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PERFORMANCE EVALUATION OF A STATE-OF-THE-ART SOLAR
AIR-HEATING SYSTEM WITH AUXILIARY HEAT PUMP

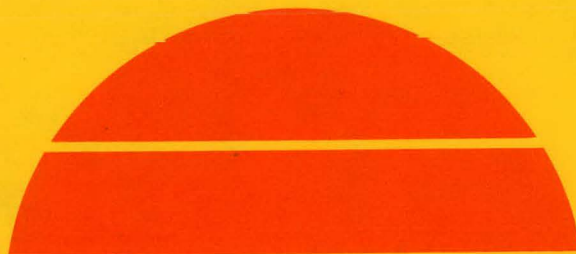
Final Report, October 1, 1978—September 30, 1979

By
Susumu Karki
Thomas E. Brisbane
Stuart S. Waterbury
Thomas G. Lantz

January 1980

Work Performed Under Contract No. AC02-79CS30122

Solar Energy Applications Laboratory
Colorado State University
Fort Collins, Colorado



U.S. Department of Energy



Solar Energy

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PERFORMANCE EVALUATION OF A
STATE-OF-THE-ART SOLAR AIR-HEATING SYSTEM
WITH AUXILIARY HEAT PUMP

FINAL REPORT

For the Period 1 October 1978 to 30 September 1979

Prepared for the
Solar Heating and Cooling Research and Development Branch
Office of Conservation and Solar Applications
U.S. Department of Energy

Work Performed Under Contract DE-AC02-79-CS-30122

Prepared by
Susumu Karaki
Thomas E. Brisbane
Stuart S. Waterbury
Thomas G. Lantz

Solar Energy Applications Laboratory
Colorado State University
Fort Collins, Colorado 80523

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EXECUTIVE SUMMARY

INTRODUCTION

The solar heating system in Solar House II, evaluated during the heating season of 1978-1979, consists of 57.9 m² of Solaron Series 3000 Collectors, 10.3 m³ of pebble bed storage, domestic water preheating capability and a Carrier air-to-air heat pump as an auxiliary heater. Although the control subsystem was specially constructed to facilitate experimental changes and data reduction, the balance of the solar system was assembled with "off-the-shelf" components. Since all components of the system are presently commercially available the system is considered to be a "state-of-the-art" solar air-heating system. The system design is one that is recommended for residential and small office buildings. A schematic diagram of the system is shown in Figure 1.

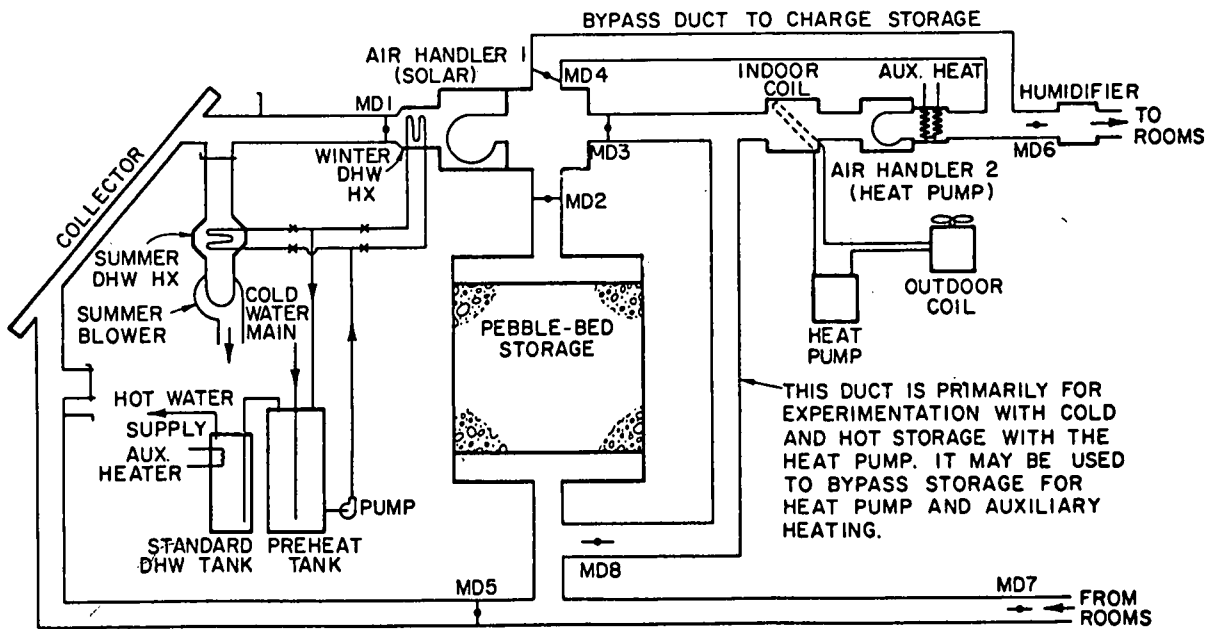


Figure 1. Schematic Diagram of Solar Heating and Heat Pump Auxiliary System in CSU Solar House II

The collectors were installed in October 1978, and after making control adjustments in November data were taken continuously from 1 December 1978 through 11 May 1979. During the summer, the pebble bed storage was cold charged with the heat pump during "off-peak" hours and room air was circulated through the pebble bed to cool the rooms during the day. Although off-peak electrical energy rates are not in effect in Fort Collins, Colorado, the experiments were conducted to determine the thermal performance of the system and to make an assessment of economic viability of operating the system in an off-peak mode.

The controlled modes for heating are the standard ones used for air systems. Some experimentation with sensor temperature levels were needed to properly control the heat pump and back-up resistance heating strips. Control temperatures for the off-peak cold charge mode were also set experimentally.

OBJECTIVES OF THE PROJECT

The objectives of the project were to:

- (1) Determine the performance of a state-of-the-art solar system with an auxiliary heat pump in terms of solar and electrical energy contributions for space and water heating.
- (2) Determine the operating characteristics of the heat pump for space heating.
- (3) Compare the performance of a state-of-the-art liquid-heating system in Solar House III, and the liquid-heating evacuated tube collector system in Solar House I.
- (4) Compare the measured performance of the air system with predicted performance using the f-chart procedure.

Objective (3) is not discussed in this report. However, performance comparisons of air and liquid systems in the houses of the CSU Solar Village are contained in a separate report.

RESULTS

Collector Performance

Measured collector efficiencies are higher than steady-state efficiencies published by the manufacturer. In Figure 2 instantaneous efficiencies measured during 1130 to 1230 periods on clear days are compared to the manufacturer's efficiency lines for the appropriate air-flow rates. While there is considerable scatter in the data, most of the triangles are above the line as are the majority of circles. Assuming τ , α , and U_L are unchanged from 0.89, 0.95 and $7.12 \text{ W}/(\text{m}^2 \cdot ^\circ\text{C})$ respectively, the difference is accountable in a larger heat removal factor, F_R , by about 10 percent for the collectors on Solar House II.

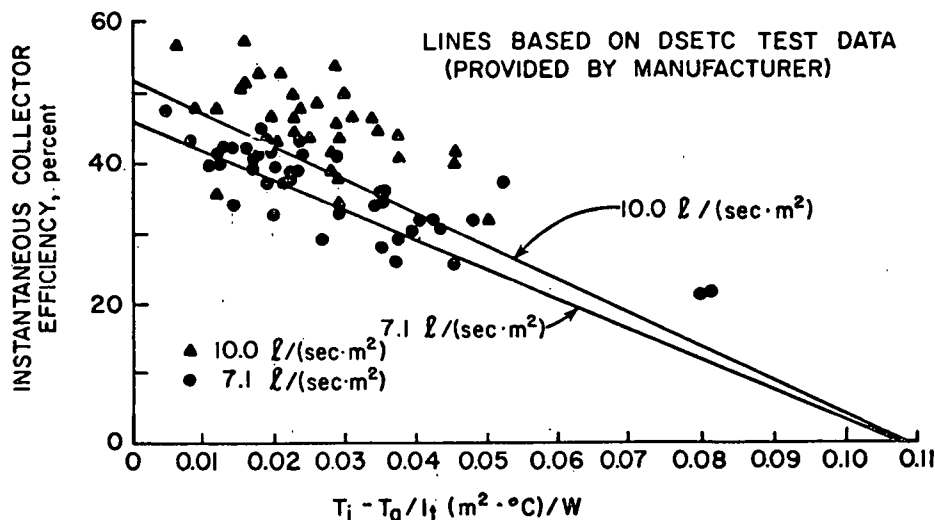


Figure 2. Measured Instantaneous Collector Efficiencies Near Solar Noon

Collector arrays with 15 percent air leakage into the array during operation produce more thermal energy than collectors with 5 percent air leakage into the array. A theoretical analysis of this effect was published by Close and Yusoff, and is supported by experimental evidence in this study.

System Performance - Space Heating

System performance from 1 December 1978 through 11 May is summarized in Table 1. The monthly average daily solar heat delivered from the collectors in relation to total solar insolation and insolation while the collectors were operating is shown in Figure 3.

On a seasonal basis (160 days) the mean solar insolation was $17.55 \text{ MJ}/(\text{m}^2 \cdot \text{day})$, of which $15.28 \text{ MJ}/(\text{m}^2 \cdot \text{day})$ was incident during collection and $5.77 \text{ MJ}/(\text{m}^2 \cdot \text{day})$ of thermal energy was delivered from the collectors. Solar utilization was 87 percent and daily collection efficiency was 33 percent, and 38 percent on the basis of solar radiation while collecting.

The COP for solar collection and storage was 26.36 (3.8 percent electrical energy use), and to retrieve thermal energy from storage the COP was 31.25 (3.2 percent electrical energy use). Monthly mean daily loads and contributions of solar energy to the load are shown in Figure 4. During the season the total load was 72.3 GJ of which 65 percent was provided by solar energy at a COP of 13.78 (7.3 percent electrical energy use).

The proportion of monthly mean daily space heating by solar energy, heat pump, and electrical resistance strips are shown in Figure 5.

Table 1. Summary of Key Monthly Mean Daily Quantities and Performance Measures

NUMBER	ITEM	UNITS	DEC	JAN	FEB	MAR	APR	MAY	SEASON
1	Total Incident Solar Insolation	(MJ/m ² ·day)	16.74	15.96	18.71	17.77	20.56	12.51	17.55
2	Insolation Solar While Collecting	(MJ/m ² ·day)	14.16	14.30	16.52	15.28	18.32	9.84	15.28
3	Thermal Energy Collected	(MJ/m ² ·day)	6.31	5.57	6.25	5.61	5.87	3.86	5.77
3a	Thermal Energy Collected	MJ/day	365.29	322.52	362.18	324.86	340.11	223.33	334.43
4	Collector Operating Efficiency	3/2	0.45	0.39	0.38	0.37	0.32	0.39	0.38
5	Collector Daily Efficiency	3a/1	0.38	0.35	0.33	0.32	0.29	0.31	0.33
6	Total Heating Load	MJ/day	594.00	614.78	447.03	377.81	265.12	337.33	451.90
6a	Space Heating Load	MJ/day	551.19	557.70	382.20	306.57	193.43	280.72	390.82
6b	DHW Load	MJ/day	42.81	57.08	64.83	71.24	71.69	56.61	61.08
7	Solar Energy Utilized	MJ/day	353.53	297.91	340.06	285.79	223.60	223.65	294.42
7a	Space Heating	MJ/day	331.68	271.91	300.96	247.82	176.59	203.60	261.16
7b	DHW Preheating	MJ/day	21.85	26.00	39.10	37.97	47.01	20.05	33.26
8	Auxiliary Thermal Energy	MJ/day	240.47	316.87	106.97	92.02	41.52	113.67	157.49
8a	Heat Pump Space	MJ/day	74.28	129.42	51.40	48.40	15.09	51.91	63.11
8b	Elec. Resistance Space	MJ/day	145.23	156.37	29.84	10.35	1.75	25.21	66.56
8c	Elec. Resistance, DHW	MJ/day	20.96	31.08	25.73	33.27	24.68	36.55	27.82
9	Elec. Energy to Collect	MJ/day	17.70	12.32	12.04	11.19	13.11	8.11	12.95
10	Elec. Energy to Dist. Solar	MJ/day	12.77	10.75	10.10	9.12	3.57	11.75	9.42
11	Elec. Energy for Heat Pump	MJ/day	50.70	84.88	27.33	22.35	7.88	24.38	37.83
12	Elec. Energy for H.P. Blower	MJ/day	8.59	13.13	3.91	2.86	1.03	3.15	5.75
13	Solar System Efficiency	7/(1-A _c)	0.36	0.32	0.31	0.28	0.19	0.31	0.29
14	COP to Collect Solar	3a/9	20.64	26.18	30.09	29.03	25.94	27.50	26.36
15	COP to Distribute Solar	7/10	27.69	27.71	33.67	31.34	62.63	19.03	31.25
16	COP Overall Solar	7/(9+10)	11.60	12.91	15.36	14.07	13.41	11.26	13.78
17	COP Heat Pump	8a/11	1.47	1.52	1.88	2.17	1.91	2.13	1.67
18	COP Auxiliary Heating	8a+8b/(8b+11+12)	1.07	1.12	1.33	1.65	1.58	1.46	1.18
19	COP Overall Heating	6/(8b+8c+9+10+11+12)	2.32	1.99	4.10	4.24	5.09	3.09	2.82
20	Number of Day of Measurement		31	30	27	31	30	11	160
21	Solar Fraction Total	7/6	0.60	0.48	0.76	0.76	0.85	0.66	0.65
22	Solar Fraction Space	7a/6a	0.60	0.49	0.79	0.81	0.91	0.73	0.67
23	Solar Fraction, DHW	7b/6b	0.51	0.46	0.60	0.53	0.66	0.35	0.54
24	F-Chart Fraction		0.55	0.45	0.72	0.78	1.00	0.61	0.64
25	Difference (percent)	(24-21)/21	-8.3	-6.2	-5.2	2.4	17.6	-7.9	-1.5

