GO TO 15
58  ADAY = TIME + 24.
59  DAY = DAY1 + AINT((TIME-TIME0)/24.)

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60      DECL = 0.40928*SIN((284.+DAY)*PI/2365)
61      SINDEC = SIN(DECL)
62      COSDEC = COS(DECL)
63      TANDEC = SINDEC/COSDEC
64      WS = ACOS(-TANDEC*TANLAT)
65      CC = COSLAT*COSDEC
66      SS = SINLAT*SINDEC
67      ECC = 1. + 0.033*COS(DAY*PI/2365)
68      ET1 = EOT((DAY-1.)*PI/2365)
69      C ET IS THE TIME SHIFT DUE TO THE ECCENTRICITY OF THE EARTHS ORBIT
15      ET = 0.
71      IF (INFO(4).EQ.NP .OR. IE.GE.0) ET = ET1
72      C
73      C FIND HOUR ANGLES FOR START AND END OF TIMESTEP, THE PORTION
74      C OF THE TIMESTEP DURING WHICH THE SUN IS DOWN IS IGNORED.
75      W1 = ANGLE(TIME-DELT)
76      W2 = ANGLE(TIME)
77      IF (W2 .LE. -WS .OR. W1 .GE. WS) GO TO 260
78      W1 = AMAX1(W1,-WS)
79      W2 = AMIN1(W2,WS)
80      IF (ABS(W2-W1) .LT. CDELT) GO TO 260
81      W = (W1+W2)*0.5
82      COSHR = COS(W)
83      SINHR = SIN(W)
84      C RECOVER ACTUAL RADIATION DATA FROM INTERPOLATED VALUES.
85      DTIME2 = S(ID)
86      DTIME1 = DTIME2 - (XIN(NRAD+2)-XIN(NRAD+1))
87      C CHECK WHETHER NEW CARD READ IN
88      IF (TIME .LT. DTIME2+0.0001) GO TO 22
89      DTIME1 = XIN(NRAD+1)
90      DTIME2 = XIN(NRAD+2)
91      S(ID) = DTIME2
92      S(ID+1) = S(ID+2)
93      S(ID+3) = S(ID+4)
94      R = 0.
95      IF (ABS(TIME-DTIME1).GT. 1.E-6) R = (DTIME2-DTIME1)/(TIME-DTIME1)
96      S(ID+2) = (XIN(1)-S(ID+1))*R + S(ID+1)
97      S(ID+4) = (XIN(2)-S(ID+3))*R + S(ID+3)
98      C SET DATA VARIABLES SO THAT DTIME1 .LE. (START OF TIMESTEP) AND
99      C DTIME2 .GE. (END OF TIMESTEP).
100     IF ((TIME-DELT) .LT. DTIME1-0.0001) GO TO 24
101     XIN1 = S(ID+2)
102     XIN2 = S(ID+4)
103     GO TO 26
104     24 DTIME1 = DTIME1 - (DTIME2-DTIME1)
105     XIN1 = S(ID+2) + S(ID+1)
106     XIN2 = S(ID+4) + S(ID+3)
107     C FIND HOUR ANGLES FOR START AND END OF DATA
108     28 WD1 = ANGLE(DTIME1)
109     WD2 = ANGLE(DTIME2)
110     WD1 = AMAX1(WD1,-WS)
111     WD2 = AMIN1(WD2,WS)
112     C CALCULATE EXTRATERRESTRIAL RADIATION FOR TIMESTEP AND THE RATIO
113     C OF EXTRATERRESTRIAL FOR TIMESTEP TO EXTRATERRESTRIAL OVER PERIOD OF
114     C DATA. RADIATION ON THE HORIZONTAL IS INTERPOLATED FROM DATA USING
115     C THE CURVE FOR EXTRATERRESTRIAL RADIATION.
116     HX1 = CC*(SIN(W2)-SIN(W1)) + SS*(W2-W1)
117     HX2 = CC*(SIN(WD2)-SIN(WD1)) + SS*(WD2-WD1)
118     HEXTRA = SCXECC*HX1/(W2-W1)
119     C OUT(19) IS SET TO HEXTRA (EXTRATERRESTRIAL RADIATION) HERE BUT
120     C RESET TO TOTAL RADIATION FOR LAST SURFACE IF SIX SURFACES ARE USED.
121     OUT(19) = HEXTRA
122     HRATIO = HX1/HX2
123     C
124     C FIND POSITION OF THE SUN
125     AZIMTH = 0.

