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UNITED STATES SPECIAL FORMAT REPORT: DESIGN, CONSTRUCTION, AND TESTING OF THE COLORADO STATE UNIVERSITY SOLAR HOUSE I HEATING AND COOLING SYSTEM

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June 1976

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Colorado State University
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ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Division of Solar Energy

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CCMS SOLAR ENERGY PILOT STUDY:

Solar Heating and Cooling Systems in Buildings

UNITED STATES SPECIAL FORMAT REPORT

DESIGN, CONSTRUCTION, AND TESTING OF THE COLORADO STATE UNIVERSITY SOLAR HOUSE I HEATING AND COOLING SYSTEM

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Energy Research and Development Administration
Division of Solar Energy
Washington, D.C. 20545

June 1976

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GENERAL DESCRIPTION OF SYSTEM PROJECT AND ENVIRONMENT

OBJECTIVES OF PROJECT

The primary objective of the project is the design, construction, testing, and evaluation of a practical system for utilizing solar energy to drive heating, cooling, and domestic hot water subsystems, supplemented as necessary with auxiliary fuel. The project is designed to provide the following information:

1. Design data for integrated systems and the various subsystems,
2. System performance for space heating, cooling, and domestic hot water heating,
3. Operating economics,
4. Verification of the University of Wisconsin system design model,
5. Design and operation of automatic controls,
6. Correlation of standard Weather Bureau data with on-site insolation data, and
7. System reliability evaluation

System design was accomplished during the first five months (September 1973 to January 1974) and construction completed during the following five month period (February to June 1974). This report details the evaluation of the system's performance during the period 1 September 1974 through 31 August 1975. Efforts are now underway to modify and improve the performance of the solar system, and conduct a comparative evaluation of the original design and the modified system.

DESCRIPTION OF THE ENVIRONMENT

Climate

According to Trewartha designation*, climate is classified as BSk, (dry, semi-arid [steppe], middle latitude) with Continental winter, anti-cyclone, and meager rainfall (mostly in summer).

Annual rain and snowfall is 36.3 cm (14.31 inches). This corresponds to a rainfall of 24.9 cm (9.82 inches) and a snowfall of 11.4 cm (4.49 inches). The snowfall can be given in equivalent water as 114 cm (44.8 inches). The values were computed as yearly averages over a 42-year period (1930 to 1972).

Percentage of maximum possible annual sunshine hours is 67 per cent (computed over a 57-year period).

Location

The CSU Solar House I is located at 40.6°N and 105.1°W, at an altitude of 1585 meters (5200 feet) above sea level. It is positioned on the south side of a gently sloping hill, approximately 100 meters from a large, three story building on the top of the hill (to the north-northeast). The front range of the Rocky Mountains is located about one kilometer to the west of the Solar House, and about 800 meters above the plain. The high altitude, limited rainfall, and exceptional air clarity provide a high level of solar insolation.

Solar Radiation

The mean monthly global (total) insolation on a plane tilted toward the south at a 45 degree angle is Tabulated in Table 1. The data were obtained during the period of this report (1 September 1974 to 31 August 1975) by the use of an Eppley pyranometer. The millivolt output of the

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*G.T. Trewartha, An Introduction to Climate (McGraw-Hill; New York), 1954.

Table 1

Mean Monthly Values of Global (Total) Insolation on a Plane Tilted Toward the South at a 45° Angle, Dry and Wet Bulb Temperatures, and Wind Speed

Month	Solar Insolation on a 45° Surface		Ambient Temperature		Wind Speed (m/sec)
	($\frac{\text{Langleys}}{\text{day}}$)	($\frac{\text{MJ}}{\text{m}^2 \cdot \text{day}}$)	Dry Bulb (°C)	Wet Bulb (°C)	
September	370	15.5	16.1	*	*
October	284	11.9	11.2	*	*
November	261	10.9	2.2	*	*
December	320	13.4	- 1.9	*	*
January	334	14.0	- 1.4	*	3.2
February	426	17.8	- 1.7	*	2.0
March	372	15.6	2.4	*	3.8
April	506	21.2	6.3	*	4.1
May	407	17.0	12.5	*	4.8
June	460	19.3	17.8	15.6	5.1
July	493	20.6	23.7	18.2	4.3
August	478	20.0	22.0	17.3	4.6

*Not recorded

pyranometer was integrated over two-minute periods and the two-minute totals recorded on magnetic tape.

Ambient Temperatures

Mean monthly dry and wet bulb temperatures are tabulated in Table 1. Based on these data, the mean annual heating degree days are 3303°C days (18°C, 65°F base), while the mean annual cooling degree days are 422°C days (18°C, 65°F base). Design temperatures (for the Denver area, 100 km to the south) are -23°C (-10°F) for winter and 35°C (95°F) dry bulb, 18°C (64°F) wet bulb for the summer.

Measurement equipment includes a copper constantan thermocouple (shaded from the sun) for dry bulb temperatures, and a dew point hydrometer. for obtaining dew point temperatures for computation of wet bulb temperatures. The hygrometer has an intake pipe for sensing ambient (outdoor) dew point. Accuracy has been determined to be within 0.5°C.

Wind

Average monthly wind speed is tabulated in Table 1. Data were obtained from a wind speed cup aeronometer, mounted on the CSU Solar House I roof ridge. The data are intergrated over five-minute periods to obtain total wind run.

DESCRIPTION OF SYSTEM

Qualitative Description

The solar heating and cooling system was installed in a residence-type building at a site on the Foothills Campus of Colorado State University in Fort Collins, Colorado. The building is a modern three-bedroom frame residence with a living area of 140 square meters (1500 square feet) and a full, heated basement, the south wall of which is entirely above grade. The design heating load was computed to be 16.1 kilowatts at -23°C (55,000 Btu/hr at -10°F; corresponding to 17,600 Btu/°F day). The design cooling load is approximately 10.5 kilowatts (3 tons or 36,000 Btu/hr). The insulation was typical, with 8.9 cm (3.5 inches) fiberglass in the walls ($R = 6.85 \frac{°Cm^2}{w}$; $12 \frac{Hr - °F - ft^2}{Btu}$) and 14 cm (5.5 inches) of fiberglass in the ceiling ($R = 10.85 \frac{°Cm^2}{w}$; $19 \frac{Hr - °F - ft^2}{Btu}$) (see Figure 1).

The solar heating and cooling system includes the conventional components such as the lithium bromide absorption cooling unit, hot water boiler, air heater coil, hot water heater, and associated piping, ducts and pumps; and the solar components, consisting of a solar collector and pump, thermal storage with heat exchanger and hot water preheat tank, and an automatic valve. Figure 2 is a cross-section schematic diagram of the installation which shows all of the components except the collector and associated piping, the control sensors, and the air distribution system. The primary modes of solar heat collection are: storing heat from the solar collector via a heat exchanger, and storing heat directly from the solar collector. A third mode of solar collection is the supply of heated fluid directly from the solar collector to the heating unit. Energy to the heating or cooling unit is provided either by use of hot water from storage, if the temperature is adequate, or from the auxiliary boiler as necessary.

An alternate heating mode utilizes whatever heat is in storage, even at temperature as low as 27°C (80°F), with the auxiliary boiler supplying hot water to an auxiliary air heating coil. In this mode the auxiliary boiler acts as a temperature booster for the solar system. In all other modes of operation, either the auxiliary or solar is used, never the two together.

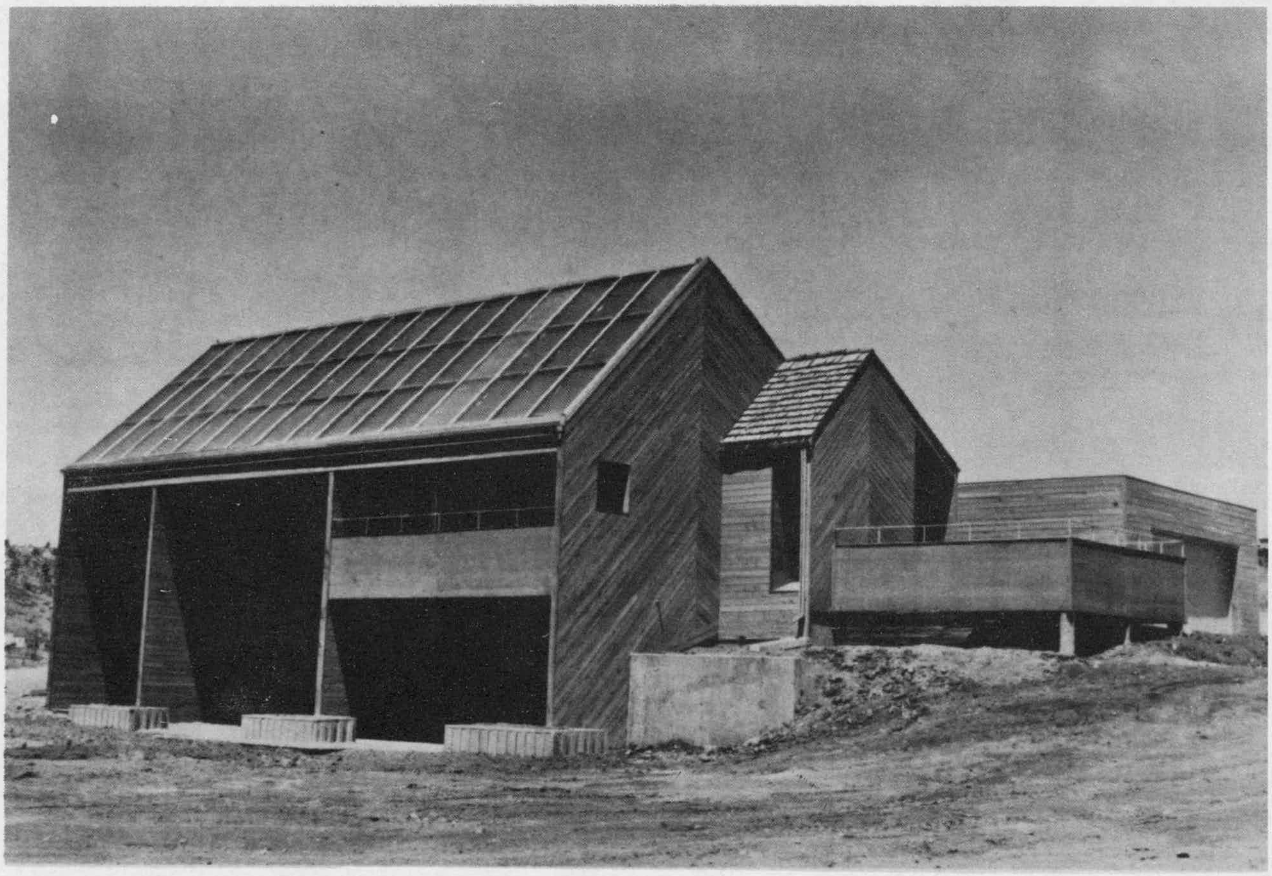


Figure 1. Colorado State University Solar House I

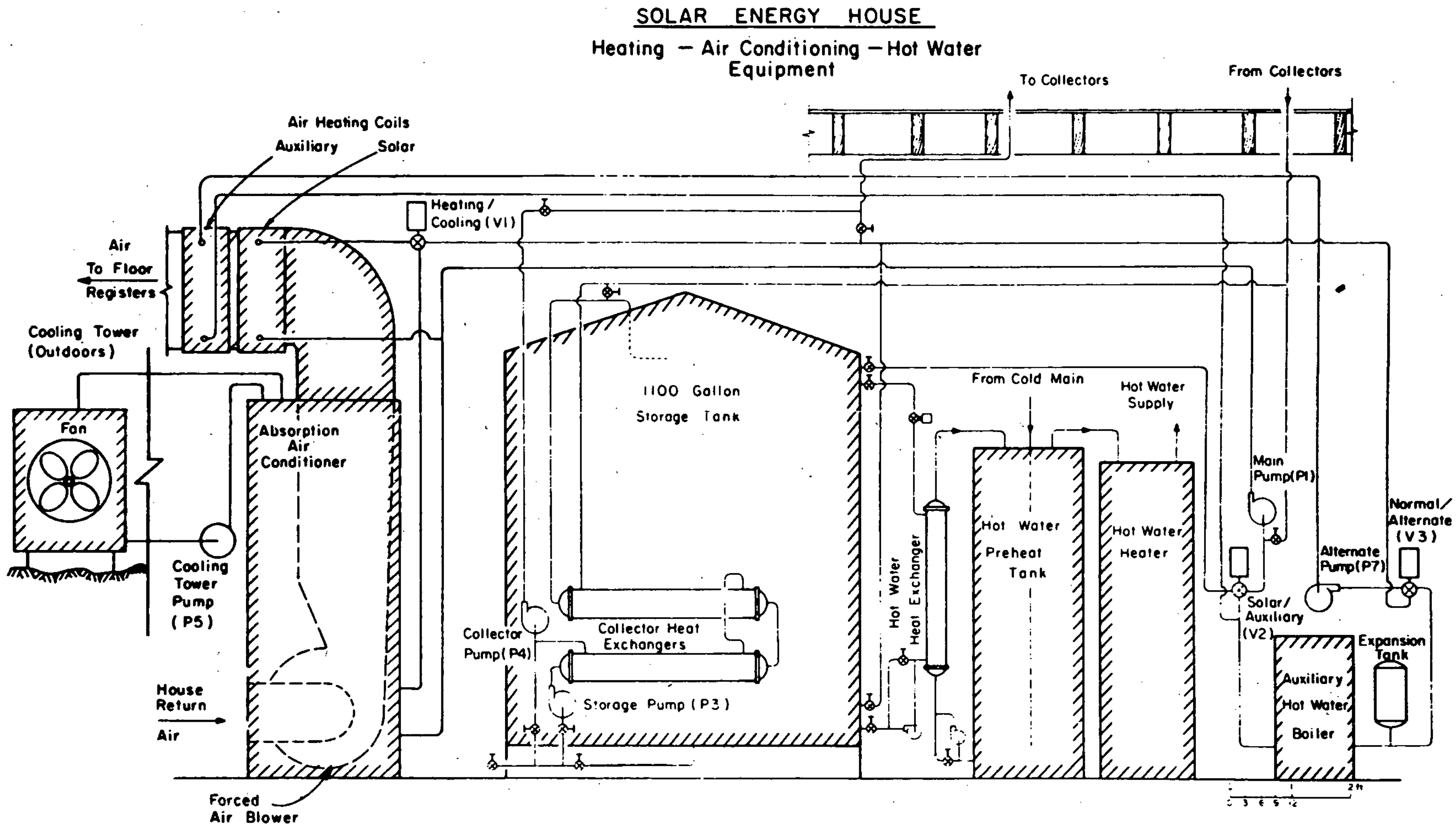


Figure 2

Solar Heating and Cooling System

The house hot water system utilizes solar storage for preheating service hot water using a tube and shell heat exchanger. Water from a cold water main enters the preheat tank, to which heat is supplied from solar storage by pumped circulation through the heat exchanger. On demand, the preheated water then flows to a conventional gas hot water heater, which maintains the required temperatures.

Because of the possibility of freeze damage by circulating water through the collector, normal operation provides solar heat collection in a 60 per cent solution of ethylene glycol (commercial automotive antifreeze) in water. The cost of several hundred gallons of glycol in the main storage system would be prohibitive, so a heat exchanger (a series of two tube-and-shell units) is employed for transfer of heat from the small volume of collector fluid (about 106 liters, 28 gallons) to a large volume of water comprising the thermal storage.

Figure 3 details the interface between the collector panels and the rest of the solar system. The collector absorber panels are made of aluminum, and to avoid corrosion they must therefore not be directly connected to the copper piping in the solar system. Rubber hose connections between the copper and aluminum piping accomplish this separation. A filter and aluminum screen "getter" (sacrificial) are also used to minimize corrosion risk.

A 113 liter (30 gallon) vented surge tank is installed on the outlet side of the collector. This tank provides volume for liquid expansion and also permits boiling to occur in the collector without pressure buildup. If the collector pump fails, boiling results in some liquid loss, but the surge tank can refill the system automatically when operation resumes.

The storage container is a light gauge vertical galvanized steel cylinder 1.83 meters (6 feet) high and 1.68 meters (5.5 feet) in diameter.

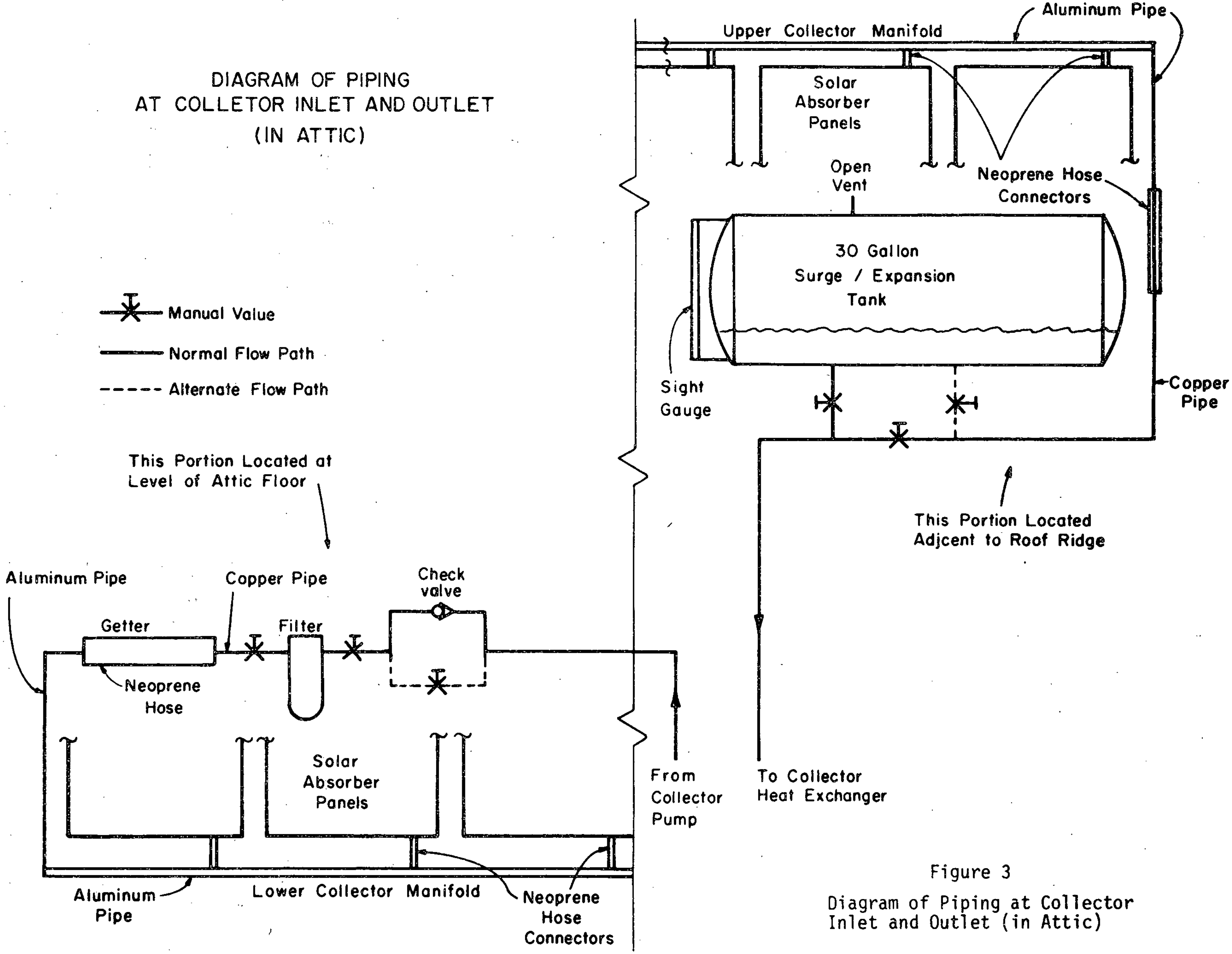


Figure 3

Diagram of Piping at Collector
Inlet and Outlet (in Attic)

It holds 4,275 liters (1131 gallons), a nominal 61 liters/m^2 of collector (1.5 gallons/ft^2). During the first year of operation and during the data collection period covered by this report, the tank was covered by two layers of bonded glass fiber double-faced batt insulation having an R factor of 17.7 $\frac{°Cm^2}{w}$ (30.4 $\frac{Hr - ft^2 - °F}{Btu}$).

QUANTITATIVE DESCRIPTION

The heating and cooling system was designed to furnish 75 per cent of the space heating and 75 per cent of the cooling load demands of the solar house. Calculations by the University of Wisconsin showed that this performance should be obtainable with a gross collector area of 71.4 square meters (768 square feet) facing due south (i.e., the angle, θ, between the projection of the sun's rays, at solar noon, on the horizontal plane and the projection of the normal to the collector on the horizontal plane is zero) at an inclination of 45 degrees (i.e., the angle between horizontal and normal to the collector), when combined with a heat storage of 4,275 liters (1131 U.S. gallons) of water.

Control System Description

CSU Solar House I utilizes a fully automatic control system for the operation of the solar heating and cooling system. Extraction of heat from the solar collectors and distribution of heat to the heating, cooling, and hot water loads are automatically controlled in response to preset temperatures or temperature differentials. This is accomplished by feedback control loops consisting of sensors, thermostats, controlled elements and the mechanical system itself. Figure 4 illustrates a typical feedback control loop. The sensors are vapor expansion bulb and capillary aquastats for the liquid temperatures, electrical resistance (thermistor)

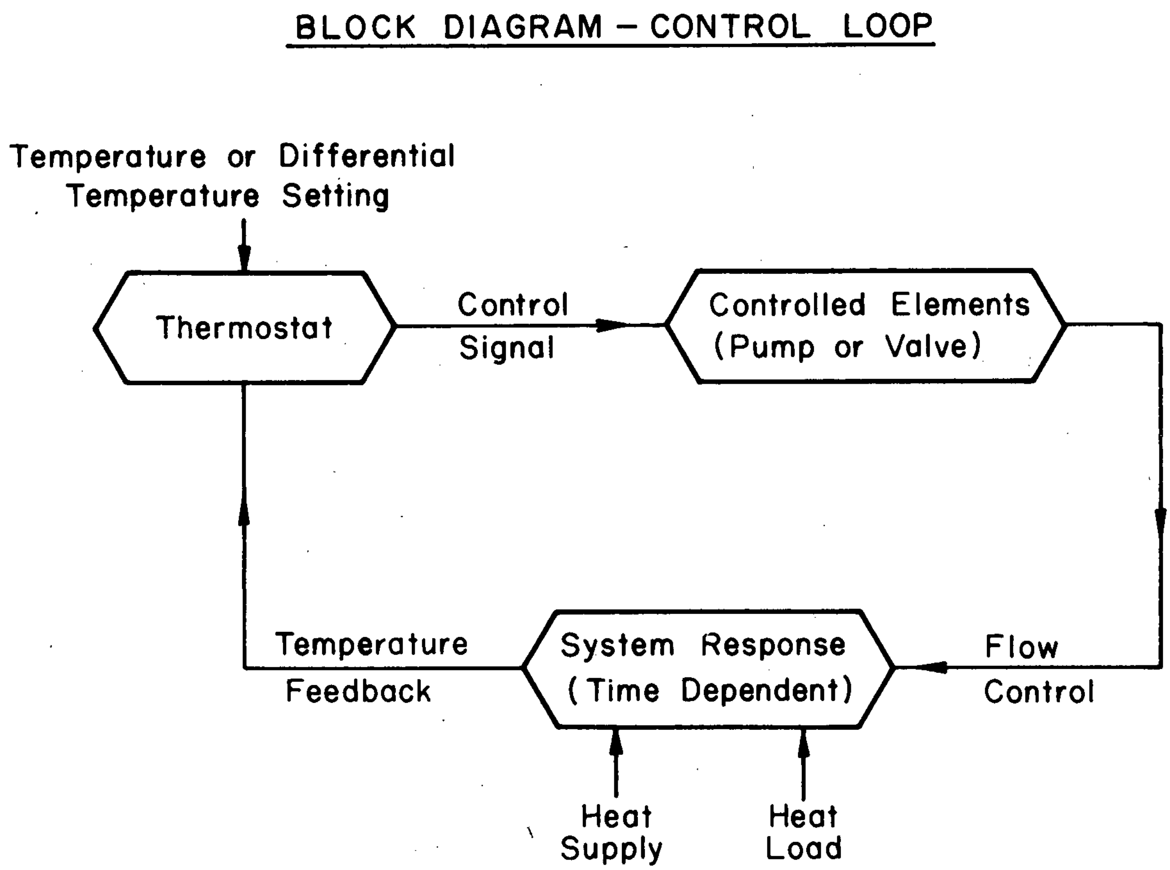


Figure 4

Block Diagram - Control Loop

elements for collector absorber plate temperature, and a bimetal coil for air temperature in the house. Thermostats are used to compare the sensor outputs with the corresponding temperature or differential temperature settings. When the sensor output is sufficiently different from the setting (or is outside of the deadband), a control signal at 24 volts is transmitted from the thermostat to a power relay. The relay opens or closes the 110 volt power line to a controlled element which is a pump, motor, or an automatic electric valve positioner, or an air fan motor. Figure 5 shows the location and identity of the control sensors in the system.

The mechanical system is the final link in the feedback control loop. It is affected by controlled elements which regulate flow to the various components. Operation of the solar air heating coil, for example, depends on the conditions of the main system pump (P1) and the heating/cooling automatic valve (V1). The mechanical system produces an output measured as temperature by the control sensor, thus completing the feedback control loop. Through operation of the air coil, for example, house air temperature change is sensed by the wall thermostat. All control action is of the on/off type with adjustable set points and deadbands.

Figure 6 is a schematic diagram of the control circuit. The lower portion of the diagram is the 24 volt wall thermostat primary control circuit. Relays are actuated from the 24 volt circuit which switch power to the controlled elements illustrated in the upper portion of the drawing. The relays are designed to provide the logic required for each control function. Relays in series comprise "AND" logic, while relays in parallel provide "OR" logic. An example of "AND" control is the hot water preheat signal to pumps P2 and P6 from sensors #1 and #2 (top line in diagram). Power is applied to these pumps to circulate storage water and service water

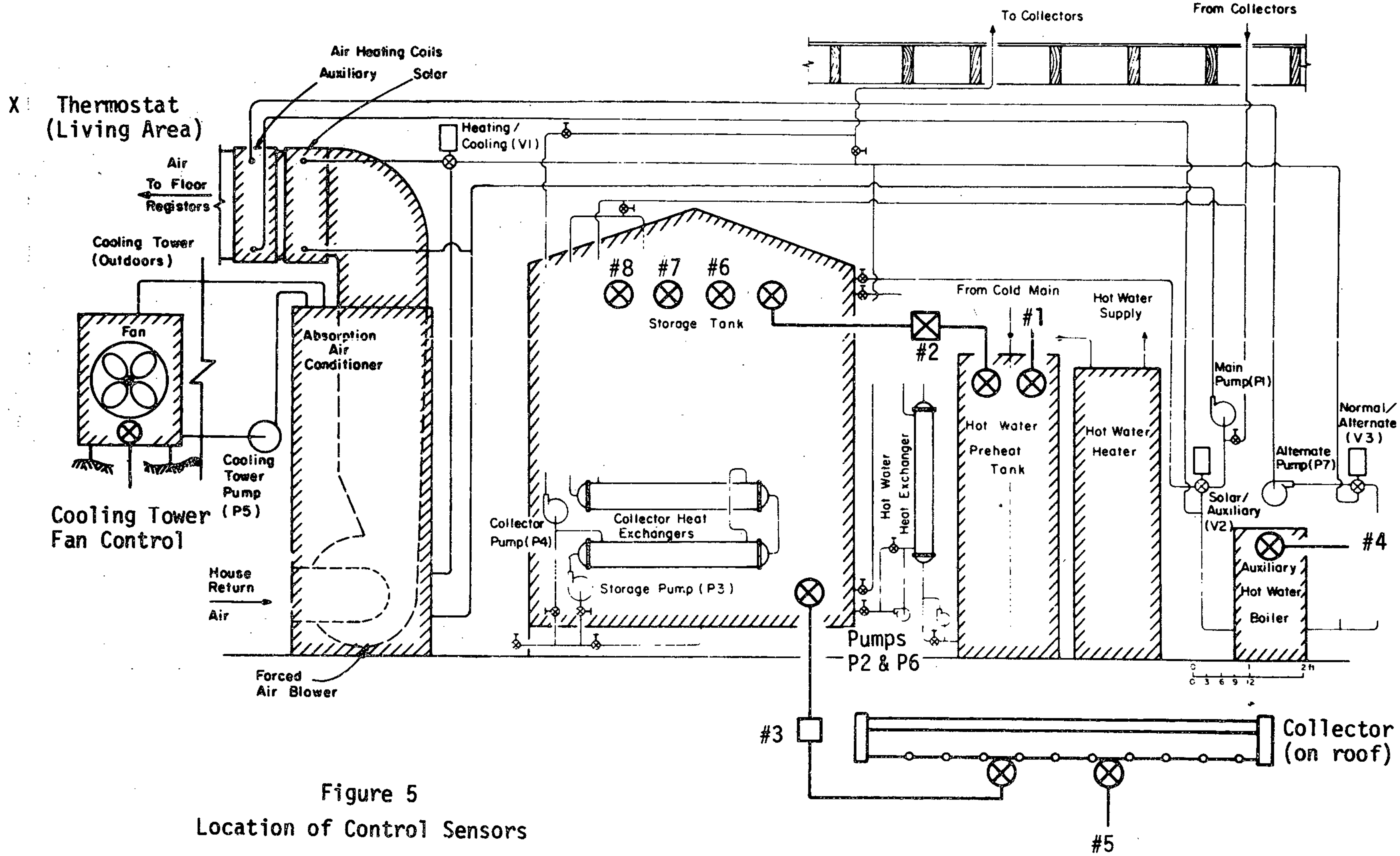


Figure 5
Location of Control Sensors

(Refer to Figure 5 for location and function of pumps and automatic valves)

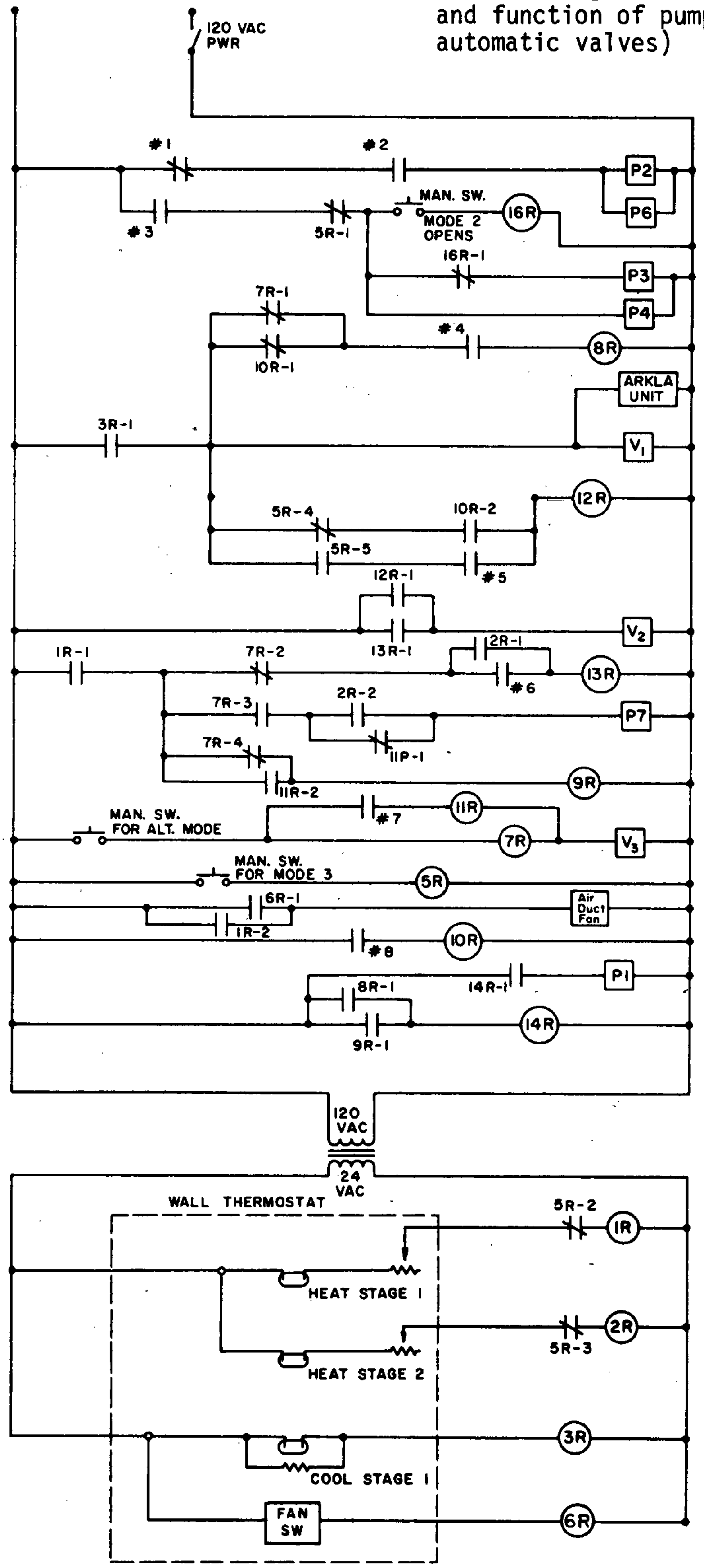


Figure 6

Schematic Diagram of Control Circuit

through the heat exchanger if the preheat tank temperature is below a set point (sensor #1) AND if the temperature of storage is a preset amount above the preheat tank temperature (sensor #2). This control is accomplished by two relays in series with control signals from the corresponding temperature sensors. An example of "OR" logic is the control of the air duct fan (near the bottom of upper section of diagram). The fan is powered for heating OR cooling, and is turned on by either of two relays in parallel; one closes upon heating demand (1R-2) and the other for cooling (3R-2).