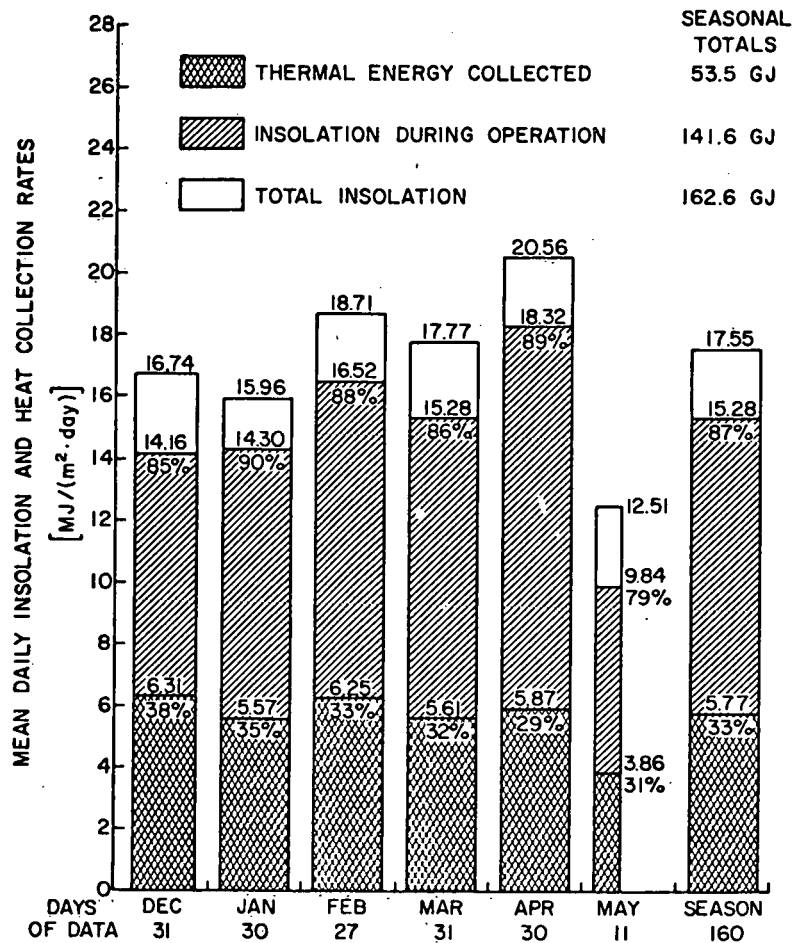


Figure 3. Solar Insolation and Thermal Energy Collected

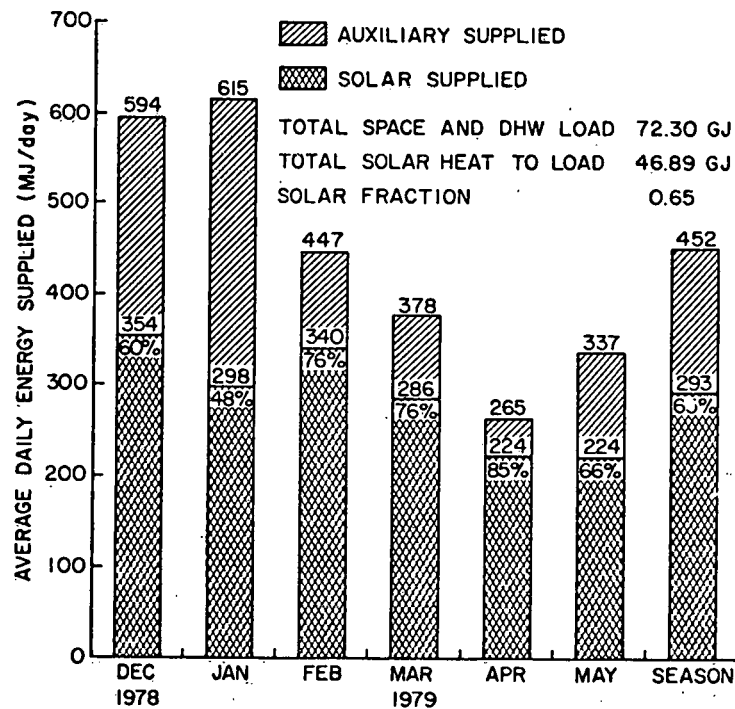


Figure 4. Mean Daily Energy Supplied to the Load

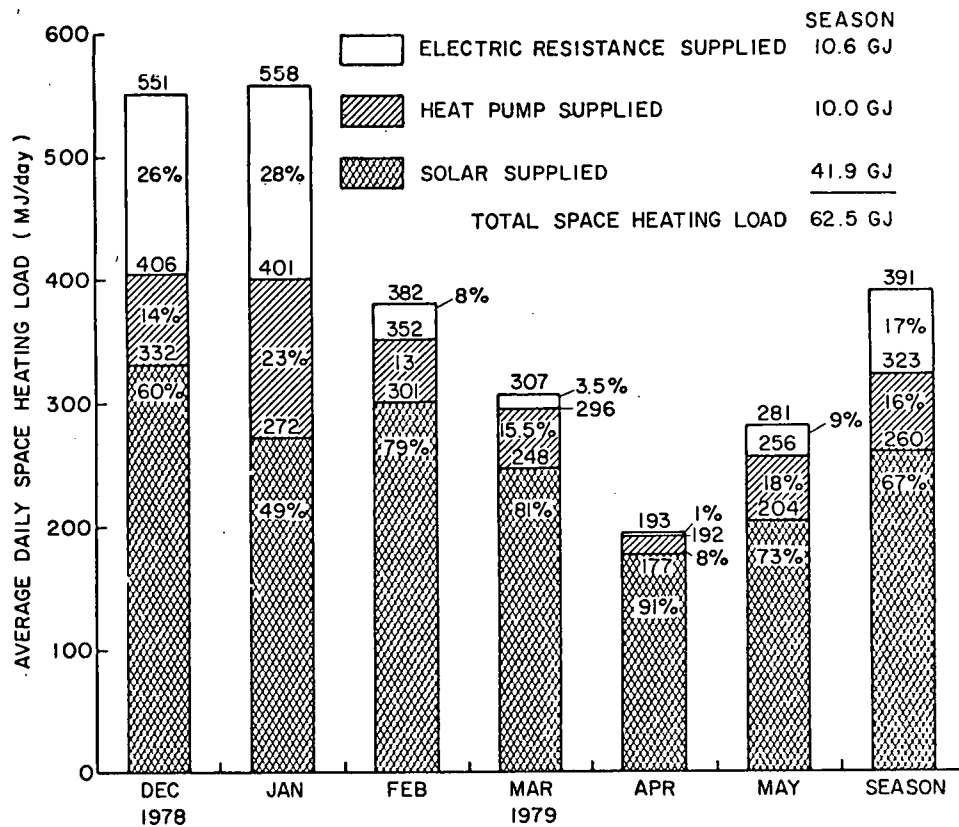


Figure 5. Monthly Average Daily Space Heating Load

Of the 33 percent auxiliary heating requirement, 16 percent was provided by the heat pump and 17 percent by electrical resistance heating. The large proportion of resistance heating caused a low overall auxiliary heating COP of 1.18. The average COP of the heat pump was 1.67 for the season which is low because operation predominates after solar heat has been depleted from storage and outside air temperature is generally low.

The overall solar system efficiency, which is solar energy utilized divided by the total solar insolation on the collectors, was 29 percent, which was the same for the site-built air heating system tested the previous year. In terms of daily collector efficiency based on solar radiation while collecting, the Solaron Series 3000 collectors were

38 percent while the site built collectors were 37 percent (1977-78 heating season). The thermal performance of the two systems were substantially the same. Measured and predicted monthly and seasonal solar fractions are shown in Figure 6. The solar fraction calculations were made by the f-chart procedure using measured solar radiation, loads and average temperatures. Comparisons of monthly and seasonal solar fractions are excellent when measured inputs are used. When average Fort Collins solar data, temperatures and calculated building UA are used, there are large variations between expected and measured amounts because of seasonal variations.

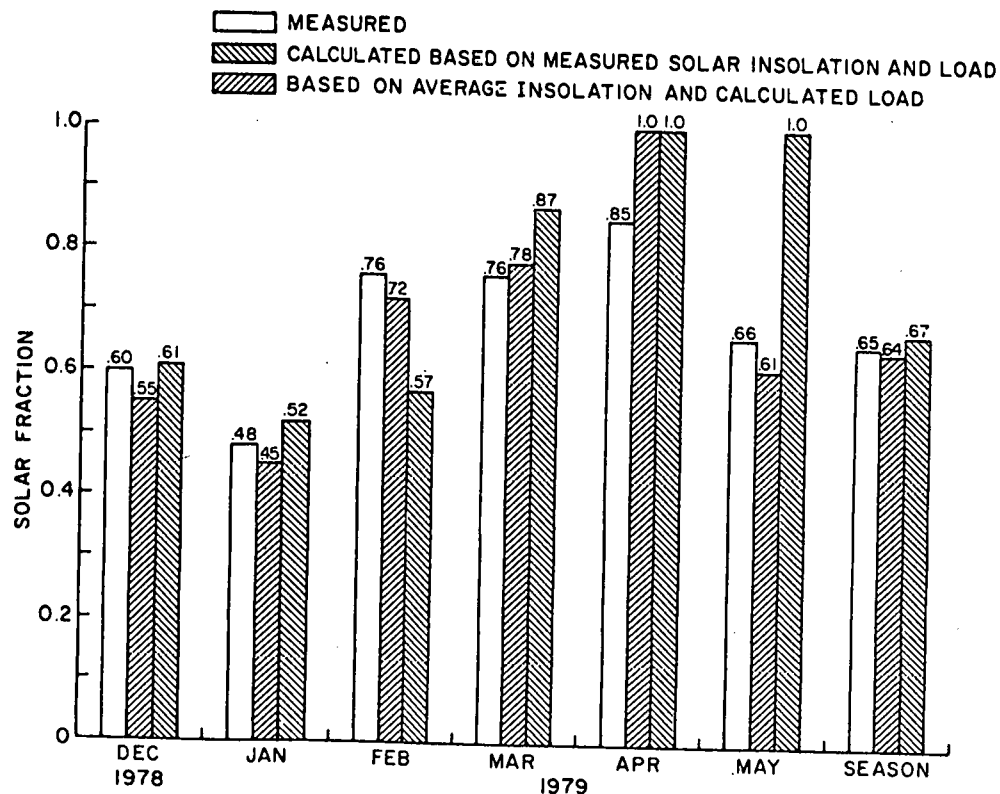


Figure 6. Comparisons of Measured and Predicted Monthly and Seasonal Solar Fractions of the Total Heating Load.

System Performance - Space Cooling

Space cooling was provided by the heat pump during the summer, primarily by off-peak cooling of the pebble bed. A summary table of cooling performance in Table 2 shows that average daily COP for cooling was 1.67. The COP for cooling from the pebble bed, which includes charging and discharging, was 1.37 while the heat pump COP for direct cooling was 2.49. If the ratio of peak to off-peak electrical energy rates is greater than 1.8, it is economically viable to use the pebble bed of a solar system for cold charge.

The pebble bed was dismantled at the end of the cooling season, and samples of rocks were examined in the laboratory with no evidence detected of unusual biological or bacteriological growth on the rock surfaces. Contrarily, the surfaces were "cleaner" than source pebbles sampled at the aggregate plant.

CONCLUSIONS

The overall performance of the commercial state-of-the-art solar air heating system with single-glazed, selective surface collectors was substantially the same as the previous site-built system with double-glazed collectors and non-selective absorber. Air leakage rates into the collector were less for the new system. Where the leakage rate was as large as 35 percent for the site-built system the largest leakage rate into the collector for the new system was 15 percent for the east half and 5 percent for the west half of the array. When efficiencies of collectors with leakages of 5 and 15 percent are compared, the array with a leakage rate of 15 percent delivered 10 percent greater quantity of thermal energy than the collector with a smaller leakage rate, with equal outflow rates.

Table 2. Monthly Average Daily Cooling Performance

Number	Item	Units	June	July	Aug	Sept	Season
1	Number of Days of Data		20	31	31	9	91
2	Heat Removed by Heat Pump during Cold Charge	MJ/day	156.28	200.52	143.95	205.26	171.99
3	Cold Charging of Pebble Bed	MJ/day	108.99	153.48	110.56	162.71	129.99
4	Room Cooling through Pebble Bed	MJ/day	110.78	146.61	101.64	155.41	124.28
5	Storage Efficiency	4/3	1.02	0.95	0.92	0.96	0.96
6	Cold Charge Efficiency	3/2	0.70	0.77	0.77	0.79	0.76
7	Direct Heat Pump Cooling	MJ/day	2.26	14.14	16.73	12.38	12.24
8	Total Room Cooling Including Cooling from Losses	MJ/day	138.69	189.40	137.51	190.70	160.71
9	Electrical Energy for Heat Pump during Cold Charge	MJ/day	64.96	84.22	61.46	84.53	72.27
10	Electrical Energy for Blower during Cold Charge	MJ/day	9.58	12.02	8.81	11.99	10.38
11	Electrical Energy for Heat Pump during Direct Cooling	MJ/day	0.81	5.72	6.80	4.68	4.91
12	Electrical Energy in Blower during Direct Cooling	MJ/day	0.12	0.74	0.88	0.63	0.64
13	Electrical Energy to Blower for Storage Discharge	MJ/day	6.33	10.01	6.17	9.90	7.88
14	Heat Pump COP for Cold Charge	2/9	2.41	2.38	2.34	2.43	2.38
15	Heat Pump COP for Direct Cooling	7/11	2.79	2.47	2.46	2.65	2.49
16	Cooling COP from Cold Charge	4/(9)+(10)+(13)	1.37	1.38	1.33	1.46	1.37
17	Average Daily COP for Cooling	8/(9)+(10)+(11)+(12)+(13)	1.70	1.68	1.63	1.71	1.67

The electrical energy consumption (parasitic energy) to operate an air-heating solar system is relatively small, requiring 3.8 percent to collect and store solar heat, 3.2 percent to deliver heat from storage to the rooms, and collectively 7.3 percent to collect, store and deliver solar heat for two blowers.

With a solar system that provides a substantial portion of the space heating needs an air-to-air heat pump will tend to operate at low coefficient of performance because of adverse operating conditions. Since the heat pump will not be required until solar heat is depleted from storage, it operates when outdoor air temperature is low and the COP is low. For the system tested, the heat pump COP for heating was 1.67 and auxiliary heating COP (heat pump plus resistance heating) was 1.18.

Use of the pebble bed as cool storage in the summer, charged during off-peak hours with a heat pump, will provide lower cost for cooling than direct cooling with a heat pump if there is at least 8 hours of off-peak rates during the evening and the electrical energy cost ratio of normal rate divided by off-peak rate is greater than 1.8. The calculation is based on a COP for direct cooling of 2.49 and COP for cooling from cold charge of 1.37.

The solar air heating system described in this report is a commercially available solar system. It is strongly recommended that solar air systems be assembled in the manner described in this report to achieve efficient and effective controlled heating.

STATE-OF-THE-ART SOLAR AIR HEATING SYSTEM WITH AUXILIARY HEAT PUMP

1. INTRODUCTION

1.1 OBJECTIVES OF THE PROJECT

The objectives of the experimental program were to:

- (1) Determine the performance of a state-of-the-art solar system with an auxiliary heat pump in terms of solar and electrical energy contributions for space and water heating.
- (2) Determine the operating characteristics of the heat pump for space heating.
- (3) Compare the performance of a state-of-the-art solar air heating system with performance of a state-of-the-art liquid-heating system in Solar House III, and the liquid-heating evacuated tube collector system in Solar House I.
- (4) Compare the measured performance of the air system with predicted performance using the f-chart procedure.

1.2 DESCRIPTION OF THE ENVIRONMENT

1.2.1 Location

Fort Collins, Colorado is 96.6 km north of Denver, Colorado and the Solar Village is situated 6.4 km west of the city center in the Foothills Research Campus of Colorado State University. The latitude at the solar village is 40.6°N , the longitude is 105.1°W of the principal meridian, and the elevation is 1585 m above sea level. The solar houses are on the south slope of a hill, about 60 m above the level of the city of

Fort Collins, and the air is generally clear of local air pollution effects. The front range of the Rocky Mountains begins approximately 1 km to the west and rises to the continental divide which is 50 km farther to the west. Eastward from the site of the solar village the terrain is generally flat.

1.2.2 Climate

The climate is characterized by moderate temperatures, light precipitation, and light winds interrupted occasionally by strong north-westerly winds. The average monthly temperatures vary from -2.5°C in January to 21.8°C in July. Winter temperatures are moderated by sporadic occurrences of warm chinook winds. The average annual precipitation is about 37 cm, most of which falls during the growing season. Afternoon thunderstorms occur frequently during the summer months but they are usually quite light in rainfall amounts. Seasonal snowfall averages 117 cm, but persistent snowcover is unusual. March is typically the month with greatest amounts of snowfall.

The normal total annual heating degree days (18.3°C base) is 3600 $^{\circ}\text{C}$ days. The monthly average daily radiation on a horizontal surface averaged over the past 4 years in Fort Collins is shown in Figure 1-1. Also shown on the figure is the monthly average daily radiation on a surface tilted southward at 45 degrees.

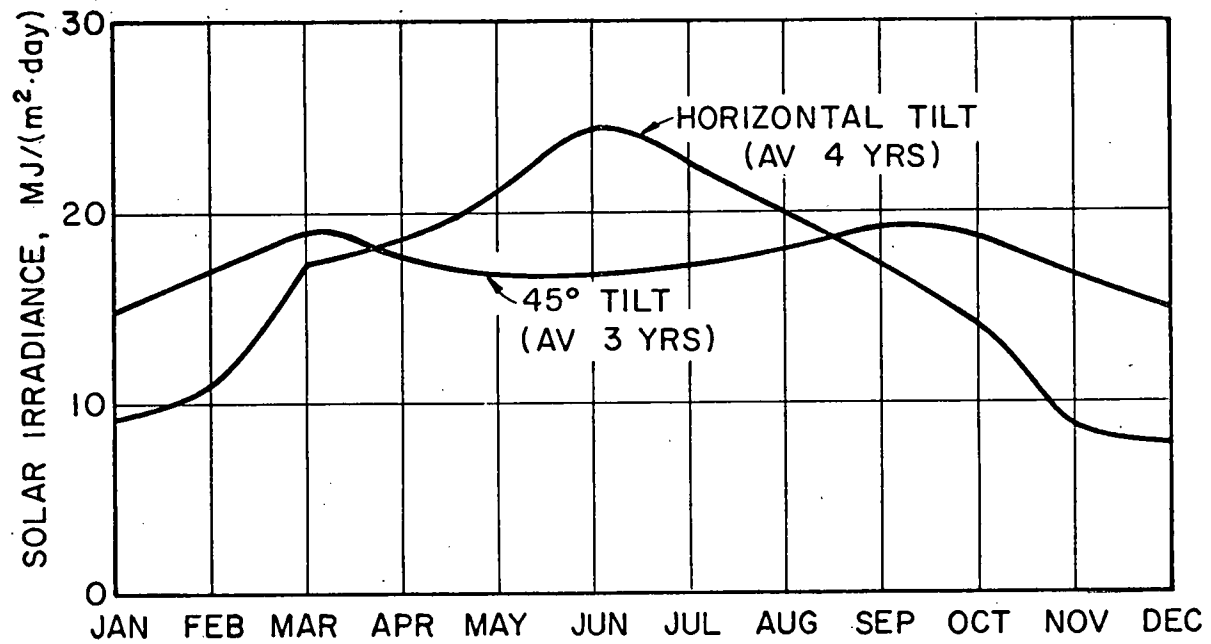


Figure 1-1. Monthly Average Daily Solar Radiation on Horizontal and 45° Tilted Surfaces in Fort Collins

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2. DESCRIPTION OF THE BUILDING AND THE SYSTEM

2.1 THE BUILDING

2.1.1 Description

Solar House II is a residential-size building located in the Solar Village at the Foothills Research Campus of Colorado State University, in Fort Collins, Colorado. The building is a three-bedroom house, although the interior is arranged for offices. The first floor is the "living" area with 128.5 m^2 floor space and the full basement has additional office space as well as space for the solar equipment. A photograph of the building is shown in Figure 2-1.