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26      COSZEN = CC*COSHR + SS
27      ZENITH = ACOS(COSZEN)
28      SINZEN = SIN(ZENITH)
29      IF (ABS(SINZEN) .LT. 1E-06) GO TO 90
30      SINAZM = COSDEC*SINHR/SINZEN
31      DERIV = COSDEC*COSHR/SINZEN -
32      .      COSLAT*COSDEC*COSDEC*SINHR*SINHR*COSZEN/(SINZEN**3)
33      C      IF THE DERIVATIVE OF SIN(AZIMUTH) WITH RESPECT TO THE HOUR
34      C      ANGLE IS NEGATIVE, THEN THE SOLAR AZIMUTH ANGLE IS GREATER
35      C      THAN 90 DEGREES. IN THIS CASE, AZIMTH = +/-PI - ASIN(SINAZM).
36      AZIMTH = ASIN(SINAZM)
37      IF (DERIV .LT. 0.) AZIMTH = SIGN(PI,AZIMTH) - AZIMTH
38      C
39      C      FIND RATE OF BEAM,DIFFUSE AND TOTAL RADIATION ON HORIZONTAL SURFACE.
40      90      HRATIO = HRATIO/DELT
41      GO TO (110,120,130,140,150), MODE
42      C      USE LIU AND JORDAN CORRELATION FOR BEAM AND DIFFUSE.
43      110      HHOR = XIN1*HRATIO
44      XKT = AMIN1(HHOR/HEXTRA,0.75)
45      HD = HHOR*(1.0045 + ((2.6313*XKT - 3.5227)*XKT + 0.04349)*XKT)
46      IF (HD .LT. 0.) HD = 0.
47      IF (HD .GT. HHOR) HD = HHOR
48      HB = HHOR - HD
49      GO TO 200
50      C      USE BOES CORRELATION FOR DIRECT NORMAL RADIATION
51      120      HHOR = XIN1*HRATIO
52      XKT = HHOR/HEXTRA
53      HDN = (1.3304 * XKT - 0.3843) * SC
54      IF (HDN .LT. 0.0) HDN = 0.0
55      IF (HDN .GT. 0.739 * SC) HDN = 0.739 * SC
56      HB = AMIN1(HDN*COSZEN,HHOR)
57      HD = HHOR - HB
58      GO TO 200
59      C      USE HOTTEL-BUGLER METHOD FOR BEAM AND DIFFUSE RADIATION
60      130      HHOR = XIN1*HRATIO
61      C      ALT=ALTITUDE IN KILOMETERS
62      AOSTAR=0.4237-0.00821*(6.0-ALT)*(6.0-ALT)
63      A1STAR=0.5053+0.00595*(6.5-ALT)*(6.5-ALT)
64      XKSTAR= 0.2711+0.01858*(2.5-ALT)*(2.5-ALT)
65      C      CORRECTION FACTORS FOR MID LATITUDE WINTER
66      R0=1.03
67      R1=1.01
68      RK=1.00
69      IF ( WS .LT. PI/2. ) GO TO 132
70      C      CORRECTION FACTORS FOR MID LATITUDE SUMMER
71      C      SEE HOTTEL (1976) FOR TROPICAL AND SUBARCTIC
72      C      SUMMER CLIMATE CORRECTION FACTORS.
73      R0=0.97
74      R1=0.99
75      RK=1.02
76      132      TAUB=AOSTAR*R0+A1STAR*R1*EXP(-XKSTAR*RK/COSZEN)
77      HCB=HEXTRA*TAUB
78      C      LIU AND JORDAN (1960) CLEAR ATMOSPHERE DIFFUSE CORRELATION
79      HCD=0.2710*HEXTRA-0.2939*TAUB*HEXTRA
80      HC=HCD+HCB
81      HHC=HHOR/HC
82      HDH=0.93
83      IF ( HHC .LT. 0.4 ) GO TO 134
84      HDH=(1.29-1.19*HHC)/(1.00-0.334*HHC)
85      IF ( HHC .GT. 1.0 ) HDH=0.15
86      134      HD=HDH*HHOR
87      HB=HHOR-HD
88      GO TO 200
89      C      INPUTS ARE BEAM AND DIFFUSE ON HORIZONTAL
90      140      HB = XIN1*HRATIO
91      HD = XIN2*HRATIO