The control system in CSU Solar House I is more complex than would be required for a single mode system. The multi-mode design was chosen to provide versatility of operation. A mode is selected manually and the control system automatically assumes control in that mode. The available modes include:

(a) Mode 1 - Mode 1 is characterized by the use of a heat exchanger which separates the collector fluid from the storage tank fluid. Figure 7 illustrates with bold lines the fluid circuits used in Mode 1. The collector fluid is pumped (pump P4) through the shell side of a commercially available shell-and-tube heat exchanger, while storage fluid is pumped through the tubes by another pump (pump P3). Two main advantages of Mode 1 are the avoidance of antifreeze in the storage system and the use of non-pressurized (vented to the atmosphere) storage tank. Provision of the heat exchanger in Mode 1 permits use of only 57 liters (15 gallons) of antifreeze in the collector loop. The storage tank then needs only water and a corrosion inhibiting additive. The second advantage of Mode 1 is a pressurized collector circuit and a non-pressurized storage tank, with the heat exchanger acting as the pressure barrier. There are two reasons for preferring a pressurized collector loop. Under pressure, the boiling temperature of the collector fluid is elevated, allowing for higher operating temperatures

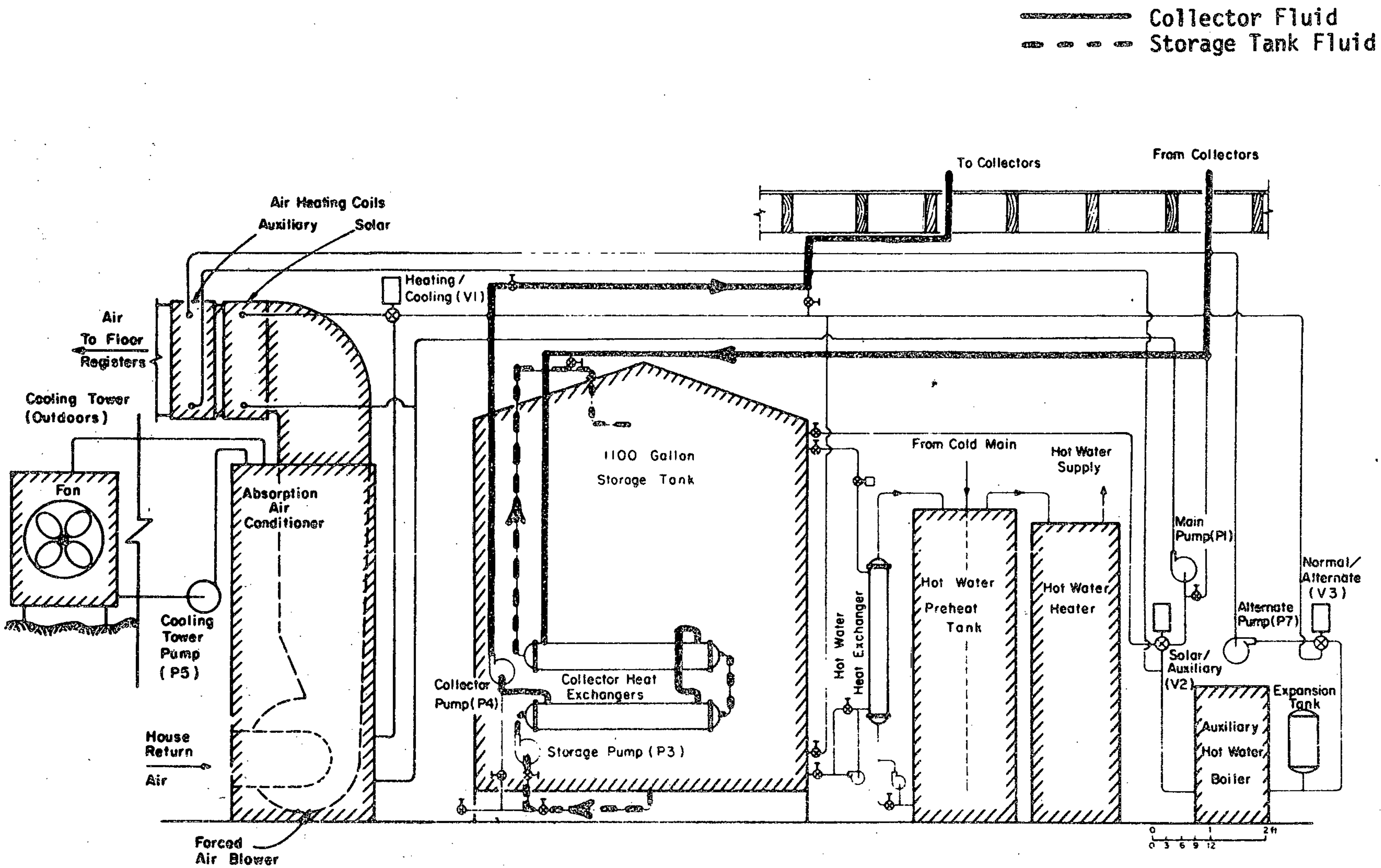


Figure 7

Mode 1 - Solar Collection Using Heat Exchanger in the collector. With the heat exchanger preventing pressure in the storage tank, the collector loop can be completely fluid filled. Consequently, there is no gravity head loss for the pump to overcome, only frictional head loss.

A third advantage of Mode 1 concerns corrosion protection of the collector absorber plates. The need for continuous filtration and deionization of the collector fluid is a major consideration. Mode 1 requires only the 106 liters (28 gallons) filling the collector loop to receive such treatment rather than the additional 4275 liters (1130 gallons) of fluid in storage.

(b) Mode 2 - Mode 2 provides collection of solar heat in water which is run directly to the storage tank. It does not utilize the collector heat exchangers nor the storage pump required in Mode 1. Figure 8 illustrates the fluid circuit for collection of solar heat in Mode 2.

Two advantages are recognized with Mode 2. There is the saving of capital and maintenance costs for the collector heat exchanger and the storage pump. A second advantage of Mode 2 is the elimination of the temperature drop across the collector heat exchangers (ranging from 0° to 6°C). The net result is an improvement in system efficiency.

(c) Mode 3 - Mode 3 is a cooling design which does not utilize heat storage but supplies solar heated fluid directly to the generator of the air conditioner. Figure 9 is a diagram of this mode.

The advantages of Mode 3 are higher water temperatures available to the generator of the air conditioner and the avoidance of some heat loss into the house from the storage tank. Heat loss from the storage tank in summer is particularly detrimental because it has a dual effect on cooling operation. Not only is less heat available to the generator, but heat lost into the house is an added cooling load which must be met by the air conditioner to maintain the desired house temperature.

SOLAR ENERGY HOUSE

Heating — Air Conditioning — Hot Water Equipment

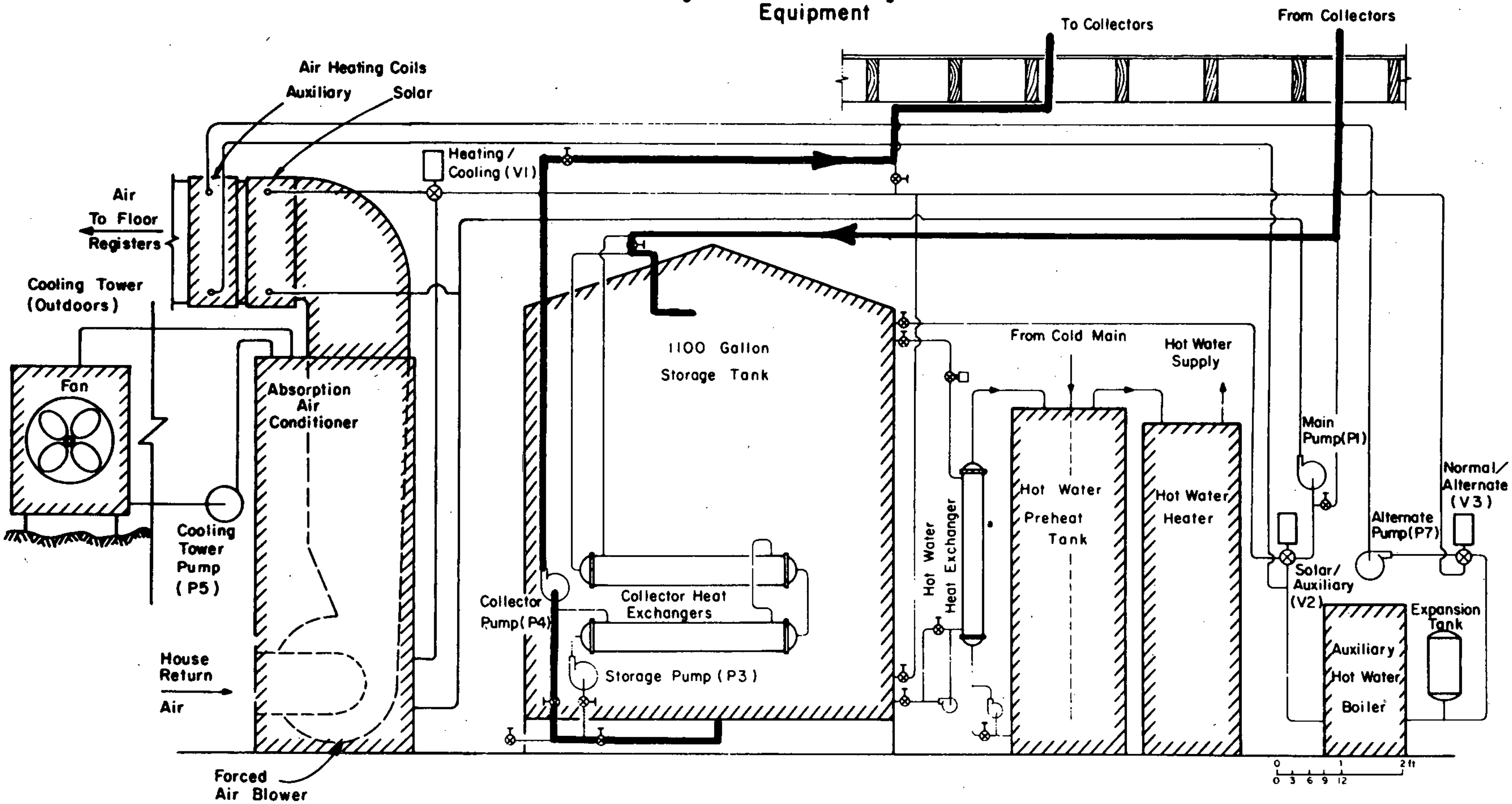


Figure 8

Mode 2 - Solar Collection Without Heat Exchanger

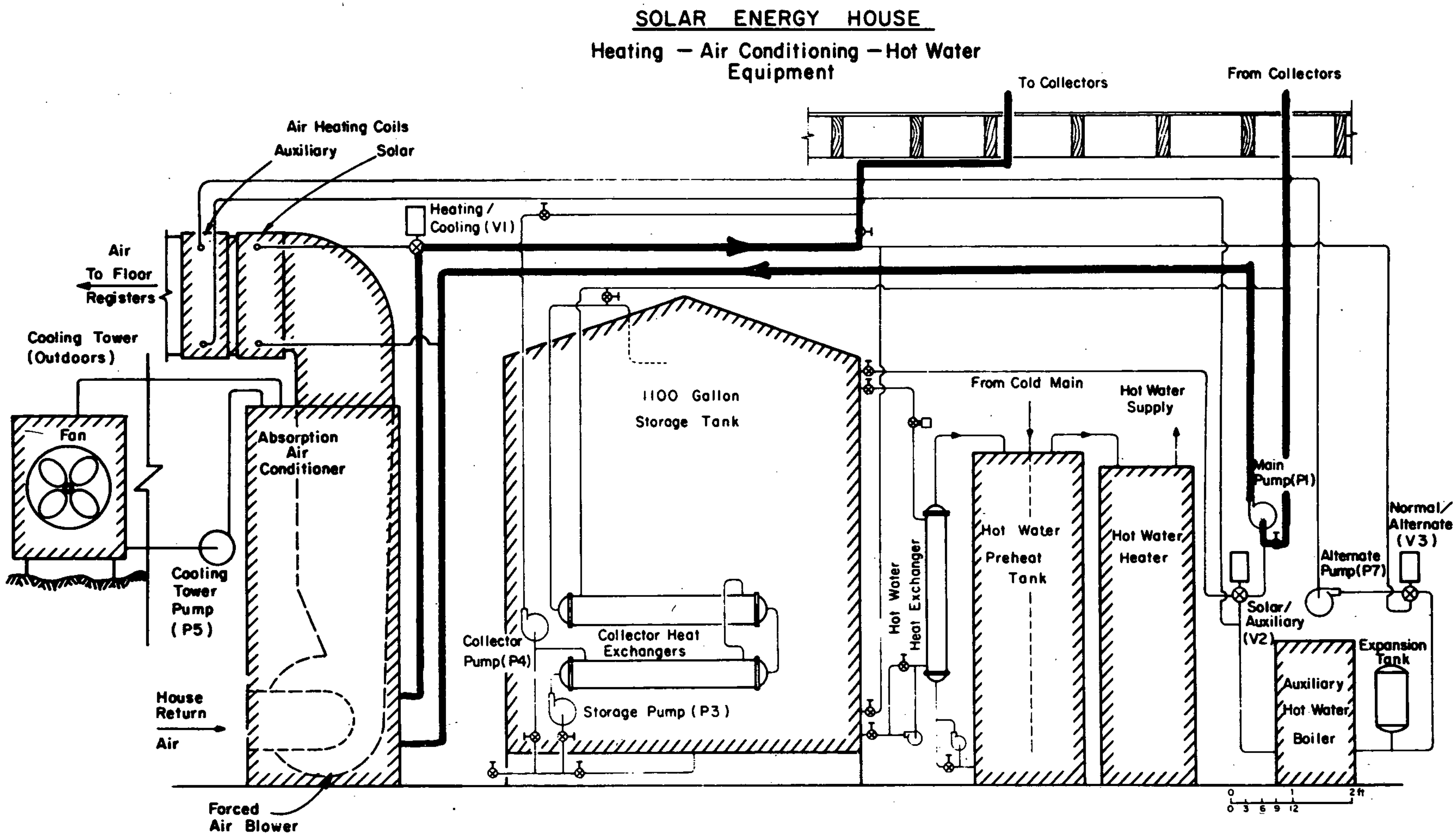


Figure 9

Mode 3 - Air Conditioning Directly from Collectors

Alternate Mode - In the heating season, there will often be a condition in which the storage tank temperature is considerably above house temperature but is not high enough to carry the entire heating load (maintain the desired house temperature setting). It is particularly desirable to use this heat at moderately low temperature because it is acquired at high collector efficiency. The liquid-to-air heating design allows for separate solar storage and auxiliary boiler loops to supply heat in the air duct. This arrangement is illustrated in Figure 10. The solar air heating coil is placed ahead of the auxiliary air heating coil in the direction of air flow. The solar coil thus preheats the air while the auxiliary coil boosts the air temperature to that required to maintain the heating demand. The net result is the use of more solar and less auxiliary heating.

Data Acquisition and Handling System

The Colorado State University Solar House has been equipped with a data acquisition system to gather 74 channels of data on climatic conditions, heating loads, and equipment performance. The system is expandable to 100 channels and records up to two channels per second. Millivolt (and microvolt) analog levels from all of the measurement sensors are digitized (A to D conversion) and presented in three output forms. A digital display on the front of the instrument allows instantaneous investigation of a single selected measurement. A paper tape print-out provides observation of all the data whenever desired. Finally, the data are continuously recorded on magnetic tape. The magnetic tape serves as storage for the data until transferred into the computer for processing. Figure 11 illustrates the flow of measurement data through the data acquisition system.

All the measurements are made at five-minute intervals except where conditions require faster speed (up to two channels per second). Parameters which do not undergo rapid changes such as temperature and circulation flow

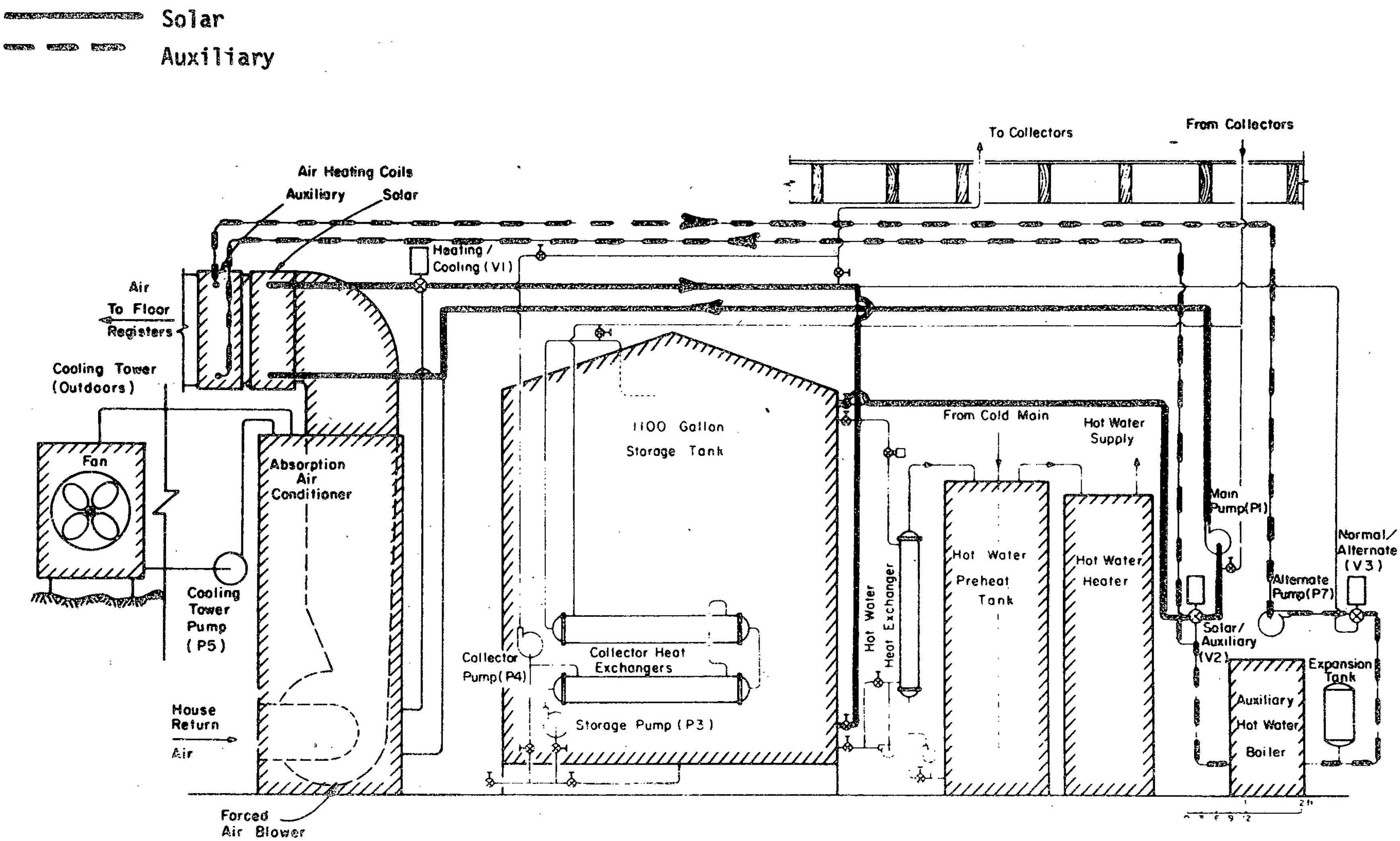


Figure 10

Alternate Mode - Solar Heating with Auxiliary Boosting When Solar Cannot Carry the Heating Load

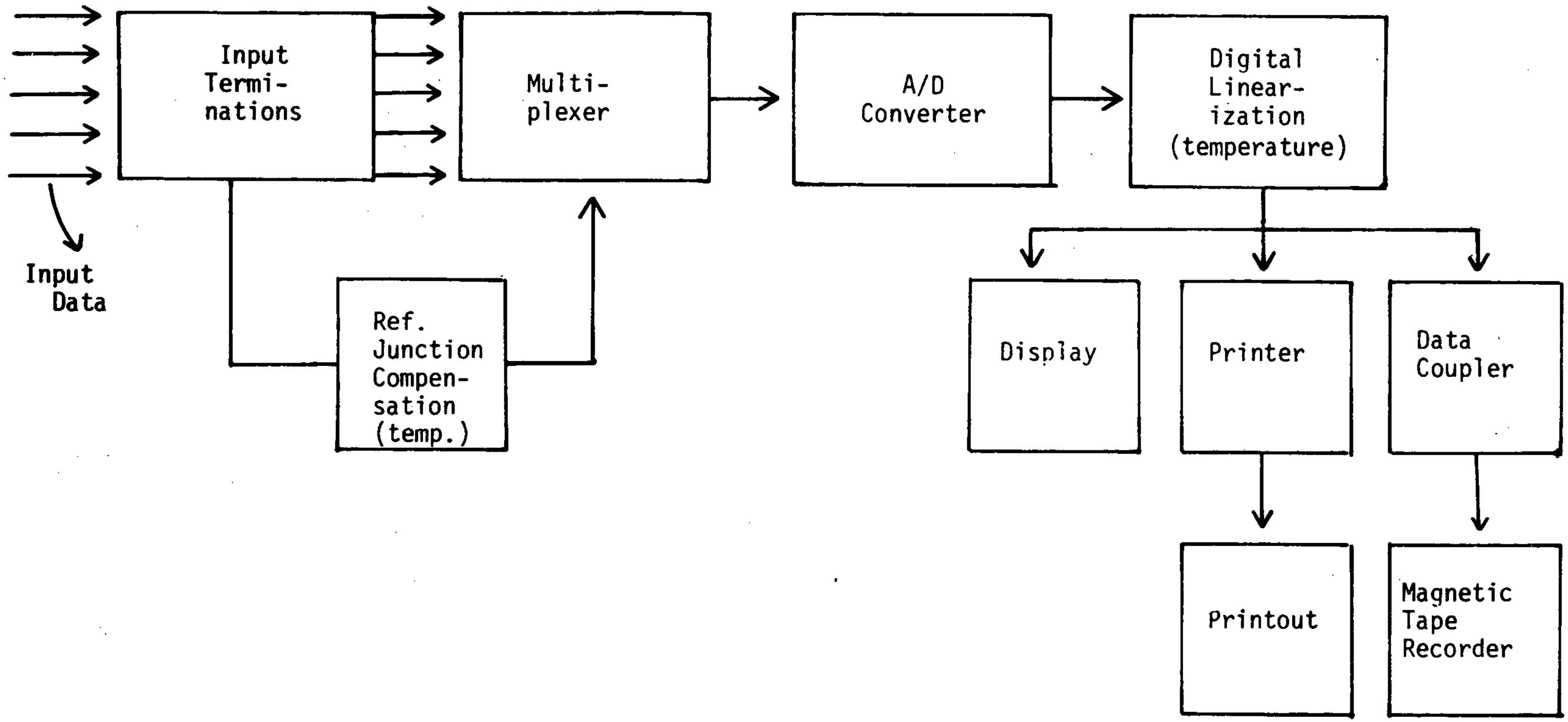


Figure 11

Data Flow Diagram.

rates are observed instantaneously each five minutes and used to compute performance (such as heat transfer rate) at that instant. Parameters which may vary widely and rapidly, such as solar radiation and hot water demand, are integrated electronically and observed as totals at the end of each five-minute period.

A listing of the measurement sensors is provided in Table 2. Temperatures are measured by copper-constantan thermocouples. The data logger has built-in zero reference and Read Only Memory (ROM) linearization. Thus the values of temperature are read and recorded directly in degrees C. The millivolt function includes all measurements other than temperatures. These values must be scaled by the data handling program in the computer to arrive at engineering units. ON/OFF function indicators are used for identification of valve positions and pump operations.

Solar radiation is measured simultaneously with two Eppley pyranometers which have been calibrated by the Eppley factory and checked by the National Bureau of Standards immediately before installation. The pyranometers are mounted at the ridge of the roof above the collectors, one in a horizontal position and the other facing south at 45° (the collector angle). The redundancy in solar radiation measurement permits more direct and accurate collector input determination as well as the customary horizontal record. A back-up to this critical measurement is also thus provided. Table 3 lists the Data Acquisition Equipment Specifications.

The information which describes total system performance is processed on a one or two-day interval by transfer from the magnetic tape files into the Colorado State University CDC 6400 for computation. The tape files are stored for future reference and for more detailed analyses. Data handling is accomplished by a computer program which converts these records to desired values and compiles them from the data. Hourly averages and

Table 2

SOLAR HOUSE MEASUREMENTS

LOCATION	NAME	DATA CHANNEL
(see Figures 12, 13, 14)		
A. Copper-Constantan Thermocouples		
Collector Inlet	TC I	54
Collector Outlet	TC 0	55
Collector #1 Outlet	TC 1	02
Coll-ctor #2 Outlet	TC 2	03
Collector #3 Outlet	TC 3	04
Collector #4 Outlet	TC 4	05
Collector #5 Outlet	TC 5	06
Collector #6 Outlet	TC 6	07
Collector #7 Outlet	TC 7	08
Collector #8 Outlet	TC 8	09
Collector #9 Outlet	TC 9	10
Collector #10 Outlet	TC 10	11
Collector #11 Outlet	TC 11	12
Collector #12 Outlet	TC 12	13
Collector #13 Outlet	TC 13	14
Collector #14 Outlet	TC 14	15
Collector #15 Outlet	TC 15	16
Collector #16 Outlet	TC 16	17
Collector #8 Inlet	TC 17	18
Collector #8	TC 18	19
Collector #8	TC 19	20
Collector #8	TC 20	21
Collector #8	TC 21	22
Collector #8	TC 22	23
Collector #8	TC 23	24
Collector #8	TC 24	25
Collector #8	TC 25	26
Collector #8	TC 26	27
Collector #8	TC 27	28
Collector #8	TC 28	29
Collector #8	TC 29	30
Collector #8	TC 30	31
Storage Tank Top	SST	32
Storage Tank Middle	SSM	33
Storage Tank Bottom	SSB	34
To Collector	TTC	35
From Collector	TFC	36
To Load	TTL	37
From Load	TFL	38
To Alternate Coil	TTAL	39
From Alternate Coil	TFAC	40
Supply Air	TSA	41

Table 2 (con't)

LOCATION	NAME	DATA CHANNEL
Return Air	TRA	42
To Cooling Tower	TTCT	43
From Cooling Tower	TFCT	44
Preheat Tank	TP	45
Boiler Flue	THW	46
Hot Water Flue	THWF	47
To Service Hot Water	TTSHW	48
From Service Hot Water	TFSHW	50
House Dry Bulb	THD	57
Outdoor Dry Bulb	TOD	01
Wet Bulb	TWB	56
B. Millivolt Measurements		
Collector Flow	FC	70
Alternate Coil Flow	FAC	71
Cooling Tower Flow	FCT	72
Load Flow	FL	73
Hot Water Flow	FHW	74
C. Integrating Millivolt Measurements		
Solar Horizontal	SH	60
Solar 45° Tilt	S 45°	61
Hot Water Gallons	HWGAL	62
Hot Water Gas	HWGAS	63
Boiler Gas	BGAS	64
Solar Equipment Electricity	SELEC	65
House Electricity	HELEC	66
Wind Run	WIND	67
D. On/Off Function Indicators		
Heat/Cool (VI) Position	VI	75
Solar/Auxiliary (V2) Position	V2	76
Normal/Alternate (V3) Position	V3	77
Hygrometer Valve Position	HV	78

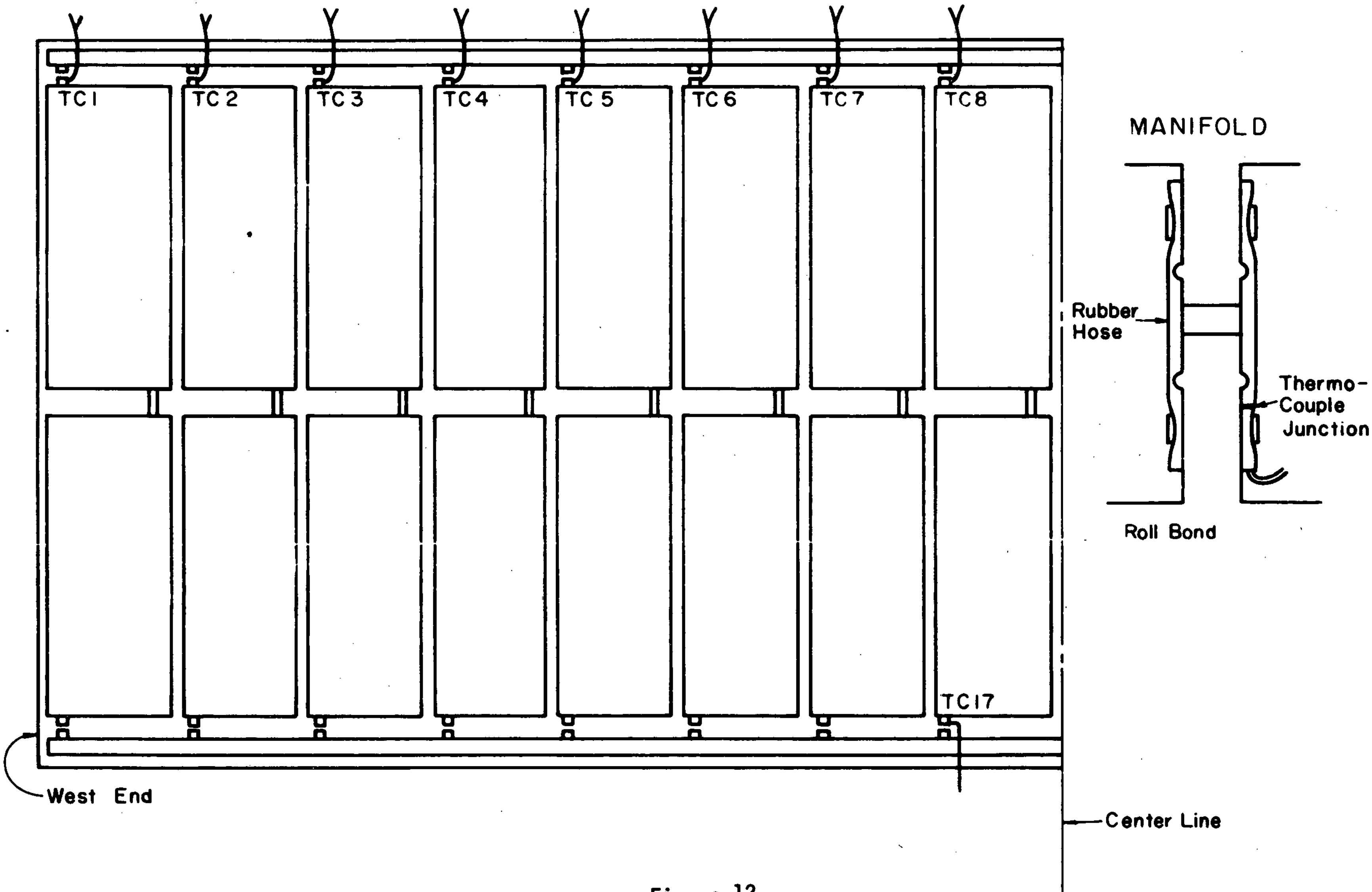
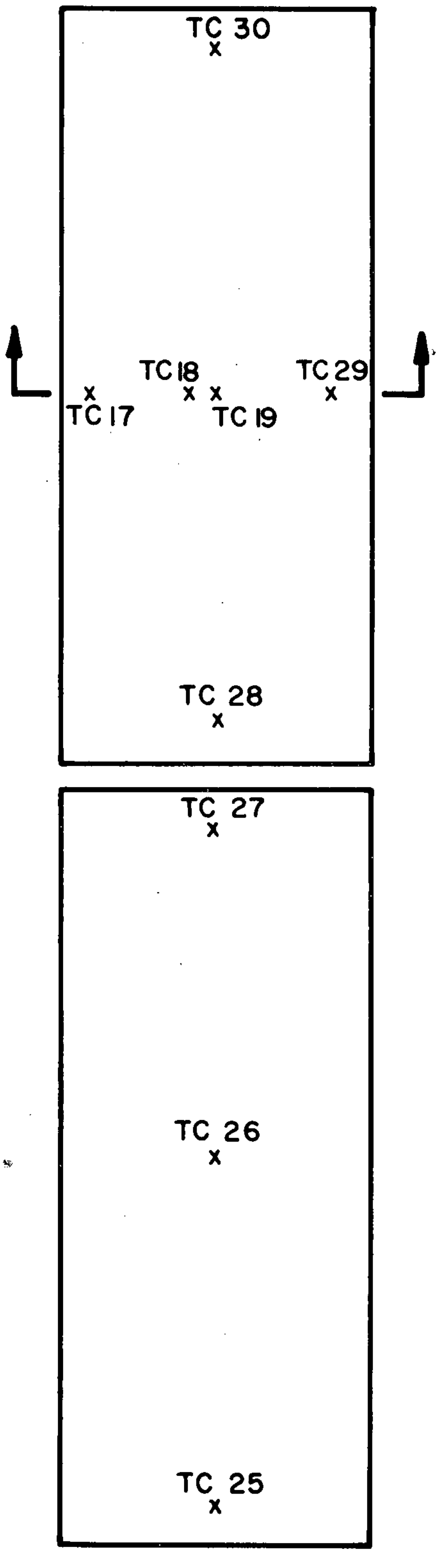