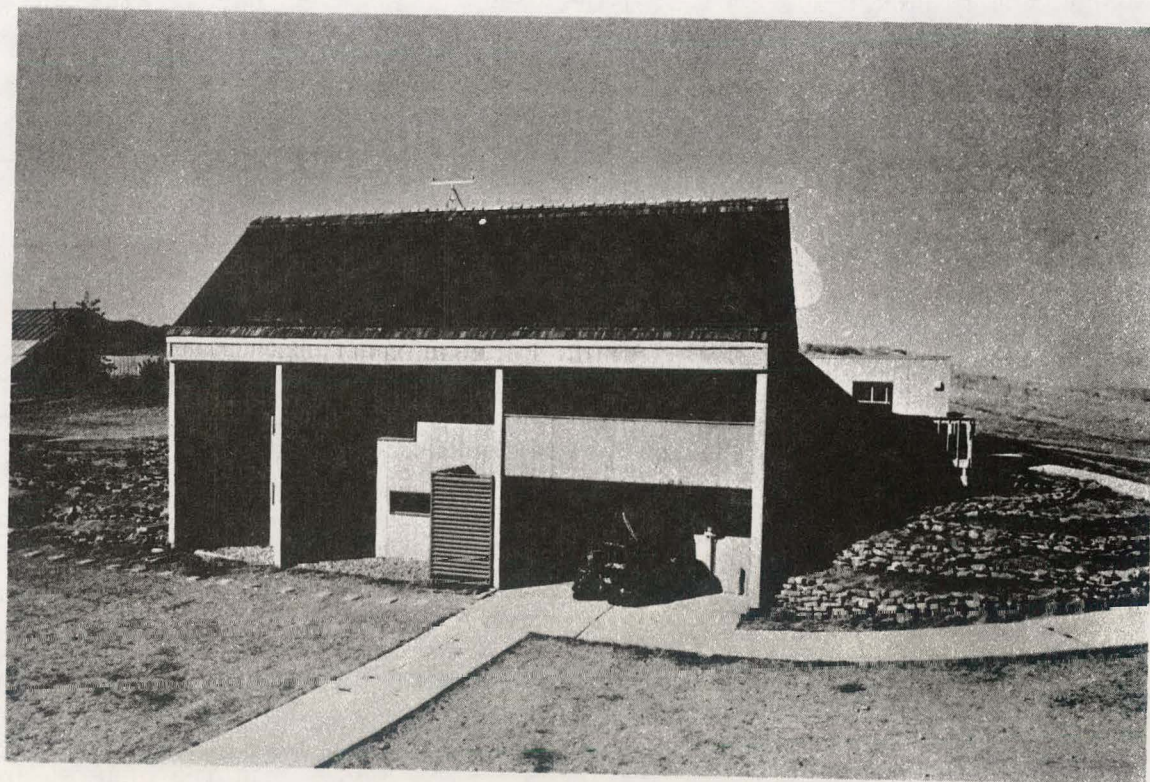


Figure 2-1. South View of CSU Solar House II

2.1.2 Plans and Cross-sections

The south side of the basement is entirely above grade while the north wall is below grade. The floor plans, elevation views and cross section of the building structure are shown on Figures 2-2 through 2-6. The "garage" is utilized as office space and is not heated or cooled by the solar system.

The collectors are on the roof of the building and face due south. As shown in Figure 2-6, there is a second weather-proof roof underlying the collectors, which is a special feature of this experimental building to permit replacement of collectors without exposing the building interior to the weather. The collector roof is supported vertically by four 1.83-m wide walls extending outward from the south wall of the building (see Figure 2-1). A 1.83-m overhang shades the south facing windows on the first floor in the summer and admits sunlight during the winter. Also, the vertical support walls extending from the south wall shade the windows in the early morning and late afternoon.

2.1.3 Building Heating Load

The building walls are constructed of 5 x 10 cm studs on 40.6 cm centers. The sheathing on the exterior is 1.27 cm thick with 1.1 cm hardboard over the sheathing. The interior wall is 1.6 cm gypsum board with 8.9 cm fiberglass batt insulation in the walls. The ceiling joists are 5 x 15 cm on 61 cm centers, with 1.6 cm gypsum board overlaid with 16.5 cm blanket insulation.

The exposed wall area of the building totals 110 m^2 and the underground wall area is 73 m^2 . There are 28.25 m^2 of double-glazed windows set in wood frame with 80 percent glass area, and 30.5 m^2 of 4.5 cm

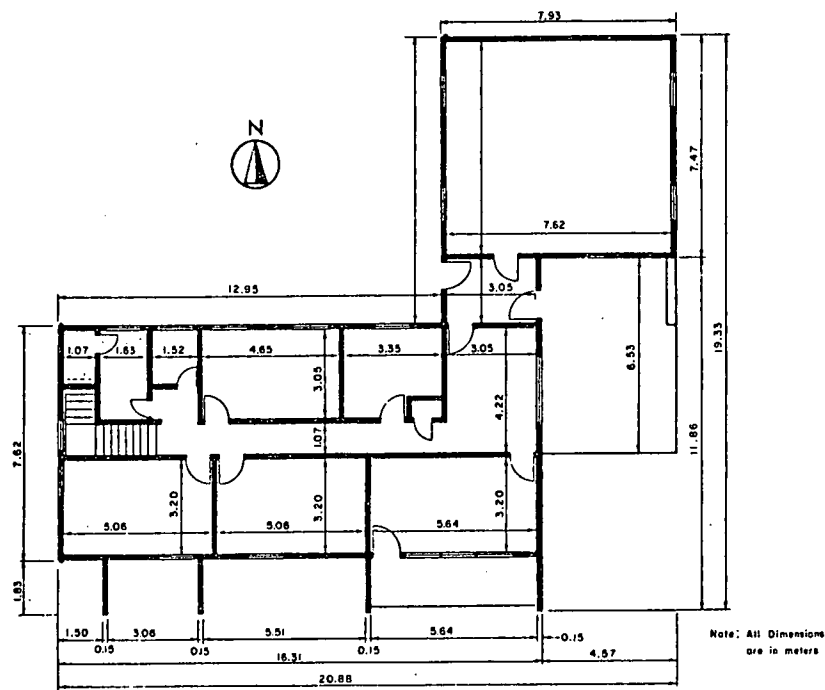


Figure 2-2. First Floor Plan of Solar House II

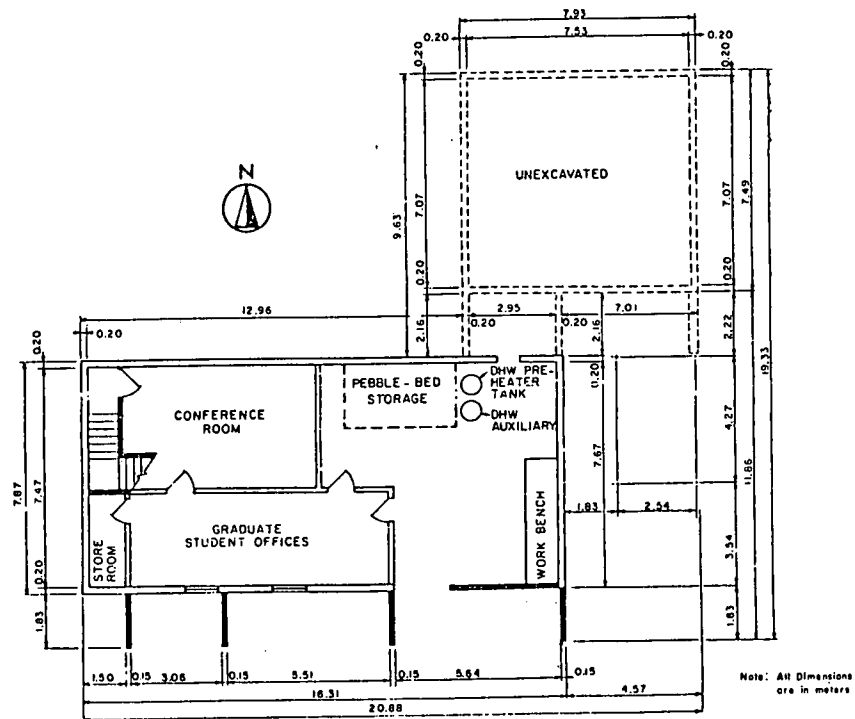


Figure 2-3. Basement Floor Plan of Solar House II

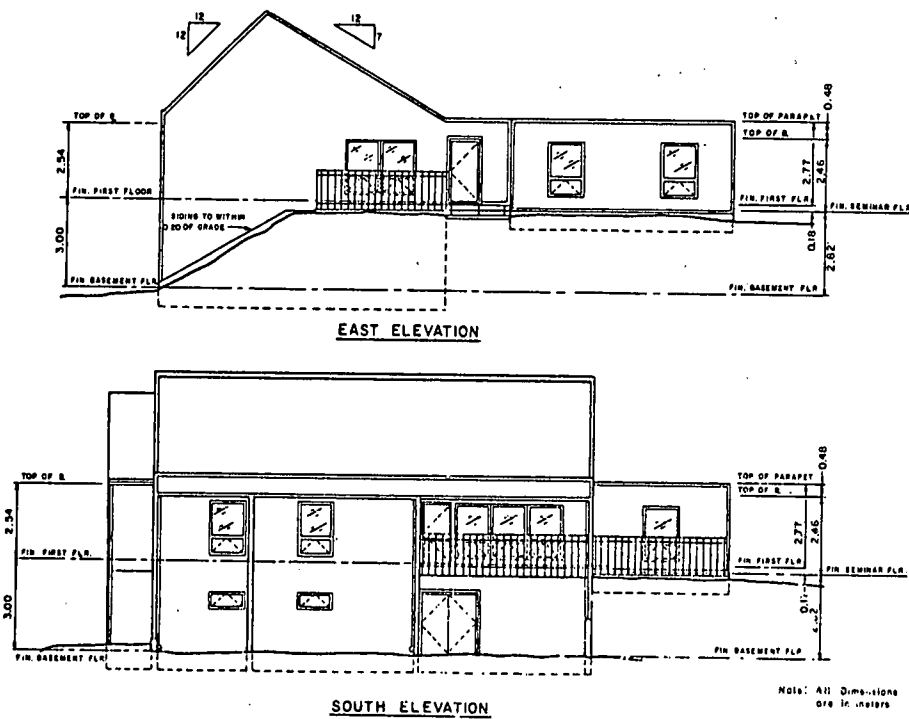


Figure 2-4. East and South Elevations of Solar House II

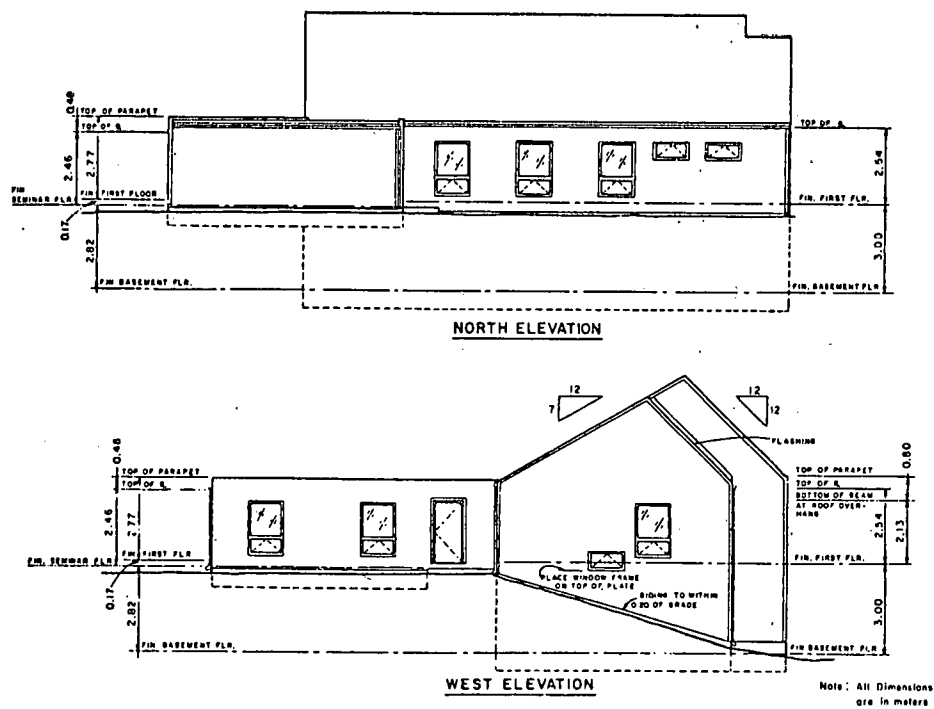


Figure 2-5. North and West Elevations of Solar House II

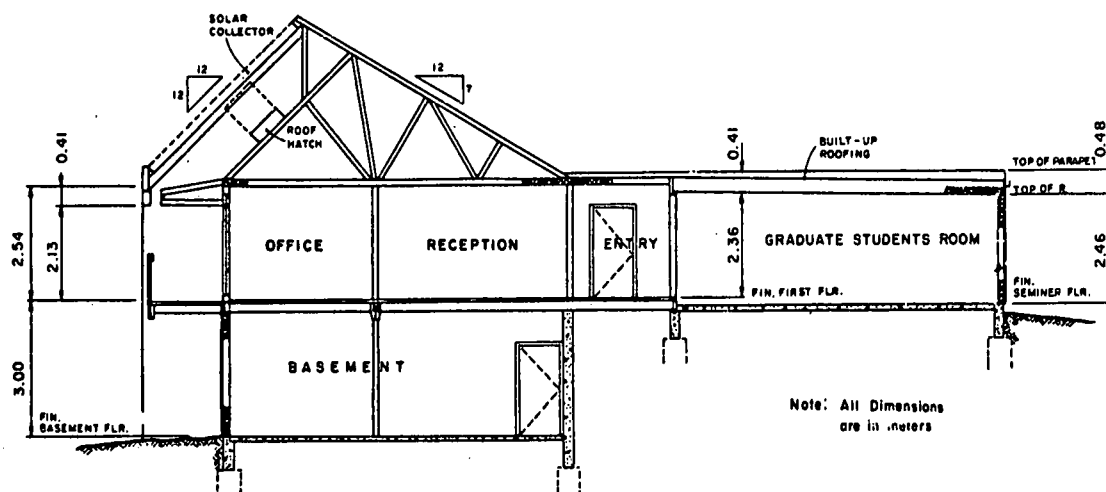


Figure 2-6. Cross Section of Solar House II

solid-core exterior doors. The overall UA of the building is calculated to be $419 \text{ W/}^\circ\text{C}$ [$36.20 \text{ MJ/}(\text{}^\circ\text{C-day})$].

2.2 THE SOLAR SYSTEM

2.2.1 Heating System

The heating system in Solar House II consists of a solar air heating system with an auxiliary heat pump as shown schematically in Figure 2-7. The solar system consists of 32 modules (55.77 m^2 gross area*) of Solaron Series 3000 air heating collectors, pebble-bed storage, a Solaron air handler containing a belt driven blower with a 750 watt

* Including perimeter insulation the gross area of the collector array is 57.93 m^2 , which is the area used in all of the appropriate calculations in this report.

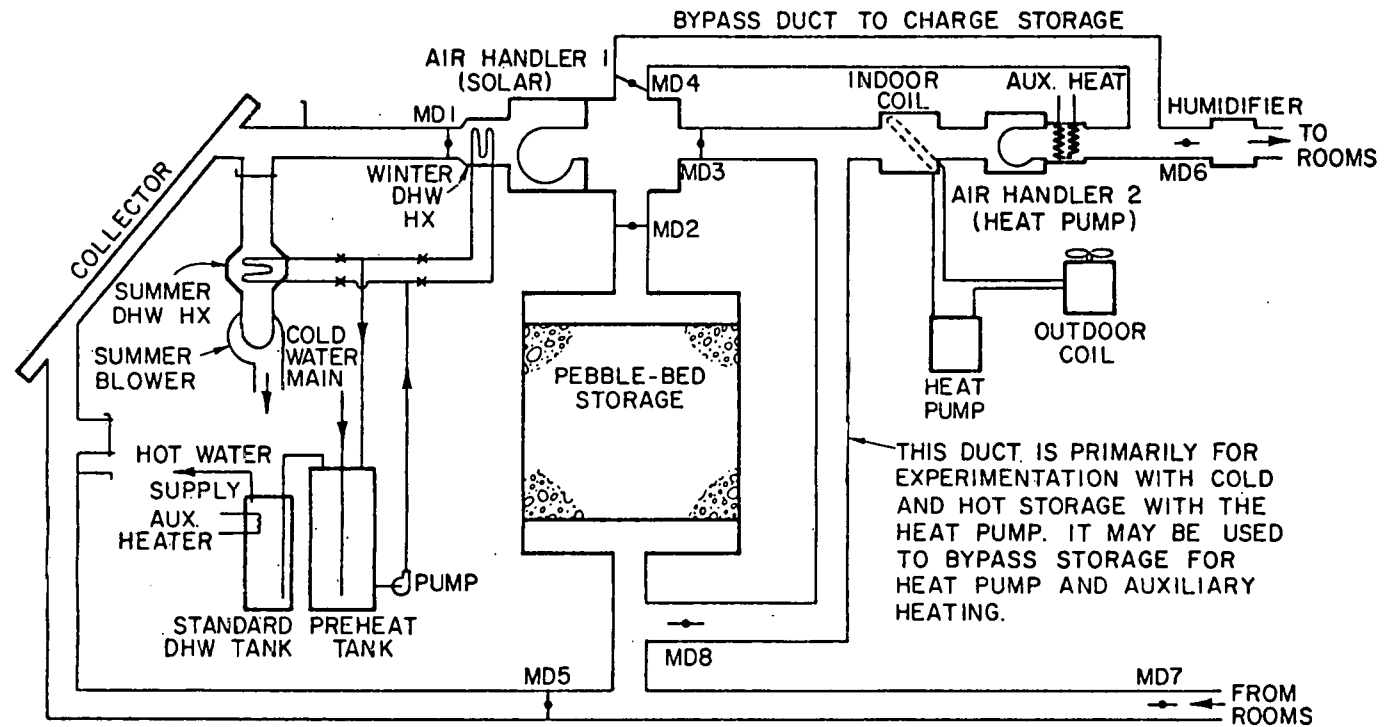


Figure 2-7. Schematic Diagram of Solar Heating and Heat Pump Auxiliary System in CSU Solar House II

motor, and automatic controls developed by the laboratory staff to collect, store and deliver solar thermal energy to the building space. The auxiliary heater is a 3-ton Carrier air-to-air heat pump with back-up electrical resistance duct heaters.