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92          HHOR = HB + HD
93          GO TO 200
94      C    INPUTS ARE TOTAL (HORIZONTAL) AND DIRECT NORMAL
95      150  HHOR = XIN1*HRATIO
96          HEN = XIN2*HRATIO
97          HB = HDN*COSZEN
98          HD = AMAX1(HHOR-HB,0.)
99      C    CHECK FOR BEAM RADIATION GREATER THAN EXTRATERRESTRIAL RADIATION
200      200  IF (HB .LE. HEXTRA) GO TO 220
201          S(ID+5) = S(ID+5) + 1.
202          HB = HEXTRA
203          IF (S(ID+5) .GT. 12.) GO TO 220
204      202  FORMAT(/,2X,24H***** WARNING ***** UNIT,I3,5H TYPE,I3/4X,
205  EXTRATERRESTRIAL AT TIME =,F10.4/
206          , 4X,31H EXTRATERRESTRIAL RADIATION USED)
207      C
208      C    SET OUTPUTS
209      220  OUT(1) = W*DGCONV
210          OUT(2) = ZENITH*DGCONV
211          OUT(3) = AZIMTH*DGCONV
212          OUT(4) = HHOR
213          OUT(5) = HD
214      C    CALCULATE BEAM RADIATION, TOTAL RADIATION AND INCIDENCE ANGLE
215      C    FOR EACH SLOPE.
216          RHO = XIN(NRAD+3)
217          NS = (INFO(3)-3)/2
218          IF (NS .LE. 0) RETURN
219          IP = NRAD + 4
220          JP = 6
221          DO 240 IS = 1,NS
222          SLP = XIN(IP)*RDCONV
223          AZM = XIN(IP+1)*RDCONV
224          IF = IP + 2
225          IF (AZM .LT. -10.) AZM = AZIMTH
226          IF (SLP .LT. -10.) SLP = ATAN(SINZEN/COSZEN*COS(AZIMTH-AZM))
227          COSSLP = COS(SLP)
228          COSTT = SINZEN*COS(AZIMTH-AZM)*SIN(SLP) + COSZEN*COSSLP
229          COSTT = AMAX1(COSTT,0.)
230          RB = COSTT/COSZEN
231          HBEAM = HB*RB
232          HDIFF = HD*(1. + COSSLP)*0.5 + HHOR*RHO*(1. - COSSLP)*0.5
233          THETA = ACOS(COSTT)*DGCONV
234      C    OUTPUT TOTAL (FLAT SURFACE) RADIATION, BEAM RADIATION,
235      C    DIFFUSE RADIATION, INCIDENCE ANGLE, AND SLOPE FOR FIRST SURFACE.
236          IF (IS .GT. 1) GO TO 230
237          OUT(JP) = HBEAM + HDIFF
238          OUT(JP+1) = HBEAM
239          OUT(JP+2) = HDIFF
240          OUT(JP+3) = THETA
241          OUT(JP+4) = SLP*DGCONV
242      C    OUT(20) IS SET TO RB HERE BUT RESET TO THETA FOR LAST SURFACE
243      C    IF SIX SURFACES ARE USED.
244          OUT(20) = RB
245          JP = JP + 5
246          GO TO 240
247      C    OUTPUT TOTAL RADIATION (ASSUMING FLAT SURFACE) AND INCIDENCE
248      C    ANGLE FOR REMAINING SURFACES.
249      230  OUT(JP) = HBEAM + HDIFF
250          OUT(JP+1) = THETA
251          JP = JP + 2
252      240  CONTINUE
253          GO TO 300
254      C
255      C    NO RADIATION
256      250  OUT(1) = (W1 + W2)*0.5*DGCONV
257          OUT(2) = 99.

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158      DO 270 I = 3,20
159      OUT(I) = 0.
160      C   SET DATA STORAGE VARIABLES.
161          S(ID) = XIN(NRAD+1)
162          S(ID+2) = 0.
163          S(ID+4) = 0.
164      C
165      C   PRINT COUNT OF TIMES BEAM RADIATION GREATER THAN EXTRATERRESTRIAL
166      300  IF (TIME .LT. TFINAL-HDELTA) RETURN
167          NERR = INT(S(ID+5)+.5)
168          IF (NERR .EQ. 0) RETURN
169      312  FORMAT(/2X,24H***** WARNING ***** UNIT,I3,SH TYPE,I3/4X,
170          . 47HBEAM RADIATION EXCEEDED EXTRATERRESTRIAL DURING,I7,
171          . 10H TIMESTEPS)
172          RETURN
173      END
-->EXIT PRT
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BPRT/S P,TYPE29

3886216516*P(1),TYPE29(10)