Figure 12

Temperature Measurement Points on the Collector Panels



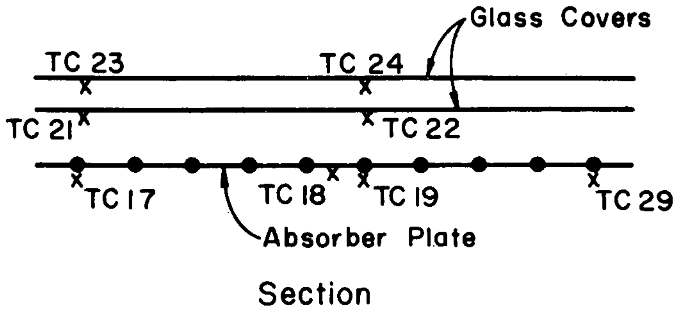


Figure 13

Temperature Measurement Points on Collector #8

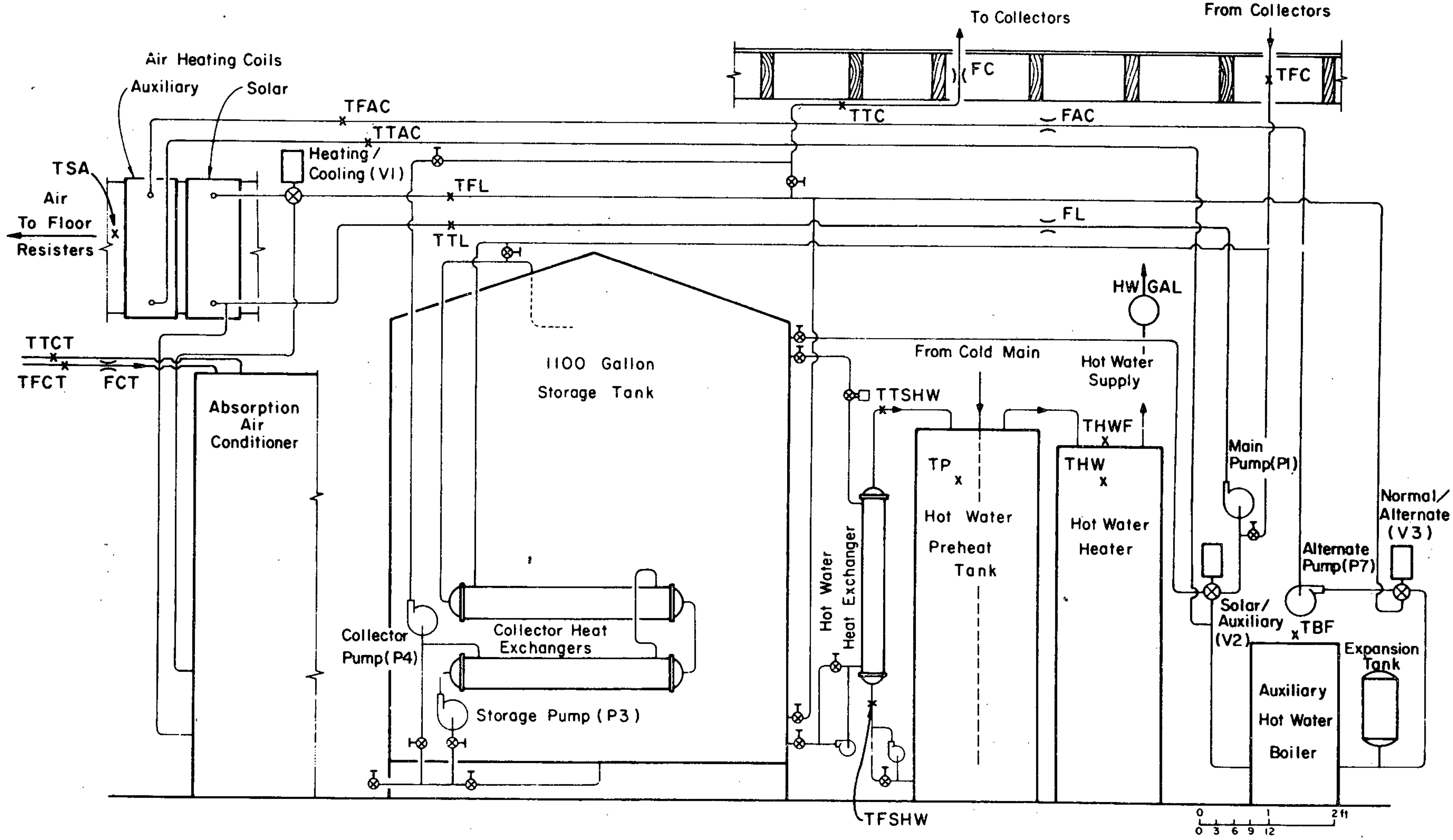


Figure 14

Temperature and Flow Measurement Points on the Mechanical System

Table 3

Data Acquisition Equipment Specifications

Data Logger	
Manufacturer	Doric Scientific
Model number	210
Temperature range	-190 to +400°C
Temperature calibration accuracy	± .3°C
Millivoltage range	± 200 Mv
Millivoltage calibration accuracy	± .004 Mv
Number of channels	100
Scan rate	2 channels/second
Magnetic Tape Recorder	
Manufacturer	Kennedy
Model	1600
Tape	7 track, 1/2 inch
Data density	556 bits/inch
Pyranometers	
Manufacturer	Eppley Laboratories, Inc.
Model	8-48
Accuracy	± 1%, 0 - 2.0 cal/cm^2 - min
Thermocouples	
Manufacturer	Thermo-Electric
Model	41403
Type	Copper-Constantan
Flowmeters	
Sensor manufacturer	Honeywell
Orifice plates and sensor cases made by CSU machine shop, calibration accuracy	± 3%
Integrators	
Solar, electricity, and natural gas integrators made by CSU electronics shop, calibration accuracy	± 2%

totals are printed for selected days, and daily and monthly averages and totals for all days are printed. Figure 15 is a sample print out of the daily values thus obtained.

Figure 15 (key)

QSTOR	Available heat in thermal storage
DELQST	Daily change in available heat in thermal storage (0000-2400)
QSHB	Solar heat delivered based on heat balance
QSOLAR	Total solar heat delivered to heating, cooling, and DHW
QCOOL	Space cooling accomplished
QCOOLS	Space cooling accomplished by solar
EFFT	Collector daily efficiency (QU/S45)
EFFO	Collector daily efficiency (QU/S450)
COP	Cooling unit Coefficient of Performance
PCTSHWS	Percent of energy delivered to domestic hot water by solar
PCTARCS	Percent of energy delivered to cooling by solar
PCTHTS	Percent of energy delivered to heating by solar
SOLCOOL	Percent of cooling accomplished by solar
QU	Energy delivered by collector to thermal storage
QSHWS	Energy delivered to domestic hot water by solar
QAIRCS	Energy delivered to cooling unit by solar
QPCS	Energy delivered to heating coils by solar
QSHWG	Energy delivered to domestic hot water by auxiliary
QAIRCG	Energy delivered to cooling unit by auxiliary
QHCG	Energy delivered to heating coil by auxiliary
HLDDD	Building heating load degree days calculated
HLDM	Building heating load degree days measured
CLDDD	Building cooling load degree days calculated
CLDM	Building cooling load degree days measured
TOD	Ambient temperature
TODO	Ambient temperature during collector pump operation
THD	Building space temperature
TSTOR	Thermal storage temperature
TSTORO	Thermal storage temperature during collector pump operation
HDEGDA	Heating degree days
CDEGDA	Cooling degree days
WIND	Wind run
WINDO	Wind run during collector pump operation
HOURO	Hours of collector pump operation
S45	Solar radiation on a 45 degree tilted surface
S450	Solar radiation on a 45 degree tilted surface during collector operation

DATE	QSTOR (MJ)	DELOST	QSHB	QSOLAR	QCOOL	QCOOLS	EFFT	EFFO	COP	PCTSHWS	PCTARCS	PCTHTS	SOLCOOL
	DAILY TOTAL HEAT RATES (MJ/DAY)						EFFICIENCY			RATIO SUPPLIED BY SOLAR			
8 1 75	959.2	88.5	141.4	92.2	210.5	83.0	.141	.256	.635	0.000	.278	0.000	.394
8 2 75	1009.6	3.5	3.6	0.0	0.0	0.0	.004	.045	0.000	0.000	0.000	0.000	0.000
8 3 75	1135.5	244.6	91.9	0.0	0.0	0.0	.174	.248	0.000	0.000	0.000	0.000	0.000
8 4 75	1138.9	-294.8	625.2	479.7	262.5	261.4	.176	.243	.565	0.000	.999	1.000	.996
8 5 75	985.9	44.9	238.0	161.7	248.4	133.4	.179	.270	.632	0.000	.412	0.000	.537
8 6 75	966.7	-56.1	152.8	63.8	245.6	60.7	.093	.244	.656	0.000	.168	.107	.247
8 7 75	973.4	53.7	102.0	23.3	149.3	19.6	.134	.286	.557	0.000	.087	0.000	.131
8 8 75	1090.8	183.1	137.0	62.6	109.0	47.3	.171	.236	.529	0.000	.303	0.000	.434
8 9 75	1141.6	-164.2	375.9	281.5	288.1	133.7	.120	.237	.522	0.000	.510	0.000	.464
8 10 75*	1008.2	-9.4	9.4	0.0	145.8	0.0	0.000	0.000	.546	0.000	0.000	0.000	0.000
8 11 75*	1003.4	36.6	117.3	79.4	463.0	50.6	.143	.292	.524	0.000	.090	0.000	.109
8 12 75	981.4	-15.9	78.0	0.0	404.7	0.0	.074	.214	.491	0.000	0.000	0.000	0.000
8 13 75	939.4	-73.8	73.8	0.0	0.0	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8 14 75	894.6	-17.7	81.8	0.0	0.0	0.0	.066	.226	0.000	0.000	0.000	0.000	0.000
8 15 75	948.0	104.5	69.9	0.0	0.0	0.0	.126	.266	0.000	0.000	0.000	0.000	0.000
8 16 75	1051.9	106.9	79.9	0.0	0.0	0.0	.133	.265	0.000	0.000	0.000	0.000	0.000
8 17 75	1099.4	2.4	106.1	0.0	0.0	0.0	.075	.229	0.000	0.000	0.000	0.000	0.000
8 18 75	1058.9	-91.6	333.7	215.2	410.1	123.8	.145	.343	.519	0.000	.273	0.000	.302
8 19 75	1066.0	-3.5	136.7	44.0	411.1	31.2	.104	.258	.510	0.000	.055	0.000	.076
8 20 75	1005.3	4.1	47.6	1.2	503.2	.8	.053	.137	.504	0.000	.001	0.000	.002
8 21 75	1021.9	18.9	244.8	178.4	288.1	106.2	.190	.293	.508	0.000	.314	0.000	.369
8 22 75	1012.0	-25.4	214.7	132.4	222.1	98.7	.132	.223	.601	0.000	.359	0.000	.445
8 23 75	1076.7	140.0	130.6	0.0	0.0	0.0	.186	.322	0.000	0.000	0.000	0.000	0.000
8 24 75	1154.5	27.2	167.1	21.7	5.3	5.3	.117	.254	.246	0.000	1.000	0.000	1.000
8 25 75	1148.9	-46.7	313.1	175.4	57.3	57.3	.145	.234	.327	0.000	1.000	0.000	1.000
8 26 75	1081.4	-73.8	495.7	363.7	242.1	197.9	.227	.312	.550	0.000	.826	0.000	.818
8 27 75	1012.0	-70.3	239.7	159.4	473.5	113.1	.126	.236	.586	0.000	.197	0.000	.239
8 28 75	993.2	11.8	295.1	207.7	563.0	150.9	.194	.313	.571	0.000	.211	0.000	.268
8 29 75	1014.7	3.0	451.7	327.6	514.9	195.8	.244	.323	.530	0.000	.337	0.000	.380
8 30 75	1021.3	-1.2	484.1	347.5	418.4	183.0	.254	.332	.497	0.000	.413	0.000	.437
8 31 75	1022.6	7.7	464.1	364.8	499.3	187.7	.246	.328	.508	0.000	.371	0.000	.376
TOTAL	31957.4	136.9	6502.7	3783.5	7135.6	2241.5							
MEAN	1030.9	4.4	209.8	122.0	230.2	72.3	.150	.272	.535	0.000	.282	.617	.314

* DATA ARE AVAILABLE ONLY FOR PART OF THIS DAY

Figure 15. Sample Print Out of Daily Values of Data Collected

DAILY TOTAL HEAT RATES (MJ/DAY)

DATE	QU	QSHWS	QAIRCS	QPCS	QSHWG	QAIRCG	QHCG	HLDDD	HLDM	CLUDD	CLDM
8 1 75	230.0	0.0	92.2	0.0	78.3	239.4	0.0	0.0	0.0	84.8	331.6
8 2 75	7.2	0.0	0.0	0.0	87.9	0.0	0.0	0.0	0.0	117.2	0.0
8 3 75	336.5	0.0	0.0	0.0	62.0	0.0	0.0	0.0	0.0	209.7	0.0
8 4 75	330.4	0.0	464.1	15.6	85.6	.6	0.0	0.0	15.6	244.1	464.8
8 5 75	262.9	0.0	161.7	0.0	77.4	230.9	0.0	0.0	0.0	177.3	392.7
8 6 75	96.7	0.0	62.9	.9	82.5	311.6	7.3	0.0	8.2	247.3	374.5
8 7 75	155.8	0.0	23.3	0.0	54.0	244.7	2.8	0.0	2.8	268.8	268.0
8 8 75	320.1	0.0	62.6	0.0	66.9	143.6	0.0	0.0	0.0	148.0	206.2
8 9 75	211.6	0.0	281.5	0.0	70.2	270.2	0.0	0.0	0.0	216.6	551.7
8 10 75*	0.0	0.0	0.0	0.0	11.3	266.9	0.0	34.4	0.0	0.0	266.9
8 11 75*	153.9	0.0	79.4	0.0	49.1	805.0	0.0	0.0	0.0	308.3	884.5
8 12 75	62.1	0.0	0.0	0.0	77.2	823.8	0.0	0.0	0.0	121.3	823.8
8 13 75	0.0	0.0	0.0	0.0	90.3	12.6	0.0	145.3	0.0	0.0	12.6
8 14 75	64.1	0.0	0.0	0.0	78.1	0.0	0.0	86.1	0.0	0.0	0.0
8 15 75	174.4	0.0	0.0	0.0	85.9	0.0	0.0	15.1	0.0	0.0	0.0
8 16 75	186.8	0.0	0.0	0.0	79.8	0.0	0.0	0.0	0.0	7.0	0.0
8 17 75	108.5	0.0	0.0	0.0	68.8	0.0	0.0	0.0	0.0	73.8	0.0
8 18 75	242.1	0.0	215.2	0.0	74.9	574.4	0.0	0.0	0.0	145.7	789.7
8 19 75	133.1	0.0	44.0	0.0	69.2	762.3	0.0	0.0	0.0	167.9	806.3
8 20 75	51.8	0.0	1.2	0.0	72.3	996.7	0.0	0.0	0.0	172.6	997.9
8 21 75	263.7	0.0	178.4	0.0	78.9	389.0	0.0	0.0	0.0	127.0	567.4
8 22 75	189.3	0.0	132.4	0.0	68.8	236.8	0.0	0.0	0.0	100.8	369.2
8 23 75	270.5	0.0	0.0	0.0	96.2	0.0	0.0	0.0	0.0	143.0	0.0
8 24 75	194.3	0.0	21.7	0.0	72.3	0.0	0.0	0.0	0.0	165.6	21.7
8 25 75	266.4	0.0	175.4	0.0	91.4	0.0	0.0	31.6	0.0	0.0	175.4
8 26 75	421.9	0.0	363.7	0.0	80.0	76.5	0.0	0.0	0.0	96.6	440.3
8 27 75	169.5	0.0	159.4	0.0	100.0	649.1	0.0	0.0	0.0	141.0	808.5
8 28 75	306.9	0.0	207.7	0.0	108.3	778.9	0.0	0.0	0.0	147.2	986.7
8 29 75	454.6	0.0	327.6	0.0	93.4	644.3	.1	0.0	.1	146.2	971.9
8 30 75	462.9	0.0	347.5	0.0	90.9	494.8	0.0	0.0	0.0	125.2	842.3
8 31 75	471.7	0.0	364.8	0.0	87.7	618.0	0.0	0.0	0.0	200.8	982.7
TOTAL	6639.6	0.0	3767.1	16.5	2389.5	9570.3	10.2	312.4	26.7	4103.8	13337.3
MEAN	214.2	0.0	121.5	.5	77.1	308.7	.3	10.1	.9	132.4	430.2

* DATA ARE AVAILABLE ONLY FOR PART OF THIS DAY

Figure 15 (con't)

DATE	TOD	TODO	THD	TSTOR	TSTORO	HDEGDA	CDEGDA	WIND	WINDO	HOURO	S45	S450
	DAILY MEAN TEMPERATURES (DEGREES CELSIUS)							DLY MEAN SPD (KM/HR)		(HRS)	INSOLATION (LANGLEYS/DAY)	
8 1 75	20.9	25.8	24.8	74.3	74.8	0.	3.	19.5	20.0	4.476	546.	301.
8 2 75	21.8	22.0	25.1	77.2	75.8	0.	4.	15.5	9.7	1.214	603.	54.
8 3 75	24.6	31.1	26.9	84.3	85.2	0.	6.	15.5	20.3	6.333	646.	454.
8 4 75	25.6	32.9	26.9	84.5	87.4	0.	7.	15.5	18.9	6.367	629.	456.
8 5 75	23.6	28.7	25.9	75.9	77.3	0.	5.	16.9	21.3	5.150	532.	351.
8 6 75	25.7	33.2	25.9	74.8	75.2	0.	7.	16.9	14.9	2.047	349.	133.
8 7 75	26.4	32.6	27.1	75.1	74.5	0.	8.	17.2	16.5	2.763	388.	183.
8 8 75	22.8	27.1	27.4	81.8	82.9	0.	4.	19.2	24.4	6.483	628.	454.
8 9 75	24.8	32.0	26.3	84.6	88.2	0.	6.	16.8	23.6	4.133	591.	299.
8 10 75*	17.3	0.0	21.1	77.1	0.0	1.	0.	14.3	0.0	0.000	2.	0.
8 11 75*	27.6	32.2	21.8	76.8	77.1	0.	9.	24.2	22.4	2.443	360.	177.
8 12 75	22.0	28.1	22.3	75.6	75.1	0.	4.	15.2	23.7	1.433	280.	97.
8 13 75	14.0	0.0	23.7	73.2	0.0	4.	0.	12.2	0.0	0.000	98.	0.
8 14 75	15.8	20.5	21.7	70.7	70.1	3.	0.	15.0	23.9	1.233	324.	95.
8 15 75	17.9	21.2	23.1	73.7	72.8	0.	0.	11.9	18.1	3.087	464.	220.
8 16 75	18.5	23.1	23.2	79.6	78.8	0.	0.	15.2	23.4	3.200	471.	236.
8 17 75	20.5	27.1	24.5	82.3	81.7	0.	2.	13.9	19.4	2.133	485.	158.
8 18 75	22.7	29.7	23.7	80.0	81.2	0.	4.	14.0	18.4	3.400	558.	236.
8 19 75	23.4	28.7	23.3	77.0	77.4	0.	5.	16.8	19.6	2.959	428.	173.
8 20 75	23.5	31.4	23.0	76.9	76.9	0.	5.	15.6	12.0	2.374	328.	126.
8 21 75	22.1	29.0	23.8	77.9	79.3	0.	4.	16.5	11.9	4.220	466.	301.
8 22 75	21.3	26.8	25.1	77.3	78.0	0.	3.	12.7	16.8	4.267	479.	284.
8 23 75	22.6	28.2	27.1	81.0	79.9	0.	4.	14.2	19.2	3.800	486.	281.
8 24 75	23.3	29.5	27.3	85.4	85.3	0.	5.	25.4	25.1	3.333	554.	256.
8 25 75	17.4	22.3	24.2	85.0	87.8	1.	0.	15.7	26.2	5.293	614.	382.
8 26 75	21.2	26.9	24.7	81.2	81.5	0.	3.	19.9	28.6	6.333	622.	453.
8 27 75	22.5	29.1	24.4	77.3	78.3	0.	4.	18.5	19.1	3.532	450.	241.
8 28 75	22.7	28.4	23.0	76.3	77.7	0.	4.	16.7	22.6	4.617	529.	329.
8 29 75	22.7	28.4	22.7	77.5	80.5	0.	4.	20.4	27.7	6.600	625.	471.
8 30 75	22.1	28.4	22.5	77.9	81.4	0.	4.	18.6	19.9	6.767	637.	487.
8 31 75	24.3	30.9	22.7	77.9	81.6	0.	6.	15.7	20.8	6.633	643.	481.
TOTAL						9.	120.	515.6	588.4	116.623	14817.	8165.
MEAN	22.0	26.3	24.4	78.4	79.4	0.	4.	16.6	19.0	3.762	478.	263.

* DATA ARE AVAILABLE ONLY FOR PART OF THIS DAY

Figure 15 (con't)

SYSTEM THERMAL PERFORMANCE

DAILY, MONTHLY, AND ANNUAL VALUES OF THE MEAN DAILY HEAT FLOWS

Total Energy Required

Tables 4 through 15 show the daily values of the total energy required for the heating and cooling loads, the supplemental energy required (natural gas is used in the auxiliary boiler), the solar energy incident on the collector (insolation measured in the plane of the collectors), solar energy collected, and solar energy delivered to load. These data were obtained during the period 1 September 1974 to 31 August 1975. Table 16 shows the monthly and annual averages of daily heat rates for the same period.

The total energy required is determined from the flow rates and temperature differences across the particular load, of the heat input by either solar or auxiliary. Supplemental energy required and solar energy delivered from storage to load is obtained by the same method, but where the position of automatic valve, V2, determines whether solar or auxiliary is actually furnishing the energy to load. Incident solar energy data were obtained from a solar pyranometer and solar energy collected and stored is based on the collector loop flow rate and temperature difference across the collector/storage heat exchanger.

Supplemental Energy Required

Supplemental energy requirements were met by an auxiliary, natural gas-fired, hot water boiler. For heating the auxiliary boiler was used whenever the solar portion of the heating system was deemed unable to meet

Table 4. (September 1974) DAILY TOTAL HEAT RATES (MJ/DAY)

Date	Total Energy Required			Supplemental Energy Required for			Incident * Solar Energy	Solar Energy Collected and Stored	Solar Energy Delivered from Storage to		
	DHW Load	Heating Load	Cooling Load	DHW Load	Heating Load	Cooling Load			DHW Load	Heating Load	Cooling Load
1	30.3	0.0	62.8	7.7	0.0	47.8	361.8	0.0	22.6	0.0	15.0
2	21.7	0.0	0.0	15.5	0.0	0.0	472.4	1.9	6.2	0.0	0.0
3	62.7	44.6	182.7	12.4	4.7	133.7	1752.1	455.0	50.3	39.9	49.1
4	40.5	0.0	539.9	7.6	0.0	214.4	1898.7	466.6	32.9	0.0	325.5
5	45.7	0.0	819.9	10.1	0.0	775.0	1013.6	103.4	35.6	0.0	44.9
6	50.2	0.5	726.2	7.2	0.0	431.3	1850.8	429.7	43.0	0.0	294.9
7	9.9	0.0	781.5	9.9	0.0	370.4	1949.5	514.7	0.0	0.0	411.1
8	41.9	0.0	728.8	7.7	0.0	715.2	1004.6	89.6	34.2	0.0	13.7
9	26.1	0.0	695.7	7.7	0.0	646.1	1007.6	169.9	18.4	0.0	49.6
10	32.6	0.0	1022.0	5.2	0.0	990.8	1408.3	157.3	27.4	0.0	31.2
11	46.0	0.0	204.6	12.9	0.0	181.6	320.0	0.0	33.1	0.0	23.0
12	18.0	95.6	0.0	14.9	0.0	0.0	436.5	0.0	3.1	95.6	0.0
13	52.8	105.6	0.0	14.3	21.0	0.0	1560.8	484.0	39.5	84.6	0.0
14	52.9	4.7	283.3	15.1	0.0	279.0	1154.1	156.4	37.8	4.7	4.3
15	36.6	0.0	38.8	12.5	0.0	38.8	912.0	98.2	24.1	0.0	0.0
16	47.3	0.0	471.0	8.4	0.0	239.7	1501.0	493.3	38.9	0.0	231.3
17	46.9	0.0	612.2	15.5	0.0	288.5		477.3	31.4	0.0	323.8
18	0.8	0.0	12.2		0.0	12.2		0.0	.8	0.0	0.0
19											
20	18.9	0.0	0.0	7.2	0.0	0.0		0.0	11.7	0.0	0.0
21	44.7	14.3	72.0	5.2	0.0	0.0	1779.0	402.6	39.5	14.3	72.0
22	39.3	0.0	0.0	7.7	0.0	0.0	959.8	232.5	14.4	0.0	0.0
23	38.9	0.0	525.8	7.3	0.0	212.2	1794.0	452.0	31.6	0.0	313.6
24	62.2	0.0	412.8	7.6	0.0	272.2	840.2	130.4	54.6	0.0	140.6
25	45.1	0.0	578.3	12.5	0.0	258.3	1820.9	462.5	32.6	0.0	320.0
26	75.7	0.0	604.4	4.8	0.0	464.9	900.0	137.3	70.9	0.0	139.5
27	35.1	0.0	119.2	15.5	0.0	112.2	170.4	0.0	19.6	0.0	7.0
28	48.2	40.1	0.0	5.6	0.0	0.0	1806.0	472.5	42.6	40.1	0.0
29	43.9	0.0	384.1	12.5	0.0	93.3	1844.8	449.6	31.4	0.0	290.8
30	28.2	0.0	389.2	7.7	0.0	160.0	1548.8	386.7	20.5	0.0	229.3
Total	1126.9	305.4	10267.6	278.2	25.7	6937.4	32076.7	7223.3	848.7	279.7	3330.2
Mean	38.89	10.5	354.1	9.6	0.9	239.2	1106.3	249.1	29.3	9.6	114.8

*On a 71.3 square meter solar collector surface

Table 5. (October 1974) DAILY TOTAL HEAT REATES (MJ/DAY)

Date	Total Energy Required			Supplemental Energy Required for			Incident * Solar Energy	Solar Energy Collected and Stored	Solar Energy Delivered from Storage to		
	DHW Load	Heating Load	Cooling Load	DHW Load	Heating Load	Cooling Load			DHW Load	Heating Load	Cooling Load
1	33.1	0.0	635.5	13.9	0.0	351.8	1731.2	419.6	19.2	0.0	283.7
2	97.7	0.0	104.6	50.6	0.0	66.6	1761.1	341.4	47.1	0.0	38.0
3	141.8	0.0	265.1	56.0	0.0	7.2	1372.4	281.3	85.8	0.0	257.9
4	33.5	0.0	529.6	7.8	0.0	326.9	1297.7	304.6	25.7	0.0	202.7
5	52.2	0.0	622.0	14.1	0.0	620.5	1172.1	97.7	38.1	0.0	1.5
6	45.9	0.0	188.2	8.4	0.0	217.6	1405.3	287.1	37.5	0.0	60.6
7	131.9	0.0	248.3	8.4	0.0	128.8	212.3	38.7	123.5	0.0	119.4
8	60.2	0.0	694.6	0.0	0.0	444.4	1447.2	427.2	60.2	0.0	250.2
9	36.1	0.0	805.7	7.2	0.0	527.9	1336.5	422.1	28.9	0.0	277.7
10	23.2	0.0	316.5	5.2	0.0	316.5	290.0	25.9	18.0	0.0	0.0
11	27.9	0.0	466.9	7.7	0.0	466.9	251.2	0.0	20.2	0.0	0.0
12	26.8	0.0	214.5	8.0	0.0	214.5	128.6	0.0	18.8	0.0	0.0
13	47.7	0.0	0.0	14.6	0.0	0.0	1770.1	443.1	33.1	0.0	0.0
14	9.9	0.0	0.0	4.8	0.0	0.0	927.0	155.6	5.1	0.0	0.0
15											
16	58.4	0.0	181.6	12.4	0.0	181.4	517.3	124.7	46.0	0.0	0.2
17	39.4	0.0	30.1	0.0	0.0	0.0	1728.2	430.4	39.4	0.0	30.1
18											
19											
20											
21	18.7	0.0	291.4	0.0	0.0	226.9	164.5	3.4	18.7	0.0	64.4
22	14.0	0.0	74.2	0.0	0.0	56.6	26.9	0.0	14.0	0.0	17.7
23	30.4	0.0	0.0	7.6	0.0	0.0	92.7	0.0	22.8	0.0	0.0
24	44.9	0.0	0.0	0.0	0.0	0.0	62.8	0.0	44.9	0.0	0.0
25	111.5	0.0	9.8	7.2	0.0	9.8	26.9	115.1	104.3	0.0	0.0
26	88.3	0.0	0.0	11.9	0.0	0.0	1471.1	317.4	76.4	0.0	0.0
27	63.2	0.0	0.0	12.8	0.0	0.0	1518.9	311.4	50.4	0.0	0.0
28	83.0	0.0	0.0	6.6	0.0	0.0	1318.6	269.2	76.4	0.0	0.0
29	46.3	8.9	0.0	6.6	0.0	0.0	406.6	0.5	39.7	8.9	0.0
30	33.6	126.6	0.0	8.3	7.0	0.0	242.2	0.0	25.3	119.6	0.0
31	18.3	148.5	0.0	13.2	0.0	0.0	248.2	19.5	5.1	148.5	0.0
Total	1418.2	284.1	5678.4	293.5	7.0	4074.1	22933.3	4834.7	1124.7	277.1	1604.2
Mean	52.6	10.6	210.4	10.9	0.3	150.9	849.2	179.1	41.7	10.3	59.4

*On a 71.3 square meter solar collector surface

Table 6 (November 1974) DAILY TOTAL HEAT RATES (MJ/DAY)