Solar Collectors - A cutaway view of the Solaron Series 3000 collectors is shown on Figure 2-8. Each collector module is 1.74 m^2 gross area, with 1.59 m^2 aperture area, and consists of a single pane of low-iron tempered glass, an air channel below the glass cover, an internal manifold arrangement, and insulation on the backside of the steel casing. The absorber surface, which is one side of the air duct, is coated with a selective black chrome surface. Minimum absorptance is 0.95 and maximum emittance is 0.15. Transmittance of the glass

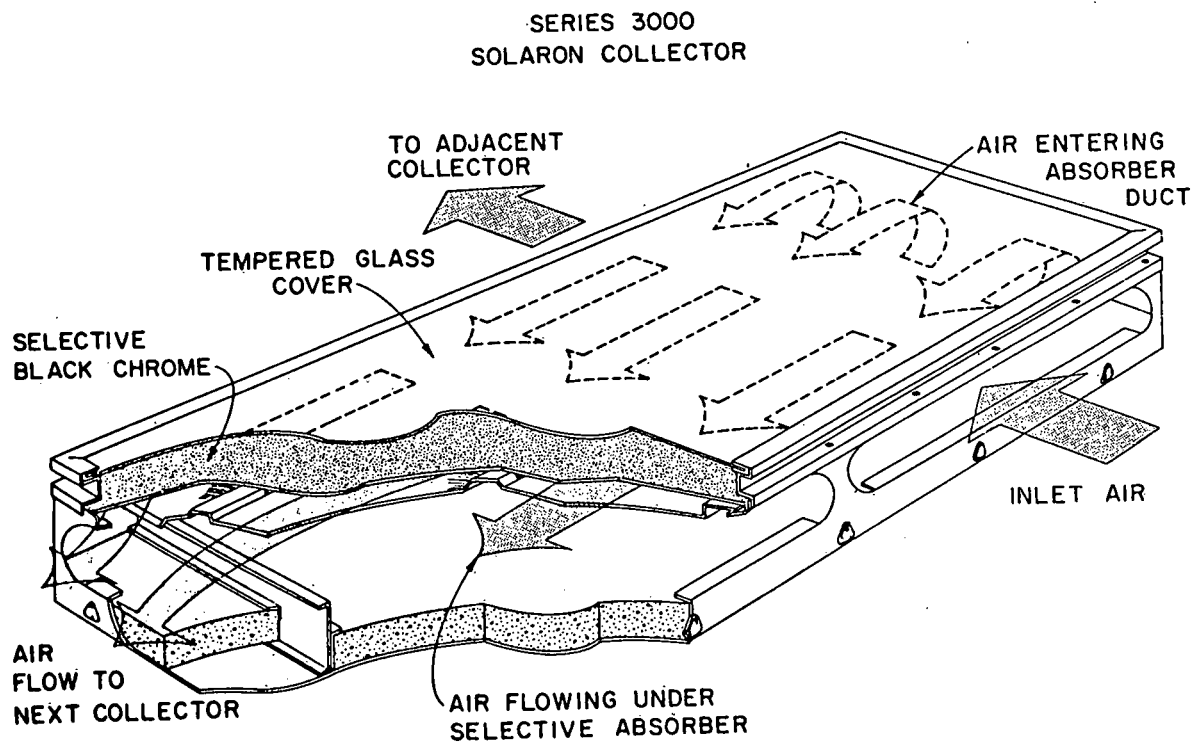


Figure 2-8. Cutaway View of the Series 3000 Solaron Collector
(Redrawn by permission of Solaron)

cover is 0.89 and is lightly patterned on the topside. There is a space between the air duct and back insulation which is designed for internal manifolding to minimize ducting for an array. The insulation has an overall heat conductance rate of $0.44 \text{ W}/(\text{m}^2 \cdot ^\circ\text{C})$. The unit is factory assembled and designed for easy mounting.

Collector Installation - The entire collector array consists of 32 modules in a 2-high arrangement and is divided into 2 equal sections of 16 modules each as shown in Figure 2-9. Air flow through the collectors is upward from the bottom row to the upper row as shown in Figure 2-10.

Two different installation procedures were used as part of a study to determine cost-effective ways to improve fabrication and installation of solar heating and cooling systems for residential buildings. To assemble the west array, all collector modules were lifted to the roof with a "cherry picker" into approximate positions as shown in Figure 2-11. The collectors were then manually moved into position and secured to the roof sheathing with lag screws, and capstrips were placed between adjacent collectors (see Figures 2-12, 2-13 and 2-14). Gaskets around the edge of the manifold ports prevent air leakage between modules (see Figure 2-15).

The east array was assembled by using the cherry picker to lift the modules into position as needed. The procedure is illustrated by Figure 2-16. Manual labor required to move the collectors into position was thereby minimized. Perimeter insulation, as seen in Figure 2-17, and flashing the entire array (Figure 2-18) completed collector installation.

Detailed time and motion studies during the installations indicated the west array required 28.2 man-hours (1.76 man hours per module) for

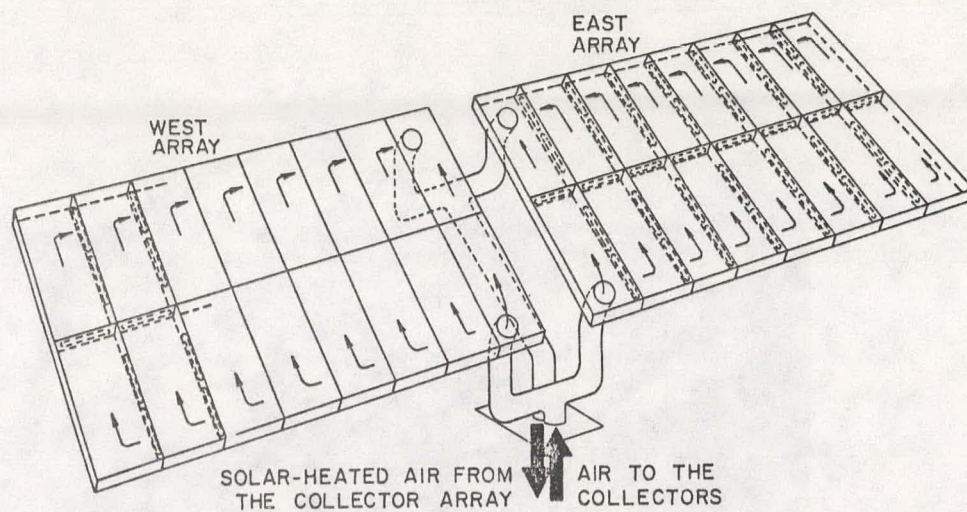


Figure 2-9. Collector Array as Installed on Solar House II

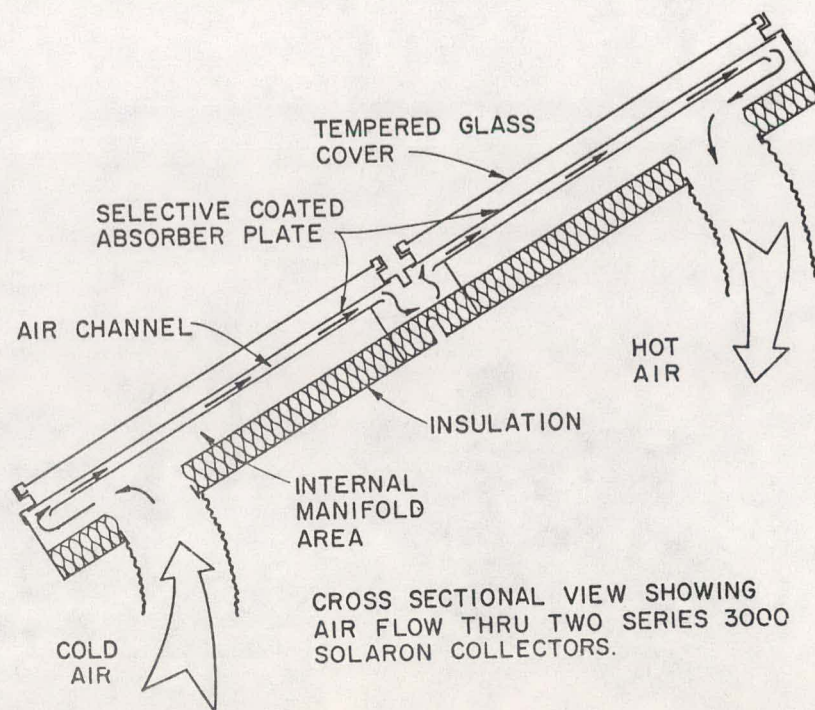


Figure 2-10. Cross-section of Solaron Collectors in a Two-high Array



Figure 2-11. Installation of the West Collector Array in Solar House II

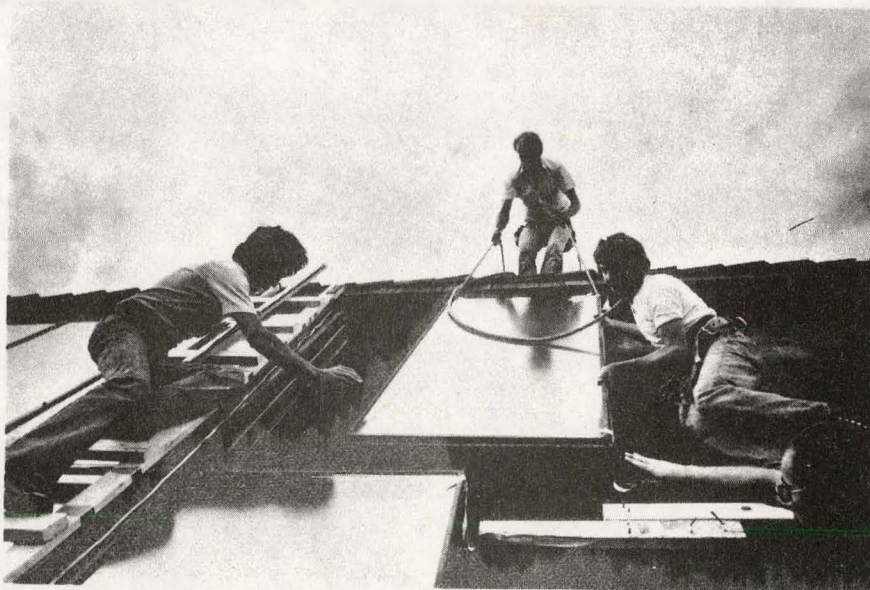


Figure 2-12. Manual Placement of Collector Modules into Position



Figure 2-13. Collectors Secured to the Roof with Lag Bolts



Figure 2-14. Cap Strips Placed between Adjacent Collector Modules

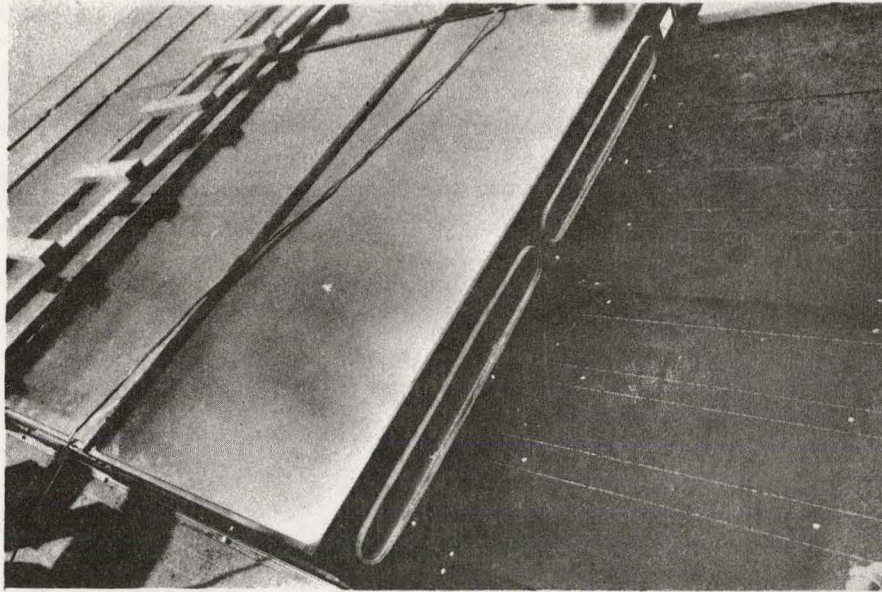


Figure 2-15. Gaskets Assemblies Around the Manifold Ports Prevent Air Leakage between Modules

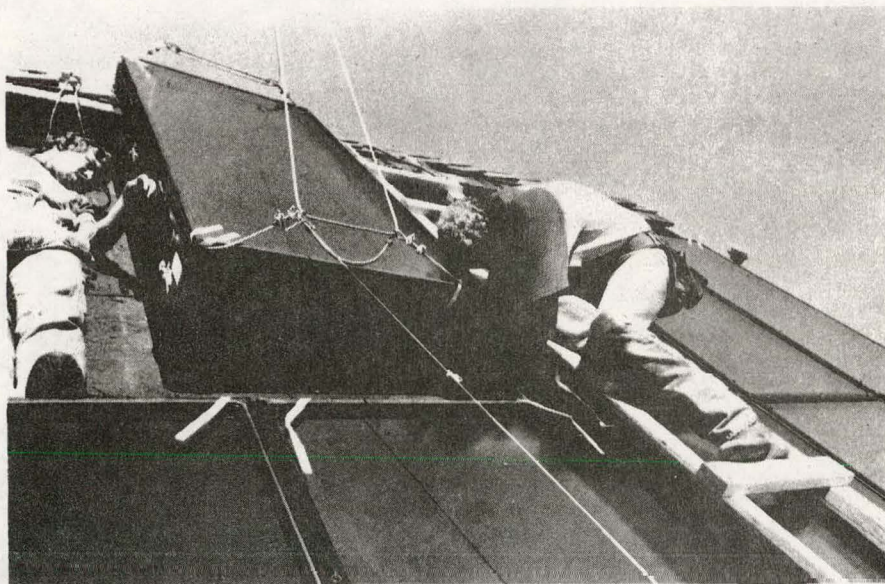


Figure 2-16. Collector Modules were Lifted into Position as Needed and Fastened into Place

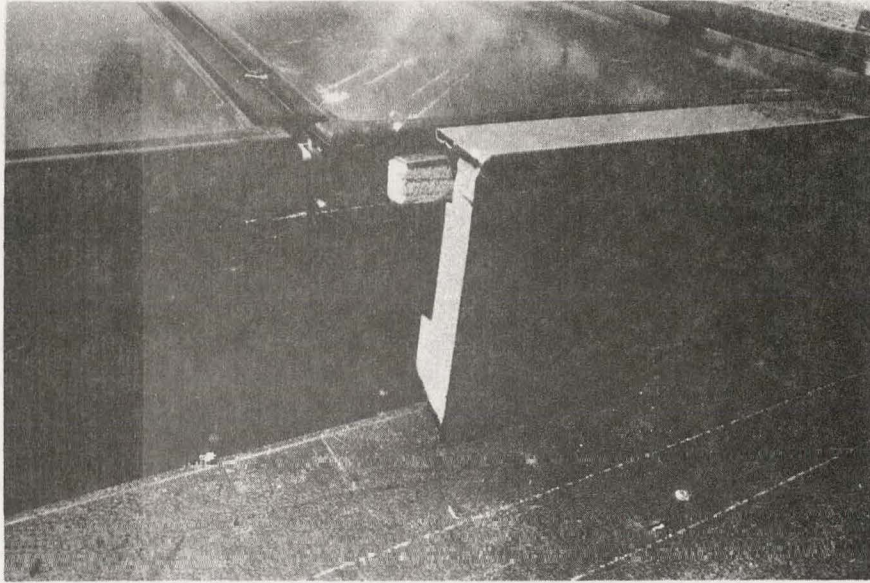


Figure 2-17. Perimeter Insulation was Placed Around Both East and West Arrays



Figure 2-18. Flashing was Installed Around the Entire Array

installation and the east array required 15.6 man-hours (0.98 man-hours per module)(Ref. 5). The time for installing the west array includes experimental time to determine the best way to fasten the collectors and attach the cap strips, and the time for installing the east array is corrected (increased) to include the same learning time to fasten collectors and the cap strips. The time and motion studies include idle times by one or more workers that are inherent in the installation process. Nevertheless the west array required 80 percent greater man-hours to install the collectors compared to the east array.

Installation Costs - Assuming a typical commercial rate for a cherry picker is \$35/hr, (including operator time) and labor cost is \$20 per man hours, the cost for installing the west array would be \$616.50, \$38.53/module, or $\$22.11/\text{m}^2$ of collector. The procedure used for the east array, at the same prices, would cost \$504.50 for the array, \$31.53/module or $\$18.09/\text{m}^2$ of collector. The difference in cost for the two procedures at the prices assumed is about 20 percent.

If the equipment charge is \$50/hr, and labor cost is \$15/hr, both installation procedures would result in about the same cost. When heavy machinery is used to handle collector modules and the charge rate is about 3 times the labor cost, total installation cost using either procedure studied would be about the same. If the ratio of equipment to labor prices are greater than 3, the one-at-a-time procedure adopted for the east array would cost more than the procedure used to install the west array.

Comments on Collector Installation - Maintaining alignment of the collector modules was at first troublesome because the lag screws were driven into the sheathing at an angle. The installation crew devised a gauge block to maintain proper spacing between the modules to overcome the difficulty. It is important to maintain correct spacing between modules to achieve a tight seal around the manifold gaskets and enable the cap strips to be installed correctly.