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1      C
2      SUBROUTINE TYPE29(TIME,XIN,OUT,T,DTDT,PAR,INFO)
3      DIMENSION PAR(15),XIN(10),OUT(15),INFO(9)
4      DIMENSION SLOPE(10),AZMTH(10),HR(10),HBT(10),HDT(10),THETA(10)
5      COMMON/SIM/TIME0,TFINAL,DELTA
6      C. THIS ROUTINE PROCESSES SOLAR RADIATION DATA MEASURED ON A
7      C. HORIZONTAL SURFACE TO ESTIMATE THE RADIATION INCIDENT ON
8      C. A TILTED SURFACE AS A FUNCTION OF:
9      C.
10     C. HT - THE TOTAL RADIATION INCIDENT UPON A HORIZONTAL SURFACE
11     C. ALAT - THE LATITUDE (DEGREES)
12     C. SLOPE - THE SLOPE OF THE COLLECTOR SURFACE WITH RESPECT TO
13     C. THE HORIZONTAL (DEGREES)
14     C. AZMTH - THE AZIMUTH OR ORIENTATION ANGLE (DEGREES)
15     C. DAY1 - THE DAY AT WHICH SIMULATION IS STARTED (USED TO
16     C. CALCULATE THE SOLAR DECLINATION)
17     C. SC - THE SOLAR CONSTANT
18     C. RHO - THE GROUND REFLECTIVITY
19     C. IOPT - AN INTEGER OF VALUE 1,2,OR 3 WHICH DETERMINES
20     C. THE MANNER IN WHICH DIFFUSE RADIATION IS TO BE TREATED
21     C.
22     C.
23     C. IOPT=1 THE SINGLE INPUT (XIN(1)) IS THE TOTAL RADIATION ON A
24     C. HORIZONTAL SURFACE. THE BEAM AND DIFFUSE RADIATION
25     C. COMPONENTS WILL BE CALCULATED FROM RELATIONSHIPS GIVEN
26     C. IN LIU AND JORDAN (SOLAR ENERGY IV-3 1960)
27     C. THE DIFFUSE COMPONENT IS TAKEN TO BE UNIFORMLY DISTRIBUTED
28     C. ACROSS THE SKY. A PROVISION FOR GROUND REFLECTANCE
29     C. ON THE TILTED SURFACE IS INCLUDED.
30     C.
31     C. IOPT=2 SIMILAR TO IOPT=1 EXCEPT THAT THE DIFFUSE AND BEAM
32     C. ARE DETERMINED BY THE RELATIONSHIPS DEVELOPED BY BOES.
33     C. BOES, E.C., 'DISTRIBUTION OF DIRECT AND TOTAL SOLAR
34     C. RADIATION AVAILABILITIES FOR THE USA', SANDIA REPORT
35     C. SAND76-0411, AUGUST, 1976
36     C.
37     C. IOPT=3 THE BEAM AND DIFFUSE COMPONENTS OF RADIATION ON A
38     C. HORIZONTAL SURFACE ARE ASSUMED TO BE THE TWO INPUTS
39     C. (XIN(1) AND XIN(2)). THE BEAM, DIFFUSE, AND GROUND
40     C. REFLECTED COMPONENTS OF THE RADIATION ON THE TILTED
41     C. SURFACE ARE TREATED IN THE SAME MANNER AS FOR IOPT=1.
42     C.
43     DATA IUNIT/0/,RDCONV/0.0174533/,ADAY/-99.0/,PI/3.1415927/
44     EOT(XX)=-(.1236*SIN(XX)-0.004289*COS(XX)+0.1539*SIN(2.*XX))+
45     1 0.06078*COS(3*XX))
46     C. EQUATION OF TIME IS FROM D.L.SIEBERS
47     C. TECH. REPORT, NO. ME-HTL-75-2
48     C. PURDUE UNIVERSITY, LAFAYETTE, INDIANA
49     IF (INFO(1).EQ.IUNIT) GO TO 2
50     IOPT=PAR(1)
51     INFO(9) = 1
52     IF (IOPT.GE.1.AND.IOPT.LE.3) GO TO 101
53     CALL TYPECK(4,INFO,0,0,0)
54     RETURN
55 101 CONTINUE
56     IUNIT=INFO(1)
57     DAY1=PAR(2)
58     ALAT=PAR(3)
59     SLOPE(1)=PAR(7)
60     AZMTH(1)=PAR(8)
61     SC=PAR(4)

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62      RHO=PAR(5)
63      D0SM=PAR(6)
64      NS=(INFO(4)-8)/2+1
65      IF (NS.LT.1.OR.NS.GT.9) CALL TYPECK(4,INFO,0,0,0)
66      IF (IOPT.LE.2.AND.INFO(3).NE.1) CALL TYPECK(3,INFO,0,0,0)
67      IF (MOD(INFO(4),2).NE.0) CALL TYPECK(4,INFO,0,0,0)
68      IF (TOPT.EQ.3.AND.INFO(3).NE.2) CALL TYPECK(3,INFO,0,0,0)
69      INFO(6)=6+NS
70      IF (NS.EQ.1) GO TO 1
71      IP=8
72      DO 29 J=2,NS
73      IP=IP+1
74      SLOPE(J)=PAR(IP)
75      IP=IP+1
76      AZHTH(J)=PAR(IP)
77      29 CONTINUE
78      1 COSLAT=COS(ALAT*RDCONV)
79      SINLAT=SIN(ALAT*RDCONV)
80      TANLAT=SINLAT/COSLAT
81      2 CONTINUE
82      DO 72 J=1,NS
83      HR(J)=0.
84      HBT(J)=0.
85      HDT(J)=0.
86      THETA(J)=90.
87      72 CONTINUE
88      HB=0.0
89      HD=0.0
90      GO TO (10,10,11),IOPT
91      10 HT=XIN(1)
92      IF (HT.LE.0.0) GO TO 17
93      GO TO 4
94      11 HB=XIN(1)
95      HD=XIN(2)
96      HT=HB+HD
97      IF (HT.LE.0.0) GO TO 17
98      4 CONTINUE
99      DAY=DAY1+AINT((TIME-TIME0)/24.0)
100     IF (DAY.LE.ADAY) GO TO 3
101     ADAY=DAY
102     DECL=23.45*SIN((284.+DAY)/365.*PI*2.)
103     COSDEC=COS(DECL*RDCONV)
104     SINDEC=SIN(DECL*RDCONV)
105     TANDEC=SINDEC/COSDEC
106     WS=ACOS(-TANDEC*TANLAT)
107     WSMAX=WS-7.5*RDCONV
108     C. WSMAX IS THE HOUR ANGLE (RADIAN) 1/2 HOUR FROM SUNSET
109     ECC=1.0+0.033*COS(2.0*PI*DAY/365.)
110     DSTAR=2.*PI/365.242*(DAY-1.)
111     ET=EOT(DSTAR)
112     C. ECC IS THE ECCENTRICITY CORRECTION FACTOR FOR THE SOLAR CONSTANT
113     3 CONTINUE
114     TC=AMOD(TIME,24.0)
115     TC=TC+ET+D0SM/15.
116     HRANG=(12.-TC)*15.0*RDCONV
117     IF (ABS(HRANG).GT.WSMAX) HRANG=SIGN(WSMAX,HRANG)
118     COSHR=COS(HRANG)
119     SINHR=SIN(HRANG)
120     COSTZ=COSLAT*COSDEC*COSHR+SINLAT*SINDEC
121     IF (COSTZ.LE.0.0) GO TO 17
122     C. COSTZ IS THE COSINE OF THE ANGLE OF BEAM RADIATION INCIDENT
123     C. ON A HORIZONTAL SURFACE
124     C.
125     HEX=SC*ECC*COSTZ
126     C. HEX IS THE EXTRATERRESTRIAL RADIATION ON A HORIZONTAL SURFACE
127     XKT=HT/HEX

```