Date	Total Energy Required			Supplemental Energy Required for			Incident * Solar Energy	Solar Energy Collected and Stored	Solar Energy Delivered from Storage to		
	DHW Load	Heating Load	Cooling Load	DHW Load	Heating Load	Cooling Load			DHW Load	Heating Load	Cooling Load
1	48.1	37.6	0.0	10.6	3.0	0.0	690.7	174.4	37.5	34.6	0.0
2	20.0	140.4	0.0	13.6	0.0	0.0	143.5	0.0	6.4	140.4	0.0
3	26.9	168.9	0.0	19.9	0.0	0.0	373.8	0.0	7.0	168.9	0.0
4	85.9	123.9	0.0	14.9	0.0	0.0	1399.3	370.6	81.0	123.9	0.0
5	35.0	72.4	0.0	6.2	0.0	0.0	1510.0	386.7	28.8	72.4	0.0
6	48.1	6.3	0.0	0.0	0.0	0.0	1055.5	194.2	48.1	6.3	0.0
7	22.7	0.0	26.0	0.0	0.0	26.0	0.0	0.0	22.7	0.0	0.0
8	35.7	19.0	191.4	7.2	0.0	191.4	1085.4	320.5	28.5	19.0	0.0
9	44.4	90.3	0.0	14.1	0.0	0.0	278.1	0.0	30.3	90.3	0.0
10	48.4	118.3	0.0	12.8	0.0	0.0	1079.4	254.8	35.6	118.3	0.0
11	29.9	111.8	0.0	7.2	0.0	0.0	1199.0	337.5	22.7	111.8	0.0
12											
13											
14											
15											
16											
17											
18											
19	36.8	72.0	0.0	21.7	0.0	0.0			15.1	72.0	0.0
20	6.9	120.9	0.0	6.4	0.0	0.0	308.0	0.0	0.5	120.9	0.0
21	22.3	0.0	0.0	9.5	0.0	0.0	3.0	0.0	12.8	0.0	0.0
22	38.5	42.2	0.0	9.5	0.0	0.0	134.6	0.0	29.0	42.2	0.0
23	61.3	98.1	0.0	8.1	0.0	0.0	1375.4	287.4	53.2	98.1	0.0
24	62.8	135.7	0.0	19.0	0.0	0.0	1306.6	200.5	43.8	135.7	0.0
25	50.9	106.4	0.0	17.7	3.3	0.0	965.8	133.9	33.2	103.1	0.0
26	79.1	78.8	0.0	17.7	0.0	0.0	1423.2	289.3	61.4	78.8	0.0
27	29.7	189.0	0.0	19.0	1.2	0.0	726.6	46.7	10.7	187.8	0.0
28	16.3	285.0	0.0	9.5	0.0	0.0	373.8	0.0	6.8	285.0	0.0
29	31.0	329.2	0.0	19.0	0.0	0.0	1100.3	188.8	12.0	329.2	0.0
30	47.2	332.8	0.0	8.4	0.0	0.0	1435.2	331.0	38.8	332.8	0.0
Total	938.0	2679.1	217.4	272.1	7.4	217.4	17970.0	3516.3	665.9	2671.7	0.0
Mean	40.8	116.5	9.5	11.8	0.3	9.5	780.4	152.9	29.0	116.2	0.0

*On a 71.3 square meter solar collector surface

Table 7. (December 1974) DAILY TOTAL HEAT RATES (MJ/DAY)

Date	Total Energy Required			Supplemental Energy Required for			Incident * Solar Energy	Solar Energy Collected and Stored	Solar Energy Delivered from Storage to		
	DHW Load	Heating Load	Cooling Load	DHW Load	Heating Load	Cooling Load			DHW Load	Heating Load	Cooling Load
1	67.6	234.2	0.0	17.7	0.0	0.0	1441.2	377.5	49.9	234.2	0.0
2	52.9	125.8	0.0	9.5	0.0	0.0	1408.2	306.6	43.4	125.8	0.0
3	44.0	119.0	0.0	8.1	0.0	0.0	1213.9	182.6	35.9	119.0	0.0
4	46.0	3.6	0.0	10.9	0.0	0.0	1465.1	277.2	35.1	3.6	0.0
5	35.0	67.2	0.0	20.4	2.5	0.0	687.7	59.7	14.6	64.7	0.0
6	70.6	98.7	0.0	9.5	0.0	0.0	1396.3	332.1	61.1	98.7	0.0
7	26.2	282.2	0.0	19.0	0.0	0.0	251.2	0.0	7.2	282.2	0.0
8	44.4	220.3	0.0	8.1	0.0	0.0	1441.2	449.0	36.3	220.3	0.0
9	68.9	130.6	0.0	19.0	0.0	0.0	1420.3	403.4	49.9	130.6	0.0
10	9.5	86.1	0.0	0.0	0.0	0.0	143.5	0.0	9.5	86.1	0.0
11											
12											
13											
14											
15											
16											
17											
18											
19	19.6	91.3	0.0	8.1	1.1	0.0	128.6	6.4	11.5	90.2	0.0
20	16.9	252.0	0.0	12.8	72.4	0.0	290.0	3.6	4.1	179.6	0.0
21	35.7	325.8	0.0	19.0	287.0	0.0	454.5	42.4	16.7	38.8	0.0
22	56.8	355.5	0.0	19.0	127.2	0.0	1453.1	451.3	37.8	228.3	0.0
23	19.2	416.8	0.0	17.7	232.2	0.0	158.5	0.0	1.5	184.6	0.0
24	31.4	357.6	0.0	9.5	198.6	0.0	1223.0	266.2	21.9	159.0	0.0
25	53.9	381.3	0.0	17.7	169.7	0.0	1483.0	442.4	36.2	211.6	0.0
26	21.8	347.7	0.0	19.0	60.1	0.0	538.2	77.2	2.8	287.6	0.0
27	50.0	253.7	0.0	8.1	143.8	0.0	1240.9	407.2	41.9	109.9	0.0
28	50.0	231.2	0.0	19.0	0.0	0.0	1172.1	349.2	31.0	231.2	0.0
29	32.0	294.5	0.0	19.0	0.0	0.0	950.8	265.0	13.0	294.5	0.0
30	54.8	237.7	0.0	14.9	0.0	0.0	938.9	252.8	39.9	237.7	0.0
31	40.8	271.1	11.2	17.7	0.0	11.2	1109.3	280.8	23.1	271.1	0.0
Total	948.2	5184.1	11.2	323.9	1294.7	11.2	22015.4	5232.5	624.3	3889.4	0.0
Mean	41.2	225.6	0.5	14.1	56.3	0.5	956.8	227.5	27.1	169.1	0.0

*On a 71.3 square meter solar collector surface

Table 8. (January 1975) DAILY TOTAL HEAT RATES (MJ/DAY)

Date	Total Energy Required			Supplemental Energy Required for			Incident * Solar Energy	Solar Energy Collected and and Stored	Solar Energy Delivered from Storage to		
	DHW Load	Heating Load	Cooling Load	DHW Load	Heating Load	Cooling Load			DHW Load	Heating Load	Cooling Load
1	39.0	265.6	0.0	14.4	0.0	0.0	1447.2	418.6	24.6	265.6	0.0
2	14.4	356.6	0.0	14.4	54.3	0.0	278.1	0.0	0.0	302.3	0.0
3	42.8	313.2	0.0	13.4	184.2	0.0	1375.4	409.3	29.4	129.0	0.0
4	26.7	234.7	0.0	6.2	0.0	0.0	1250.0	359.2	20.5	234.7	0.0
5	36.4	253.4	0.0	13.4	0.0	0.0	1336.5	383.6	23.0	253.4	0.0
6	55.3	193.9	0.0	14.4	0.0	0.0	1399.3	387.6	40.9	193.9	0.0
7	84.1	192.4	0.0	18.9	0.8	0.0	822.3	127.7	65.2	191.6	0.0
8	38.0	222.9	0.0	25.3	0.0	0.0	639.9	137.9	12.7	222.9	0.0
9	30.6	221.9	0.0	20.7	0.0	0.0	941.9	196.1	9.9	221.9	0.0
10	24.9	385.0	0.0	16.6	157.5	0.0	750.5	184.7	8.3	227.5	0.0
11	24.3	710.2	0.0	21.4	632.8	0.0	215.3	0.0	2.9	77.4	0.0
12	41.5	510.8	0.0	23.6	302.3	0.0	1058.5	219.1	17.9	208.5	0.0
13	54.5	301.4	0.0	46.1	208.6	0.0	705.6	120.5	8.4	92.8	0.0
14	53.1	117.7	0.0	14.5	54.1	0.0	1178.1	352.4	38.6	63.6	0.0
15	43.5	218.6	0.0	32.5	0.0	0.0	735.5	136.9	11.0	218.6	0.0
16	43.1	211.6	0.0	38.1	18.9	0.0	651.8	125.2	5.0	192.7	0.0
17	68.8	141.8	0.0	30.8	60.7	0.0	1019.6	299.5	38.0	81.1	0.0
18	48.7	124.8	0.0	26.1	0.0	0.0	1228.9	324.5	22.6	124.8	0.0
19	44.9	197.3	0.0	20.3	0.0	0.0	1459.1	384.1	24.6	197.3	0.0
20	57.3	140.1	0.0	23.1	0.0	0.0	1213.9	264.3	34.2	140.1	0.0
21	39.7	204.3	0.0	19.0	0.0	0.0	99.27	216.0	20.7	204.3	0.0
22	39.2	203.4	0.0	29.8	0.0	0.0	1480.1	373.3	9.4	203.4	0.0
23	46.3	150.8	0.0	28.3	3.4	0.0	843.2	156.5	18.0	147.4	0.0
24	14.7	132.2	0.0	13.9	0.0	0.0	648.8	179.2	0.8	132.2	0.0
25											
26											
27	35.3	292.7	0.0	35.3	208.7	0.0	131.6	0.0	0.0	84.0	0.0
28	77.3	379.8	0.0	53.2	308.0	0.0	849.2	184.0	24.1	71.8	0.0
29	98.9	189.4	0.0	43.8	0.0	0.0	1512.9	436.8	55.1	189.4	0.0
30	53.8	230.2	0.0	53.8	0.0	0.0	1231.9	393.3	0.0	230.2	0.0
31	85.0	225.0	0.0	39.7	99.3	0.0	1512.9	833.8	45.3	125.7	0.0
Total	1362.4	7322.0	0.0	751.2	2293.8	0.0	28919.3	7604.3	611.2	5028.2	0.0
Mean	47.0	252.6	0.0	25.9	79.1	0.0	998.7	262.2	21.1	173.4	0.0

* On a 71.3 square meter solar collector surface

Table 9. (February 1975) DAILY TOTAL HEAT RATES (MJ/DAY)

Date	Total Energy Required			Supplemental Energy Required for			Incident * Solar Energy	Solar Energy Collected and Stored	Solar Energy Delivered from Storage to		
	DHW Load	Heating Load	Cooling Load	DHW Load	Heating Load	Cooling Load			DHW Load	Heating Load	Cooling Load
1	86.1	256.2	0.0	18.3	172.4	0.0	1602.6	545.0	67.8	83.8	0.0
2	54.3	220.9	0.0	9.8	0.0	0.0	1617.6	546.6	54.5	220.9	0.0
3	50.1	126.9	0.0	21.1	0.0	0.0	1184.0	346.8	29.0	126.9	0.0
4	88.0	187.4	0.0	48.2	0.0	0.0	110.6	0.0	39.8	187.9	0.0
5	98.3	363.4	0.0	89.5	174.4	0.0	559.1	3.0	8.8	189.0	0.0
6	87.6	389.5	0.0	43.0	371.5	0.0	1644.5	443.1	44.6	18.0	0.0
7	88.6	247.4	0.0	26.0	164.9	0.0	1477.1	351.4	62.6	82.5	0.0
8	37.4	425.2	0.0	37.4	0.0	0.0	379.7	0.0	0.0	425.2	0.0
9	91.5	413.6	0.0	74.8	313.5	0.0	717.6	113.4	16.7	100.1	0.0
10	64.2	151.4	0.0	62.9	101.5	0.0	777.4	167.6	1.3	49.9	0.0
11	118.1	139.3	0.0	48.4	0.0	0.0	1728.2	581.3	69.7	139.3	0.0
12	95.4	128.1	0.0	29.4	16.7	0.0	1357.5	332.4	66.0	111.4	0.0
13	88.3	99.3	0.0	32.9	0.0	0.0	756.5	128.6	55.4	99.3	0.0
14	56.7	124.6	0.0	38.2	0.0	0.0	278.1	0.0	18.5	124.6	0.0
15	91.0	294.9	0.0	72.8	1.4	0.0	1106.3	84.4	18.2	293.5	0.0
16	82.3	313.0	0.0	52.6	38.2	0.0	1722.2	426.8	29.7	274.8	0.0
17	130.7	211.4	0.0	99.9	0.0	0.0	1258.8	321.7	30.8	211.4	0.0
18	144.9	273.4	0.0	70.6	0.0	0.0	1856.8	573.9	74.3	273.4	0.0
19	114.7	298.7	0.0	50.4	0.0	0.0	1704.3	498.1	64.3	298.7	0.0
20	76.2	271.3	0.0	29.4	4.4	0.0	1357.5	303.1	46.8	266.9	0.0
21	74.0	380.6	0.0	33.3	0.0	0.0	1608.6	441.9	40.7	380.6	0.0
22	95.6	378.6	0.0	26.8	0.0	0.0	1776.1	527.2	68.8	378.6	0.0
23	45.7	321.0	0.0	29.9	0.0	0.0	1085.4	286.0	15.8	321.0	0.0
24	80.8	67.6	0.0	6.2	0.0	0.0	1297.7	326.5	74.6	67.6	0.0
25	98.0	202.9	0.0	18.9	0.0	0.0	1770.1	394.4	79.1	202.9	0.0
26	110.6	179.1	0.0	32.4	0.0	0.0	1770.1	414.6	78.2	179.1	0.0
27	128.4	91.0	0.0	18.3	1.7	0.0	1719.3	365,0	110.1	89.3	0.0
28	90.5	76.7	0.0	20.1	0.0	0.0	1477.1	256.9	70.4	76.6	0.0
Total	2478.1	6633.3	0.0	1141.6	1360.5	0.0	35703.6	8774.5	1336.5	5272.8	0.0
Mean	88.5	236.9	0.0	40.8	48.6	0.0	1273.7	313.4	47.7	188.3	0.0

*On a 71.3 square meter solar collector surface

Table 10. (March 1975) DAILY TOTAL HEAT RATES (MJ/DAY)

Date	Total Energy Required			Supplemental Energy Required for			Incident * Solar Energy	Solar Energy Collected and Stored	Solar Energy Delivered from Storage to		
	DHW Load	Heating Load	Cooling Load	DHW Load	Heating Load	Cooling Load			DHW Load	Heating Load	Cooling Load
1	70.0	59.7	0.0	12.9	1.9	0.0	1219.9	189.3	57.1	57.8	0.0
2	90.8	110.8	0.0	23.8	8.6	0.0	1581.7	300.5	67.0	102.2	0.0
3	68.4	84.5	0.0	18.1	5.4	0.0	1157.1	176.6	50.3	79.1	0.0
4	98.8	0.0	0.0	19.7	0.0	0.0	1662.4	355.2	79.1	0.0	0.0
5	99.2	0.0	0.0	20.7	0.0	0.0	1890.0	406.3	78.5	0.0	0.0
6	62.2	0.0	0.0	12.8	0.0	0.0	361.8	0.0	49.4	0.0	0.0
7	66.1	0.0	0.0	40.5	0.0	0.0	445.5	0.0	25.6	0.0	0.0
8	68.8	0.0	0.0	35.9	0.0	0.0	1261.8	348.2	32.9	0.0	0.0
9	51.9	0.0	0.0	51.9	0.0	0.0	463.5	43.5	0.0	0.0	0.0
10	31.2	0.0	0.0	31.2	0.0	0.0	364.8	19.1	0.0	0.0	0.0
11	45.1	223.0	0.0	45.1	223.0	0.0	212.3	0.0	0.0	0.0	0.0
12	119.5	300.5	0.0	48.1	182.2	0.0	1797.0	570.2	71.4	118.3	0.0
13	123.3	221.4	0.0	46.7	0.0	0.0	1695.3	500.1	76.6	221.4	0.0
14	97.6	143.9	0.0	14.9	0.0	0.0	1734.2	338.7	82.7	143.9	0.0
15	57.1	179.2	0.0	25.3	0.0	0.0	894.0	97.7	31.8	179.2	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0
17	67.2	32.5	0.0	34.1	0.0	0.0	580.1	36.3	33.1	32.5	0.0
18	162.9	74.7	0.0	88.7	0.0	0.0	1662.4	126.1	74.2	74.7	0.0
19	154.3	29.6	0.0	83.8	0.0	0.0	1701.3	144.5	70.5	29.6	0.0
20	191.6	0.0	0.0	81.7	0.0	0.0	1824.0	162.0	109.9	0.0	0.0
21	133.4	4.6	0.0	74.3	0.0	0.0	1142.2	46.6	59.1	4.6	0.0
22	136.8	165.4	0.0	85.8	0.0	0.0	1444.2	76.5	51.0	165.4	0.0
23	98.0	391.0	0.0	98.0	0.0	0.0	1130.2	5.7	0.0	391.0	0.0
24	171.5	236.2	0.0	101.6	15.1	0.0	1949.5	85.3	69.9	221.1	0.0
25	173.0	81.0	0.0	97.2	0.0	0.0	290.0	0.0	75.8	81.0	0.0
26	144.0	239.3	0.0	130.0	89.0	0.0	511.3	0.0	14.0	150.3	0.0
27	154.7	648.7	0.0	135.8	648.3	0.0	1456.1	0.0	18.9	0.4	0.0
28	167.5	373.4	0.0	127.1	232.5	0.0	1952.5	0.0	40.4	140.9	0.0
29											
30	92.6	88.6	0.0	52.0	0.0	0.0	538.2	0.0	40.6	88.6	0.0
31	137.4	199.2	0.0	119.8	0.0	0.0	415.6	0.0	17.6	199.2	0.0
Total	3135.1	3887.2	0.0	1757.8	1406.0	0.0	33344.5	4028.5	1377.3	2481.2	0.0
Mean	104.5	129.6	0.0	58.6	46.9	0.0	1112.3	134.3	45.9	82.7	0.0

*On a 71.3 square meter solar collector surface

Table 11. (April 1975) DAILY TOTAL HEAT RATES (MJ/DAY)

Date	Total Energy Required			Supplemental Energy Required for			Incident * Solar Energy	Solar Energy Collected and Stored	Solar Energy Delivered from Storage to		
	DHW Load	Heating Load	Cooling Load	DHW Load	Heating Load	Cooling Load			DHW Load	Heating Load	Cooling Load
1	146.6	446.3	0.0	132.6	413.0	0.0	917.9	0.0	14.0	33.3	0.0
2	170.7	365.8	0.0	133.6	199.2	0.0	2245.5	0.0	37.1	166.6	0.0
3	212.0	224.6	0.0	119.0	7.5	0.0	1838.9	288.2	93.0	217.1	0.0
4	144.2	134.9	0.0	106.2	0.0	0.0	2093.0	484.2	38.0	134.9	0.0
5	209.9	103.4	0.0	84.4	0.0	0.0	1937.5	320.7	125.5	103.4	0.0
6	155.3	102.5	0.0	84.8	0.0	0.0	1898.7	330.0	70.5	102.5	0.0
7	143.0	167.0	0.0	91.9	0.0	0.0	1112.3	148.4	51.1	167.0	0.0
8	150.5	170.3	0.0	102.3	0.0	0.0	1124.2	47.3	48.2	170.3	0.0
9	132.7	177.7	0.0	94.2	0.0	0.0	1569.8	290.0	38.5	177.7	0.0
10	122.8	218.5	0.0	119.0	0.0	0.0	331.9	0.0	3.8	218.5	0.0
11	161.1	206.8	0.0	133.9	185.7	0.0	517.3	0.5	27.2	21.1	0.0
12	165.0	197.8	0.0	97.3	117.3	0.0	1883.7	527.5	67.7	80.5	0.0
13	168.7	206.2	0.0	107.9	0.0	0.0	1862.8	448.9	60.8	206.2	0.0
14	158.2	106.7	0.0	89.9	0.0	0.0	1545.8	394.9	68.3	106.7	0.0
15	166.0	43.7	0.0	94.6	0.0	0.0	1525.0	262.4	71.4	43.7	0.0
16	179.8	0.0	0.0	88.1	0.0	0.0	1811.9	354.4	91.7	0.0	0.0
17	136.3	12.8	0.0	85.3	0.0	0.0	735.5	6.7	51.0	12.8	0.0
18	154.3	123.2	0.0	92.6	0.0	0.0	1770.1	286.5	61.7	123.2	0.0
19	168.0	145.5	0.0	103.3	0.0	0.0	1955.5	385.2	64.7	145.5	0.0
20	110.5	73.3	0.0	76.8	0.0	0.0	1575.7	230.9	33.7	73.3	0.0
21	179.5	5.0	0.0	53.5	0.0	0.0	1387.4	217.9	126.0	5.0	0.0
22	164.6	35.7	0.0	88.2	0.0	0.0	1961.4	380.9	76.4	35.7	0.0
23	151.3	0.0	0.0	80.9	0.0	0.0	1342.5	124.4	70.4	0.0	0.0
24	196.6	0.0	0.0	89.9	0.0	0.0	1970.4	364.0	106.7	0.0	0.0
25	133.2	0.0	0.0	88.4	0.0	0.0	2045.2	345.8	44.8	0.0	0.0
26	136.7	0.0	0.0	99.7	0.0	0.0	1910.6	189.5	37.0	0.0	0.0
27	112.3	133.0	0.0	97.6	0.0	0.0	639.9	0.0	14.7	133.1	0.0
28	148.8	41.0	0.0	72.4	0.0	0.0	1844.8	338.4	76.4	41.1	0.0
29	155.5	108.8	0.0	111.4	0.0	0.0	1043.5	57.1	44.1	108.8	0.0
30	159.5	93.9	0.0	124.2	0.0	0.0	1010.6	83.4	35.3	93.9	0.0
Total	4693.6	3644.6	0.0	2944.0	922.9	0.0	45418.1	6917.1	1749.6	2721.7	0.0
Mean	156.4	121.5	0.0	98.1	30.8	0.0	1512.9	230.0	58.3	90.7	0.0

*On a 71.3 square meter solar collector surface

Table 12. (May 1975) DAILY TOTAL HEAT RATES (MJ/DAY)

Date	Total Energy Required			Supplemental Energy Required for			Incident * Solar Energy	Solar Energy Collected and Stored	Solar Energy Delivered from Storage to		
	DHW Load	Heating Load	Cooling Load	DHW Load	Heating Load	Cooling Load			DHW Load	Heating Load	Cooling Load
1	180.1	68.2	0.0	104.1	0.0	0.0	1444.2	327.0	76.0	68.2	0.0
2	151.7	12.3	0.0	97.8	0.0	0.0	1518.9	254.9	53.9	12.3	0.0
3	219.0	7.0	0.0	99.2	0.0	0.0	1817.9	347.5	119.8	7.0	0.0
4	215.2	30.0	0.0	100.9	0.0	0.0	1800.0	300.6	114.3	0.0	0.0
5	231.4	10.0	0.0	82.3	0.0	0.0	1234.9	160.9	149.1	0.0	0.0
6	191.3	78.6	0.0	100.7	22.7	0.0	1441.2	164.6	90.6	57.9	0.0
7	181.2	55.2	0.0	112.6	0.0	0.0	744.4	10.6	68.6	55.2	0.0
8	134.0	37.7	0.0	111.2	0.0	0.0	1118.3	146.7	22.8	37.7	0.0
9	168.1	6.1	0.0	74.8	0.0	0.0	1411.3	368.0	93.3	6.1	0.0
10	90.5	0.0	0.0	58.8	0.0	0.0	1007.6	97.6	31.7	0.0	0.0
11	124.4	0.0	0.0	92.3	0.0	0.0	1629.6	309.9	32.1	0:0	0.0
12	120.1	8.0	0.0	94.8	0.0	0.0	891.0	63.7	25.3	8.0	0.0
13	166.8	4.4	0.0	100.2	0.0	0.0	1806.0	354.9	66.6	4.4	0.0
14	125.5	11.8	0.0	85.9	0.0	0.0	1892.7	319.1	39.6	11.8	0.0
15	91.5	0.0	0.0	74.9	0.0	0.0	1324.6	225.0	16.6	0.0	0.0
16	124.6	0.0	0.0	82.5	0.0	0.0	1372.4	162.2	42.1	0.0	0.0
17	107.1	0.0	0.0	80.6	0.0	0.0	1258.8	172.1	26.5	0.0	0.0
18	119.8	0.0	0.0	84.7	0.0	0.0	1216.9	215.7	35.1	0.0	0.0
19	144.7	0.0	0.0	81.3	0.0	0.0	1417.1	184.0	63.4	0.0	0.0
20	146.6	0.0	0.0	81.4	0.0	0.0	367.8	0.0	65.2	0.0	0.0
21	149.5	31.2	0.0	86.2	0.0	0.0	236.2	0.0	63.3	31.2	0.0
22	145.8	3.3	0.0	76.0	0.0	0.0	421.6	30.8	69.8	3.3	0.0
23	275.5	23.3	0.0	133.9	0.0	0.0	1058.5	118.8	141.6	23.3	0.0
24	220.9	1.2	0.0	112.1	0.0	0.0	1877.7	433.5	108.8	1.2	0.0
25	205.1	0.0	0.0	97.6	0.0	0.0	183.4	13.0	107.5	0.0	0.0
26	193.5	30.3	0.0	90.6	0.0	0.0	1898.7	348.2	102.9	30.3	0.0
27	173.2	0.0	0.0	90.8	0.0	0.0	1184.0	0.0	82.4	0.0	0.0
28	183.6	0.0	0.0	110.3	0.0	0.0	212.3	0.0	73.3	0.0	0.0
29	148.1	58.8	0.0	119.3	0.0	0.0	508.3	0.0	28.8	58.8	0.0
30	177.7	34.8	0.0	115.3	0.0	0.0	1614.6	346.3	62.4	34.8	0.0
31	88.7	0.0	0.0	62.2	0.0	0.0	1124.2	188.7	26.5	0.0	0.0
Total	4995.1	474.2	0:0	2895.4	22.7	0.0	37725.0	5664.75	2099.7	451.5	0.0
Mean	161.1	15.3	0.0	93.4	0.7	0.0	1216.9	182.7	67.7	14.6	0.0

*On a 71.3 square meter solar collector surface

Table 13. (June 1975) DAILY TOTAL HEAT RATES (MJ/DAY)

Date	Total Energy Required			Supplemental Energy Required for			Incident * Solar Energy	Solar Energy Collected and Stored	Solar Energy Delivered from Storage to		
	DHW Load	Heating Load	Cooling Load	DHW Load	Heating Load	Cooling Load			DHW Load	Heating Load	Cooling Load
1	166.0	5.9	0.0	101.7	0.0	0.0	1859.8	360.0	64.3	5.9	0.0
2	174.8	0.0	0.0	89.9	0.0	0.0	1797.0	237.0	84.9	0.0	0.0
3	183.7	0.0	349.7	79.5	0.0	349.7	1399.3	118.2	104.2	0.0	0.0
4	168.7	0.0	0.0	84.4	0.0	0.0	1689.4	295.4	84.3	0.0	0.0
5	155.9	0.0	0.0	79.6	0.0	0.0	1916.6	303.2	76.3	0.0	0.0
6	131.2	0.0	502.8	74.2	0.0	358.0	1566.8	180.4	57.0	0.0	144.9
7	160.9	1.3	589.6	94.2	1.3	555.9	1208.0	181.2	66.7	0.0	33.7
8	149.4	1.3	335.7	89.1	1.3	333.9	795.3	35.6	60.3	0.0	1.8
9	127.0	0.0	0.0	88.5	0.0	0.0	849.2	64.3	38.5	0.0	0.0
10	137.0	15.5	28.2	104.8	0.0	28.2	693.7	14.1	32.2	15.5	0.0
11	149.6	12.4	234.1	96.5	0.0	234.1	1770.1	378.4	53.1	12.4	0.0
12	102.8	5.2	431.5	86.7	1.1	431.5	1387.4	244.6	16.1	4.1	0.0
13	114.7	0.0	419.1	83.5	0.0	372.5	1629.6	229.9	31.2	0.0	46.5
14	117.0	0.0	605.6	99.4	- 2.7	605.6	1220.0	74.5	17.6	0.0	0.0
15	95.1	0.0	348.5	69.6	0.0	249.7	1806.0	329.3	25.5	0.0	98.7
16	45.0	1.0	353.1	38.4	0.0	353.1	633.8	4.0	6.6	1.0	0.0
17	101.1	0.0	276.0	48.0	0.0	275.0	819.3	65.7	53.1	0.0	1.1
18	95.9	0.0	315.4	70.6	0.0	315.4	780.4	101.2	25.3	0.0	0.0
19	138.2	0.0	253.1	64.1	0.0	253.1	1510.0	223.7	74.1	0.0	0.0
20	150.7	0.0	529.2	85.7	0.0	426.6	1629.6	302.5	65.0	0.0	102.7
21	149.3	0.0	380.0	81.1	0.0	378.3	1136.0	113.9	68.2	0.0	1.7
22	136.3	0.0	182.4	76.2	0.0	182.4	1387.4	200.1	60.1	0.0	0.0
23	77.8	0.0	396.1	64.5	0.0	158.5	1818.0	327.3	13.3	0.0	237.5
24	129.7	0.0	613.2	53.9	0.0	477.3	1527.9	282.4	75.8	0.0	135.9
25	138.7	0.0	627.8	64.9	0.0	479.7	1507.0	281.8	73.8	0.0	148.1
26											
27											
28											
29											
30											
Total	3295.9	39.9	7771.2	1968.7	1.0	6818.5	34373.0	4968.6	1327.2	38.9	952.6
Mean	131.8	1.6	310.8	78.7	0.0	272.7	1375.4	198.7	53.1	1.6	38.1

*On a 71.3 square meter solar collector surface

Table 14. (July 1975) DAILY TOTAL HEAT RATES (MJ/DAY)

Date	Total Energy Required			Supplemental Energy Required for			Incident * Solar Energy	Solar Energy Collected and Stored	Solar Energy Delivered from Storage to		
	DHW Load	Heating Load	Cooling Load	DHW Load	Heating Load	Cooling Load			DHW Load	Heating Load	Cooling Load
1	51.5	0.0	653.0	61.5	0.0	495.4	1892.7	396.0	0.0	0.0	157.6
2	65.4	0.0	681.1	65.4	0.0	454.8	1665.4	342.3	0.0	0.0	226.3
3	63.1	2.5	526.6	63.1	2.5	354.3	1405.3	304.2	0.0	0.0	172.3
4	68.7	2.7	729.9	68.7	4.7	486.6	1811.9	371.5	0.0	0.0	243.3
5	79.1	1.5	452.7	79.1	1.5	295.9	1184.0	237.5	0.0	0.0	156.9
6											
7	55.5	0.0	663.2	55.5	0.0	585.9	1142.2	152.9	0.0	0.0	77.3
8	88.4	0.0	823.0	88.4	0.0	606.2	1764.1	335.1	0.0	0.0	216.7
9	76.2	0.0	200.6	76.2	0.0	222.2	1097.3	137.4	0.0	0.0	- 21.4
10	73.5	0.0	587.8	73.5	0.0	414.6	1623.6	282.2	0.0	0.0	173.1
11	85.9	0.0	340.5	85.9	0.0	114.6	1725.2	339.7	0.0	0.0	225.9
12	76.5	0.0	107.0	76.5	0.0	0.0	1826.9	320.0	0.0	0.0	107.0
13	69.2	0.0	273.1	69.2	0.0	0.0	1773.1	310.4	0.0	0.0	273.1
14	69.4	0.0	393.1	69.4	0.0	316.1	1016.6	63.2	0.0	0.0	77.1
15	97.4	0.0	345.9	97.4	0.0	124.3	1336.5	208.3	0.0	0.0	221.5
16	74.0	0.0	360.2	74.0	0.0	85.1	1306.6	250.6	0.0	0.0	275.1
17	94.2	0.0	346.1	94.2	0.0	346.1	1264.8	149.4	0.0	0.0	0.0
18	63.2	0.0	231.4	63.2	0.0	221.9	1327.6	161.6	0.0	0.0	0.0
19	85.7	0.0	265.0	85.7	0.0	220.4	1465.1	186.7	0.0	0.0	9.4
20	65.8	0.0	0.0	65.8	0.0	0.0	1067.4	111.8	0.0	0.0	44.6
21	46.2	0.0	455.8	46.2	0.0	371.6	1207.9	158.4	0.0	0.0	84.2
22	58.8	0.0	422.8	58.8	0.0	268.1	1507.0	256.3	0.0	0.0	154.7
23	81.7	0.0	531.2	81.7	0.0	531.2	1261.8	128.7	0.0	0.0	0.0
24	90.9	0.0	420.8	90.9	0.0	209.4	1722.2	263.2	0.0	0.0	211.4
25	85.9	0.0	378.4	85.9	0.0	148.7	1824.0	125.2	0.0	0.0	229.8
26	62.2	0.0	0.0	62.2	0.0	0.0	1826.9	342.9	0.0	0.0	0.0
27	69.2	0.0	0.0	69.2	0.0	0.0	1853.8	298.8	0.0	0.0	0.0
28	90.1	0.0	300.1	90.1	0.0	0.0	1303.6	148.3	0.0	0.0	300.1
29	64.1	0.6	326.8	64.1	0.0	218.2	1572.7	267.8	0.0	0.0	108.6
30	86.6	0.0	293.2	86.6	0.0	166.0	1214.0	105.5	0.0	0.0	127.2
31	90.9	0.0	294.6	90.9	0.0	233.0	1211.0	111.8	0.0	0.0	61.3
Total	2238.9	9.3	11403.7	2238.9	8.7	7490.7	44204.2	6868.1	0.0	0.0	3913.1
Mean	74.6	0.3	380.1	74.6	0.3	249.7	1474.1	228.9	0.0	0.0	130.4