The manufacturer designed the cap strips so that they would be fastened by self-starting screws into a back-up metal strip which fits between the collector modules. However, it was found that in a position as shown in Figure 2-19, it was not possible to apply a force great enough to start the screws. Even with a more direct position as shown in Figure 2-20 it was difficult to drive the self-starting screw through the back-up plate. A better procedure is to have the back-up plates pre-drilled at the factory to match the holes in the cap strip.

The west array resulted in less air leakage than the east array. Although this may not be directly attributable to installation procedure, it is thought that manual manipulation of the collector modules into position resulted in a "better" installation. A cherry picker was selected for lifting the collectors because the operator would be directly above the installation which greatly facilitates placement. The collector modules in the east array were manipulated into position primarily by the equipment operator, although workers on the roof guided the operator, applied the gauge blocks to space the modules, and "nudged" the units into final position. The east array was installed in less overall time, and with less man-hours because one fewer worker was required on the roof. Apparently less attention could be devoted



Figure 2-19. Attaching the Cap Strips
between Collector Modules



Figure 2-20. Attaching Cap Strips with
Better Procedure

to the gaskets as the collector modules were pushed into position, and greater leakage was the result. As will be shown in the collector performance, however, the greater leakage was not detrimental to collector performance.

Pebble-bed Storage - The pebble-bed storage is located in the basement of Solar House II. The container, as illustrated in Figure 2-21 is constructed of 5 x 10 cm frames with plywood sheathing and drywall lining on the inside, 8.9-cm fiberglass batt insulation between the studs and 1.27-cm outer plywood facing. The inside dimensions of the box are 1.83 m wide by 3.35 m long by 2.20 m high with a rock volume of 10.2 m^3 . The corners of the box are sealed with silicone sealant to prevent air leaks into or out from the box.

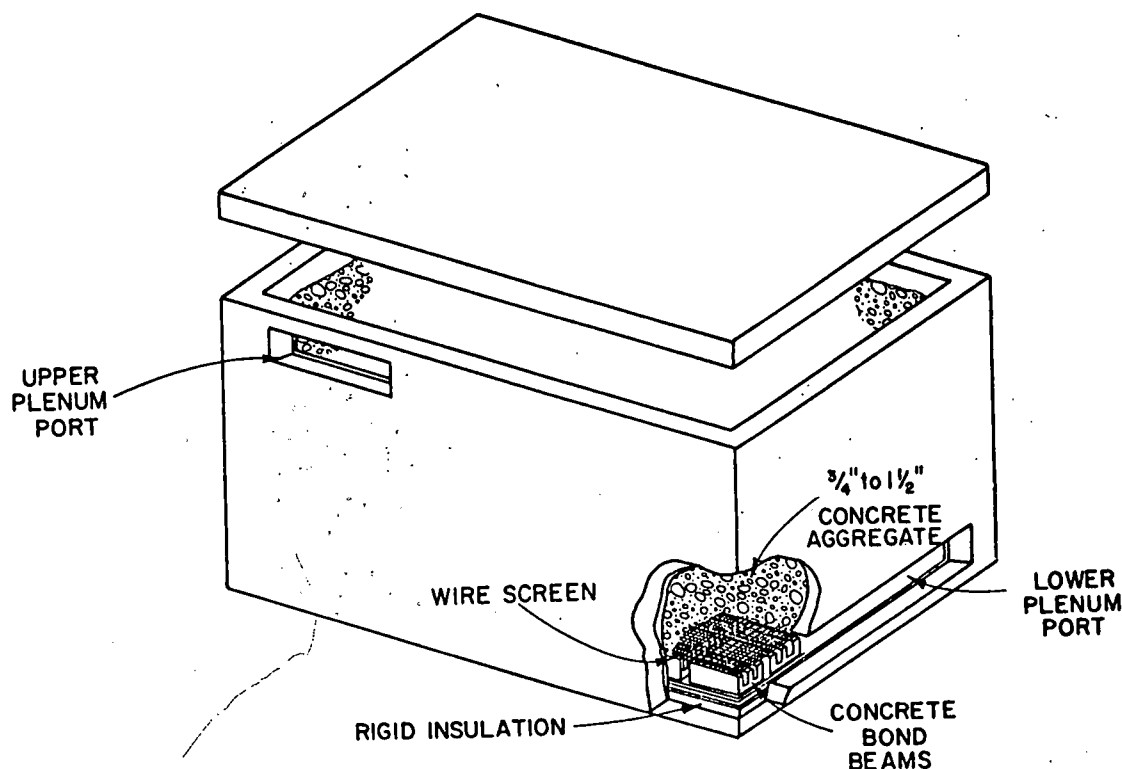


Figure 2-21. Pebble-Bed Storage Unit

A 1.27-cm plywood floor is placed over the concrete basement floor inside the box. On this plywood there is a 3.8 cm-thick rigid fiberglass insulation, and on top of the rigid fiberglass there is a layer of 0.64-cm asbestos cement board. Six rows of 20 x 20 x 40 cm concrete bond beams are placed length-wise in the box on top of the asbestos cement board with about 7.6-cm spacing between the rows and between the ends of each concrete block. A layer of heavy-duty expanded metal is then placed over the bond beams which supports a 1.68-m depth of pebble bed (gravel). The bottom plenum is therefore 20-cm high while the top plenum is 30-cm high. The gravel sizes range from 2 cm to 4 cm and was washed before placement in the storage box. There are internal steel strap ties to prevent the walls of the box from bowing out with the pressure of the gravel.

Heat Pump - A Carrier Weathermaster III, split system, 3-ton, air-to-air heat pump was selected as the auxiliary heating unit. Primarily because of the space requirement to install thermopiles across the indoor coil unit, the heat pump was arranged in 4 sections; the outdoor coil unit, indoor compressor unit, indoor coil unit, and the air handler/electric heater unit. The installed arrangement is shown schematically in Figure 2-7. The fan is provided with a 3-speed, direct drive, 560 watt motor, but only the maximum speed was connected to the controls, primarily to match the single-speed Solaron air handler.

Although storage could be by-passed when heating with the heat pump, the by pass was not used. Return air from the room was always circulated through storage and the indoor coil before delivery back to the rooms and the heat pump did not operate when the air temperature from storage was

greater than about 35°C. The by-pass was used only during the cooling season when heating was needed because the pebble bed was used as cool storage.

Dampers - There are 8 Honeywell dampers and motor operators in the system. The dampers are provided with neoprene strips attached to the blades to minimize leakage, which is reasonably effective for uni-directional ducts, but when the dampers are pressurized from the reverse direction, there is a measurable amount of air leakage through the closed damper.

2.2.2 The Cooling System

Cooling is accomplished in Solar House II by utilizing the pebble bed storage as a heat sink. Although the 3-ton heat pump has the capacity to cool the rooms for the majority of summer days, in this experimental system, the heat pump is used during the off-peak hours to cool the pebble bed. During the day, the warm room air is circulated through the pebble bed and cool air is returned to the rooms.

By operating the heat pump at night, there is a decided economic advantage with the system in regions where off-peak electrical energy rates are, or will be, in effect. The COP of the heat pump is somewhat lower during the cool hours of the night, compared to operation during the day, because the air temperature to the indoor coil is low.

2.2.3 Domestic Water Preheating

Air-to-Water Heat Exchangers - There are two heat exchangers in the system; one is located in the basement, adjacent to the air handler for

winter use and the other is located in the attic for summer use. Because the pebble bed storage is used as a heat sink during the summer, warm air cannot be circulated through it. With two heat exchangers in the system warm air circulation can be kept completely outside the insulated building envelope during the cooling season.

Preheat Tank - The hot water preheat tank is a 300-liter standard electric water heater manufactured by the A.O. Smith Company. The electric heating elements are not connected and the drain spigot has been replaced with a piping connection to enable pumped recirculation through the heat exchangers and the preheat tank.

Auxiliary Water Heater - A 150-liter standard electric water heater stands adjacent to the preheater tank. Only the upper elements in the tank is connected to maintain a minimum water temperature of 60°C. Cold water from the mains is delivered to the bottom of the preheat tank and solar-heated water is delivered to the bottom of the auxiliary water tank. In a solar air-heating system it is important to install a separate auxiliary water heater, rather than a one tank solar/auxiliary unit, because the water temperatures delivered from a reasonably-sized air-to-water heat exchanger will be colder than is desirable in a domestic hot water delivery system. Hence, for a one-tank system, auxiliary energy (electricity in this case) which heats the water to a minimum level (60°C in this system) would minimize solar energy use for domestic water heating. By using a two-tank system, domestic water can be preheated and because preheating is accomplished only during the day, while solar

heat is being stored, preheating of domestic water to temperatures less than 40°C is prevalent during the winter.

Preheater Circulation Pump - The circulation pump used during the winter season was a March Model 809-03, 25-watt, pump. For the summer a change was made to a Grundfos Model UP26-64F adjustable flow rate pump. Recirculation rate was larger during the summer to improve the effectiveness of the air-water heat exchanger.

3. MODES OF SYSTEM OPERATION

There are three basic modes for heating, (1) heating from the collector, (2) storing heat and (3) heating from storage. Three basic modes were used for cooling, (1) cold charging the pebble bed, (2) cooling the rooms from storage, (3) cooling with the heat pump. To measure the thermal performance of the system, however, every achievable condition in the system must be identified as a separate mode because air flow rates change when dampers in the system open or close and operation of the auxiliary heat pump or resistance heaters also change the thermal balance in the system. For the heating season the controller was arranged for 11 identifiable modes and for the summer there were 13 additional modes.

3.1 BASIC HEATING MODES

3.1.1 Heating from Collectors

Solar heating of space, with heat delivered directly from the collectors to the rooms, can be achieved as shown in Figure 3-1. Solar heat is collected whenever there is sufficient intensity of solar radiation. If solar heat is being collected and the room requires heating, as determined by the room thermostat, the dampers are positioned by the controller to enable air circulation from the collectors to the rooms. If the heat delivery rate from the collectors is insufficient the heat pump is activated and damper MD4 closes and MD3 opens. When the combination of solar collectors and heat pump is not sufficient to meet the heating requirement in the rooms, the electrical resistance elements in the ducts adds still more thermal energy to the air stream.

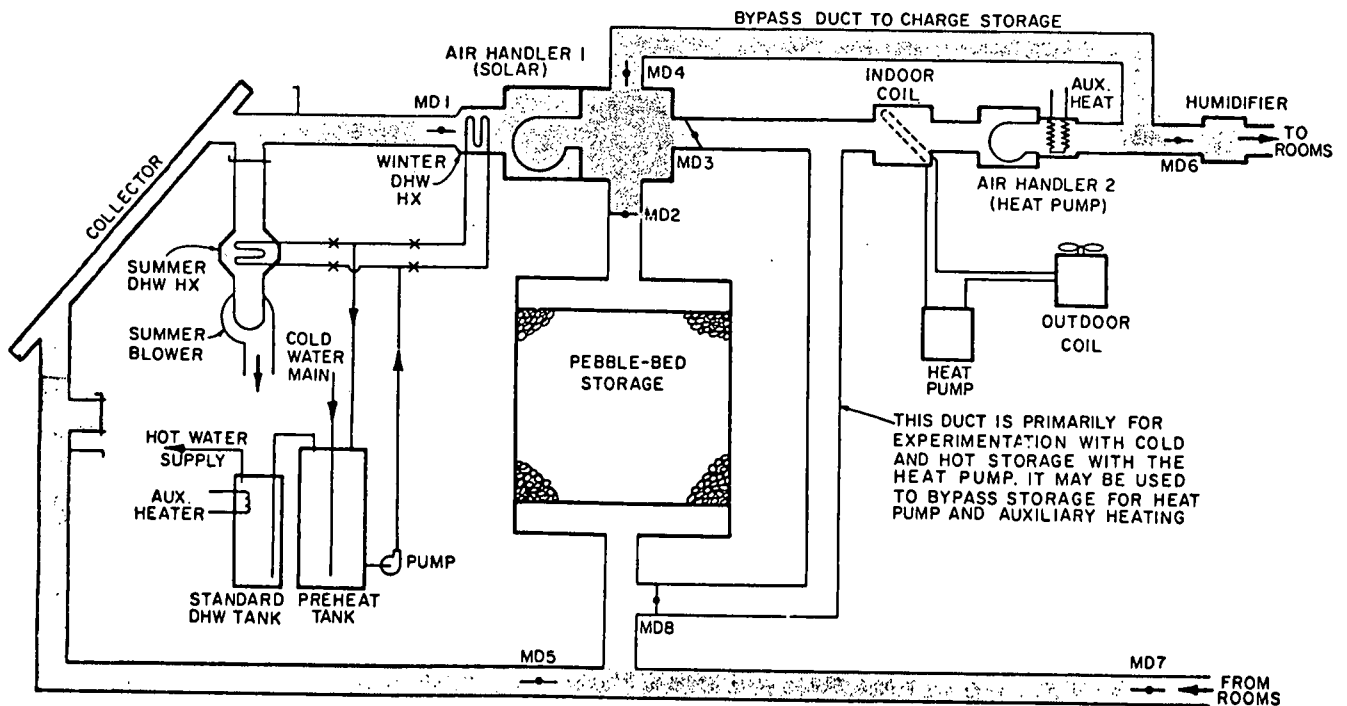


Figure 3-1. Heating from Collectors

The heat pump is activated by a temperature sensor immediately upstream from the indoor coil and the electrical resistance strips in the duct are controlled by the second stage of the two-stage thermostat. In the event that the second stage circuit of the thermostat is completed, both the heat pump and resistance elements are activated regardless of the temperature of the air stream ahead of the indoor coil. Such an occasion could arise if there is a sudden cooling of the rooms (when a door is left open) or if the thermostat setting is manually raised.

In general, heat pumps should not be operated when the indoor coil is subjected to hot air stream because the compressor will be subject

to over-pressure. Simultaneous operation of the heat pump and solar heating occurs if the temperature of the solar-heated air stream is less than 30°C at the entrance to the indoor coil.

3.1.2 Storing Solar Heat

When heating is not required in the rooms the thermostat contact is open and the solar-heated air stream is circulated through storage as shown by Figure 3-2. With the air handler positioned as shown, the collectors are subjected to slightly subatmospheric (negative) pressure and the pebble-bed container is slightly above atmospheric (positive) pressure. The air handler position in the system, as shown, is superior

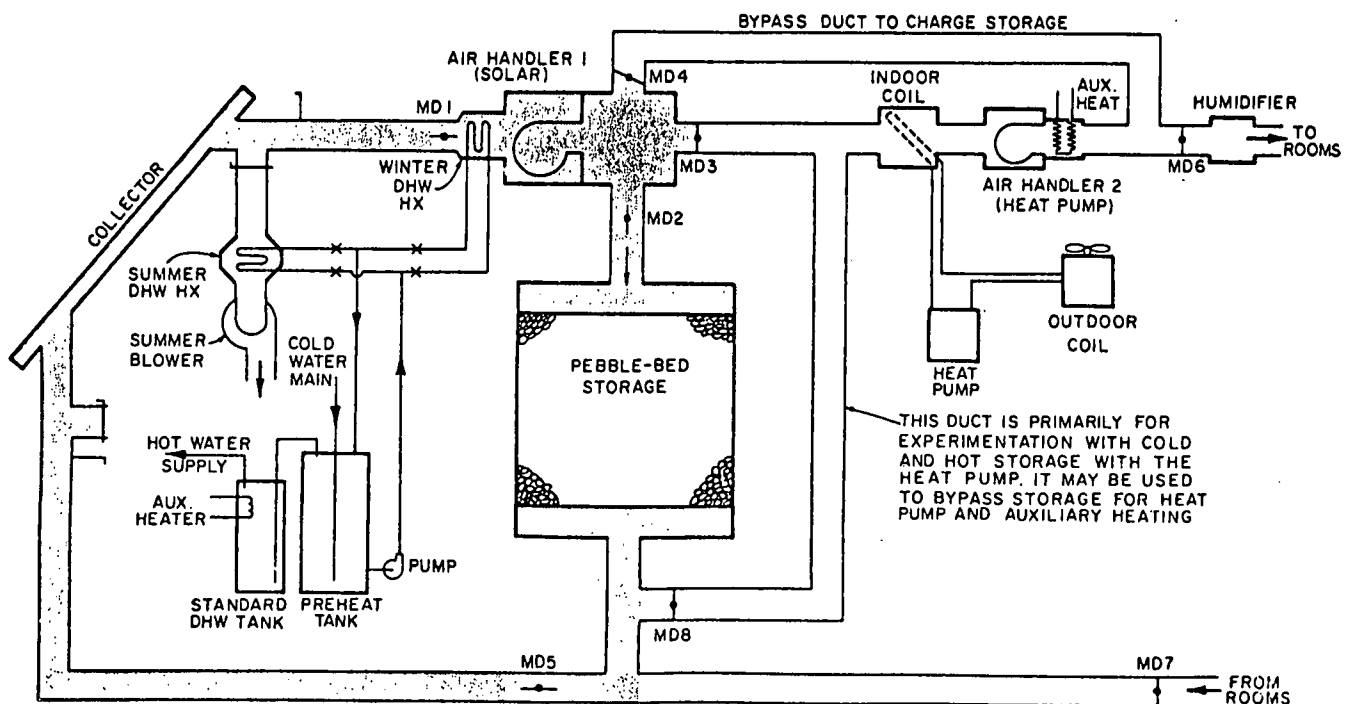


Figure 3-2. Storing Solar Heat

to an air handler position which pressurizes the collector and subjects the storage container to subatmospheric pressure. With the collector under subatmospheric pressure air leaks into the collector and the ambient air is heated by the collector or mixes with the heated air stream. An equivalent mass of warm air will flow from the system into the rooms across dampers or out from cracks in the storage box. Warm air therefore flows into the rooms at a rate equivalent to the inflow leakage rate. If the collector is pressurized, warm air will flow out of the collectors and cause cold air to be drawn into the rooms (infiltration) necessitating additional room heating. A thermal energy balance around the building envelope will show that for the same air mass leakage rate, the situation where air leaks into the collector is advantageous, in terms of net thermal energy, compared to air leaking out of the collector.