```

128      OUT(19) = HEX @ ***** TEMP *****
129      GO 69 J=1,NS
130      COSAZM=COS(AZMTH(J)*RDCONV)
131      SINAZM=SIN(AZMTH(J)*RDCONV)
132      COSSLP=COS(SLOPE(J)*RDCONV)
133      SINSLP=SIN(SLOPE(J)*RDCONV)
134      RB=0.
135      THETA(J)=90.
136      RD=(1.0+COSSLP)/2.
137      RR=(1.0-COSSLP)/2.0*RHO
138      COSTT=SINDEC*SINLAT*COSSLP-SINDEC*COSLAT*SINSLP*COSAZM
139      1      +COSDEC*COSLAT*COSSLP*COSHR
140      2      +COSDEC*SINLAT*SINSLP*COSAZM*COSHR+COSDEC*SINSLP*SINAZM*SINHR
141      C. COSTT IS THE COSINE OF THE ANGLE OF RADIATION INCIDENT ON
142      C. THE TILTED SURFACE
143      IF (COSTT.LE.0.0) GO TO 18
144      THETA(J)=ACOS(COSTT)/RDCONV
145      RB=COSTT/COSTZ
146      OUT(20) = RB @ ***** TEMP *****
147      C.
148      18 - CONTINUE
149      GO TO (51,52,53),IOPT
150      C.
151      51 CONTINUE
152      C. IOPT=1 BEAM AND DIFFUSE RADIATION ARE DETERMINED BY THE
153      C. METHOD OF LIU AND JORDAN.
154      IF (XKT.GT.0.75) XKT=0.75
155      HD=HT*(1.0045+((2.6313*XKT-3.5227)*XKT+0.04349)*XKT)
156      IF (HD.LE.0.0) HD=0.0
157      HB=HT-HD
158      C. HD IS THE DIFFUSE RADIATION ON A HORIZONTAL SURFACE.
159      C. HT IS THE TOTAL RADIATION ON A HORIZONTAL SURFACE.
160      C. THE CORRELATION BETWEEN HD AND HT IS DUE TO LIU AND JORDAN.
161      C. XKT IS THE RATIO OF TOTAL RADIATION ON A HORIZONTAL SURFACE
162      C. TO THE EXTRATERRESTRIAL RADIATION.
163      C. LIU AND JORDAN'S CORRELATION IS FOR DAILY RADIATION TOTALS, BUT
164      C. HERE IT IS BEING USED FOR INSTANTANEOUS OR HOURLY MEASUREMENTS.
165      C.
166      53 CONTINUE
167      HBT(J)=HB*RB
168      HDT(J)=HD*RD+RR*HT
169      HR(J)=HBT(J)+HDT(J)
170      GO TO 69
171      C.
172      52 CONTINUE
173      C. IOPT=2. BOES' CORRELATION IS USED TO ESTIMATE THE BEAM AND
174      C. DIFFUSE COMPONENTS OF THE HORIZONTAL RADIATION.
175      DN=3600.0*(1.80*XKT-0.52)
176      IF (DN.LE.0.0) DN=0.0
177      IF (DN.GT.3600.) DN=3600.
178      HB=DN*COSTZ
179      IF (HB.LE.0.0) HB=0.0
180      HD=HT-HB
181      IF (HD.LE.0.0) HD=0.0
182      GO TO 53
183      69 CONTINUE
184      17 CONTINUE
185      OUT(1)=HR(1)
186      OUT(2)=HBT(1)
187      OUT(3)=HDT(1)
188      C. HR(J),HBT(J), AND HDT(J) ARE THE TOTAL, BEAM, AND DIFFUSE RADIATION
189      C. THE TILTED SURFACE
190      OUT(4)=HT
191      OUT(5)=HB
192      OUT(6)=HD
193      C. HT,HB, AND HD ARE THE TOTAL, BEAM, AND DIFFUSE RADIATION ON A
194      C. HORIZONTAL SURFACE

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```
194      C.      OUT(7)=THETA(1)
195
196      C.      THETA IS THE ANGLE OF INCIDENT BEAM RADIATION ON THE FILTED
197      C.      SURFACE IN DEGREES
198              IF (NS.EQ.1) GO TO 999
199              IP=7
200              DO 71 J=2,NS
201              IP=IP+1
202              OUT(IP)=HR(J)
203      71      CONTINUE
204      999      CONTINUE
205              OUT(20)=DECL
206              RETURN
207              END
----->EXIT PRT
```

RPRT,S P,TYPE16

IS IN EXCLUSIVE USE BY ANOTHER RUN

FAC STATUS: 400001200000

-----EXIT PRT

RPRT,S P,TYPE32

3883213518*P(1),TYPE32(9)