*On a 71.3 square meter solar collector surface

Table 15. (August 1975) DAILY TOTAL HEAT RATES (MJ/DAY)

Date	Total Energy Required			Supplemental Energy Required for			Incident * Solar Energy	Solar Energy Collected and Stored	Solar Energy Delivered from Storage to		
	DHW Load	Heating Load	Cooling Load	DHW Load	Heating Load	Cooling Load			DHW Load	Heating Load	Cooling Load
1	78.3	0.0	331.6	78.3	0.0	239.4	1632.5	230.0	0.0	0.0	92.2
2	87.9	0.0	0.0	87.9	0.0	0.0	1803.0	7.2	0.0	0.0	0.0
3	62.0	0.0	0.0	62.0	0.0	0.0	1931.5	336.5	0.0	0.0	0.0
4	85.6	15.6	464.8	85.6	0.0	0.6	1880.7	330.4	0.0	15.6	464.1
5	77.4	0.0	392.7	77.4	0.0	230.9	1590.7	282.9	0.0	0.0	161.7
6	82.5	8.2	374.5	82.5	7.3	311.6	1043.5	96.7	0.0	0.9	62.9
7	54.0	2.8	268.0	54.0	2.8	244.7	1160.1	155.8	0.0	0.0	23.3
8	66.9	0.0	206.2	66.9	0.0	143.6	1877.7	320.1	0.0	0.0	62.6
9	70.2	0.0	551.7	70.2	0.0	270.2	1767.1	211.6	0.0	0.0	281.5
10	11.3	0.0	266.9	11.3	0.0	266.9	6.0	0.0	0.0	0.0	0.0
11	49.1	0.0	884.5	49.1	0.0	805.0	1076.4	153.9	0.0	0.0	79.4
12	77.2	0.0	823.8	77.2	0.0	823.8	837.2	62.1	0.0	0.0	0.0
13	90.3	0.0	12.6	90.3	0.0	12.6	293.0	0.0	0.0	0.0	0.0
14	78.1	0.0	0.0	78.1	0.0	0.0	968.8	64.1	0.0	0.0	0.0
15	85.9	0.0	0.0	85.9	0.0	0.0	1387.4	174.4	0.0	0.0	0.0
16	79.8	0.0	0.0	79.8	0.0	0.0	1408.3	186.8	0.0	0.0	0.0
17	68.8	0.0	0.0	68.8	0.0	0.0	1450.2	108.5	0.0	0.0	0.0
18	74.9	0.0	789.7	74.9	0.0	574.4	1668.4	242.1	0.0	0.0	215.2
19	69.2	0.0	806.3	69.2	0.0	762.3	1279.7	133.1	0.0	0.0	44.0
20	72.3	0.0	997.9	72.3	0.0	996.7	980.7	51.8	0.0	0.0	1.2
21	78.9	0.0	567.4	78.9	0.0	389.0	1393.3	263.7	0.0	0.0	178.4
22	68.8	0.0	369.2	68.8	0.0	236.8	1432.2	189.3	0.0	0.0	132.4
23	96.2	0.0	0.0	96.2	0.0	0.0	1453.1	270.5	0.0	0.0	0.0
24	72.3	0.0	21.7	72.3	0.0	0.0	1656.5	194.3	0.0	0.0	21.7
25	91.4	0.0	175.4	91.4	0.0	0.0	1835.9	266.4	0.0	0.0	175.4
26	80.0	0.0	440.3	80.0	0.0	76.5	1859.8	421.9	0.0	0.0	363.7
27	100.0	0.0	808.5	100.0	0.0	649.1	1345.5	169.5	0.0	0.0	159.4
28	108.3	0.0	986.7	108.3	0.0	778.9	1581.7	306.9	0.0	0.0	207.7
29	93.4	0.0	971.9	93.4	0.1	644.3	1868.8	454.6	0.0	0.0	327.6
30	90.9	0.0	842.3	90.0	0.0	494.8	1904.6	482.9	0.0	0.0	347.5
31	87.7	0.0	982.7	87.7	0.0	618.0	1922.6	471.7	0.0	0.0	364.8
Total	2389.5	26.7	13337.3	2389.5	10.2	9570.3	44302.8	6639.6	0.0	16.5	3767.1
Mean	77.1	0.8	430.2	77.1	0.3	308.7	1429.2	214.2	0.0	0.5	121.5

*On a 71.3 square meter solar collector surface

Table 16. Monthly and Annual Values of Mean Daily Heat Rates

Date	Total Energy Required			Supplemental Energy Required			Incident Solar Energy *	Solar Energy Collected	Solar Energy Delivered to		
	DHW Load	Heating Load	Cooling Load	To DHW	To Heating	To Cooling			DHW	Heating	Cooling
September 1974	38.9	10.5	354.1	9.6	0.9	239.2	1106.3	249.1	29.3	9.6	114.8
October 1974	52.6	10.6	210.4	10.9	0.3	150.9	849.2	179.1	41.7	10.3	59.4
November 1974	40.8	116.5	9.5	11.8	0.3	9.5	780.4	152.9	29.0	116.2	–
December 1974	41.2	225.6	0.5	14.1	56.3	0.5	956.8	227.5	27.1	169.1	–
January 1975	47.0	252.6	–	25.9	79.1	–	998.7	262.2	21.1	173.4	–
February 1975	88.5	236.9	–	40.8	48.6	–	1273.7	313.4	47.7	188.3	–
March 1975	104.5	129.6	–	58.6	46.9	–	1112.3	134.3	45.9	82.7	–
April 1975	156.4	121.5	–	98.1	30.8	–	1512.9	230.0	58.3	90.7	–
May 1975	161.1	15.3	–	93.4	0.7	–	1216.9	182.7	67.7	14.6	–
June 1975	131.8	1.6	310.8	78.7	0.0	272.7	1375.4	198.7	53.1	1.6	38.1
July 1975	74.6	0.3	380.1	74.6	0.3	249.7	1474.1	228.9	0.0	0.0	130.4
August 1975	77.1	0.8	430.2	77.1	0.3	308.7	1429.2	214.2	0.0	0.5	121.5
Annual	84.5	93.5	141.3	49.5	22.0	102.6	1173.8	214.4	35.1	71.4	38.7

*On a 71.3 square meter solar collector surface

the heating demand. Whenever the temperature of the building fell below a preset value at the thermostat (e.g., 20°C, 68°F), the solar portion of the system delivered heat to the heating coils. If the building temperature reached 19°C (66°F), or the thermal storage unit temperature was below some preset selected value (e.g., 38°C, 100°F), the auxiliary began supplying heat to the building.

For cooling the decision to use the auxiliary gas boiler was based only on a selected preset temperature of the thermal storage unit. Above this particular temperature (e.g., 82°C, 180°F), the solar portion of the system delivers heat to the cooling unit and is used to meet the cooling load; below this temperature the auxiliary delivers the heat to the cooling unit.

QUALITY OF THERMAL PERFORMANCE OF THE SYSTEM

The quality of thermal performance of the system is determined by the departure of measured room temperature from the design temperature over the reporting period. In CSU Solar House I, the design temperature is selected by setting the room thermostat. For winter heating operations and summer cooling operations the settings were 20°C (68°F) and 22°C (72°F), respectively. Table 17 shows the daily mean building temperatures for the reporting period (1 September 1974 to 31 August 1975). Note that the cooling system was not operational in the spring until 1 June.

SOLAR CONTRIBUTION TO ENERGY REQUIREMENTS

Tables 18 through 20 show the daily and monthly values of per cent solar contribution to energy requirements for domestic hot water (DHW), space heating, and space cooling, respectively. The annual solar percentages are 42 per cent for DHW, 76 per cent for space heating, and 27 per

Table 17. DAILY MEAN BUILDING TEMPERATURE (°C)

Date	Sept 1974	Oct 1974	Nov 1974	Dec 1974	Jan 1975	Feb 1975	March 1975	April 1975	May 1975	June 1975	July 1975	August 1975
1	21.7	22.8	18.6	18.2	18.4	19.4	19.8	18.9	20.5	20.6	25.5	24.8
2	19.4	23.4	17.9	19.1	17.8	19.7	19.5	18.8	21.8	23.2	23.2	25.1
3	20.3	23.4	17.7	19.3	18.6	20.0	20.2	19.5	21.3	25.9	23.9	26.9
4	21.8	23.0	18.1	20.9	18.4	19.1	21.1	20.6	22.3	25.4	22.9	26.9
5	22.4	22.3	18.6	19.8	18.2	18.6	21.3	21.1	22.7	25.6	22.7	25.9
6	22.3	21.6	19.9	20.0	19.2	19.2	19.8	21.0	20.3	25.0	–	25.9
7	22.3	22.3	20.5	18.4	18.9	19.4	19.0	20.9	21.3	22.2	23.2	27.1
8	22.7	22.4	20.4	18.4	18.8	17.9	19.2	20.5	22.0	22.1	22.8	27.4
9	22.5	22.8	18.4	19.7	18.5	17.9	19.3	20.3	21.7	20.4	25.6	26.3
10	22.1	23.0	18.3	19.0	17.9	19.7	18.2	19.9	22.2	20.4	23.9	21.1
11	21.4	22.9	18.2	–	17.5	20.1	19.6	19.1	21.7	21.1	24.4	21.8
12	18.6	21.9	–	–	17.7	21.7	19.2	18.5	21.5	22.1	23.2	22.3
13	19.6	21.9	–	–	19.4	22.2	19.6	18.8	21.8	23.3	23.6	23.7
14	20.1	22.6	–	–	20.2	20.0	20.3	20.1	23.4	22.5	24.8	21.7
15	20.8	–	–	–	19.7	18.3	20.0	21.7	24.8	22.9	25.2	23.1
16	20.9	24.1	–	–	19.2	18.2	19.7	23.0	25.0	22.7	25.0	23.2
17	21.3	23.0	–	–	20.0	19.8	20.9	21.2	25.0	22.3	24.9	24.5
18	20.7	–	–	–	19.3	20.1	21.1	19.7	24.2	22.4	27.2	23.7
19	–	–	19.2	20.0	18.4	20.5	22.5	19.1	24.8	23.5	28.1	23.3
20	20.4	–	19.0	19.4	18.8	20.5	23.7	19.6	23.2	23.0	26.9	23.0
21	20.2	24.6	21.9	19.5	18.5	19.0	21.5	20.9	19.8	22.4	25.3	23.8
22	20.3	24.0	19.8	19.2	18.5	19.4	19.6	21.3	21.1	23.0	26.0	25.1
23	21.9	21.4	19.9	18.2	19.2	19.4	18.5	23.0	20.5	23.3	25.2	27.1
24	22.0	20.5	19.7	19.2	20.3	21.2	18.7	21.1	20.9	23.6	24.2	27.3
25	22.1	20.9	20.0	19.2	–	19.9	19.5	23.3	21.3	23.1	26.0	24.2
26	22.5	19.9	18.8	18.7	–	19.7	18.5	24.4	21.1	–	29.0	24.7
27	21.2	20.3	18.2	19.7	18.7	20.5	17.6	21.1	22.3	–	29.8	24.4
28	20.3	20.6	17.6	19.7	19.4	20.0	18.2	19.9	20.6	–	27.4	23.0
29	21.6	19.6	17.2	19.3	19.0		–	20.0	19.2	–	27.1	22.7
30	21.9	19.3	17.5	19.2	19.4		19.4	19.7	20.5	–	27.6	22.5
31		19.1		18.7	19.5		19.0		20.7		25.8	22.7
Monthly Average	21.2	22.0	18.9	19.3	18.9	19.7	19.8	20.6	21.9	22.9	25.3	24.4

Table 18. Solar Contribution to Energy Requirements
Domestic Hot Water (DHW) Per Cent of Load

Date	Sept 1974	Oct 1974	Nov 1974	Dec 1974	Jan 1975	Feb 1975	March 1975	April 1975	May 1975	June 1975	July 1975	August 1975
1	74.5	58.0	78.0	73.8	63.0	78.7	81.5	9.5	42.2	38.7	0.0	0.0
2	28.6	48.2	32.0	82.0	0.0	84.8	73.8	21.7	35.5	48.6	0.0	0.0
3	80.3	60.5	26.0	81.5	68.6	57.9	73.5	43.9	54.7	56.7	0.0	0.0
4	81.4	76.8	84.5	76.4	76.7	45.2	80.1	26.3	53.1	50.0	0.0	0.0
5	77.9	73.0	82.3	41.8	63.1	8.9	79.2	59.8	64.4	48.9	0.0	0.0
6	85.8	81.6	100.0	86.5	73.9	50.9	79.4	45.4	47.3	43.4	0.0	0.0
7	0.0	93.6	100.0	27.5	77.5	70.7	38.8	35.7	37.8	41.4	0.0	0.0
8	81.6	100.0	79.8	81.7	33.5	0.0	47.8	32.0	17.0	40.4	0.0	0.0
9	70.4	80.2	68.3	72.4	32.3	18.2	0.0	29.0	55.5	30.3	0.0	0.0
10	84.1	77.8	73.5	100.0	33.5	2.0	0.0	3.1	35.0	23.5	0.0	0.0
11	71.9	72.3	75.8	0.0	12.0	59.0	0.0	16.9	25.8	35.5	0.0	0.0
12	17.2	70.1	0.0	0.0	43.1	69.1	59.8	41.0	21.1	15.6	0.0	0.0
13	73.4	69.3	0.0	0.0	15.4	62.7	62.1	36.1	39.9	27.2	0.0	0.0
14	71.5	51.6	0.0	0.0	72.7	32.7	84.7	43.2	31.5	15.1	0.0	0.0
15	65.8	0.0	0.0	0.0	25.3	20.0	55.7	43.0	18.1	26.9	0.0	0.0
16	82.2	78.8	0.0	0.0	11.7	36.1	0.0	51.0	33.8	14.6	0.0	0.0
17	67.0	100.0	0.0	0.0	55.2	23.6	49.3	37.4	24.7	52.5	0.0	0.0
18	100.0	0.0	0.0	0.0	46.4	51.3	45.6	40.0	20.3	26.4	0.0	0.0
19	0.0	0.0	41.0	58.5	54.8	56.1	45.7	38.5	43.8	53.6	0.0	0.0
20	62.1	0.0	7.6	24.1	59.7	61.4	57.3	30.5	44.5	43.1	0.0	0.0
21	88.4	100.0	57.3	46.8	52.2	55.1	44.3	70.2	42.4	45.7	0.0	0.0
22	65.1	100.0	75.3	66.5	24.0	71.9	37.3	46.4	47.9	44.1	0.0	0.0
23	81.1	75.0	86.7	7.9	38.9	34.6	0.0	46.5	51.4	17.1	0.0	0.0
24	87.9	100.0	69.7	69.7	5.2	92.3	40.8	54.3	49.2	58.4	0.0	0.0
25	72.3	93.5	65.3	67.2	0.0	80.7	43.8	33.7	52.4	53.2	0.0	0.0
26	93.7	86.5	77.7	12.7	0.0	70.7	9.7	27.0	53.3	0.0	0.0	0.0
27	55.9	79.7	36.1	83.7	0.0	85.8	12.2	13.1	47.7	0.0	0.0	0.0
28	88.3	92.0	41.8	62.0	31.2	77.8	24.1	51.3	39.9	0.0	0.0	0.0
29	71.5	85.7	38.6	40.6	55.7		0.0	28.4	19.5	0.0	0.0	0.0
30	72.5	75.2	82.1	72.8	0.0		43.8	22.1	35.1	0.0	0.0	0.0
31		27.8		56.7	53.3		12.8		29.8		0.0	0.0
Monthly Average	75.3	79.3	71.0	65.8	44.9	53.9	43.9	37.3	42.0	40.3	0.0	0.0

Table 19. Solar Contribution to Energy Requirements
Space Heating (Per Cent of Load)

Date	Sept 1974	Oct 1974	Nov 1974	Dec 1974	Jan 1975	Feb 1975	March 1975	April 1975	May 1975	June 1975	July 1975	August 1975
1	—	—	92.1	100.0	100.0	32.7	96.8	7.5	100.0	100.0	-	-
2	—	—	100.0	100.0	84.8	100.0	92.2	45.5	100.0	—	-	-
3	89.5	—	100.0	100.0	41.2	100.0	93.6	96.6	100.0	—	0.0	-
4	—	—	100.0	100.0	100.0	100.0	100.0	100.0	—	—	0.0	100.0
5	—	—	100.0	96.3	100.0	52.0	100.0	100.0	—	—	0.0	
6	100.0	—	100.0	100.0	100.0	4.6	100.0	100.0	71.8	—	-	10.7
7	—	—	—	100.0	99.6	33.4	100.0	100.0	100.0	0.0	-	0.0
8	—	—	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	-	-
9	—	—	100.0	100.0	100.0	24.2	100.0	100.0	100.0	—	-	-
10	—	—	100.0	100.0	59.1	33.0	100.0	100.0	—	100.0	-	-
11	—	—	100.0	—	10.9	100.0	0.0	10.2	—	100.0	-	-
12	100.0	—	—	—	40.8	86.9	39.4	40.7	100.0	78.7	-	-
13	80.1	—	—	—	30.8	100.0	100.0	100.0	100.0	—	-	-
14	100.0	—	—	—	54.0	100.0	100.0	100.0	100.0	0.0	-	-
15	—	—	—	—	100.0	99.5	100.0	100.0	—	—	-	-
16	—	—	—	—	91.1	87.8	—	—	—	100.0	-	-
17	—	—	—	—	57.2	100.0	100.0	100.0	—	-	-	-
18	—	—	—	—	100.0	100.0	100.0	100.0	—	-	-	-
19	—	—	100.0	98.7	100.0	100.0	100.0	100.0	—	-	-	-
20	—	—	100.0	71.3	100.0	98.4	—	100.0	—	-	-	-
21	100.0	—	—	11.9	100.0	100.0	100.0	100.0	100.0	-	-	-
22	—	—	100.0	64.2	100.0	100.0	100.0	100.0	100.0	-	-	-
23	—	—	100.0	44.3	97.7	100.0	100.0	—	100.0	-	-	-
24	—	—	100.0	44.5	100.0	100.0	93.6	—	100.0	-	-	-
25	—	—	96.9	55.5	—	100.0	100.0	—	—	-	-	-
26	—	—	100.0	82.7	—	100.0	62.8	—	100.0	-	-	-
27	—	—	99.4	43.3	28.7	98.1	0.1	100.0	—	-	-	-
28	100.0	—	100.0	100.0	18.9	100.0	37.7	100.0	—	-	-	-
29	—	100.0	100.0	100.0	100.0		—	100.0	100.0	-	100.0	0.0
30	—	94.5	100.0	100.0	100.0		100.0	100.0	100.0		-	-
31		100.0		100.0	55.9		100.0		—		-	-
Monthly Average	91.6	97.5	99.7	75.0	68.7	79.5	86.3	74.7	95.2	97.4	6.4	61.7

Table 20. Solar Contribution to Energy Requirements
Space Cooling (Per Cent of Load)

Date	Sept 1974	Oct 1974	Nov 1974	Dec 1974	Jan 1975	Feb 1975	March 1975	April 1975	May 1975	June 1975	July 1975	August 1975
1	23.9	44.6	-	-	-	-	-	-	-	-	24.1	27.8
2	-	36.3	-	-	-	-	-	-	-	-	33.2	-
3	26.8	97.3	-	-	-	-	-	-	-	0.0	32.7	-
4	60.3	38.3	-	-	-	-	-	-	-	-	33.3	99.9
5	5.5	0.2	-	-	-	-	-	-	-	-	34.6	41.2
6	40.6	32.2	-	-	-	-	-	-	-	28.8	-	16.8
7	52.6	48.1	0.0	-	-	-	-	-	-	5.7	11.7	8.7
8	1.9	36.0	0.0	-	-	-	-	-	-	0.5	26.3	30.3
9	7.1	34.5	-	-	-	-	-	-	-	-	0.0	51.0
10	3.1	0.0	-	-	-	-	-	-	-	0.0	29.5	0.0
11	11.2	0.0	-	-	-	-	-	-	-	0.0	66.3	9.0
12	-	0.0	-	-	-	-	-	-	-	0.0	100.0	0.0
13	--	-	-	-	-	-	-	-	-	11.1	100.0	0.0
14	1.5	-	-	-	-	-	-	-	-	0.0	19.6	-
15	38.8	-	-	-	-	-	-	-	-	28.3	64.1	-
16	49.1	0.1	-	-	-	-	-	-	-	0.0	76.4	-
17	52.9	100.0	-	-	-	-	-	-	-	0.4	0.0	-
18	-	-	-	-	-	-	-	-	-	0.0	4.1	27.3
19	-	-	-	-	-	-	-	-	-	0.0	16.8	5.5
20	-	-	-	-	-	-	-	-	-	19.4	-	0.1
21	100.0	22.1	-	-	-	-	-	-	-	0.5	18.5	31.4
22	-	23.8	-	-	-	-	-	-	-	0.0	36.6	35.9
23	59.6	-	-	-	-	-	-	-	-	60.0	0.0	-
24	34.1	-	-	-	-	-	-	-	-	22.2	50.2	100.0
25	55.3	0.0	-	-	-	-	-	-	-	23.6	60.7	100.0
26	23.1	-	-	-	-	-	-	-	-	-	-	82.6
27	5.9	-	-	-	-	-	-	-	-	-	-	19.7
28	-	-	-	-	-	-	-	-	-	-	100.0	21.1
29	75.7	-	-	-	-	-	-	-	-	-	33.2	33.7
30	38.9	-	-	-	-	-	-	-	-	-	43.4	41.3
31		-	-	0.0	-		-		-		20.8	37.1
Monthly Average	32.4	28.3	0.0	0.0	-	-	-	-	-	12.3	34.3	28.2

cent for space cooling. These values, however, were heavily influenced by the experimental nature of the project and do not adequately show the normal operation of the system. By accounting for these extraordinary effects (see sections on Heating System Performance and Cooling System Performance), the annual percentage carried by solar becomes 49 per cent of the domestic hot water load, 87 per cent of the space heating load, and 81 per cent of the space cooling load.

MONTHLY AND ANNUAL ENERGY OR FUEL SAVINGS

Table 21 shows the monthly and annual quantities of gas heat saved by use of the solar heating and cooling system. Savings of energy for domestic water heating are tabulated in column [1]. These values are obtained from Tables 4 through 15 and account for the heat losses from the domestic hot water solar preheat tank and the combustion efficiency of the auxiliary domestic hot water unit.

Energy savings for space heating (column [2]) correspond to the useful solar energy delivered to thermal storage for all heating purposes, less that used for domestic hot water heating (heat losses from storage and piping being useful for space heating). Heat losses from the domestic hot water preheat tank also contribute to meeting the heating load and are included in the figures in column [2].

In summer operation, the energy savings in column [3] are solar delivery to the cooling load less the energy required for producing sufficient cooling to match (remove) the heat losses from the solar system (storage tank, DHW preheat tank, piping, valves, etc.). Column [4] shows the effects on the energy savings for cooling operations if it is assumed that the solar system heat losses did not contribute to the cooling load (i.e., if the solar equipment were located outside the building's air

Table 21. Monthly and Annual Energy Savings (MJ)

Month	[1] Domestic Hot Water (DHW)1	[2] Space Heating 2	[3] Space Cooling 2	[4]	[5] Totals	[6]
September, 1974	627.1	790.9	776.0	4041.5	2194.0	5459.5
October, 1974	1118.2	3544.7	1255.7	2198.0	5918.6	6860.9
November, 1974	504.4	5100.9	0.0	0.0	5605.3	5605.3
December, 1974	447.5	8146.1	0.0	0.0	8593.6	8593.6
January, 1975	336.5	9554.6	0.0	0.0	9891.1	9891.1
February, 1975	1269.1	9478.2	0.0	0.0	10747.3	10747.3
March, 1975	1708.6	4739.0	0.0	0.0	6447.6	6447.6
April, 1975	1812.6	6722.7	0.0	0.0	8535.3	8535.3
May, 1975	2273.2	4777.8	0.0	0.0	7051.0	7051.0
June, 1975	1508.2	598.4	-1966.7	1156.1	139.9	3262.7
July, 1975	0.0*	0.0	1188.8	4749.0	1188.8	4749.0
August, 1975	0.0*	0.0	1163.2	4571.7	1163.2	4571.7
Annual Totals	11605.4	53453.3	2417.0	16716.3	67,476.8	81755.0

1 - Gas water heater has a measured combustion efficiency of 76.0%

2 - Gas boiler has a measured combustion efficiency of 82.4%

* - DHW solar preheat tank by-passed during months of July and August

conditioned space). Sample calculations to obtain the values in Table 21 are shown below.

Sample Calculations - Table 21

Column [1] - For September the heat losses from the DHW solar preheat tank (Q_L(preheat)) were calculated to be 373 MJ/month (based on the average solar preheat tank temperatures and the experimentally determined heat loss rate for a particular temperature difference). The useful solar energy delivered to the DHW load (Q_u(DHW)) is given by:

$$Q_u(\text{DHW}) = Q_{DHW} - Q_L(\text{preheat})$$

where Q_{DHW} is the solar heat delivered to DHW load (listed in Table 4). The energy savings, E_{DHW}, listed in column [1] of Table 21 is then Q_u(DHW) divided by the auxiliary DHW unit's combustion efficiency (76%) Thus:

$$E_{DHW} \text{ (column [1])} = \frac{Q_{DHW} - Q_L(\text{preheat})}{0.76}$$

For September:

$$E_{DHW} \text{ (column [1])} = \frac{848.7 \text{ MJ} - 373.0 \text{ MJ}}{0.76} = 627.1 \text{ MJ}$$

Column [2] - The energy savings for space heating, E_H, is the total useful energy delivered to the storage unit, Q_u, less that heat delivered to the DHW system, Q_u(DHW), divided by the gas boiler combustion efficiency, η_B. This is due to the fact that all heat losses from storage, piping, and the DHW system contribute to the solar space heating contribution.

For February (from Table 9):

Q_u = 8774.5 MJ $\qquad$ E_{DHW} = 1269.1 MJ

Now:

$$Q_u\ (DHW) = 0.76\, E_{DHW} = 964.5\ MJ$$

and

$$E_H = \frac{Q_u - Q_u(DHW)}{\eta_B} = \frac{8774.5\ MJ - 964.5\ MJ}{0.824}$$

$$E_H = 9478.2\ MJ$$

Column [3] - Q_{AIRS} is the amount of solar heat delivered to the cooling unit. However, the heat losses from the solar system add to the cooling load, and therefore must be accounted for in determining the energy savings for space cooling, E_c. Therefore:

$$\eta_B E_c = Q_{AIRS} - \{Q_u - Q_{DHW} - Q_{HCS} - Q_{AIRS} - \Delta Q_s\}$$

where

Q_u is the useful energy delivered to storage,

Q_{DHW} is the storage heat delivered to domestic hot water,

Q_{HCS} is the storage heat delivered to space heating,

Q_{AIRS} is the storage heat delivered to space cooling,

and ΔQ_s is the change in storage heat.

For June (from Tables 13 and 23):

$$E_c \eta_B = 952.6\ MJ - \{4968.6 - 1327.2 - 39.9 - 952.6 - 75.7\}MJ$$

$$E_c \eta_B = -1620.6\ MJ$$

$$E_c = -1966.7\ MJ$$

Column [4] - Assuming no solar heat losses contributing to the cooling load, we can obtain the energy savings for space cooling by:

$$E_c\ (\text{column [4]}) = Q_{AIRS}/\eta_B$$

For June (from Table 13),

$$E_c \text{ (column [4])} = 952.6\text{ MJ}/.824 = 1156.1\text{ MJ}$$

Column [5]

Column [5] = column [1] + column [2] + column [3]

Column [6]

Colume [6] = column [1] + column [2] + column [4].

ENERGY AND MASS BALANCES

Energy balances of significant energy flow rates in and out of a specific component can be obtained from the data presented. Table 22 shows energy supply, withdrawal, and accumulation during several days. The distinctive difference between winter and summer heat losses is due to the difference in storage temperatures. The average storage temperature during the days shown in Table 22 were 50.7°C (winter) and 78.6°C (summer). At these temperatures heat is lost at rates of 47.2 MJ/day (winter) and 85.9 MJ/day (summer), at house temperatures of 20°C and 22°C, respectively.

Table 23 identifies the critical parameters which affect the thermal storage heat losses, including the thermal storage temperature, the heat in storage at the end of each day, the daily change in heat in storage, the thermal storage heat balance, the total solar heat to loads, and the heating system daily heat loss. In evaluating Table 23, it is important to know the source of the data presented. For example:

Table 22. Selected Energy Balances on Thermal Storage Unit

Date	Delivered to Storage (MJ/day)	Increase in Storage (MJ/day)	Storage Heat Delivered to: DHW (MJ/day)	Heating (MJ/day)	Cooling (MJ/day)	Storage Heat Losses * (MJ/day)	(MJ/hr)	(Btu/hr)
1/01/75	418.6	85.3	24.6	256.6	0.0	43.1	1.8	1890
1/02/75	0.0	-346.4	0.0	302.3	0.0	44.1	1.8	1940
1/05/75	383.6	55.3	23.0	253.4	0.0	51.9	2.2	2280
2/12/75	332.4	105.4	66.0	111.4	0.0	49.6	2.1	2180
2/19/75	498.1	87.7	64.3	298.7	0.0	47.4	2.0	2080
Winter Average						47.2	2.0	2080
7/10/75	282.2	25.4	0.0	0.0	173.1	83.7	3.5	3680
7/14/75	63.2	-106.9	0.0	0.0	77.1	93.0	3.9	4090
7/18/75	161.6	76.7	0.0	0.0	9.4	75.5	3.1	3320
7/21/75	158.4	- 9.4	0.0	0.0	84.2	83.6	3.5	3680
7/27/75	298.8	205.1	0.0	0.0	0.0	93.7	3.9	4120
Summer Average						85.9	3.6	3780

*Losses computed by difference

Table 23. Monthly and Annual Averages of Daily Mean Values (Heating Systems)

Month	[1] Thermal Storage Temperature (°C)	[2] Heat in Thermal Storage (MJ)	[3] Monthly Change in Heat in Thermal Storage (MJ)	[4] Thermal Storage Heat Balance (MJ/day)	[5] Total Solar Heat to Loads (MJ/day)	[6] Heating System Heat Losses (MJ/day)	[7] Actual Solar Heat to Heating Load (MJ/day)
September	69.5	874.3	81.7	246.4	153.7	92.7	—
October	71.3	905.9	- 361.0	190.7	111.3	79.4	89.7
November *	62.6	751.4	77.2	206.0	146.2	59.8	176.0
December *	49.9	526.8	- 135.2	218.5	170.8	47.7	216.8
January	45.3	446.2	122.3	258.3	194.5	63.8	237.2
February	48.4	501.2	149.4	308.1	236.0	72.1	260.4
March *	54.9	615.2	- 532.0	239.5	191.3	48.2	130.9
April	63.3	763.6	306.4	219.8	149.0	70.8	161.5
May	64.4	783.4	262.9	174.2	82.3	91.9	111.9
June	69.7	877.2	75.7	196.2	92.8	103.4	—
July	76.7	1001.7	26.8	228.0	130.5	97.5	—
August	78.4	1030.0	63.4	212.2	122.0	90.2	—
Annual Average	62.9	756.5		210.0	148.4	61.6	133.0

* Data for part of month only

Column [1]	Thermal storage temperature is an average of three temperature probes inserted in the storage tank at the top, middle, and bottom
Column [2]	Heat in thermal storage is the average heat available, based on the thermal storage temperature (above 20°C, 68°F - room temperature) and the total volume of water in the tank (4275 liters, 1130 gallons)
Column [3]	Change in heat in thermal storage is the monthly change from first of month to the first of the next month
Column [4]	Thermal storage heat balance is the difference between the total daily collected solar heat (see Table 16) and the daily change in heat in thermal storage
Column [5]	Total solar heat to loads is the sum of all solar heat delivered to the domestic hot water, heating, and cooling loads (from Table 16)
Column [6]	Heating system heat losses is the difference between the thermal storage heat balance (column [4]) and the total solar heat delivered to load (column [5])
Column [7]	"Actual" solar heat to heating load is the total of the solar heat delivered to the heating load (Table 16) and the thermal storage heat losses (column [6])

From Table 23, we can obtain a more complete picture of the magnitude of the thermal storage unit and associated equipment heat losses, where the correlation between the storage temperature and the amount of heat loss is more apparent (note that we are assuming a constant building temperature of 20°C, a condition that is not in fact constant - see Table 17). If we account for the variation in average daily building temperatures, we can obtain an annual average heat loss rate of:

$$U_L = 71.2 \text{ MJ/day} \div (62.9°\text{C} - 21.2°\text{C})$$

$$U_L = 1.71 \text{ MJ/day}\cdot°\text{C}$$

Column [7] of Table 23 accounts for this heat loss from the solar storage to the heated space (for the months of October through May) by including it in the total solar heat contributed to load. This "actual" solar heat delivered to the heated space represents 87 per cent of the total heating requirements.