3.1.3 Heating from Storage

The pebble-bed storage is the heat source when solar energy is not available directly from the collectors. To recover heat from storage air is circulated in a reverse direction to the storing mode. Although the directions for the air stream to store and retrieve heat are not vitally important, normally air is circulated from top to bottom while storing and reversed from bottom to top to recover the stored thermal energy. The circulation path for this mode is shown in Figure 3-3.

The thermostat commands the controller to circulate room air through storage. When heat from storage is not delivered at a rate sufficient to meet the demand, the heat pump and electrical resistance heater add thermal energy to the air stream. The heat pump is controlled by the

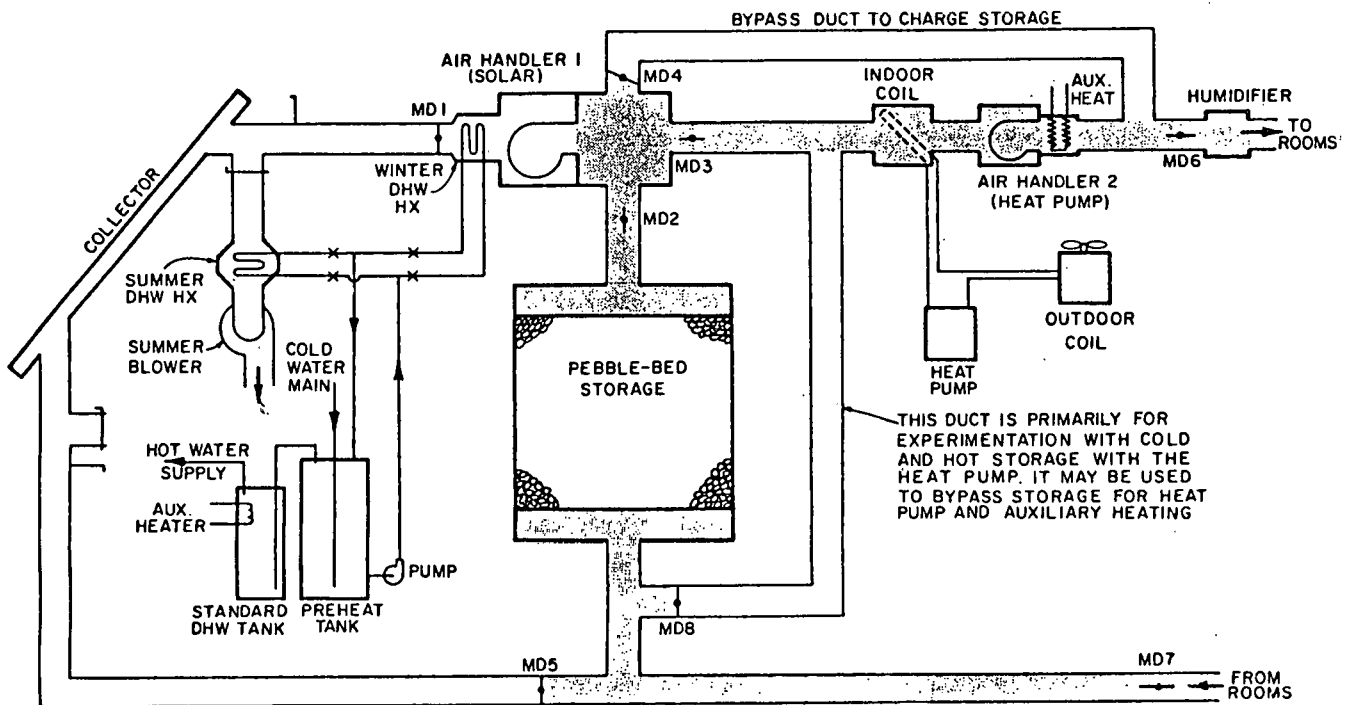


Figure 3-3. Heating from Storage

air temperature ahead of the indoor coil and the resistance heater is activated by the second stage of the thermostat.

3.1.4 Domestic Water Preheating

Preheating of domestic water is accomplished only during the heat-storage mode. When heating the house from the collector, priority is given to space heating over domestic water heating. Experience has also shown that the direct heating mode occurs principally early in the day when air temperature from the collector is low and water heating in the heat exchanger is ineffective compared to heating during mid-day.

3.1.5 Identification of Modes for the Heating Season

Submodes of the three basic heating modes were identified as separate "modes of operation" so that measurements of air flow rates and calculations of heat transport rates could be facilitated. To achieve rapid changes in control strategy and to facilitate changing from winter to summer operation, a pin-programmable controller was assembled. The winter season modes are identified in Table 3-1.

Table 3-1. Heating Season Modes

Mode	Label	Explanation
1	DN	Do Nothing (Identified to facilitate data processing)
2	HFC	Heating the rooms directly from the collectors
3	HFC/HP	Heating the rooms from the collector plus the heat pump
4	HFC/HP/AH	Heating the rooms from the collectors plus heat pump plus electrical resistance heating
5	HFS	Heating the rooms from storage
6	HFS/HP	Heating the rooms from storage plus the heat pump
7	HFS/AP/AH	Heating the room from storage plus heat pump plus electrical resistance heating
8	CS*	Start heat storage in special circumstance
9	CS/HW	Storing heat and preheating domestic water
10	FP	Freeze protection of the heat exchanger in the event of damper leakage
11	C/S	Collector to storage, normal heat storage

*When the bottom of storage is warmer than the top, which occurs at change-over from cold storage to heat storage (summer to winter) a special condition is used in the controls to initiate start of heat storage.

3.2 BASIC COOLING MODES

3.2.1 Cold Charging the Pebble Bed

Although a heat pump can be used whenever there is cooling demand, it may be economically advantageous to use the pebble bed of the solar heating system as a part of an off-peak cooling scheme. During the hours when off-peak electrical energy rate is in effect, the heat pump can be used to cold charge the pebble bed as shown in Figure 3-4. If house heating is required during the same period, the controls can be arranged to by-pass storage as shown in Figure 3-5. (The heat pump can also be used to cool the rooms directly, which is one of the basic modes of operation).

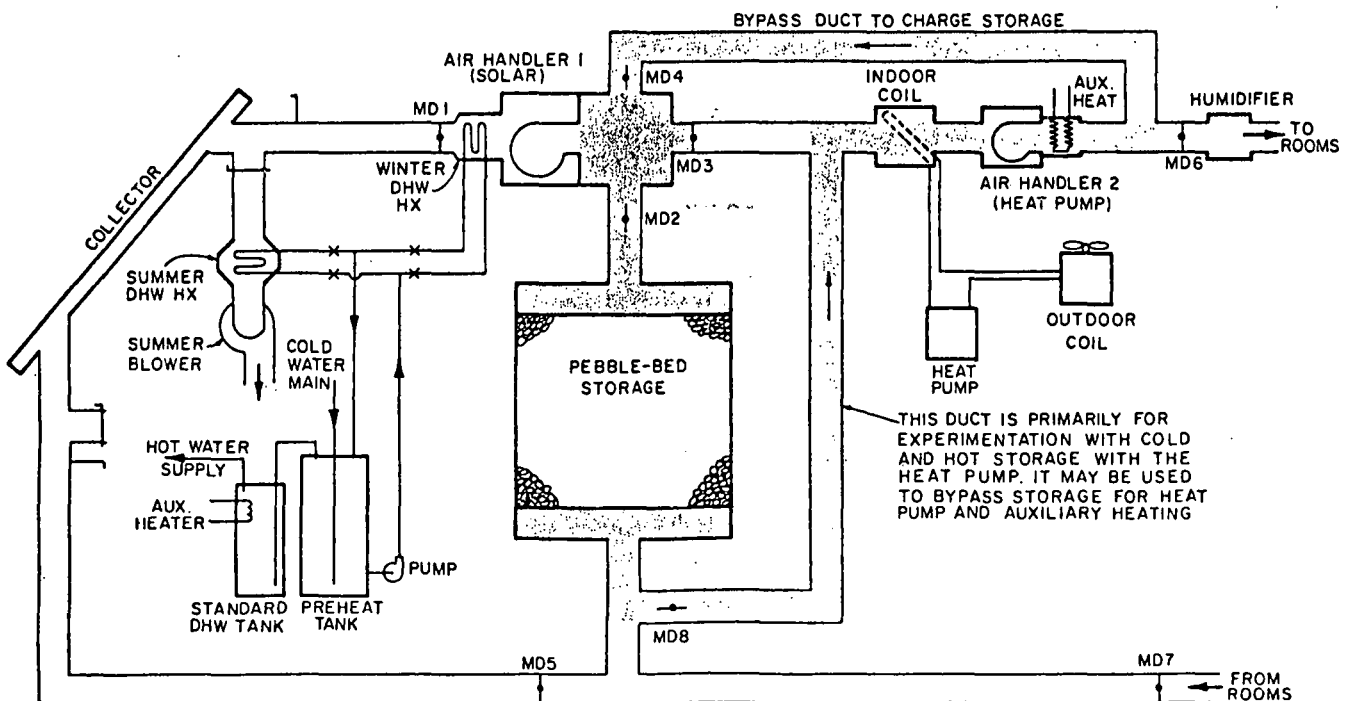


Figure 3-4. Cold Charging the Pebble Bed

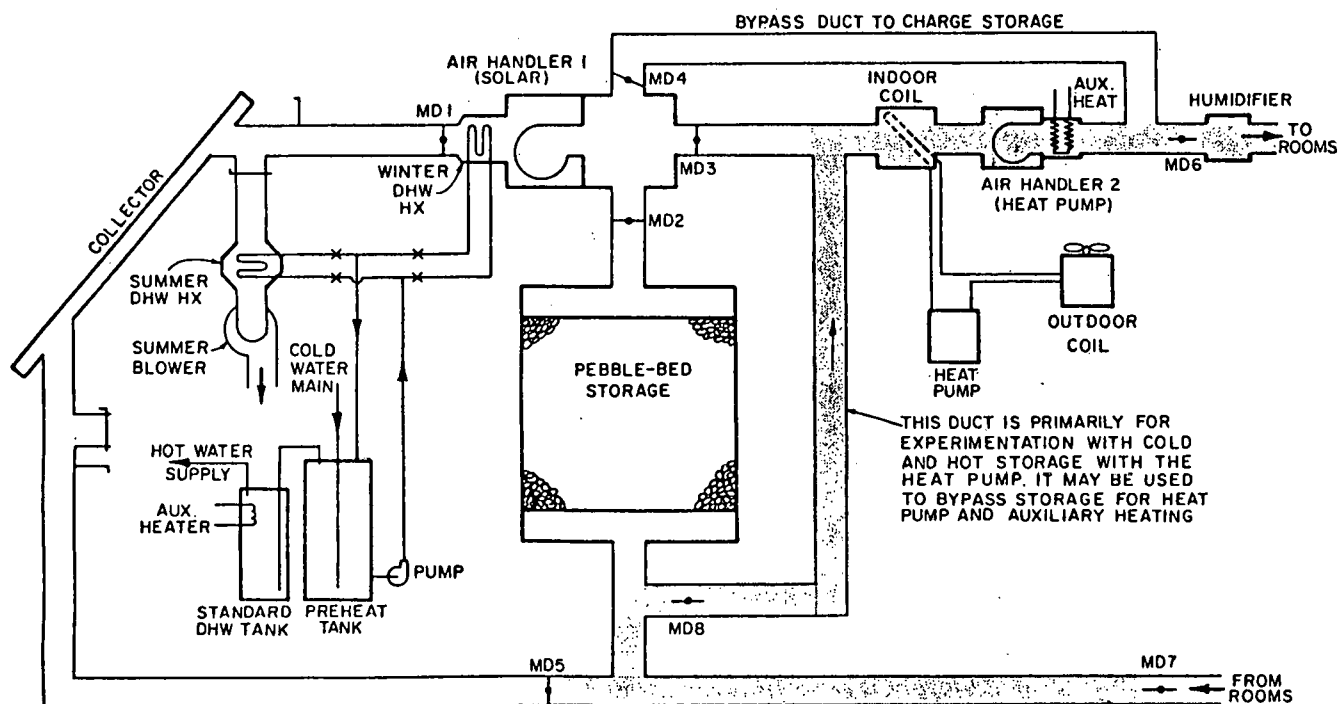


Figure 3-5. Cooling the Rooms with Heat Pump

3.2.2 Cooling from Storage

During the day when cooling is in demand, as determined by the thermostat in the room, air is circulated through the pebble bed which becomes a heat sink. Because only the air handler of the heat pump is used to achieve room cooling, consumption of electrical energy is minimized during (peak) hours when cooling is required. Air circulation path is the same as shown in Figure 3-3 for heating of rooms from storage.

3.2.3 Domestic Water Preheating

During the summer season domestic water is preheated by circulating air from the attic space through the collectors and subsequently through

the air-water heat exchanger. Hot air emerging from the blower is discharged outdoors. The arrangement, shown in Figure 3-6, achieves preheating of domestic water and cooling of collectors when water heating is not required. Circulation of outdoor air through the attic reduces the air temperature in the attic space which helps to reduce the cooling load. Since the collectors should be "protected" during the summer against prolonged stagnation, air should be circulated through the collectors and in the process water can be preheated by installing a second air-water heat exchanger in the attic. Capital investment for the blower, heat exchanger and additional copper piping, however, will add to the cost of the solar system. Even if the pebble bed is not used for cold storage it is not advisable to circulate hot air through storage only to preheat domestic water during the summer because heat losses from ducts will add substantially to the cooling load.

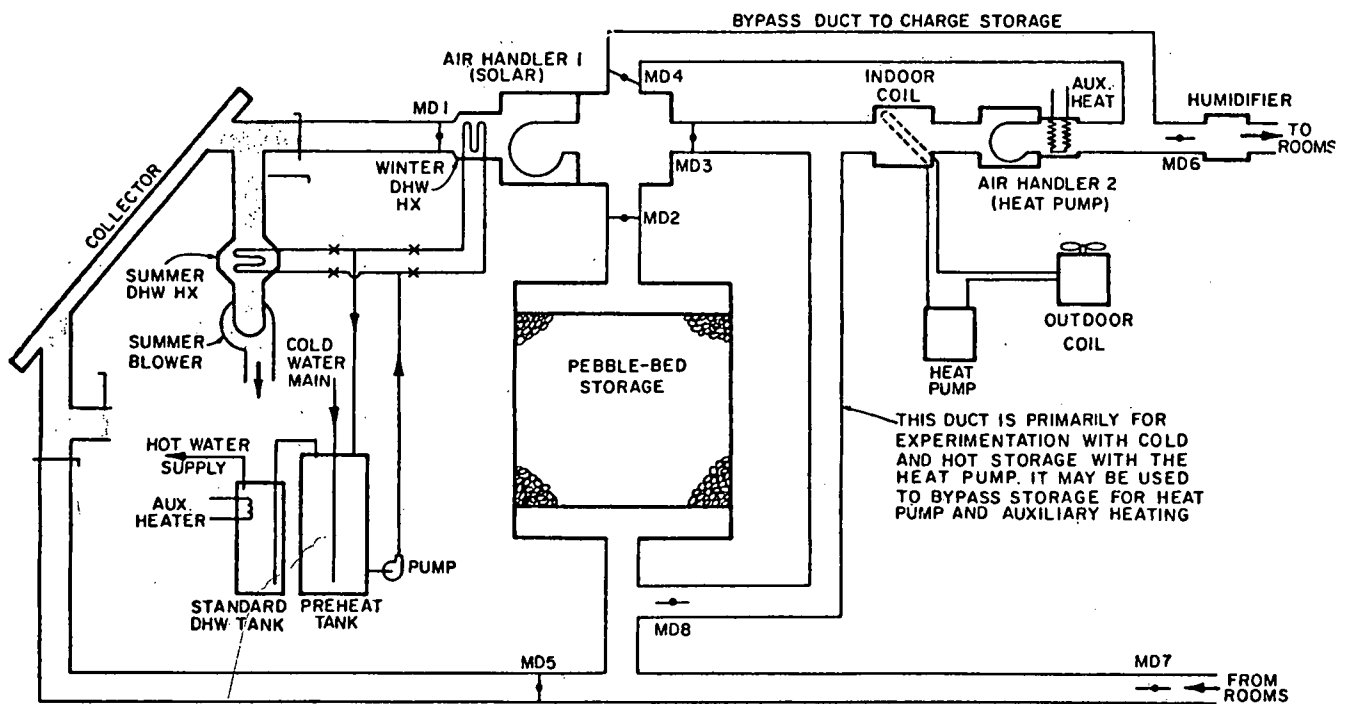


Figure 3-6. Domestic Hot Water Preheat during Summer Cooling Season and Collector Protection

3.2.4 Identification of Modes for the Summer Season

Submodes of basic operational cooling modes are labeled as modes for purpose of identification in the data analysis process. The controller was reprogrammed for the modes listed in Table 3-2.