```

1      SUBROUTINE TYPE32(TIME,XIN,OUT,T,DTDT,PAR,INFO)
2      DIMENSION XIN(20),OUT(20),PAR(20),INFO(10),GAM(5,5)
3      C  CONTROLLER FOR ARLINGTON HOUSE
4      C  MODE 1=CS 2=CL 3=SL 4=AUX 5=IDLE
5      C  T1=COLLECTORS T2=BOTTON OF ROCK BED T3=COLLECTOR RETURN
6      C  T4=BOTTON OF PREHEAT TANK T5=AVERAGE ROCK BED
7      C  T6=BED SET POINT T7=ROOM TEMP T8=OVERTEMP IN PREHEAT TANK
8      C  TSET1=STAGE 1 HEAT TSET2= STAGE 2 HEAT TSET3=TURN OFF HEAT
9      C  TON1=TURN ON COLLECTORS TON2=TURN OFF COLLECTORS
10     C  MSUB=IS PREHEAT TANK OVERHEATED
11         IF(INFO(7).GE.0) GO TO 5
12         INFO(5)=7
13         INFO(9)=1
14         CALL TYPECK(1,INFO,9,7,0)
15     C  STICKEY CONTROLLER
16     5  IF(INFO(7).GE.NSTK)RETURN
17     DATA GAM/1.,0.,0.,1.,1.,0.,1.,1.,1.,1.,1.,0.,1.,1.,1.,0.,0.,
18     *0.,1.,0.,.762,.648,.952,1.,0./
19     NSTK=PAR(1)
20     TSET1=PAR(2)
21     TSET2=PAR(3)
22     TSET3=PAR(4)
23     TON1=PAR(5)
24     TON2=PAR(6)
25     OT=PAR(7)
26     T1=XIN(1)
27     T2=XIN(2)
28     T3=XIN(3)
29     T5=XIN(4)
30     T6=XIN(5)
31     T7=XIN(6)
32     T8=XIN(7)
33     XMODE=XIN(8)
34     MODE=IFIX(XMODE+0.1)
35     NOFPK=XIN(9)+0.2
36     MSUB=0
37     C  CHECK TO SEE IF HOUSE IS CURRENTLY BEING HEATED
38     C  (HYSTERESIS IN CONTROLLER)
39         GO TO (19,10,10,19,19),MODE
40     10  IF(T7.GE.TSET3) GO TO 50
41         IF(T7.GE.TSET2) GO TO 20
42         GO TO 42
43     19  IF(T7.GE.TSET1) GO TO 50
44         IF(T7.GE.TSET2) GO TO 20
45         GO TO 42
46     C  HOW TO HEAT HOUSE?
47     20  GO TO(30,30,25,42,25),MODE
48     25  IF(T1.GE.(T2+TON1)) GO TO 45
49         GO TO 42
50     30  IF(T3.GE.(T2+TON2)) GO TO 45
51     42  NMODE=3
52         GO TO 100
53     45  NMODE=2
54     46  IF(T8.LE.OT) GO TO 48
55         GO TO 100
56     48  MSUB=1

```

```
57          GO TO 100
58      C   HOUSE DOES NOT NEED HEAT
59      50  IF(NDFPK.EQ.0) GO TO 60
60          IF(T5.GE.T3) GO TO 55
61          NMODE=4
62          GO TO 100
63      55  NMODE=5
64          GO TO 100
65      60  IF(MODE.EQ.1) GO TO 65
66          IF(T1.LT.(T2+TON1)) GO TO 55
67      63  NMODE=1
68          GO TO 46
69      65  IF(T3.LT.(T2+TON2)) GO TO 55
70          GO TO 63
71      100 MODE=NMODE
72          DO 120 J=1,5
73      120 OUT(J)=CAH(MODE,J)
74          OUT(6)=MSUB
75          XMODE=FLOAT(MODE)
76          OUT(7)=XMODE
77          RETURN
78          END
----->EXIT PRT
```

BPRT,5 P. TYPE35