Total Energy Delivered

Total annual energy delivered by solar was 53,000 MJ (12,810 MJ to domestic hot water; 26,060 MJ to heating; and 14,130 MJ to cooling), out of a total demand of 116,540 MJ (30,840 MJ to domestic hot water; 34,130 MJ to heating; and 51,570 MJ to cooling). Auxiliary accounted for 63,540 MJ (18,030 MJ to domestic hot water; 8,070 MJ to heating; and 37,440 MJ to cooling).

SYSTEM ECONOMIC ANALYSIS

In the process of constructing the solar system and its installation in the house, detailed cost accounting was performed. The results are associated with the following applicable factors:

1. The unit is a custom design of comparatively small size,
2. In evaluating the necessary man-hours for repetitive tasks, the time requirement for the last units was used so that learning time would not be included,
3. University shop personnel, normally accustomed to new and unique work assignments, did most of the assembly and installation,
4. Tooling costs were minor and are not included, and
5. Extra costs are associated with the research aspects of the facilities, including redundancy in operating methods.

Since the cost of solar heating and cooling is the most important consideration in its adoption and practical use, there must be a clear understanding of criteria.

First, it is necessary to separate the cost of the solar components from the cost of the house itself. The cost of the house should be considered to include a conventional heating and cooling system, capable of meeting maximum demands. The solar energy system cost is then the additional costs of the solar components, such as the solar collector, thermal storage, associated piping, valves, etc. Not included are costs of furnace, distribution ducting, an air conditioner, water heater, and conventional controls because they would be used in a fuel-operated system, and they are also the conventional parts of the solar operated system. The air conditioner might be of a cheaper type in a conventional system, however.

TOTAL COST OF THE SOLAR PORTION OF THE SYSTEM

Based on the criteria established in the above section, the total cost of the solar components (including installation) for CSU Solar House I is approximately $10,100.00. This does not include the cost of the conventional components of the system (those necessary for a complete HVAC unit), the cost of distribution ductwork, and those costs associated with overhead and profit. This cost relates to the construction of the solar system, as depicted by Mode 1 (see Figure 7), and designed to meet 75 per cent of the space heating and cooling loads.

LABOR COSTS

Table 24 lists the labor time and costs associated with on-site fabrication and installation of the solar collectors (man-hours and crane time). The cost of labor for installing the rest of the solar components is shown in Table 24 as $1,600.00. The total labor cost for fabricating and installing the solar heating and cooling system (exclusive of the conventional, non-solar facilities) is therefore $3,684.00. Labor for installing non-solar equipment is shown to total $400.

MATERIALS COSTS

Tables 24 and 25 show the costs of materials in the solar collector ($3,022.00 total), and of the other solar components in the system ($3,400.00). The total solar material cost is therefore $6,422.00. The total cost of conventional heating and cooling equipment (materials only) is $2,200.00.

OPERATIONAL COSTS

Operational costs include the expense of natural gas for auxiliary energy and electricity for powering pumps and blowers. Table 26 shows the

Table 24. Solar Collector Costs

Material

Item		Quantity	Total Cost	Cost/Ft^2
1/8" double strength, window (DSB) glass	[34" X 66"] *	100 sheets	$ 526.00	$ 0.33
3/8" Butyl tape	(15' Rolls)	142 rolls	312.40	--
4" x 1.72" Aluminum Channel (rafter)		240 feet	386.40	--
1 3/4" X 3" Aluminum Tube		240 feet	350.40	--
1" X 1" Aluminum Angles		992 feet	198.40	--
1/8" X 2" Aluminum Rectangle		304 feet	97.28	--
1" X 2" Aluminum T-Bar		364 feet	76.44	--
33" X 8' ROLL-BOND® absorber plates	**	32 sheets	612.48	0.85
Primer		3 gallons	20.25	0.02
NEXTEL black coating		5 gallons	90.00	0.12
Insulation B-Fiber with Fesco-Foam		750 ft^2	322.50	0.43
Miscellaneous			30.00	--
768 ft^2 collector Total material costs			$ 3022.55	

Labor

Item	Man-Hours	Cost***
Cleaning Absorber Plate (32 @ 1/4 hours)	8	$ 48.00
Painting Absorber Plate (32 @ 1/2 hours)	16	96.00
Baking Absorber Plates (32 @ 1/2 hours)	16	96.00
Aluminum and Glass Frame Fabrication	18	108.00
Glass Preparation	6	36.00
Installing Aluminum Beams	28	168.00
Installing Manifolds	20	120.00
Installing Insulation/Absorber Plate/Plumbing/ Glass Units for 16 Panels [3 panels/day with 3 men]	128	768.00
Crane Time (@ $10/hour)	44	440.00
Miscellaneous	34	204.00
Total labor costs	318	$2084.00

Total Collector Costs $5106.55

or

$ 6.65/ft^2

+ Includes shipping to job site
* Allows for 4% glass breakage
** Does not include design and set up charges
*** @ $6.00/hour

Table 25. Solar Heating and Cooling System Costs

"Solar"		
ITEM	COST	
Thermal storage tank with insulation	$ 350	
Collector and exchanger pumps	150	
Collector/storage heat exchanger	400	
Preheat tank	100	
Automatic by-pass valves	200	
Associated piping, valves, fittings, insulation, etc.	500	
Extra cost of absorption cooling equipment compared with conventional vapor compression type *	1500	
Controls	200	
Labor	1600	
SUBTOTAL	$ 5000	5000
"Conventional"		
ITEM	COST	
Vapor compression air conditioner	$ 1100	
Automatic valve	100	
Hot water boiler	500	
40 gallon hot water heater	100	
Circulating pump	50	
Heating coils	125	
Control instrumentation	25	
Associated piping, valves, fittings, etc	200	
Labor	400	
SUBTOTAL	$ 2600	2600
TOTAL		$ 7600

* ARKLA 3-ton, lithium bromide cooling unit	2000
Cooling tower	500
Cooling tower pump	50

Table 26. Supplemental Energy Usage and Costs
(1 September 1974 to 31 August 1975)

Energy Source and Use	Usage	Cost[1]
Auxiliary Energy (natural gas)		
Domestic hot water		
Heating		
Cooling		
Total	86,490 ft^3, 72,143 MJ	$ 83.46
Electrical energy (pumps, blowers, etc.)		
Domestic hot water		
Heating		
Cooling		
Total	3760 kw·hr	$ 125.96

[1] Assumes a boiler efficiency of 82.4%, an energy content of 0.834 MJ per cubic foot of gas, and a cost of $0.965 per thousand cubic feet of gas OR

An electrical rate of $0.0335 per kilowatt-hour total energy usage and associated costs of supplemental energy during the period 1 September 1974 through 31 August 1975.

LOCAL ECONOMIC FACTORS

In the Fort Collins, Colorado region during the period 1 September 1974 to 31 August 1975, interest rates ranged from eight to nine per cent for home mortgages (new homes and remodeling of existing buildings), with amortization periods of 20 to 30 years. The local inflation rate averaged approximately eight per cent during the same period.

EXPECTED SELLING PRICE OR COSTS

The solar heating and cooling equipment at Colorado State University is part of an experimental system not expected to be sold in full or in part. But if it were commercialized in its present form, with collectors built on-site, and typical labor wage scales applied, along with customary overhead and profit, the total installed price of the system would be fifty to one hundred per cent higher than the expenditure shown above.

MAINTENANCE FREQUENCY AND COSTS

During the period from 1 September 1974 through 31 August 1975, required maintenance was limited to one service call on the lithium bromide absorption cooling unit. This service required six man-hours at a total cost of $86.00. No collector maintenance was required, and non-experimental servicing of solar equipment by laboratory personnel involved approximately 24 man-hours at a nominal value of $144.00.

USER REACTION AND COMMENTS

Not applicable.

SUBSYSTEM PERFORMANCE

SOLAR COLLECTORS

Description of Physical Configuration

The collector consists of sixteen 0.9 meter by 4.9 meter (three foot by sixteen foot) sections, for a total collector area of 71.3 square meters (768 square feet). The total exposed glass area is 65.7 square meters (707 square feet). Horizontal manifold pipes, 5 cm (2 inches) in diameter, at the top and bottom of the collector sections, run the length of the collector array (14.6 m, 48 ft).

Because of the experimental nature of the installation, and the need to replace the collector with new designs at a later date, a watertight sub-roof was made an integral part of the house design. This requirement imposed some restrictions on the collector design; e.g., the installation of a prefabricated modular unit becomes more difficult when the back side of the collector is unavailable for making plumbing connections. It was also desired to have a neat-appearing watertight solar collector capable of acting as a roof. These requirements further limited the possibilities of utilizing modular construction. The design finally developed is shown in Figure 16.

The collector is composed of aluminum structural supports, two sheets of B-quality double strength (1/8 inch) window glass, an aluminum absorber plate with internal tubes ("ROLL-BOND" R), and insulation beneath. The cover glasses are attached to the aluminum structure by a butyl tape and an aluminum cap strip. Approximately one-third of the glass covers have undergone an anti-reflection treatment (RCA "Magicote" process), courtesy of Honeywell, Inc. As shown in Figure 17, the aluminum panel has a tube

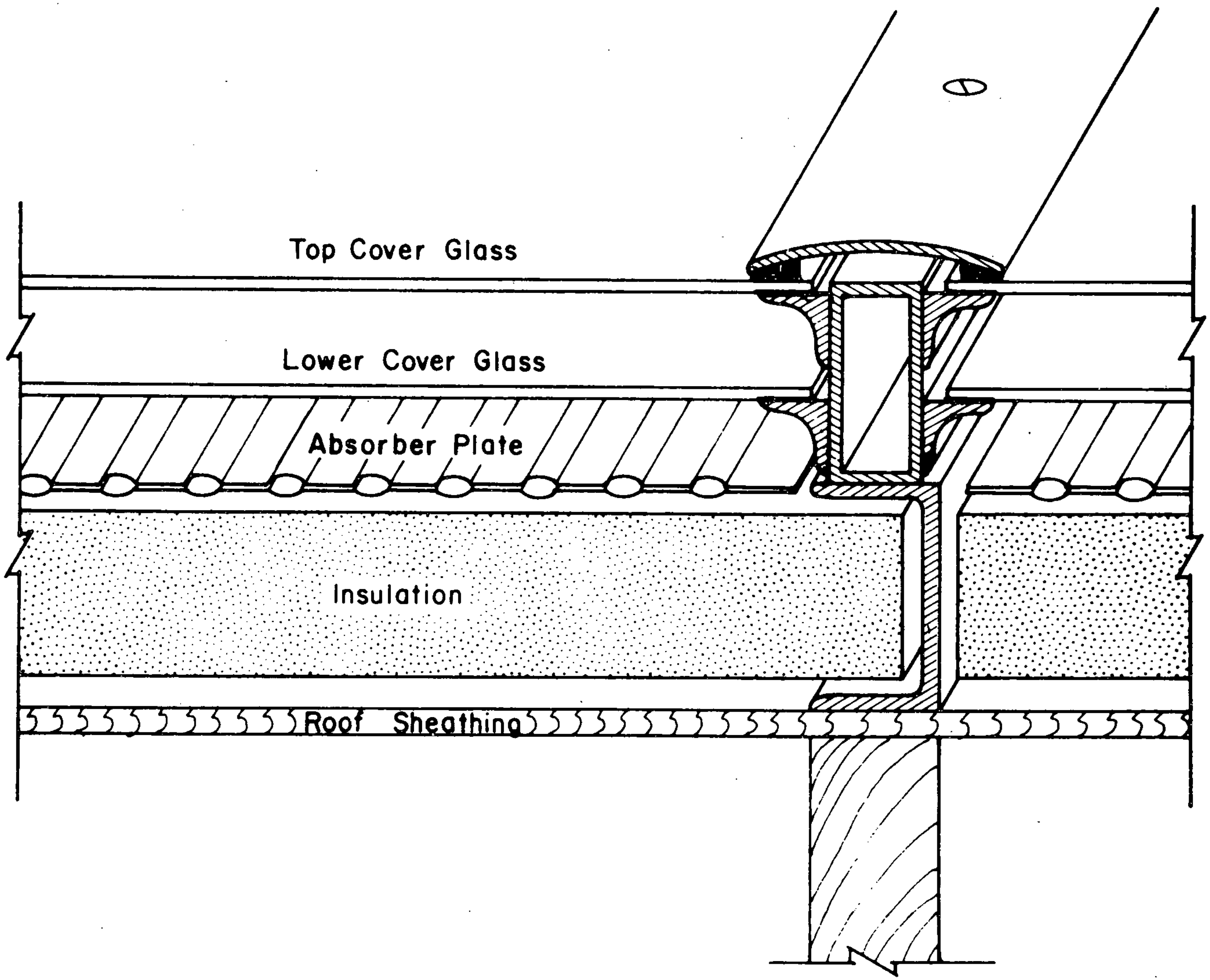


Figure 16
Solar Collector Cross Section

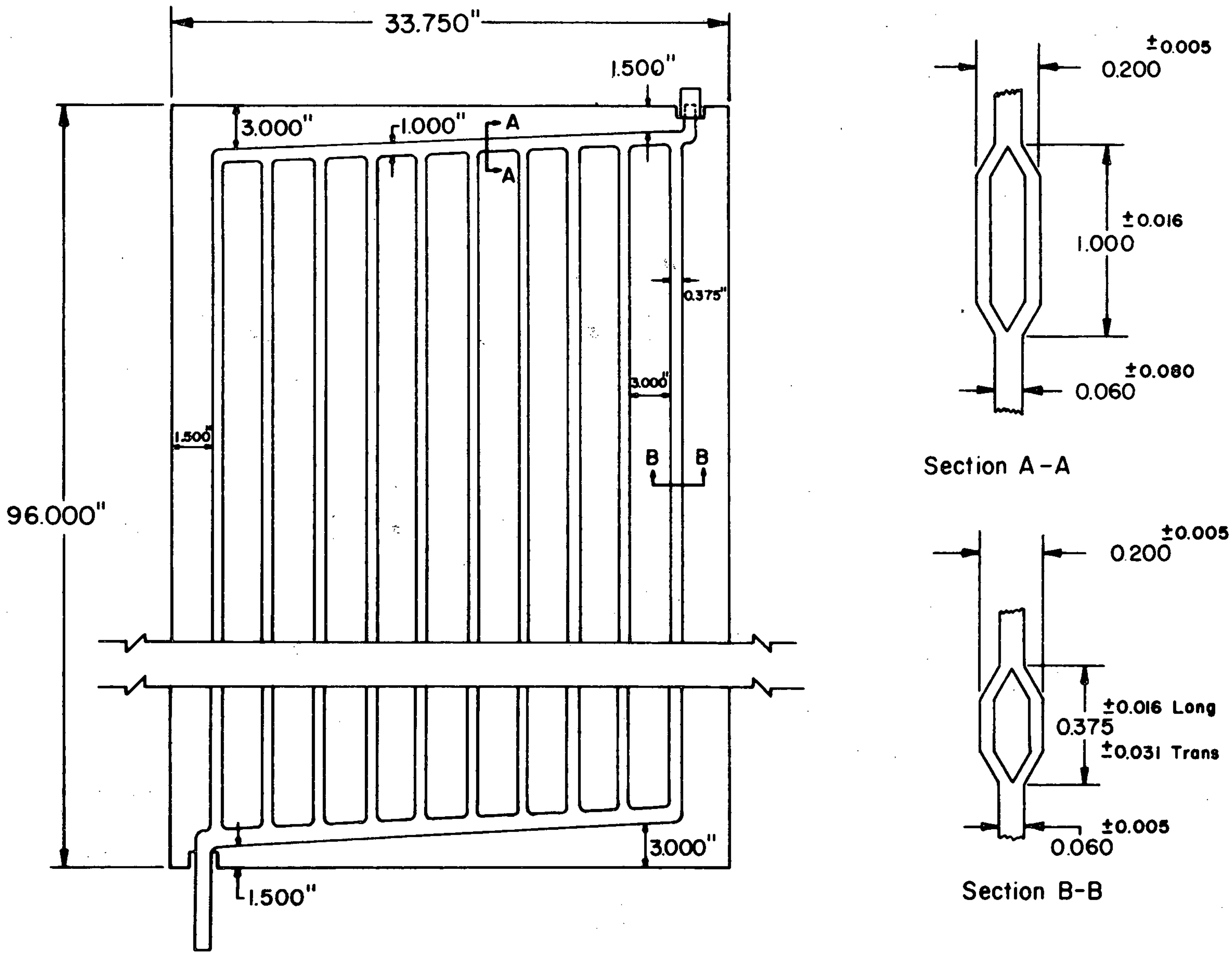


Figure 17

Absorber Panel Design

pattern of parallel flow in multiple straight tubes between internal sloping manifolds. A flat-black "Nextel" R acrylic coating was baked on the aluminum surface at a temperature of 200°C (400°F). The insulation consists of 2.54 cm (one inch) unbonded glass fiber mat on a 3.81 cm (1.5 inch) "Fesco-Foam" R composite insulation. The overall insulating factor was computed to be $R = 10.7 \frac{°Cm^2}{w}$ (18.8 Hr-ft^2-°F/Btu).

Each sixteen foot section contains six sheets of glass and two absorber panels. The glass sheets measure 0.86 m (34 in) wide by 1.37 m (54 in) long, and are separately supported in the collector by a butyl caulking tape resting on an aluminum structural angle-iron. The absorber panels each measure 0.9 meters by 2.4 meters (3 feet by 8 feet), and are connected in series as shown in Figure 18.

A particular advantage of the ROLL-BOND aluminum absorber plate is its availability with preformed internal tubes. Thermal conductivity between the plate surface and the fluid circulated through the tubes is therefore maximized. In addition, there is an exceptional versatility in tube pattern design. Finally, panels were readily available at costs of $6.50 to $8.50 per square meter ($0.60 to $0.80 per square foot) in 1974.

Selection of a tube pattern (see Figures 17 and 18) is based on two concerns: drainage and rate of flow (which affect heat transfer rate and pressure drop). Provision for drainage of the solar collector during non-daylight hours can alleviate freezing problems and eliminate heat loss from the water in the collector at night.

The rate of flow was designed to produce a maximum temperature rise of 8°C (15°F) in the heat transfer fluid as it passes through the collector. At a solar radiation level of 950 watts/ m^2 (300 Btu/hr-ft^2), and a solar collector efficiency of 40 per cent, this temperature increase is achieved at a flow rate of 3.78 liters/min (1 gpm) per panel. Thus for all sixteen

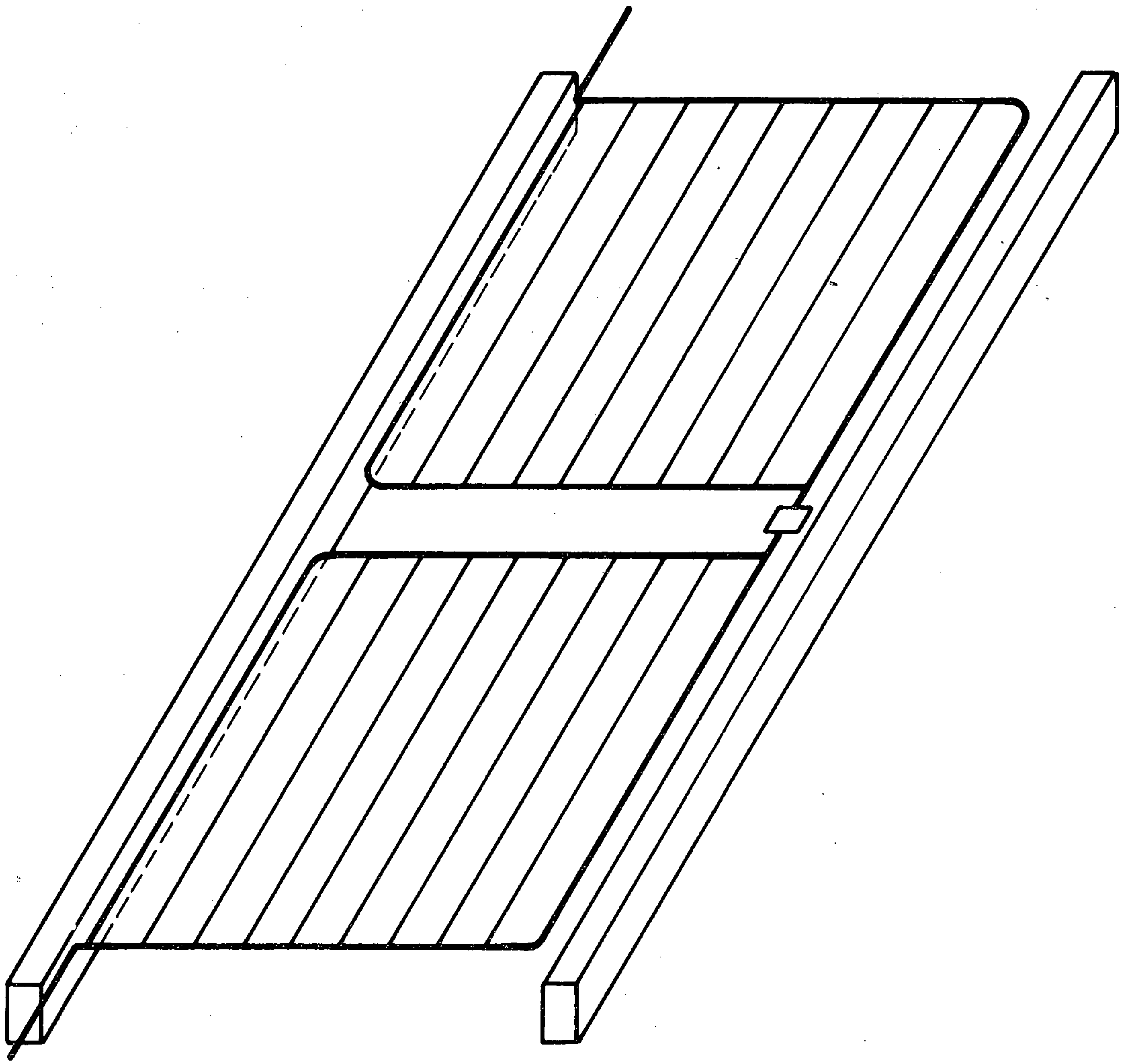


Figure 18

Collector Section Tube Pattern

panels, the total flow to and from the collector is 60.5 liters/min (16 gpm).

The aluminum absorber plate is coated with a flat black, high absorptivity paint. The 3M Nextel [R] black coating has a total reflectance (3 to 35 microns) of less than two per cent. Application of the paint required a thorough cleaning of the absorber plate, the use of a primer, painting, and subsequent baking at 200°C (400°F) to prevent any possible off-gasing of the paint when the collector became operational.

Several panels of the Colorado State University solar collector contain glass treated by Honeywell, Inc. to reduce reflection losses (normally 8 per cent at normal incidence for glass with a refractive index of 1.5). Treatment was accomplished by a process originally developed by RCA, requiring dipping the glass in hydrofluosilicic acid. The surface should be durable inasmuch as glass treated 15 years ago by this process and exposed to the weather since then shows 96 per cent solar transmission.

Of the sixteen sections in the solar collector, four contain glass which has been treated to reduce the reflection loss from 8 per cent to approximately 5 per cent. In addition, five sections contain glass that was partially treated (reducing reflection loss from 8 per cent to about 6 per cent). The remaining sections, with one exception, contain untreated glass. A special section contains two layers of glass having an infrared reflective coating on the interior surface of each piece of glass (supplied by Libbey-Owens-Ford). The purpose of the coating is to reflect the infrared reradiation from the absorber panel back to the black surface. During the period covered by this report, two layers of infrared reflective glass were used, but excessive solar absorption in the coatings showed the desirability of later substitution of ordinary glass for the top layer of treated glass.

Experience has indicated that imperfections in the edge of the glass, such as small chips or rough cut surfaces, have a strong tendency to cause cracking and subsequent breaking in the interior glass sheets due to thermal stressing. Consequently, the edges of each sheet were sanded along the entire perimeter to remove these slight imperfections. In addition, glass that was chipped in shipping or handling was discarded. However, one panel was loaded with glass that contained some chipped edges as a comparison check.

Each sheet of glass was supported on all four edges by structural aluminum, and held in place by an adhesive butyl rubber tape. A primer improved adherence of the butyl tape to the aluminum. Adhesion to the glass, however, was insufficient to prevent creep of the interior glass at temperatures over 120°C (250°F). Glass movement in a test panel at a 45° tilt amounted to about 20 cm (8 inches) over a period of three days. Small braces were therefore added to the cross bracing to prevent subsequent creeping.

While some of the structural aluminum was cut and preassembled in the shop, the main components of the collector were assembled on the subroof. Aluminum channels were first laid down and bolted to the subroof. Small teflon strips were inserted at each bolt connection to allow for differences in the thermal expansion between the aluminum collector and wood subroof. Each collector panel was then assembled one at a time.

Insulation was first placed between the aluminum channels, and the absorber panels were then laid on the top surface of the insulation. Rectangular aluminum tubes with L-shaped ledges were then bolted to the channels. Plumbing connections between the panels and the manifolds were made. Adhesive butyl tape was attached to the aluminum structural components, and each sheet of glass was then set in place. Aluminum cap strips were then secured to the rectangular tubes, and with butyl tape between the glass and the strips, watertight closure was effected.

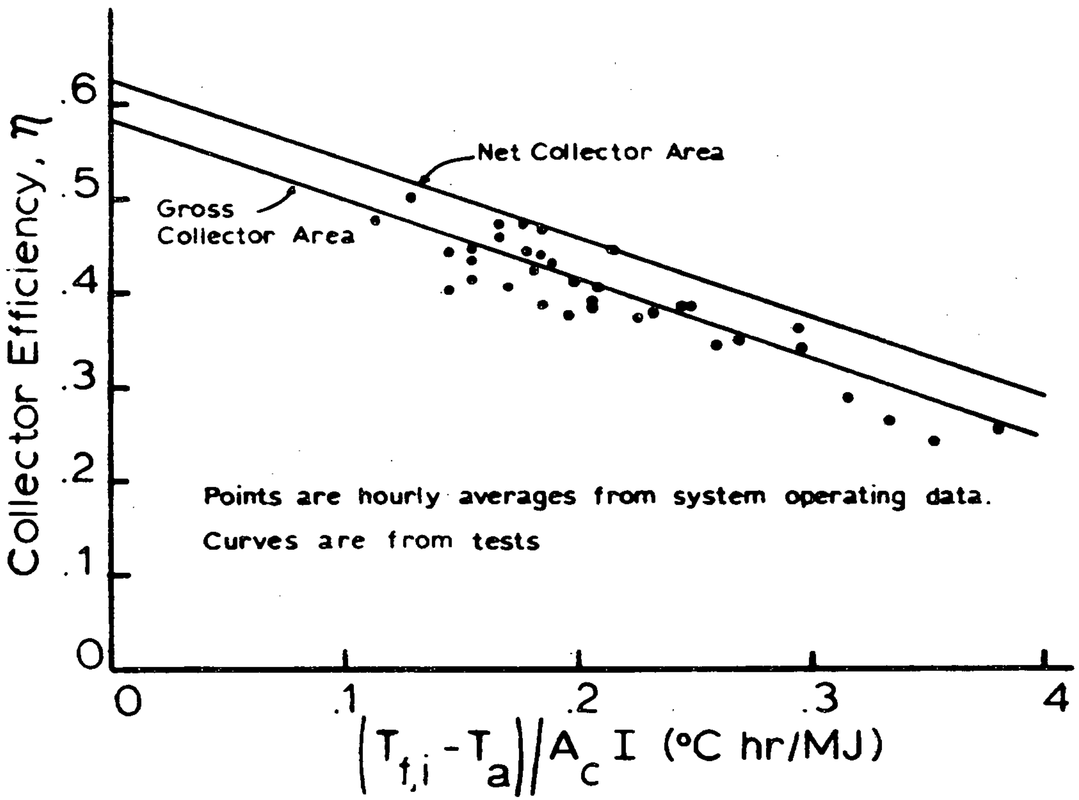
On-site collector construction involved high labor requirements. In addition to bad weather considerations, glass handling on a steep roof, working across a one-meter span on a partially completed panel, and the movement of tools and personnel to and from the subroof added considerably to the labor costs of the project. Prefabricated collectors (not available at start of project) are considerably more cost-effective.

One advantage of the particular installation method was the venting capability. As each of the collector sections was completed in place, its ends were left open. Natural convection through the panel thus prevented excessive temperatures in the collectors during installation. The ends were then closed following start-up of the collector pumping system.

Thermal Performance Characteristics

Collector Efficiency - Collector efficiency as a function of temperature and incident solar radiation was experimentally determined by operation of a collector test module. The results are shown in Figure 19. Efficiency is plotted against $\Delta T/H_R$, where ΔT is the difference between the temperature of the inlet water to the collector and the ambient air, and H_R is the incident solar radiation on a 45° tilted surface (normal to the collector). Wind speed was less than 1 Km/hr. The efficiency is defined as the useful energy delivered divided by the incident solar radiation.

Typical operating conditions involve a temperature difference of 50° to 55°C and an incident radiation of 750 to 900 watts/m^2. These conditions provide an effective operating range of $\Delta T/H_R$ = 35°C m^2/Kw to $\Delta T/H_R$ = 27°C m^2/Kw, corresponding to a collector effiency of 27 to 35 per cent. However, this instantaneous collector efficiency is obtained under



Performance of CSU Solar House I Collectors

Figure 19.

steady-state conditions and is not representative of typical operation in a house heating system. A more useful measure is the mean daily collector efficiency defined in two ways. η_D is the total daily useful energy delivered to load (or thermal storage) divided by the total measured incident solar radiation during the full day, H_R; η_{DO} is the total daily useful energy delivered to load (or thermal storage) divided by the incident solar radiation received during the operating hours of the collector.

Table 27 shows the mean monthly values of daily efficiency and the daily efficiency (during collector operations) for the period 1 September 1974 through 31 August 1975, as well as total daily solar radiation and radiation during collector operation. Although daily efficiency based on solar energy during operating hours was fairly constant, month-to-month, efficiency based on daily total radiation varies considerably. Most of the differences in the latter set of figures are due to variation in periods of collector operation, caused in turn by large variations in heat demand (very little energy is needed in April-May, and September-October), and by seasonal changes in storage temperature, atmospheric temperature, and hours of sunshine.

Efficiencies of 30 to 35 per cent when operating, and 20 to 25 per cent based on total daily solar radiation, may appear lower than expected of a well-designed double-glazed collector. But these levels are satisfactory at the average temperatures of operation which usually prevailed. During the summer, mainly for air-conditioner operation, storage temperatures equaled or exceeded 80°C most of the time, so ($T_{in} - T_{ambient}$) usually exceeded 60°C (108°F). The high percentage of seasonal heating load carried by solar (87 per cent) and the fact that 100 per cent of the load was met by solar until 18 December, were possible because of

Table 27. Mean Monthly Averages of Daily Collector Efficiencies

Month	Average η_{DO}	[1]Average H_{RO} (MJ/day)[3]	Average Ambient T_{AO} (°C)	Average Storage T_{SO} (°C)	[2]Average η_D	[2]Average H_R (MJ/day)[3]
September	31.5	792	16.4	72.0	22.5	1106
October	20.4	589	13.4	73.9	21.2	849
November	31.2	490	3.7	63.6	19.6	780
December	33.3	688	2.4	50.0	23.8	967
January	33.0	745	2.9	46.3	24.6	999
February	36.9	849	2.9	48.7	24.6	1274
March	34.5	827	6.2	53.8	18.9	1395
April	32.3	715	10.5	65.1	15.2	1513
May	35.9	511	15.6	65.1	15.0	1217
June	34.3	580	22.9	70.0	14.5	1375
July	22.9	999	29.4	77.1	15.6	1474
August	27.2	786	26.3	74.3	15.0	1429

[1]Includes solar radiation only when collector is operating

[2]Includes days when collector did not operate at all

[3]Total MJ/day on a 71.3 square meter solar collector surface

relatively high storage temperature (usually above 50°C). Collector efficiency was limited by the elevated temperature, and adequate for the requirements. The self-regulating effect of temperature on efficiency is clearly evident - ample heat in storage causes a reduction in collection efficiency because of high collector inlet temperature. This efficiency decrease is not a penalty, however, because it occurs when high collection is not needed and, in fact, not usable.