Table 3-2. Summer Season Modes

Mode	Label	Explanation
1	DN	Do Nothing
2	CS	Cold charge of storage, controlled for off-peak hours only
3	CFS	Cooling from storage
4	CFS/HW	Cooling from storage plus domestic water preheating
5	CFS/CC	Cooling from storage plus cooling collectors
6	CHP*	Cooling with heat pump
7	CHP/HW*	Cooling with heat pump plus heating water
8	CHP/CC*	Cooling with heat pump plus cooling collectors
9	HW	Preheating domestic water
10	CC	Air circulation to cool the collectors without preheating water
11	HHP	Summer heating with the heat pump
12	H/HW	Heating with heat pump plus heating water
13	H/CC	Heating with heat pump plus cooling collector

*Room air was circulated through the pebble bed and the indoor coil and heat pump was actuated when air temperature to the coil reached a preset temperature.

4. SYSTEM CONTROLS

4.1 CONTROL FUNCTIONS

The solid-state diode pin-programmable controller for the heating and cooling system in Solar House II requires input signals from six temperature sensors and the room thermostat to regulate all the mechanical devices (dampers, blowers, pump and compressor) of the solar system. The basic control functions are to: (1) collect solar heat from the collectors and store in the pebble bed; (2) collect heat from the collectors to heat the room directly; (3) heat the rooms from storage; (4) call on the heat pump and finally the resistive strip heaters when necessary to maintain comfort conditions in the rooms; (5) regulate the domestic water preheating; (6) cool the pebble-bed storage at night and (7) cool the room air during the day from either the cool storage or directly by the heat pump. The control unit is responsive to a two-stage heat, one stage cool thermostat in the conditioned space, one temperature sensor in the collector, two sensors in storage, two in the DHW preheater tank, and one sensor located in the DHW heat exchanger coil during winter operation. A block diagram of the control unit is shown in Figure 4-1.

4.2 CONTROL SENSOR LOCATIONS

A thermostat with two-stage contacts for heating and one-stage contact for cooling "regulates" the comfort condition in the building. The thermostat, located in the east room of the building on the first floor, (see Figure 2-2) must be manually switched to heating or cooling mode with changes in season. Six silicon diode temperature sensors are

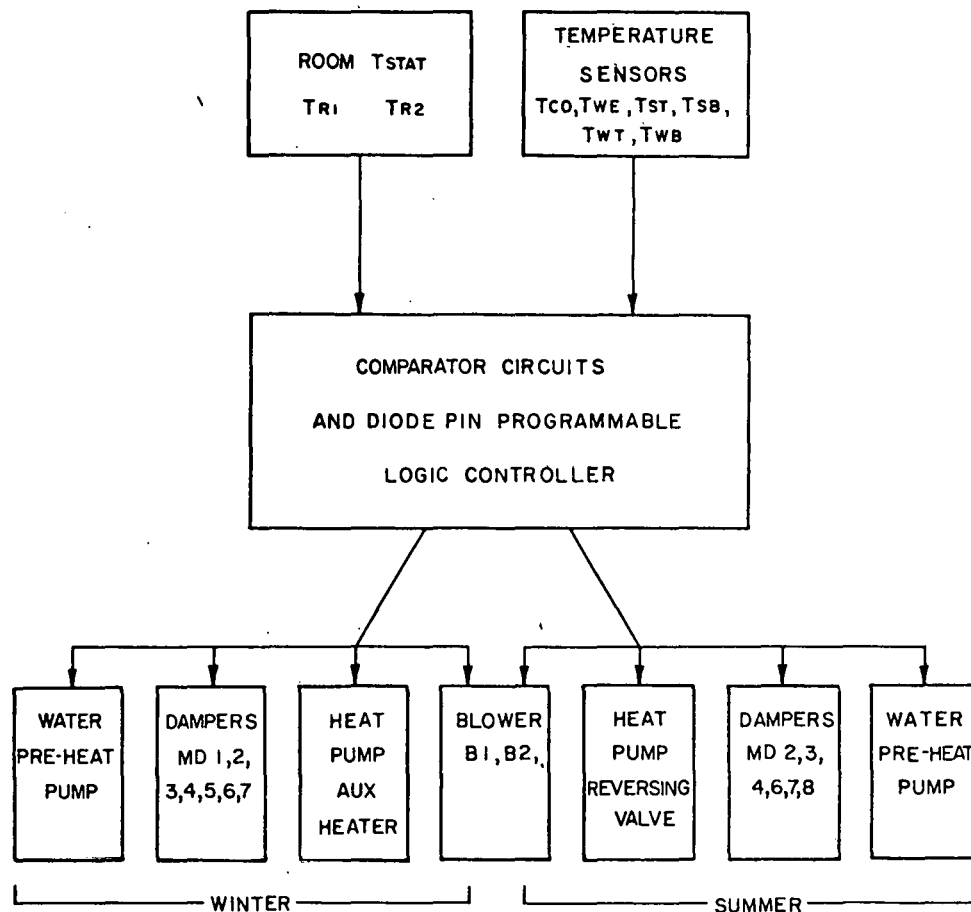


Figure 4-1. Block Diagram of the Solar House II Control Unit

located in the system as shown in Figure 4-2. Two sensors at the collector outlet, T_{CO} , are located inside the collector absorber duct at the top of a central collector in each array. Only one of the sensors is connected to the controller at any time. A sensor is located at the top of storage, T_{ST} , and another, T_{SB} , is located at the bottom of the pebble-bed storage. Sensor T_{ST} is one pebble layer beneath the top rock surface and 46 cm inward from the top plenum port. Sensor T_{SB} is located just above the rock support screen at the bottom of the storage box and located at mid-length along the south side.

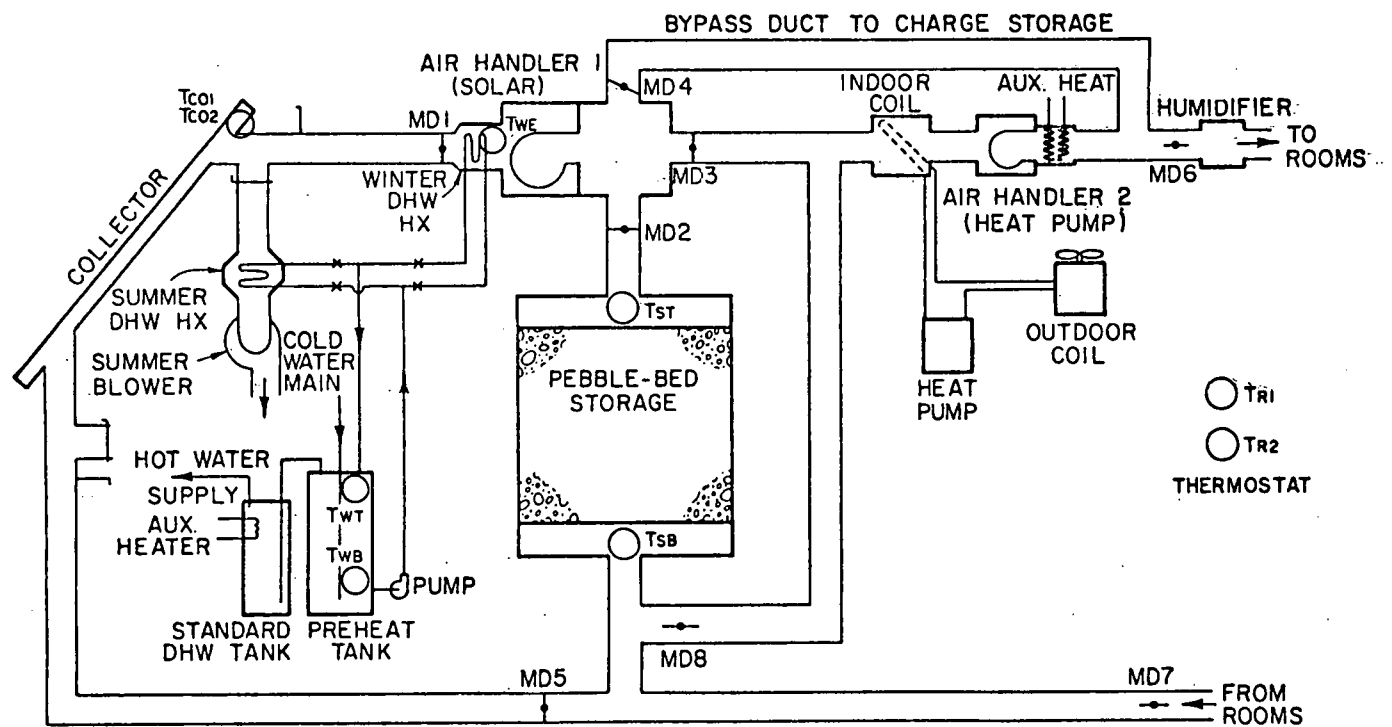


Figure 4-2. Location of Control Sensors (Diodes)

For winter operation the domestic hot water pre-heater circulation system operates in conjunction with storing heat from the collector. Temperature sensor T_{WB} is located inside the pre-heat tank approximately 5 cm off the bottom. A comparison of T_{CO} to T_{WB} is made in the controller and the pre-heat pump is engaged when useful energy can be gained from the solar heated air.

In the summer mode the domestic hot water pre-heat is a completely independent operation which can function with any other summer operation except cold charge. Since DHW is the only use for the solar-heated air it is possible to actually reach a temperature above normal domestic hot water set temperature. A sensor T_{WT} is located at the top of the pre-heat tank within the return line from the heat exchanger which provides the control temperature for high limit shut off. In both winter and summer operation an aquastat is also placed in line with the power line to the pump motor as a final safety limit to prevent boiling.

Temperature sensor, T_{WE} , is located within the domestic hot water heat exchanger coil used during the winter heating season. This sensor is for freeze protection when air leakage past dampers can cause low enough temperatures to freeze water in the coil. When T_{WE} detects freezing temperatures the hot water circulation pump is started to circulate warm water through the heat exchanger coil.

4.3 CONTROL LOGIC AND TRUTH TABLE

The controller has essentially 3 basic sections or components as indicated in Figures 4-3a, 4-3b, and 4-3c, each with a distinct function in the

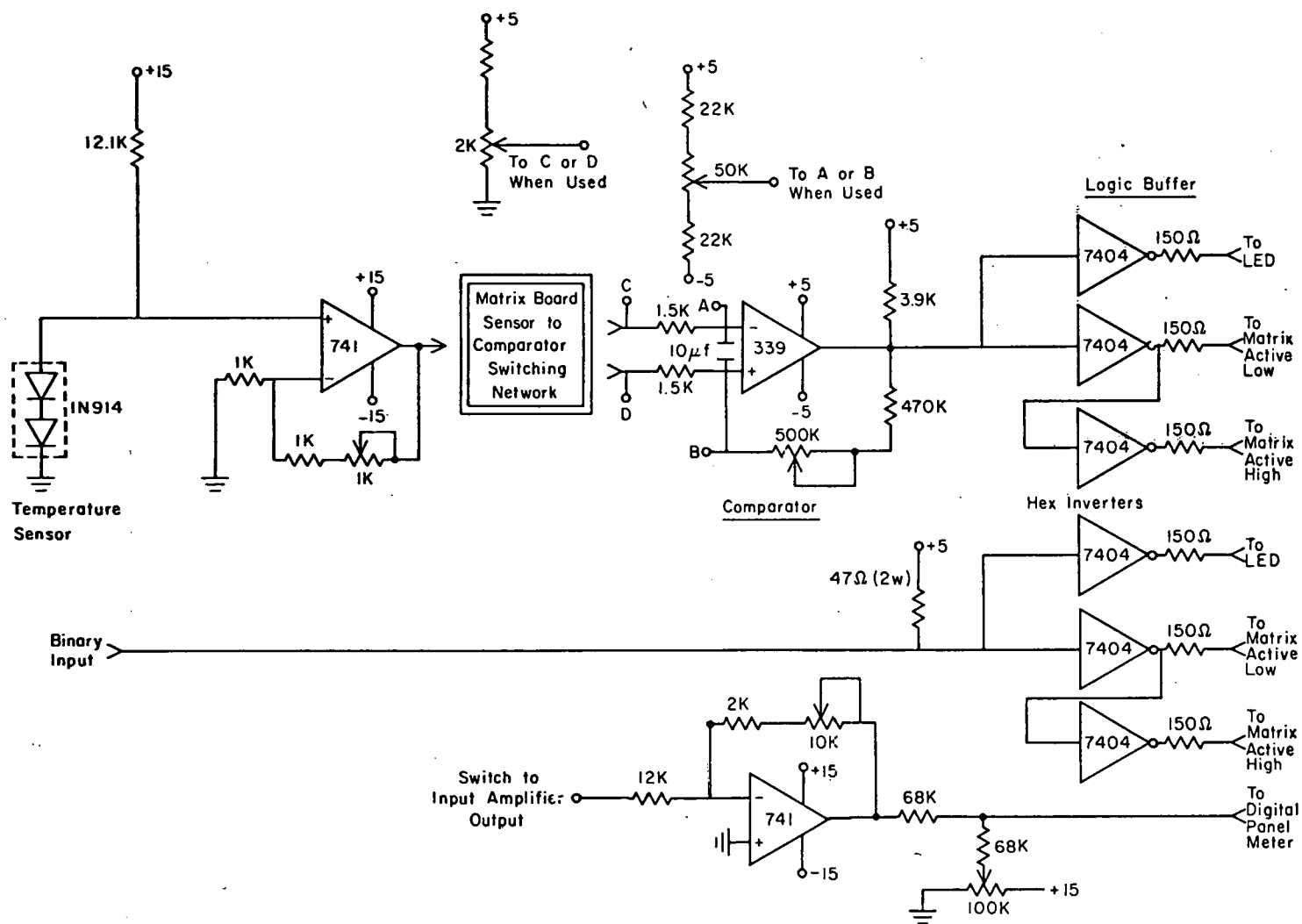


Figure 4-3a. Input Signal Conditioning and Comparator Circuits for Controller

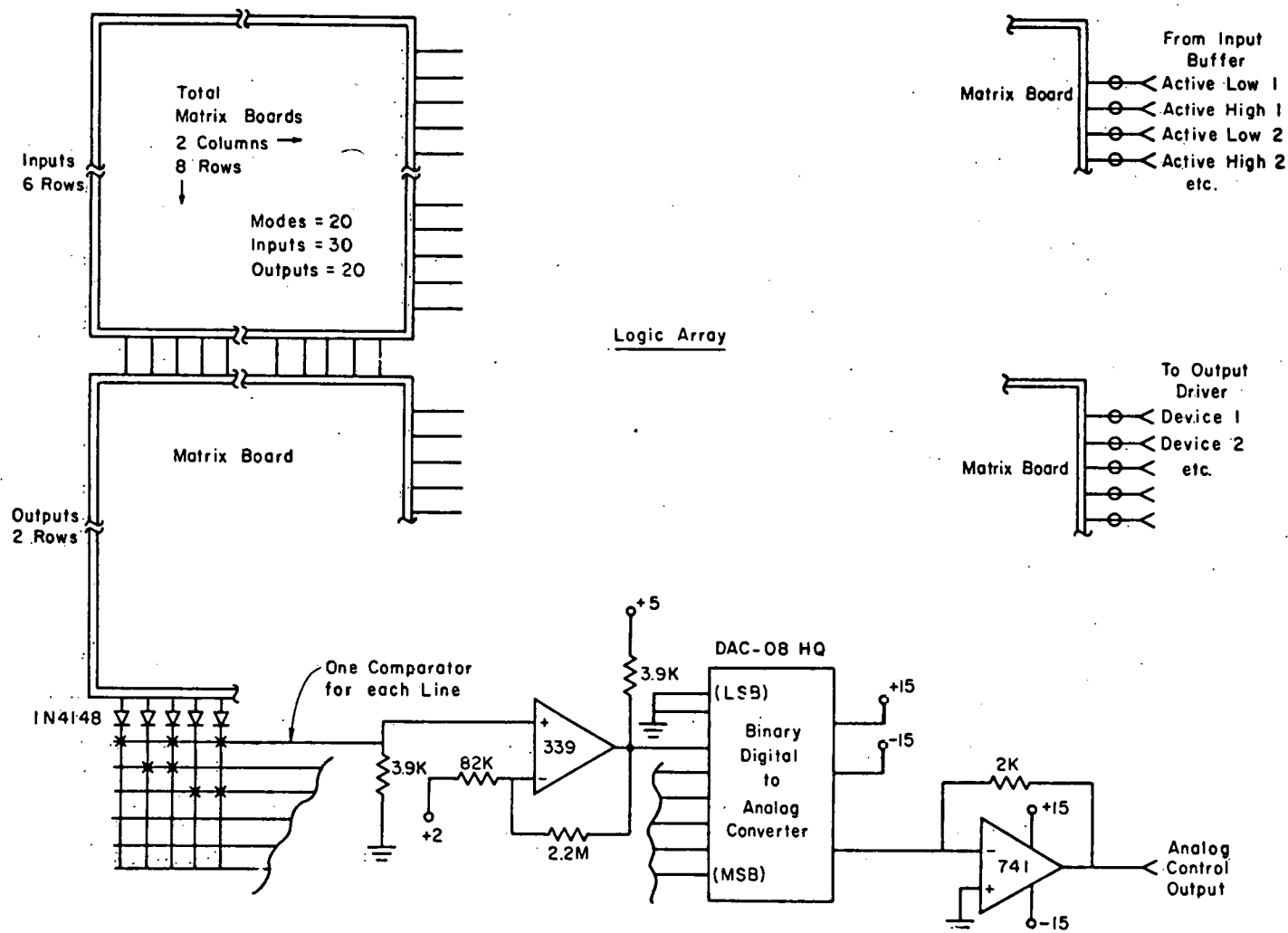


Figure 4-3b. Typical Schematic of Logic Section of Controller

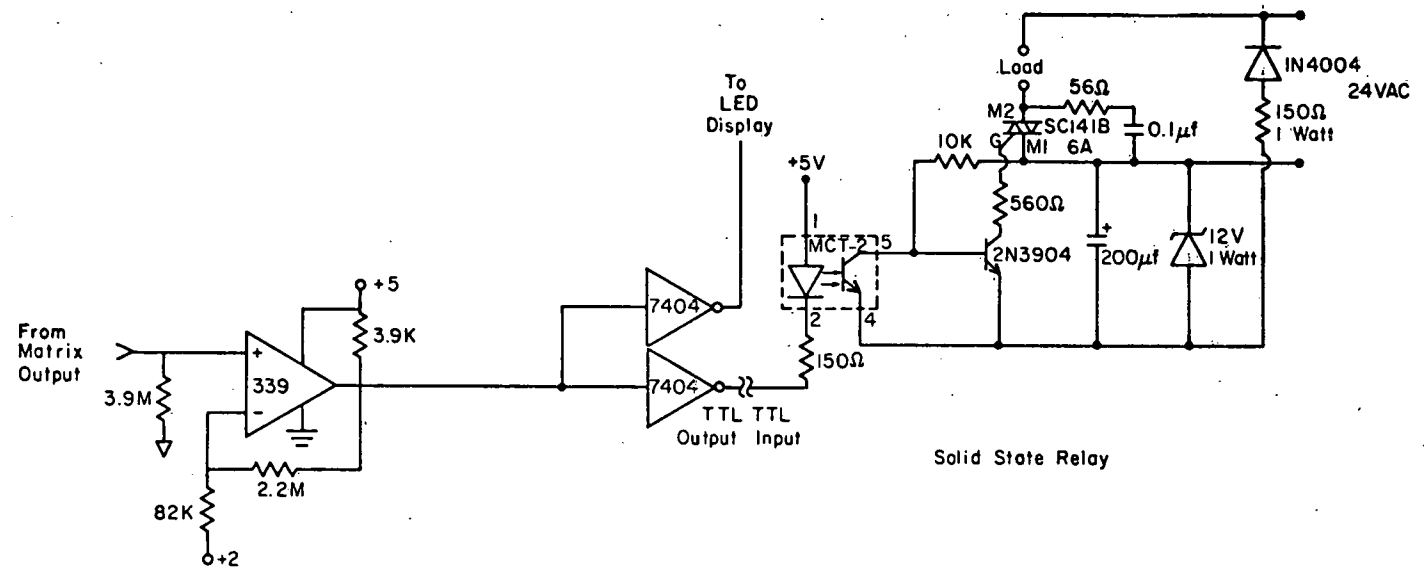


Figure 4-3c. Typical Controller Output Section from Logic with 24 Vac Control Signal