```

3886216510*P(1),TYPE35(15)
1      SUBROUTINE TYPE35(TIME,XIN,OUT,T,DTOT,PAR,INFO)
2      DIMENSION OUT(20),INFO(9)
3      IF(INFO(7)) 1,10,400
4      1  INFO(6)=6
5      INFO(9)=1
6      CALL TYPECK(1,INFO,0,0,0)
7      C READ INITIAL DATA
8      READ(11,500) TM1
9      READ(11,501) A1,B1,C1
10     READ(11,502) D1,E1
11     READ(11,500) TM2
12     READ(11,501) A2,B2,C2
13     READ(11,502) D2,E2
14     TM1=0.0
15     TM2=TM2-10080.
16     C CONVERSIONS FOR INITIAL DATA
17     A1=A1
18     B1=B1
19     D1=D1
20     E1=(E1+.2675)/.0105/1000.*3600.
21     IF(E1.LT.0.)E1=0.
22     IF(E1.LT.10.) E1=0.
23     A2=A2
24     B2=B2
25     D2=D2
26     E2=(E2+.2675)/.0105/1000.*3600.
27     IF(E2.LT.0.) E2=0.
28     IF(E2.LT.10.) E2=0.
29     C WRITE INITIAL DATA TO GET IT NEXT TIME
30     OUT(7)=TM1
31     OUT(8)=A1
32     OUT(9)=B1
33     OUT(10)=C1
34     OUT(11)=D1
35     OUT(12)=E1
36     OUT(13)=TM2
37     OUT(14)=A2
38     OUT(15)=B2
39     OUT(16)=C2
40     OUT(17)=D2
41     OUT(18)=E2
42     GO TO 400
43     C HERE ON FIRST CALL OF A TIMESTEP
44     10  TM2=OUT(13)
45     A2=OUT(14)
46     B2=OUT(15)
47     C2=OUT(16)
48     D2=OUT(17)
49     E2=OUT(18)
50     C SEE IF NEED TO READ MORE DATA
51     15  IF(TIME.LT.TM2) GO TO 30
52     C READ NEW DATA
53     TM1=TM2
54     A1=A2
55     B1=B2
56     C1=C2
57     D1=D2
58     E1=E2
59     READ(11,500) TM2
60     READ(11,501) A2,B2,C2
61     READ(11,502) D2,E2

```

```

82          TH2=TH2-10080.
83      C   CONVERT DATA
84          A2=A2
85          B2=B2
86          D2=D2
87          E2=(E2+.2675)/.0105/1000.*3600.
88          IF(E2.LT.0.) E2=0.
89          IF(E2.LT.10.) E2=0.
90          IF(TIME.GE.TH2) GO TO 15
91          GO TO 60
92      C   USE OLD DATA
93          50  TH1=OUT(7)
94              A1=OUT(8)
95              B1=OUT(9)
96              C1=OUT(10)
97              D1=OUT(11)
98              E1=OUT(12)
99          60  R=(TIME-TH1)/(TH2-TH1)
100             OUT(1)=A1+R*(A2-A1)
101             OUT(2)=B1+R*(B2-B1)
102             OUT(3)=C1+R*(C2-C1)
103             OUT(4)=D1+R*(D2-D1)
104             OUT(5)=E1+R*(E2-E1)
105             OUT(6)=TH1+R*(TH2-TH1)
106             OUT(7)=TH1
107             OUT(8)=A1
108             OUT(9)=B1
109             OUT(10)=C1
110             OUT(11)=D1
111             OUT(12)=E1
112             OUT(13)=TH2
113             OUT(14)=A2
114             OUT(15)=B2
115             OUT(16)=C2
116             OUT(17)=D2
117             OUT(18)=E2
118             OUT(19)=TIME-.188867
119             OUT(20)=TIME
120          400 CONTINUE
121          RETURN
122          500 FORMAT(F11.4)
123          501 FORMAT(F8.2,8X,F8.2,/,40X,F8.1,/)
124          502 FORMAT(56X,F8.3,8X,F8.3,/)
125          505 FORMAT(5X,F11.4,2(F8.2),F8.1,2(F8.3))
126          END
-----EXIT PRT

```

RPRTVS DATA,PERF

```

0888216518*DATA(1),PERF(26)
1      DIMENSION S1(15),S2(15),S3(15),S4(15),S5(15),S6(15),S7(15),S8(15)
2      *,S9(15),S10(15),S11(15),QCOLT(2500),PTIME(2500)
3      TOLD=10440.1254
4      TNEW=TOLD
5      TO=10440.1254
6      J=0
7      I=0
8      TNEW=TNEW+12.
9      1  RHOR=0.0
10     R60=0.0
11     DCOIL=0.0
12     DLOAD=0.0
13     AUX=0.0
14     WHTR=0.0
15     DOM=0.0
16     PARA=0.0
17     QCOLL=0.0
18     HXWAT=0.0
19     HXAIR=0.0
20     IF(I.EQ.2052) GO TO 110
21     IF(I.EQ.0) GO TO 5
22     2  TNEW=TNEW+24.
23     5  I=I+1
24     READ(12,9) TIME
25     READ(12,10) C0,C1,C2,C3,C4,C5,C6,C7,C8,C9
26     READ(12,11) C10,C11,C12,C13,C14,C15,C16,C17,C18,C19
27     READ(12,12) C20,C21,C22,C23,C24,C25,C26,C27,C28,C29
28     READ(12,13) C30,C31,C32,C33,C34,C35,C36,C37,C38,C39
29     READ(12,15) C40,C41,C42,C43,C44,C45
30     TN=TIME
31     DT=TN-TO
32     C  FROM ERDMAN APPENDIX D
33     PBAR=.491*(27.771+.04456*C18)
34     PV12=C12*200./394.5
35     PV13=C13*200./398.8
36     PV14=C14*200./245.45
37     RHO12=144.*PBAR/(53.34*(C29+273.))*1.8)
38     RHO13=144.*PBAR/(53.34*(C26+273.))*1.8)
39     RHO14=144.*PBAR/(53.34*(C19+273.))*1.8)
40     V12=1096.5*(PV12/RHO12)**0.5
41     V13=1096.5*(PV13/RHO13)**0.5
42     V14=1096.5*(PV14/RHO14)**0.5
43     XM12=60.*RHO12*V12*0.667/2.2046
44     XM13=60.*RHO13*V13*0.667/2.2046
45     XM14=60.*RHO14*V14*0.444/2.2046
46     QC=XM13*1.012*(C10-C11)*DT*1000.
47     QCOLT(I)=QC
48     PTIME(I)=TIME
49     WAT=C3*9.65*(C43-C42)*4.19*1000.
50     AIR=XM13*1.012*DT*(C26-C27)*1000.
51     C  SUM UP DATA
52     RHOR=RHOR+(C39+.2675)/.0105*40.70*3600.*DT
53     R60=R60+(C37+.2675)/.00869*40.70*3600.*DT
54     DCOIL=DCOIL+C3*9.65
55     DLOAD=DLOAD+C4*25.9
56     IF(C5.GE.0.) GO TO 80
57     AUX=AUX-C5*1.441E6
58     80  WHTR=WHTR+C6*3.602E5
59     DOM=DOM+C7*2.869E3
60     PARA=PARA+C8*5.34E4
61     QCOLL=QCOLL+QC
62     HXWAT=HXWAT+WAT

```