Pressure Drop Through Collectors - The pressure drop through the collectors was determined by calculation and by experimental confirmation of the pressure loss through a single absorber panel. Because of the varying flow rate through the collector (due to viscosity changes caused by temperature variations), the pressure drop varied over a considerable range. An equation was therefore developed, relating flow rate, pressure drop, density, and viscosity. Utilizing this calculated relationship, and the density and viscosity relationships of the collector fluid, the pressure drop due to friction across one absorber panel as a function of liquid type and liquid temperature was obtained. The correlation is shown graphically in Figure 20.

Thermal Loss Coefficient - Thermal loss coefficient as a function of the difference between the ambient and absorber plate temperature for no wind conditions was determined experimentally to be: $U_L = 4.2\ w/m^2\cdot°C$, where the area is the overall dimensions of the collector and the temperature difference is the average plate temperature minus ambient temperature.

Lifetime Performance Characteristics

Corrosion - The metals and alloys in the solar collector liquid circuit consist of aluminum solar collector absorber plates, aluminum manifolds, copper pipe, a brass heat exchanger, and an iron-bronze pump.

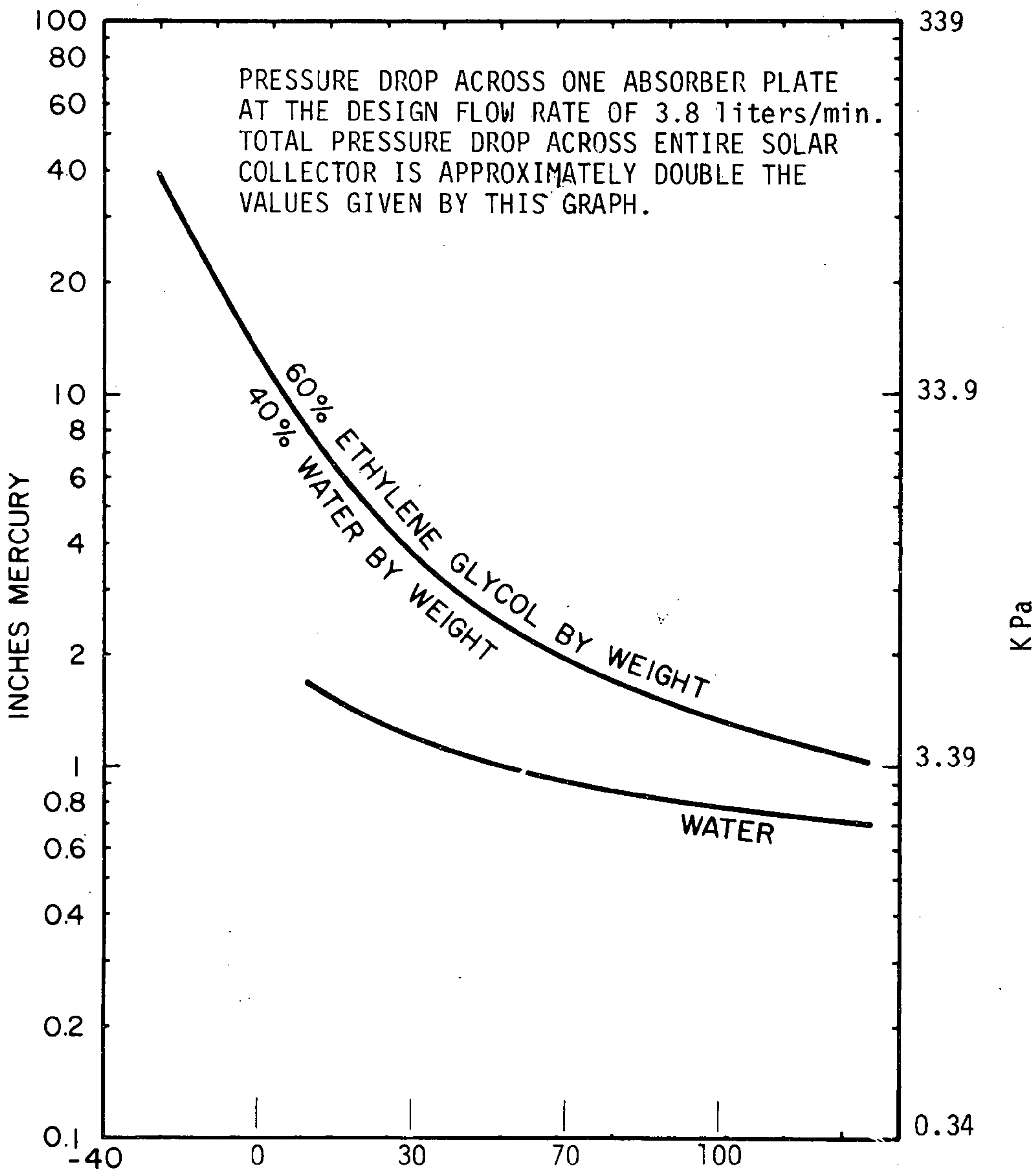


Figure 20. Pressure Drop Due to Friction Across One Absorber Plate as a Function of Liquid Type and Liquid Temperature

In order to reduce corrosion, the heat transfer fluid design velocity should be less than two to three feet per second. The CSU design velocity is about one foot per second.

The manufacturer of the ethylene glycol (antifreeze) recommends at least a 33 per cent concentration for protection against rust and corrosion. A corrosion inhibitor specially recommended by the manufacturer (Continental Oil Company) for use in cooling systems containing aluminum is an additive to the ethylene glycol antifreeze solution. Sixty weight per cent of ethylene glycol (50 per cent by volume) affords the maximum antifreeze protection (-52°C or -62°F), and this concentration raises the boiling point by 10°C (18°F). Although a solution of less than 60 per cent concentration could have been used in the CSU solar collector loop with adequate antifreeze protection, it was judged desirable to have the higher boiling point possible with this concentration.

Dielectric Pipe Connections - To minimize the possibility of galvanic corrosion of the aluminum absorber panels, non-conducting, neoprene rubber radiator hose was used as connectors between absorber panels and aluminum manifolds and between manifolds and the copper piping in the collector liquid circuit. Hose clamps were used at all these connections.

Filtration - Aluminum can be severely pitted by galvanic corrosion in the vicinity of small metal particles (copper, brass, iron) that might be carried into the collector by the circulating liquid. To prevent this attack, all of the liquid passing through the collector loop is continuously filtered. The filter cartridges used removed particles as small as 50 microns, with a corresponding pressure drop of 14.5 KPa [at a flow rate of the ethylene glycol-water mixture of 60.5 liters/minute, at a temperature of 96°C]. The pressure drop across the filter appears to vary inversely with the diameter of the smallest particle size removed.

A fine filter cartridge was used first. While the flow rate appeared to be satisfactory initially, it eventually dropped to an unacceptably low value due to plugging. The material causing the plugging appeared to be impurities in the antifreeze used.

A medium filter cartridge was then installed and also performed satisfactorily for a time. After it became plugged, it was replaced by the coarse filter cartridge which has remained in service for over 9 months.

Getter - Heavy metal ions (copper, iron) that may be dissolved in the circulating fluid can react with aluminum by displacement of the aluminum and deposition of the other metal. In order to minimize this action in the collector, an ion "getter" is installed in the piping between the filter and the collector. The "getter" is a coil of aluminum window screen placed inside a 5.1 cm (2 inch) diameter radiator type rubber hose. The only metal between the getter and the aluminum solar absorber plates is aluminum. Reaction between dissolved copper ions and the fine aluminum wire is expected to provide protection for the collector.

Composition Monitoring - So that corrosive conditions, such as organic acids, can be prevented in the collector fluid, periodic chemical analysis of the solution is performed. Measurement of pH, aluminum ion, and heavy metal ion content is made at suitable intervals. No hazardous conditions have been encountered, but several solution replacement have occurred for various reasons.

Corrosion Summary - In the total period of operation, no evidence of corrosion of the collector or any other components has been observed.

Leakage - There has been no apparent leakage of the collector heat transfer fluid from the collector array. Slight cover glass leakage, however, has allowed rain and melted snow to enter the collector occasionaly, without damage.

Hot Spots - Prevention of hot spots is accomplished by good flow distribution through the collector array and through the individual absorber plates. Quantitatively uniform flow is accomplished by ensuring that the head loss due to friction across the solar collector header and riser tubes (ΔH) is significantly greater than the total head loss in either header, top or bottom (Δh), i.e., the ratio of $\Delta h/\Delta H$ should be small (<0.1).

The value of $\Delta h/\Delta H$ for the CSU solar collector array is approximately 0.04 for a flow rate of one liter per second (16 gallons per minute) of water at a temperature of 95°C (203°F). The value of $\Delta h/\Delta H$ for a 60 per cent ethylene glycol solution is less at the same temperature because Δh will increase less than ΔH. Calculations show that the flow in the middle collector section will be 99 per cent of the flow in the two end sections, which is the maximum possible difference in flow rates between units (the end collector sections will have the same highest flow rates).

Experimental efforts show that the flow distribution in the CSU solar collector is quite uniform, with deviations of less than 0.5 per cent. The average outlet temperature for each section as 94°C, with the greatest variation of the observed collector outlet temperature being 94.3°C, indicating equal flow distribution in all collector sections.

Flow Distribution in the Absorber Plate

Experiments were conducted with the absorber plate in order to determine its flow distribution experimentally. At a flow rate of 3.8 liters per minute (through one absorber plate, corresponding to the design flow rate of 60 liters/minute through the entire collector) at 81°C (178°F), the ratio of the head loss in one header (Δh) divided by the total head loss across the absorber plate (ΔH) is about 0.1. This implies that the driving head across the middle tubes is about 91.7 per cent of the driving head across the end tubes. Therefore, the flow rate through the middle tube is about 94 per cent of the flow rate through the end tubes.

In addition to the above tests, a thermal infrared scanner (AGA Thermovision 680/120B) was used to photograph the temperatures of the entire absorber plate at the same time. Color photographs were made of the bottom, middle, and top (flow was from the bottom to the top; the absorber plate was mounted vertically) as 81°C (178°F), 60 per cent ethylene glycol solution was pumped through the absorber plate at the rate of 3.8 liters/minute (1 gpm), and allowed to radiate heat to the room. The photographs showed an approximately equal flow distribution and, in addition, that the manifold was considerably hotter than the surrounding absorber plate area (including the tubes), indicating an efficient energy collection by this manifold without excessive heat losses.

Breakage - Glass breakage during the installation of the collector involved only one plate out of a total of ninety-six installed. Breakage during the approximate two years of collector operation has been limited to one lower glass cover, located in the middle section of the easternmost collector section. The breakage consists of one long crack which has caused no noticeable difference in collector operating efficiency.

Stability of Collector Working Fluid - Periodic tests were conducted to identify possible corrosion, including measurements of pH and conductivity and an atomic absorption analysis of the collector fluid. These results are shown in Tables 28 and 29. The initial high concentrations of zinc were probably due to the fact that the aluminum absorber panels had connections brazed onto the panels, and the brazing was the source of the zinc concentration.

Table 28. pH and Conductivity Measurements

Date	23 October 1974	15 December 1974	5 May 1975	Control Sample
Temperature	45°C	24°C	21°C	23°C
pH	8.74	8.50	9.10	8.80
Conductivity (using K=0.1 cell)	3600 $\frac{mhos}{cm}$	2000 $\frac{mhos}{cm}$	—	2500 $\frac{mhos}{cm}$

Table 29. Atomic Absorption Analysis of Collector Fluids

Sample	Results - Micrograms/liter of			
	Aluminum	Copper	Iron	Zinc
1	0.7	190	460	26
2	0.3	44	110	870
1*	-	-	300	85
2*	-	-	150	237
3*	-	-	152	153

Sample 1 is a new solution made up of 60% ethylene glycol and Fort Collins tap water for collector control (2/6/75)

Sample 2 is a composite of five 100 ml samples of collector fluid, taken over a period of 25 minutes (2/6/75)

Sample 3 (same composition as Sample 2, and taken on 3/6/75) [no analysis performed until 4/11/75]

*Additional analysis on 4/11/75

HEAT TRANSFER SUBSYSTEM

Description of Physical Configuration

Working Fluids - Fluids in the heat transfer subsystem are an ethylene-glycol/water solution in the collector loop and water (with corrosion inhibitor) in the thermal storage unit, and heat exchangers (see section on Thermal Energy Storage Subsystem).

In the collector loop the heat transfer liquid is an aqueous solution of 60 per cent ethylene glycol, by weight.

Circulating Pumps - The circulating pumps are all 1750 RPM centrifugal type with direct-coupled motors. The hot water preheat and cooling tower pumps are of standard manufacture. The other pumps in the system were adapted to specific pressure (head) versus flow rate requirements. This was accomplished by using pumps slightly larger than needed and reducing (trimming) impeller diameters to obtain the exact specifications.

Heat Exchangers - For liquid-to-liquid heat exchange without mixing of the liquids, shell-and-tube type heat exchangers were selected, with single-pass, counterflow design; the single-pass counterflow arrangement allows the temperature difference between fluids to be nearly constant along the exchanger. This feature results in a relatively small temperature loss across the exchanger. The collector heat exchanger is made up of two units in series because a single unit of sufficient length was unavailable.

The single-pass design involves multiple parallel tubes and a relatively high pumping rate to develop turbulent flow in the tubes. On the storage side of the collector heat exchanger, a flow rate of 95 liters per minute (25 gpm) is obtainable with modest pump power because resistance in that loop is low. The high flow rate does, however, nearly eliminate temperature stratification in the storage tank. Highly stratified storage temperatures would thus come at the cost of a larger exchanger or a higher temperature loss.

Air Duct Coils - Solar heating requires a larger air duct coil surface than does auxiliary boiler heating. The increased size is due to the lower temperatures from solar storage (65°C design temperature down to as low as 25°C) compared with the boiler water at 90°C. The air duct coil size required for solar heating was thus selected and the same size coils were obtained for both solar and auxiliary because of easier installation and smaller air pressure loss with the identical coils. The coils consist of copper tubes with aluminum fins housed in a 50 by 56 cm (20 by 22 inch) duct section.

Other System Components

Domestic Hot Water and Solar Preheat Tank - An automatic gas-fired hot water heater acts as the auxiliary heater for domestic hot water. It is a 40 gallon (150 liter) glass lined tank with 35 gallon per hour recovery rate at 100°F temperature rise (132 liters/hour at 55°C ΔT). The rated output is 39.8 MJ/hr (42,000 Btu/hr).

The hot water solar preheat tank is a standard insulated 80 gallon (300 liter) glass lined electric hot water heater with the heating element and control non-operational.

Auxiliary Hot Water Boiler - The hot water boiler is a stock manufactured unit for domestic hot water heating systems. It was selected to provide the full heating and cooling requirements of the building when no solar heat is in storage. The boiler is gas-fired with a rated input of 85.3 MJ/hr (90,000 Btu/hr) and output of 68.2 MJ/hr (72,000 Btu/hr). At the 1585 meters (5200 feet) altitude of Fort Collins, corresponding ratings are 68.2 MJ/hr (72,000 Btu/hr) and 54.6 MJ/hr (57,600 Btu/hr), respectively.

Heating System Performance

Heat losses from the solar components during the heating season contribute to the supply of heat for the building. Thus the solar contribution to the heating load (space heating and hot water) is equal to the useful energy delivered from the solar collector to the thermal storage unit. Tables 4 through 16 show the solar and auxiliary heat supplied for space heating during the period 1 September 1974 to 31 August 1975. Prior to 18 December 1974, solar provided 100 per cent of the heating load. Gas usage is seen to be primarily during periods of high heat demand, and only on twenty-three days did it have to supply more than half the total requirements. There were no days during which fuel supplied the full load.

An important influence on the auxiliary energy required by the heating and cooling system is exerted by the operating characteristics of the auxiliary gas boiler. Previously the control instrumentation required the maintenance of a preset temperature in the boiler. Gas required simply for this temperature maintenance can be a significant portion of the total usage because of limited fuel heat demand (auxiliary heat was required only 20 days out of 123 during the period 1 October 1974 to 31 January 1975). The principal heat loss from the boiler is to air continually rising through the hot boiler tubes to the stack and outdoor atmosphere.

The boiler in CSU Solar House I was found to require, for temperature maintenance only, 3400 liters (120 cubic feet) of gas per day when thermostatted at 88°C (190°F) (cooling season) and 2300 liters (80 cubic feet) of gas per day at a setting of 65°C (150°F) (heating season). During the month of August the requirements of a "hot boiler" accounted for more than 5 per cent of the total gas volume utilized. In the first half of the heating season (1 September to 31 January), the hot boiler condition required 6330 MJ out of a total gas usage of 9480 MJ; i.e., two-thirds of the gas usage was for maintaining boiler temperature.

THERMAL ENERGY STORAGE SUBSYSTEM

Description of Physical Configuration

The thermal energy storage system consists of 4275 liters of water in a steel tank. The storage tank was fabricated from 16 gauge (1.5 mm) galvanized sheet steel. Seams and pipe connections to the tank are arc welded. A 60 cm (24 inch) diameter manhole in the top of the tank allows complete access to the inside. Each piping connection on the tank is provided with a shut-off valve and a neoprene hose connection to the copper piping. The tank is electrically isolated from all other plumbing components to prevent electrolytic corrosion of the tank.

The specification of the storage tank are:

Diameter	1.67 meters	(5.5 feet)
Height	1.82 meters	(6.0 feet)
Height of top cone section	.27 meters	(0.9 feet)
Volume	4275 liters	(1131 U.S. gallons)
Weight empty	213 kilograms	470 pounds
Weight filled	4374 kilograms	9644 pounds

Corrosion Control - Table 30 shows the composition of the corrosion inhibitor used. When added to distilled and/or demineralized water, the resulting pH of the aqueous solution should be between 7.5 and 8.0.

Insulation on the storage tank consists of two layers of bonded glass fiber double-faced batt insulation having an R factor of 17.7 $\frac{°Cm^2}{W}$ (30.4 $\frac{Hr\text{-}°F\text{-}ft^2}{Btu}$). Measured heat loss greatly exceeded this specified

Table 30. Compositon of Corrosion Inhibitor

Ingredient	Per Cent by Weight
Mercaptobenzothiazole (technical grade, 92 per cent min)	15.1
Sodium borate decahydrate, $Na_2B_4O_7 \cdot 10H_2O$	75.7
Disodium phosphate anhydrous $Na_2H\ PO_4$	9.2
	100.0

rating, probably because of air circulation between insulation and the tank wall. Subsequent to the period of this report, the glass fiber batts were replaced by a sprayed-on cellulose insulation.

Thermal Performance Characteristics

The storage unit is located in the heated basement of the building where there is a mean temperature of the immediate surroundings of 20° to 22°C (68° - 72°F) during the entire year. Thermal losses are therefore dependent almost entirely upon the storage tank temperature. These losses are discussed in the section on Energy and Mass Balances.

The storage capacity is 4275 liters of water. For a temperature range of 25°C to 95°F (78°F to 203°F), storage of 1090 MJ (1.15×10^6 Btu) is provided. The storage tank must operate at local atmospheric pressure, so the temperature is limited by the local boiling point of water (95°C 203°F).

AIR CONDITIONING SUBSYSTEM

Description of Physical Configuration

The cooling subsystem selected for CSU Solar House I is an ARKLA-Servel 3-ton, lithium bromide absorption air-conditioner, modified to utilize hot water (instead of natural gas) as the heat supply to the generator. The ARKLA gas-fired unit was initially rated at 3.5 tons (39.8 MJ/hr). With solar heat supply, it is rated at 3 tons, 34 MJ/hr. A forced draft cooling tower is employed for cooling the water circulated through the condenser and absorber of the air conditioner.

Heat Rejection Method - In order to match the capacity of the ARKLA air conditioner, the cooling tower must have a capacity of about 85 MJ/hr (90,000 Btu/hr) with a 6°C (10°F) approach and a 10°C (18°F) range.

The unit chosen is a galvanized steel, asbestos-packed cooling tower with a nominal capacity of 8 tons (91 MJ/hr; 96,000 Btu/hr). The air fan is driven by a .45 kw (1/3 horsepower) electric motor. The tower is designed for water flow rates of 1.0 to 1.7 l/sec (16 to 27 gpm).

A Penn Aquastat electric fan control permits operation of the cooling tower fan only when required for a preset discharge water temperature. There are two conditions, both of which must be met, for the fan to operate. First, the ARKLA unit must be running, and second, the water temperature from the tower must be at least 24°C (75°F).

Thermal Performance Characteristics

Design Characteristics - The generator in a gas-fired ARKLA machine was replaced at the factory with one supplied by hot water entering at the bottom. With 38 l/min (10 gpm) of cooling water at 24°C (75°F), a hot water supply of 42 l/min (11 gpm) at 87°C (188°F) will provide the full

3-ton capacity (34.1 MJ/hr). At lower hot water temperatures, cooling capacity is lower, reaching 77 per cent at about 81°C (178°F). Design temperature limits for hot water supply are 80° to 95°C (175° to 202°F). The temperature inside the evaporator is in the range of 3° to 10°C (35° to 50°F) (direct expansion) with a normal operating temperature of 7°C (45°F). Performance data are presented in Figure 21. Operation at a temperature as low as 80°C is possible at this location because of a dependable cooling water temperature of 24°C rather than a usual cooling water design temperature of 30°C. While lower cooling water temperature permits a lower generator temperature, cooling capacity is not appreciably affected.

Because of cooling water temperature typically about 5°C (10°F) lower than even the reduced 24°C (75°F) design level, heat supply temperatures can be about 3°C (6°F) lower than usual. For effective operation at these conditions, the concentration of the lithium bromide solution has been reduced to 51 to 54 per cent, from the customary 54 to 57 per cent. Temperature-concentration diagrams show that crystallization cannot occur in the absorber or in the generator provided that generator input temperature does not fall below 80°C (175°F). Below this temperature vapor formation occurs at a rate too low for effective lifting of the LiBr solution in the bubble pump, so after a time, the concentration in the generator could increase to the crystallization point. The generator is therefore always provided a heat supply at a temperature no lower than 80°C (175°F).

The unit has been modified also by the installation of a diverter valve for the cooling water to the absorber. The valve will divert (directly to the condenser) approximately 50 per cent of the cooling water when its temperature falls below 18.3°C (65°F). The valve remains

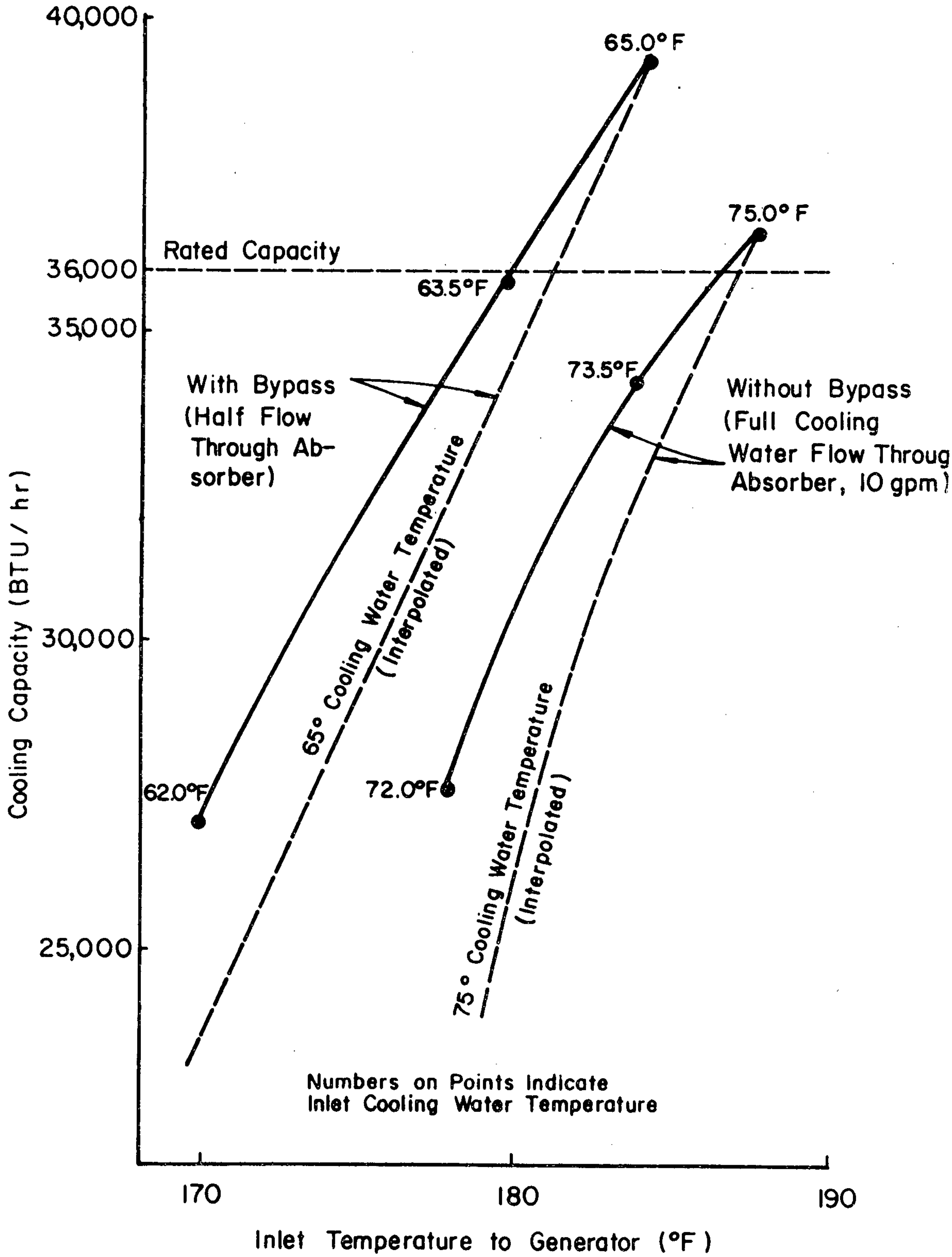


Figure 21. Measured Performance of ARKLA 3-ton Lithium Bromide Absorption Cooler

open until the cooling water temperature rises to 20.5°C (69°F), giving an effective dead band of 2.2°C (4°F). The effect of the bypass valve is an increase in the capacity of the cooling unit by approximately 2.8 MJ/hr (3000 Btu/hr) at the design generator temperatures. However, this advantage is lost when the input temperature to the generator is near its lower limit.

These modifications permit advantage to be taken of prevailing low wet bulb temperatures and, consequently, allow an increase in capacity over most of the range of generator temperatures. The location of the Colorado State University solar house at 1585 meters (5200 feet) elevation puts an upper limit of 95°C (202°F) on hot water temperature (local boiling point) because a non-pressurized system is used.

As the air cooling capacity of the unit decreases at lower generator temperatures, dehumidification performance also declines. Operating at full capacity, the refrigerant finishes vaporizing at Point B (see Figure 22), thereby cooling the entire evaporator surface on which moisture condenses. At a lower generator temperature, the reduced quantity of the refrigerant finishes vaporization at a position such as Point C, so the condensate covers only the upper portion of the finned area. Air temperature reduction is then about 77 per cent of the full capacity, but about 10 per cent of the condensate formed on the upper portion of the finned area will re-evaporate as it flows down over the lower, uncooled area. The net result is an air cooling capacity of 77 per cent and a dehumidification capacity of about 65 per cent of rating.

Experimental Characteristics - Figure 23 shows the quantitites of solar heat and auxiliary heat delivered to the cooling unit during the month of August, 1974.

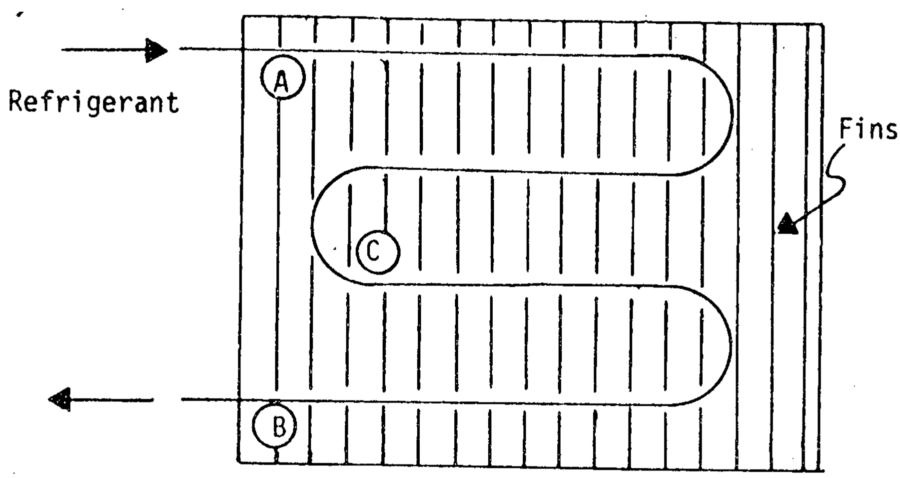


Figure 22. Evaporator Schematic

The cooling load of CSU Solar House I is not representative of typical home cooling loads because of the large number of people occupying and visiting the building. Approximately 3,000 persons visited the House during the month of August, so the percentage of this unusual cooling load carried by solar is of less significance than the quantity of solar energy provided for cooling purposes. Even more important is the cooling load carried by solar under various control procedures.

During the period 1-10 August, a two-stage control was utilized for selecting solar or auxiliary to meet the cooling load. One contact in the thermostat provided cooling by solar whenever the temperature in the building rose above 22°C (71.6°F) and the temperature of thermal storage exceeded 82°C (180°F). If the cooling demand could not be met, and the house temperature continued to rise above 23.4°C (74.1°F), fuel was then used to supply hot water to the air conditioner so that the full cooling load could be met even though the storage temperature exceeded the minimum required inlet temperature to the generator of the cooling unit.

This control system was modified on 10 August to provide solar cooling whenever the thermal storage temperature exceeded the minimum generator

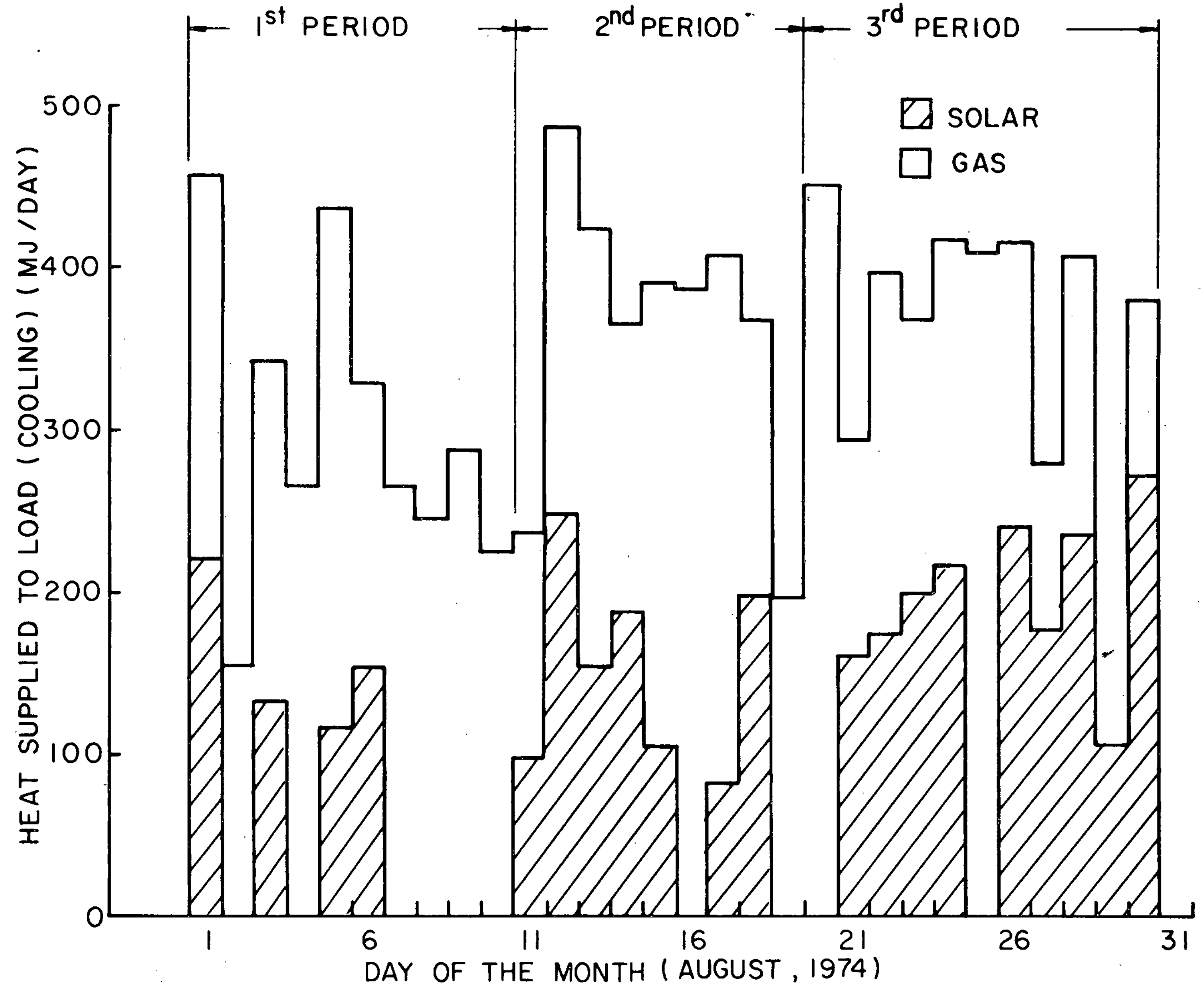


Figure 23. Relative Contributions to Cooling Unit by Solar and Auxiliary (August 1974)

inlet temperature (82°C, 180°F). The period of operation from 11-20 August shows the benefits (Figure 23) of the control instrumentation modification, by increasing the solar energy delivered to the cooling unit from 612.4 MJ to 1048.8 MJ. An equally important improvement was obtained during the last ten days in August by lowering the minimum generator supply temperature from 82°C (180°F) to 77°C (170.6°F). The increase in total solar energy delivered to the cooling unit as a result of the lower generator temperature requirement was 500 MJ (∿50 MJ/day). Table 31 summarizes the effects of the control system modifications.

Table 31. Relative Contributions to the Cooling Load by Solar and Auxiliary (August 1974) - Ten Day Totals

Time Span	* Cooling Gas	(MJ) Solar	Per Cent Solar Cooling	Q_U (MJ)
1 - 10 August	1011.8	364.7	26.5	2143.5
10 - 20 August	1442.8	745.8	34.1	2824.1
21 - 31 August	946.2	1192.2	55.8	3882.6
Total	3400.8	2302.7	40.4	8850.2

*MJ of heat removed from building by cooling unit (Heat delivered to generator of air-conditioner times coefficient of performance)

Because of the low humidity in CSU SolarHouse I, most of the operating data were obtained during periods when no condensation occurred on the cooling coils. Absence of dehumidification substantially reduced the coefficient of performance of the unit. This is to be expected, because in normal operation, a heat input of 56.5 MJ/hr (53,500 Btu/hr) produces sensible cooling of 28.5 MJ/hr (26,980 Btu/hr) and 10.6 MJ/hr (10,050 Btu/hr) of latent heat removal by condensation. But when the latent load is zero, the COP is thus reduced from 0.69 to 0.50. This "overfired" situation results in the failure of part of the refrigerant to vaporize in the evaporator, thereby flowing as liquid into the absorber.

The average COP of the cooling unit when on auxiliary heat supply was 0.48 (11-30 August). Of particular note, however, is the fact that when solar heat was supplied to the air-conditioner during the same period, an average COP of 0.70 was obtained. This higher value was due to a combination of a lower hot water flow rate to the generator when supplied from solar storage, and a lower average operating temperature of the storage unit compared with auxiliary heat supply temperatures. The heat input rate to the generator thus decreased from 56.5 MJ/hr (as in the case of gas-supplied heat) to 40 MJ/hr (average for solar), a heat rate which could normally be expected to deliver 32.3 MJ/hr of combined sensible and latent cooling (85 per cent of capacity). This heat removal rate nevertheless exceeds the 28.5 MJ/hr sensible cooling load. The reduced heat supply rate nearly matched the sensible heat removal requirements (condensation being absent), less heat was therefore wasted than when the design heat supply rate was provided, and a favorable solar COP of 0.71 (28.5 MJ/hr divided by 40 MJ/hr) was obtained. This value is in good agreement with the daily average solar COP of 0.70.

Because of the improved COP of solar cooling, the percentage of the cooling requirements (actual heat removed from the building) provided by solar is increased from 36 per cent to over 40 per cent. Figure 24 shows the cooling load met by solar and auxiliary during the month of August. Note also Table 31, which shows that under optimum conditions of the last ten days of August, solar supplied almost 56 per cent of the cooling requirements.

The change in the control instrumentation, whereby the inlet generator temperature was lowered (mentioned above), also had the effect of increasing

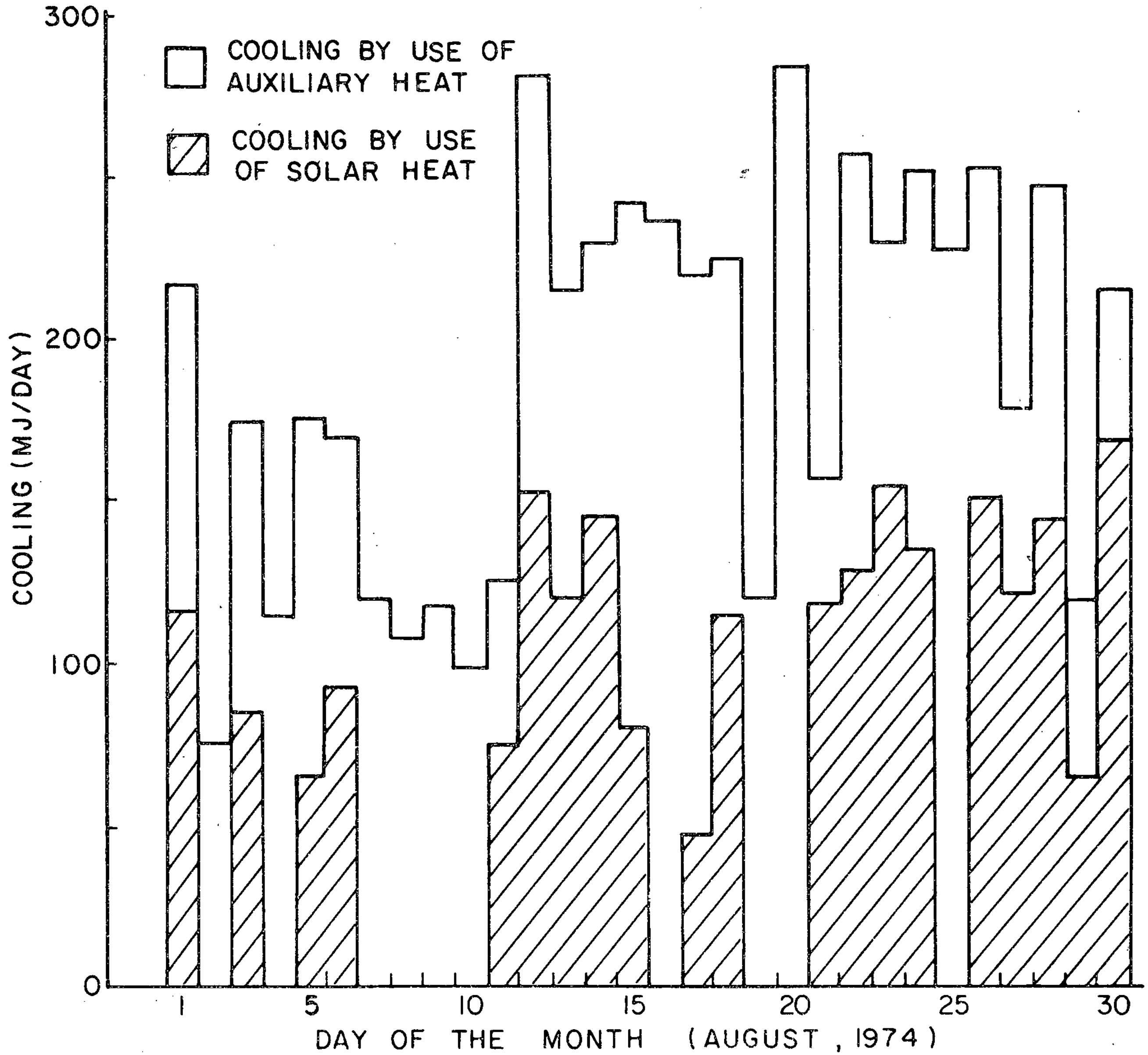


Figure 24. Relative Contributions to Cooling Load by Solar and Auxiliary (August 1974)

the COP from an average of 0.43 to 0.48 when operated by auxiliary. When solar-operated, the modification caused an increase in COP from 0.60 to 0.70.

A much more significant variation in the COP of the cooling unit is due to its operating characteristics, particularly during start-up. Figure 25 is an example of the manner in which cooling performance varies during a period of time. Point A represents the time at which the thermostat initially provides a cooling demand signal (when the absorption unit comes on). The gradual rise of the heat supply curve (Q_L) shows that the initial heat delivered is used partially to warm up the metals and liquids in the unit (prior to operation at normal cooling capacity) for a period as long as fifteen minutes. The delivery of full cooling output is also delayed, as shown by the Q_{CT}-Q_L and COP curves.

During days of high cooling demand, the air conditioner encounters these start-up conditions in the morning and then runs nearly continuously at a satisfactory COP. The loss of cooling during start-up is a small fraction of the day's total output, and the COP for the day corresponds to the design value. However, when cooling demand is low, the unit runs intermittently, and the numerous start-ups (as many as 40 in a 24 hour period) require heat to replace the thermal losses occurring during the non-running intervals. Without heat supply, the generator cools off in about ten minutes; so if it runs only ten minutes, the heat losses in one stop-start cycle result in a COP decrease from 0.60 to about 0.30. It is significant that the start-up heat is added to the building when the cooling unit shuts down, so the cycling of the absorption machine not only causes a lowering of the COP but also adds to the cooling load.

Inefficiencies resulting from intermittent operation of the air-conditioner could be greatly reduced by the use of cold-side storage.

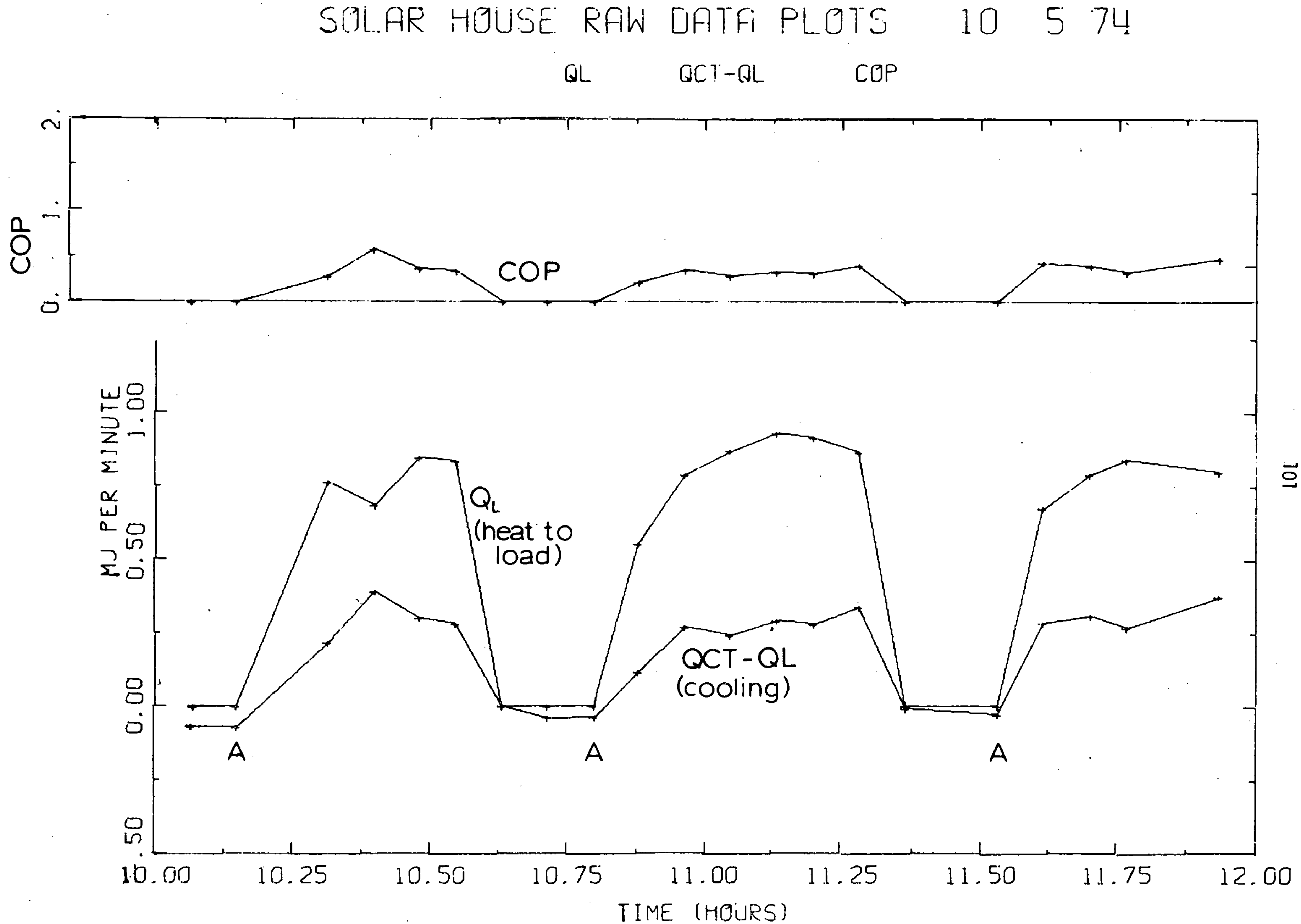


Figure 25. Coefficient of Performance and Cooling Rate versus Time of Start-Up for Absorption Cooling Unit

The absorption unit could be run continuously during the day so that waste of heat involved in frequent cycling could be avoided.

Additional cooling demands not normally encountered in conventional systems were imposed by the thermal losses from solar components. Measurements of losses from the solar thermal storage tank, for example, showed a rate of 0.04 MJ/hr·°C (approximately double that computed from reported properties of the insulation). During the month of August there was an average heat loss rate of 1.88 MJ/hr (1780 Btu/hr). This 45 MJ/day heat loss (1395 MJ/month) can be compared to the hourly sensible heat removed by the cooling unit (ranging from 22.8 to 28.4 MJ). The air-conditioner must therefore operate for almost two hours per day to remove the heat added to the house by leakage from storage.

Other heat losses, from the solar preheat tank (hot water system) of 0.492 MJ/hr (372 MJ/month) and from the surface of the auxiliary hot water tank, pumps, piping, and heat exchangers, added 2619 MJ to the cooling demand in August. Total heat losses from solar equipment aggregate 46 per cent of the total cooling demand of 5703 MJ. Had these losses been eliminated, solar heat would have provided 74.7 per cent of the cooling requirements. Figure 26 indicates the relative amounts of solar and gas heat which would be delivered to the cooling unit if these thermal losses were eliminated. Losses during the heating season do not appreciably affect auxiliary fuel requirements because the heat is utilized in heating the building directly.

Substantial progress in the reduction of these heat losses has been made in preparation for the next cooling season. These efforts are directed toward better insulation of equipment and the outdoor venting of excess heat from the heating and cooling system components.

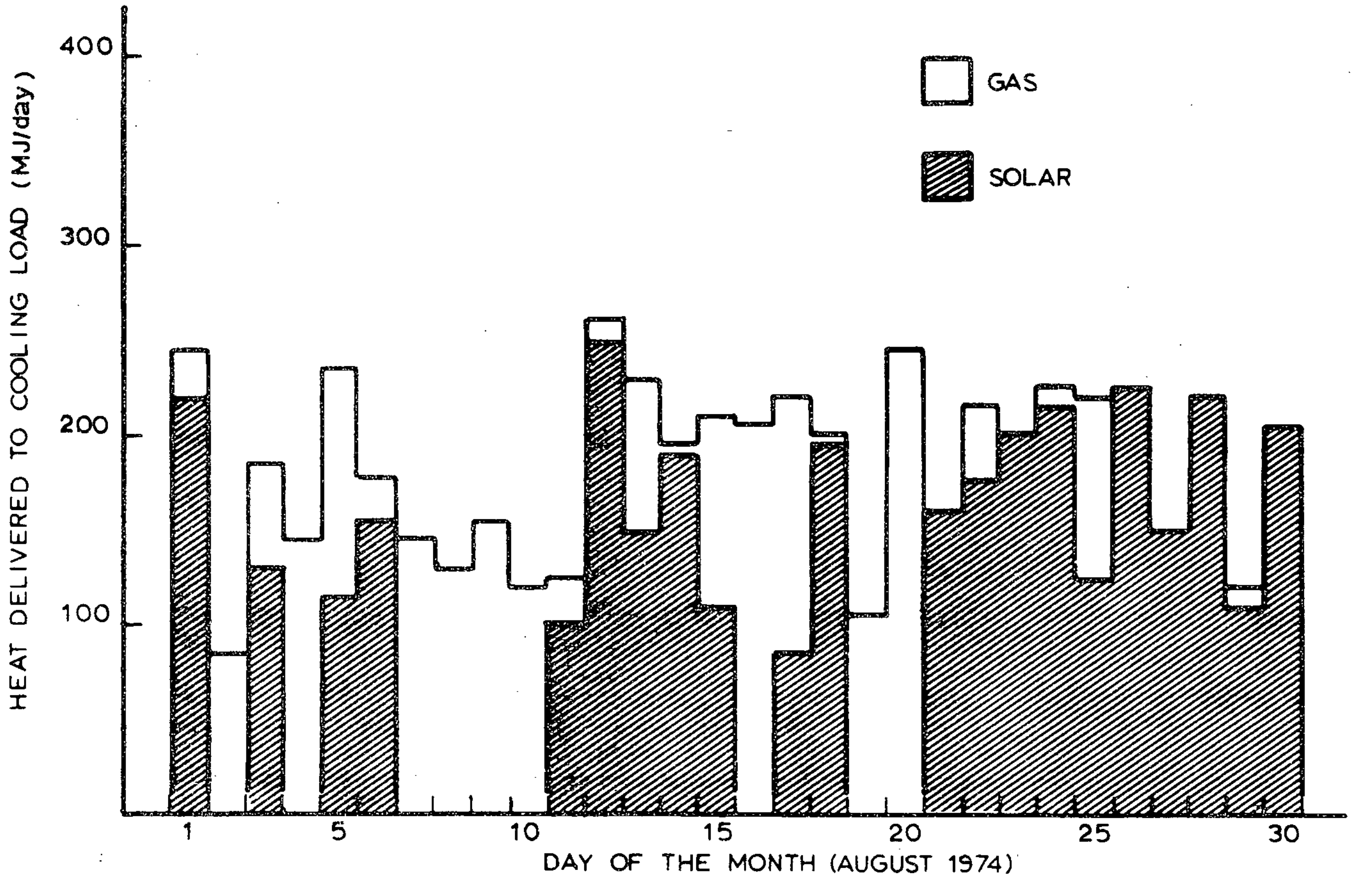


Figure 26. Relative Contributions to Cooling Load by Solar and Auxiliary (Normal Cooling Load Only)

Summary of Cooling Performance

Tables 4 through 16 provide values of daily energy totals delivered by solar and auxiliary to the space cooling load. Table 20 lists the per cent solar contributions to the daily energy requirements for space cooling. Numerous factors must be considered in order to evaluate these data.

These factors are summarized in Table 32, and will be discussed below. In Table 32, column [1] is the total heat delivered to the cooling machine by auxiliary and solar energy sources. It represents the total heat delivered to the cooling unit. Column [2] is the coefficient of performance (COP) of the absorption cooling unit. The COP is obtained by dividing the actual cooling (heat extracted from the building) by the total heat delivered to the cooling unit. Column [3] represents the total actual cooling of the building air (i.e., the heat extracted from the building); therefore COP equals column [3] divided by column [1].

The results of Table 32 indicate a COP during the cooling season of approximately 0.59. As pointed out above, however, there is the potential for a significant decrease in the cooling unit's COP under conditions of low cooling loads. For example, in September 1974, when the cooling load (heat extracted from the building) was only 132.4 MJ/day (down from a seasonal average of 221.6 MJ/day), the COP fell to 0.37. Similarly in October, the cooling load of 85.7 MJ/day yielded a COP of 40.8.

This lowering of the COP is due to the "warm up" time of the cooling unit (i.e., the time it takes to reach expected cooling performance from the initial input of heat to the generator). See Figure 25. When the cooling demand is low, the unit cycles on and off many times during the day, and the unit's COP drops drastically. In the day shown in Figure 25, the cooling unit cycled on and off 39 times, yielding a COP of 0.4.

Table 32. Monthly Averages of Cooling Values

Month	[1] Heat to Cooling Unit (MJ/day)	[2] COP	[3] Total Cooling Load (MJ/day)	[4] Total Imposed Load (MJ/day)	[5] "Revised" Cooling Load (MJ/day)	[6] Total Cooling by Solar (MJ/day)	[7] Per Cent Cooling by Solar	[8]	[9]
							Solar Heat to Cooling Unit ÷ Column [1]*	Column [6] ÷ Column [3]	Column [6] ÷ Column [5]
June	310.8	0.59	182.3	103.4	78.9	33.9	12.3	18.6	43.0
July	380.1	0.66	252.3	97.5	154.8	100.2	34.3	39.7	64.7
August	430.2	0.54	230.2	90.2	140.0	72.3	28.2	31.4	51.6
Season	373.7	0.59	221.6	97.0	124.6	68.8	25.9	31.0	55.1
7/10 - 8/7 **	—	—	191.3	85.2	106.1	86.1	—	—	81.1

** Special period during which cooling unit was not allowed to run at night

* Derived from Table 16 and based on solar heat supply to the generator

The per cent cooling by solar (column [7]) is calculated by dividing the total heat delivered by solar to the cooling unit (see Tables 13 through 16) by the total heat (solar and auxiliary) delivered to the cooling unit, column [1]. However, the COP of the absorption cooling unit, when operated by solar was normally higher ($\sim$0.71) than the corresponding COP for the auxiliary ($\sim$0.50); again, due to a low latent cooling load at the CSU Solar House I site. With this difference in COP, we can consider a per cent cooling load by solar as the total cooling (heat extracted from the building) by solar, column [6]; divided by the total cooling load, column [3]. This yields an increased per cent load by solar of 25.9 to 31.0 per cent.

Another significant factor in the cooling performance is the additional cooling load caused by the heat losses from the solar equipment to the building's interior. This "imposed load" on the cooling load by the solar system heat losses has already been described in Table 23 and is listed in column [4] of Table 32 for convenience. If we assume that these heat losses are eliminated (i.e., the solar equipment is located outside of the building's interior such that equipment heat losses do not contribute to the cooling load), then we can obtain a "revised" cooling load. This revised cooling load is shown in column [5] of Table 32 and equals column [3] minus column [4].

Under these conditions we can obtain another "per cent cooling by solar" as the total cooling by solar, column [6], divided by the total "revised" cooling load, column [5]. This yields a solar contribution to cooling of 55.1 per cent.

A final adjustment to the value of the solar contribution to cooling load can be considered by attempting to limit the absorption unit cycling and consequent reduction in COP, discussed above. During the period 10 July through 7 August, the cooling unit was deenergized during night time periods. This eliminated much of the cycling of the unit (the Solar House frequently had very low cooling loads at night due to the low humidity conditions in Fort Collins).

Table 32 shows the effect of this experiment on the bottom row of the table. Using the cooling load based on no solar equipment heat losses contribution to the cooling load (i.e., the "revised" cooling load in column [5] and the total cooling by solar in column [6]), we obtain a solar contribution to the cooling load of 81.1 per cent.

RECOMMENDED

CCMS SOLAR ENERGY PILOT STUDY

REPORTING FORMAT FOR

HEATING AND COOLING SYSTEMS IN BUILDINGS

August 1975

The objective of this special reporting format is to assure that sufficient information is provided to enable the reader to make his own assessment of the performance of a solar heating and/or cooling system and to relate that performance, which was carried out in one particular climate and economic environment, to a different climate and economic environment.

All details of the format are to be followed as completely as possible. In addition, information on all related back-up reports is requested, including specific instructions on how they may be obtained.

FORMAT FOR REPORTING SYSTEM PERFORMANCE

I. General Description of System Project and Environment

A. Objective of Project

- Brief description of objective and strategy of project, including duration and major milestones.

B. Description of the Environment - each section to be included if appropriate

1. Climate

- Brief description of type of climate, according to the Trewartha* worldwide classification system.
- Annual rain and snow fall (mm per year).

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* G. T. Trewartha, An Introduction to Climate (McGraw Hill: New York, 1968).

- o Description of typical sky conditions relative to "clear sky"; either average daily sunshine hours, number of sunshine hours per year, the percentage of maximum possible sunshine hours or annual average cloud cover fraction may be used.

2. <u>Location</u>

- o Latitude, longitude, and altitude (in m) of system.
- o Description of the configuration of the location and distance from solar or wind obstructions or significant geographic features (sea, mountains, etc., in km).
- o Comment on air quality, i.e. dust precipitation.

3. <u>Solar Radiation</u>

- o Mean monthly global (total) and, if relevant, diffuse insolation on a surface whose orientation is described. The number of years over which this mean is defined should be specified, as well as the time intervals of the data.
- o Description of the measurement equipment.

4. <u>Ambient Temperatures</u>

- o Mean monthly dry and wet bulb temperatures (relative humidity may be used in place of wet bulb temperature).
- o Number and basis of degree-days of location.
- o Description of the measurement equipment.

5. <u>Wind</u>

- o Average monthly wind speed and prevailing direction (0 - 360^{o} from North towards East).
- o Description of measuring equipment.

C. <u>Description of System</u>

1. <u>Qualitative Description</u>

- o Description of the entire system, as well as the solar system, by narrative, photographs, or drawings.

2. Quantitative Description

- o Description of the system performance characteristics, including schematic drawings.
- o Orientation* and inclination+ of collectors.
- o Control system descritpion, performance characteristics, and location within the system. The operating modes should be described.
- o Measurement system description, performance characteristics (such as precision and repeatability), and location within the system.

II. System Thermal Performance - The information in sections A, B, C and D is essential and therefore should be as complete as possible.

A. Daily, Monthly and Annual Values** of the Mean Daily (Tabular or Graphical Form)

- o Total energy required (thermal load, heating or cooling, on system).
- o Supplemental energy required (amount, kind, and purpose).
- o Solar energy incident on collectors.++

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* Angle between the projection of the sun's rays, at solar noon, on the horizontal plane and the projection of the normal to the collector on the horizontal plane.

\+ Angle between horizontal and normal to collector.

** The monthly value of the mean daily quantities is the most important of the three. Daily values may be provided as optional information.

++ It is suggested that this be based on (at least) hourly values of the global (and/or direct, if appropriate) insolation measured in the plane of the collectors. If the global insolation is only measured on a horizontal surface, it should be so provided and the method used to determine the amount incident on the plane of the collectors should be described.

- o Solar energy collected.
- o Solar energy used.

The criteria for the use of supplemental energy must be described.

B. Record of the Quality of Thermal Performance of the System (e.g. departure from the design temperature over reporting period)

C. Solar Contribution to Energy Requirements - daily, monthly and annual values* of percent solar contribution to the energy requirements.

D. Monthly and Annual Energy or Fuel Savings - based on primary fuel (state type).

E. Energy and Mass Balances

This information is of secondary importance in that it is this information that is used to determine the quantities reported in II A. If possible, it is suggested (optional) that a typical day be used to show:

- o Significant energy flow rates - additions and losses.
- o Significant mass flow rates - additions and losses.
- o Temperature and pressure at critical locations.
- o Temperature drop and pressure drop across major components.

III. System Economic Analysis

The following costs and factors should relate to the solar portion of the project but could also be specified for the entire project.

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* The monthly value of the mean daily quantities is the most important of the three. Daily values may be provided as optional information.

A. Total Cost of the Solar Portion of the System - with a specific definition made of the interface between the solar and non-solar portions of the system. If possible, separate design costs from component and installation costs.

B. Labor Costs - in man-hours and in local currency, for the installation of the system.

C. Materials Costs - in weight or volume as appropriate and in local currency.

D. Operational Costs - including supplemental energy costs, in local currency.

Since operational costs depend on the assumed system lifetime, it is suggested that the assumed system lifetime be stated along with the depreciation rate.

E. Local Economic Factors - such as inflation, interest rates and amortization periods.

F. Expected Selling Price or Costs - assuming that the system or solar components are mass produced.

G. Maintenance Frequency and Costs - in hours and material.

H. User Reactions and Comments

FORMAT FOR REPORTING SUB-SYSTEM PERFORMANCE

A. Solar Collectors

1. Description of Physical Configuration

- Description of solar collectors by narrative, photographs, and drawings, including collector materials, design, dimension, and construction.

2. Thermal Performance Characteristics

   - Collector efficiency curves (efficiency as a function of average fluid temperature or inlet coolant temperature, ambient air temperature, solar radiation normal to the collector, and wind speed) or equivalent collector performance indication (such as heat production) for several days that typify the full range of operation of the system.

   - Pressure drop through collectors.

   - Optical efficiency vs. incident angle, daily, monthly, and annual optical efficiency.*

   - Thermal loss coefficient as a function of the difference between the ambient and the mean plate temperature, for known wind speeds.*

3. Lifetime Performance Characteristics

   - Corrosion

   - Leakage

   - Hot spots

   - Breakage

   - Stability of collector working fluid

B. Heat Transfer Sub-system

1. Description of Physical Configuration

   - Description of heat transfer sub-system by narrative, photographs, and drawings. Specify construction materials and working fluids.

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* Optional information to be included if known.

2. Thermal Performance Characteristics*

- o Inlet and outlet temperatures on both sides of exchanger.
- o Inlet and outlet pressures on both sides of exchanger.
- o Mass flow rates on both sides of exchanger.
- o Pumping power.

C. Thermal Energy Storage Sub-systems

1. Description of Physical Configuration

- o Description of thermal energy storage sub-system by narrative, photographs, and drawings.
- o Specify construction materials and working fluids, location within system, insulation details (material and construction), mass and volume of storage sub-system, storage duration and/or energy stored at same temperature.

2. Thermal Performance Characteristics*

- o Mean temperature, hourly and daily, of the immediate surroundings.
- o Thermal loss or gain, hourly and daily.
- o Storage capacity.
- o Inlet and outlet temperatures and pressures.
- o Flow rates and pumping power.
- o If phase change materials are used, specify compound and thermal characteristics.

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* This information is of secondary importance in that it is this information that is used to determine the quantities reported in II A. If possible, it is suggested (optional) that a typical day be used to show:

- o Significant energy flow rates - additions and losses.
- o Significant mass flow rates - additions and losses.
- o Temperature and pressure at critical locations.
- o Temperature drop and pressure drop across major components.

D. Air-Conditioning Sub-system

1. Description of Physical Configuration

- o Description of air-conditioning unit by narrative, photographs and drawings.
- o Type of sub-system - heat pump, absorption, passive, etc.
- o Heat rejection method.

2. Thermal Performance Characteristics

- o Capacity at design inlet (to air-conditioning unit) temperature.*
- o Capacity+ and coefficient of performance COP curves (inlet temperature as variable).*
- o Sensitivity of the capacity and COP to variations in inlet temperature, evaporation temperature, wet and dry bulb temperature.

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* Condenser, absorber and evaporator temperatures should be stated.

\+ Including the ratio of sensible to latent heat removal.

The international System (S.I.) will be used exclusively* with the following recommendations:

Pressure	-	given in Kpa.
Temperature	-	°C
Energy	-	MJ and/or Kwh
Energy Flow Rate	-	Kw, w
Solar Radiation	-	the intensity will be given in W/m^2, the hourly, daily, monthly or annual totals will be given in MJ/m^2 day averaged over a day, month, or year.
Wind Speed	-	m/sec
Mass Flow Rate	-	l/sec or kg/sec

* According to the resolutions of the Converence Générale des Poids et Mesures, 1960.