```

63         HXAIR=HXAIR+AIR
64         TQ=TN
65         IF(I.EQ.2052) GO TO 100
66         IF(TN.GE.TNEW) GO TO 100
67         GO TO 5
68     100    J=J+1
69           S1(J)=RHOR
70           S2(J)=R60
71           S3(J)=DCOIL
72           S4(J)=DLOAD
73           S5(J)=AUX
74           S6(J)=WHTR
75           S7(J)=DOM
76           S8(J)=PARA
77           S9(J)=QCOLL
78           S10(J)=HXWAT
79           S11(J)=HXAIR
80           WRITE(-,-) TNEW,TOLD
81           GO TO 1
82     110    WRITE(-,190)
83           DO 150 J=1,14
84           WRITE(-,200) J,S1(J),S2(J),S3(J),S4(J),S5(J),S6(J),S7(J),
85           *S8(J),S9(J),S10(J),S11(J)
86           RHOR=RHOR+S1(J)
87           R60=R60+S2(J)
88           DCOIL=DCOIL+S3(J)
89           DLOAD=DLOAD+S4(J)
90           AUX=AUX+S5(J)
91           WHTR=WHTR+S6(J)
92           DOM=DOM+S7(J)
93           PARA=PARA+S8(J)
94           QCOLL=QCOLL+S9(J)
95           HXWAT=HXWAT+S10(J)
96     150    HXAIR=HXAIR+S11(J)
97           WRITE(-,209)
98           WRITE(-,200) J,RHOR,R60,DCOIL,DLOAD,AUX,WHTR,DOM,PARA,
99           *QCOLL,HXWAT,HXAIR
100          CALL GRAPH(PTIME,+1,QCOLL,+1,2412,4HNONE,SHSOLID,'TIME##',
101          *'QCOLL KJ##',+1,'ENERGY COLL-HOOT*CF*(CH10-CH11)##',50,0,10,3)
102     190    FORMAT(3X,'DAY',5X,'RHOR',7X,'R60',7X,'DCOIL',6X,'DLOAD',7X,
103          *'AUX',8X,'WHTR',7X,'DOM',7X,'PARA',7X,'QCOLL',7X,'HXWAT',6X,
104          *'HXAIR')
105     200    FORMAT(3X,I2,11(1X,E10,4))
106     209    FORMAT(45X,'TOTALS')
107           FORMAT(F11.4)
108           10  FORMAT(3(F8.2),6(F8.3),F8.2)
109           11  FORMAT(2(F8.1),3(F8.4),F8.1,3(F8.3),F8.2)
110           12  FORMAT(10(F8.1))
111           13  FORMAT(7(F8.1),F8.3,F8.4,F8.3)
112           15  FORMAT(F8.3,5(F8.1),/)
113          STOP
114          END
----->EXIT PRT

```

Appendix E

Daily Totals

13 noon-noon days February 25 - March 10, 1978

Day	Q _{collector}		Q _{aux}		Q _{wat aux}	
	Data	Simulation	Data	Simulation	Data	Simulation
1	.256	.300	.435	.259	.000	.013
2	.255	.280	.377	.076	.038	.013
3	.075	.052	.382	.454	.027	.014
4	.325	.354	.255	.432	.002	.014
5	.354	.334	.027	.044	.000	.013
6	.250	.110	.366	.302	.033	.014
7	.346	.283	.361	.562	.006	.019
8	.376	.400	.106	.128	.032	.014
9	.238	.244	.489	.324	.000	.014
10	.345	.378	.096	.130	.013	.014
11	.356	.355	.016	.152	.037	.018
12	.446	.455	.000	.043	.000	.014
13	.416	.447	.000	.000	.000	.013

(all values in GJ)