control process. The input section (Figure 4-3a) contains all the signal conditioning required for the diode temperature sensors. These sensors provide a linear temperature to forward voltage relationship. The input section also contains the comparators and set point circuitry for making the various temperature comparisons between sensors and between sensors and "fixed" temperatures. The logic controller (Figure 4-3b) is the second section and consists of a diode pin-programmable matrix. The pattern of diode placement serves as the memory for the controller producing unique operating modes for the input conditions to the matrix. The output section (Figure 4-3c) receives the signals from the diode matrix board and interfaces between the logic lines and the actual devices being activated. Light emitting diodes (LED) mounted on the front panel of the controller can be observed to monitor the logic level of all inputs and outputs as well as internal voltages. The temperature sensor signal conditioning also is used to drive a digital display to monitor selected sensors at the control panel.

4.3.1 Space and Water Heating

The controller requires a manual change of diode pins to program system operation for the heating or cooling season. This is due primarily to a limit of 20 lines for designation of modes. There are 23 separate modes which require identification for summer and winter operation, primarily for performance monitoring purposes. If it were not for monitoring purposes a standard controller would require identification of only a few modes. House space can be heated during the summer operation by use of the heat pump, but cooling during the heating season was not programmed.

The first stage contact of the thermostat, T_{R1} , (as are all the thermostat contacts), is simply a switch closure which provides a logic level signal directly to the logic control. When the room air temperature drops below a preset temperature at the thermostat, a circuit is completed and a logic level high is received at the logic inputs indicating that space heating is required. There are several options for providing heat; (1) from the collectors, (2) from storage, or (3) from the auxiliary heater.

To be able to deliver heat from the collectors the air temperature at the top of the collectors must be warmer than a preset temperature, 34°C . Sensor T_{C02} is compared to a set temperature (at the input comparators), and the temperature difference signal is sensed at the logic board. Depending upon the level of the signal, that is, whether T_{C02} is much greater than the set point, much less than the set point, or within a hysteresis band about the set point (which is determined by an adjustable potentiometer on the comparator), the input state is interpreted as "true" or "false" respectively by the diode pin program board. When all the input states to the diode logic board meet the pre-programmed conditions, the circuit to the starter relay of B1 is completed, dampers 1, 4, 5, 6 and 7 (see Figure 4-2) are properly activated and heat is delivered from the collectors to the rooms. The set of "truth" conditions for input and output states, winter modes, of the diode logic section to heat the rooms from the collectors is indicated on the mode 2 line of the truth table, Table 4-1.

If the air temperature at the top of the collectors is warmer than another set point, $T_{C01} > 28^{\circ}$, but not warmer than the higher set point of 34°C indicated by T_{C02} (T_{C01} and T_{C02} are designations for the

Table 4-1. Truth Table for Modes of Operation

MODE NUMBER	WINTER MODES	SENSOR CONDITIONS												OUTPUT DEVICES												
		CLOCK	$T_{ST} < 18^{\circ}$	$T_{CO1} > 38^{\circ}$	$T_{SB} > 13^{\circ}$	$T_{WT} > 70^{\circ}$	$T_{CO} > T_{WB}$	T_{R1}	T_{R2}	$T_{WE} > 3^{\circ}\text{C}$	$T_{CO1} > 28^{\circ}\text{C}$	$T_{CO2} > 34^{\circ}\text{C}$	$T_{ST} > 20.5^{\circ}\text{C}$	$T_{CO} > T_{SB}$	M01 & 5	M02	M03	M04	M06 & 7	M08	B-1	B-2	HEAT PUMP	AUX HEATERS	REVERSING VALVE	WATER PREHEAT
1	DO NOTHING																									
2	HEATING FROM COLLECTOR							1	0		1				1	0	0	1	1	0	1	0	0	0	0	0
3	HEATING FROM COLLECTOR & HEAT PUMP							1	0		1	0			1	0	1	0	1	0	1	1	1	0	0	0
4	HEATING FROM COLLECTOR & HEAT PUMP & AUX							1	1		1				1	0	1	0	1	0	1	1	1	1	0	0
5	HEATING FROM STORAGE							1	0		0		1		0	1	1	0	1	0	0	1	0	0	0	0
6	HEATING FROM STORAGE & HEAT PUMP							1	0		0		0		0	1	1	0	1	0	0	1	1	0	0	0
7	HEATING FROM STORAGE & HEAT PUMP & AUX							1	1		0				0	1	1	0	1	0	0	1	1	1	0	0
8	START COLLECTOR TO STORAGE							0	0		1		0	1	1	1	0	0	0	0	1	0	0	0	0	0
9	COLLECTOR TO STORAGE & WATER PREHEAT							1	0	0	1		1	1	1	1	0	0	0	0	1	0	0	0	0	1
10	FREEZE PROTECT WATER PRE-HEAT COIL							0			0				0	0	0	0	0	0	0	0	0	0	0	1
11	COLLECTOR TO STORAGE							0	0	0	1		1	1	1	1	0	0	0	0	1	0	0	0	0	0
SUMMER MODES																										
1	DO NOTHING																									
2	COLD CHARGE STORAGE	1			1				0							0	1	0	1	0	1	0	1	1	0	1
3	COOL FROM STORAGE	0	1				0	1	0							0	1	1	0	1	0	0	1	0	0	0
4	COOL FROM STORAGE & WATER PRE-HEAT	0	1	1		0	1	1	0							0	1	1	0	1	0	1	1	0	0	1
5	COOL FROM STORAGE & PROTECT COLLECTOR	0	1			1	1	1	0							0	1	1	0	1	0	1	1	0	0	0
6	COOL WITH HEAT PUMP	0	0				0	1	0							0	0	0	0	1	1	0	1	1	0	1
7	COOL WITH HEAT PUMP & WATER PRE-HEAT	0	0	1		0	1	1	0							0	0	0	0	1	1	1	1	0	1	1
8	COOL WITH HEAT PUMP & PROTECT COLLECTOR	0	0			1	1	1	0							0	0	0	0	1	1	1	1	1	0	1
9	WATER PRE-HEAT	0		1		0	1	0	0							0	0	0	0	0	1	0	0	0	0	1
10	PROTECT COLLECTOR	0				1	1	0	0							0	0	0	0	0	0	1	0	0	0	0
11	HEATING WITH HEAT PUMP						0	0	1							0	0	0	0	1	1	0	1	1	0	0
12	HEATING WITH HEAT PUMP & WATER PRE-HEAT	0		1		0	1	0	1							0	0	0	0	1	1	1	1	1	0	0
12	HEATING WITH HEAT PUMP & PROTECT COLLECTOR	0				1	1	0	1							0	0	0	0	1	1	1	1	1	0	0

same sensor at the collector but the signal is used to drive two separate comparators in the input section of the controller) the collectors alone cannot provide heat at a sufficient rate to the house to satisfy the demand. In this case, represented by winter mode 3 on Table 4-1, the heat pump as well as blower B2 are cycled on and damper MD3 is activated while MD4 is deactivated (closed). A high temperature limit of 34°C is used to protect the heat pump.

If, despite auxiliary heating with the heat pump, the temperature in the house continues to drop, the second stage heating thermostat, T_{R2} , will make contact and the resistive strip heaters will be activated to provide further heat input to the house. When the T_{R2} contact opens resistance heating terminates. This is represented by winter mode 4 in Table 4-1.

Collection of solar heat to storage is initiated when T_{C01} , is greater than 28°C , T_{C0} is greater than T_{SB} by a preset amount of 6°C , and T_{R1} is open. The system will continue to collect heat once started, until $T_{C0}-T_{SB}$ is equal to 1°C . A hysteresis of 5°C prevents cycling of blower B1 at startup and shut down. A large hysteresis was set in the T_{C01} comparator to fixed temperature to continue collection, once started, until the $T_{C0}-T_{SB}$ comparator terminated collection. Two modes for storage of solar heat are identified, modes 8, and 11. Mode 8 is used to initiate collection on special occasions when T_{ST} would be less than T_{SB} , as for instance in switching from summer cooling to winter heating. Mode 8 is normally active for a short time, until T_{ST} is above room temperature. Mode 11 is the normal collector to storage mode.

Domestic water heating, Mode 9, is permitted if T_{C0} is greater than T_{WB} by 6.5°C and the top of storage, T_{ST} , is greater than room temperature,

20.5°C. The latter requirement prevents cooling the top of storage below room temperature which is possible if the domestic preheat coil extracts heat from the air stream late in the afternoon.

To heat the rooms from storage, the temperature at the top of storage, T_{ST} , must be greater than room temperature, the collector must be cold (T_{CO1} must be less than the preset temperature) and T_{R1} (and T_{R2}) circuit must be completed. If T_{ST} is below 34°C the logic is set up so that the heat pump turns on. During the winter, air at this temperature will not heat the rooms adequately, and rather than allow a large temperature variation in the rooms, supplemental heat is provided from the heat pump. When there is a large heat loss rate from the building, T_{R2} is activated and the auxiliary strip heaters will turn on.

Mode 10 is to protect the air-water heat exchanger from freezing. If sufficient leakage occurs across damper MD1 while the rooms are being heated from storage, air at subfreezing temperatures can be drawn across the domestic hot water pre-heat coil and freeze the unit. Mode 10 controls circulation of preheated water from the pre-heat tank when T_{WE} senses temperatures below 3°C at the pre-heat coil.

4.3.2 Space Cooling

The system is designed to cold charge the pebble bed during off-peak hours and the cold pebble bed is used as a heat sink to cool the rooms during the day. Clock time is used as an input to the logic to control cold charging during a specific time period consistent with time of day rate structure of the utility company. Cold charging was

selected for 8 hours from 2400 hours to 0800 hours mountain standard time. While this may actually overlap into morning peak rate times the 8-hour block was selected to coincide with the beginning of the clock day for convenience of data analysis. When both the clock timer is true and temperature at the bottom of storage is greater than 13°C , cold charge can begin. A temperature limit on T_{SB} is selected to protect the indoor coil from freezing and cause reduction of air flow rate. Summer mode 2 in Table 4-1 shows the conditions required for cold charge.

While the clock timer is true no other summer mode can be activated. When the house requires cooling, as signaled by T_{R1} and the pebble bed has been cold charged so that T_{ST} is less than 18°C , room air will be circulated through storage for house cooling. The appropriate dampers, as indicated by summer Mode 3 in Table 4-1, along with blower B2 will activate to circulate room air through storage.

After the cold charge in storage has been depleted the temperature in top of storage, T_{ST} , will no longer be less than 18°C and the system will switch to direct cooling with the heat pump. Room air by-passes storage during the direct cooling mode.

Occasionally there are days during the cooling season, especially in the fall, when heating may be required. Thermostat contact T_{R2} is used to control space heating with the heat pump. The resistive strip heaters cannot be activated in the summer heating mode.

During summer operation solar-heated air remains outside the building envelope. Blower B1 for summer cooling refers physically to a third blower located in the attic space, but is given the same designation as B1 during the winter season. A second domestic hot water pre-heat coil is conneted to preheat tank and the winter use heat exchanger is valved out

of the circuit. Thus solar-heated air continues to provide domestic hot water preheating during the summer cooling mode. Hot water preheating and collector protection can operate independently of any cooling mode. The collector protect mode is used to limit the temperature of water in the preheat tank. When T_{WT} , the temperature at the top of preheat storage exceeds 70°C the circulating pump shuts off but B1 remains activated.

An alternative strategy is to let the collectors stagnate, but in the long term it is believed that preventing the collector from attaining very high temperatures is a superior control strategy for the system. Because of the heat exchanger size used in the system, limiting temperature in the preheat tank was seldom attained and control for B1 was principally by the temperature difference $T_{CO}-T_{WB}$.

5. DATA ACQUISITION SYSTEM

5.1 GENERAL DESCRIPTION

The data acquisition system (DAS) consists of (1) instruments and transducers of various kinds to sense temperatures, temperature differences, solar radiation, air and water flow rates, pressures and pressure differences, (2) an analog-to-digital (A/D) converter and data logger, (3) a magnetic tape recorder to store data in digital form, (4) an on-line desk-top computer with peripherals for real-time data reduction, and (5) an uninterruptible power supply. The components of the DAS are depicted in Figure 5-1.

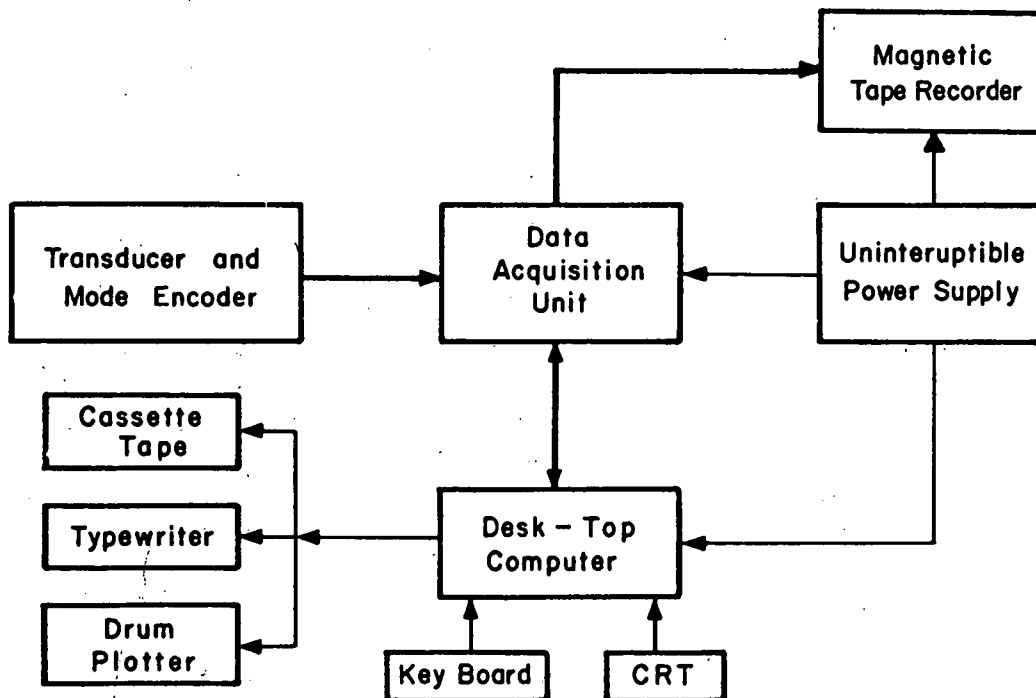


Figure 5-1. Block Diagram of the Data Acquisition System

5.2 INSTRUMENTS

The instruments used to determine temperatures, temperature differences, air flow rates, differential pressures, solar flux, and auxiliary energy quantities are listed in Table 5-1. Listed also in the table are instrument types, manufacturers and models, the range of each instrument, accuracies, and comments which reflect the experience in Solar House II as well as other comments to aid potential users of similar instruments for the purpose of monitoring solar system performance.

5.2.1 Solar Flux

Solar radiation measurements are made with an Eppley PSP pyranometer placed at the center of the roof in between the two collector arrays and in a plane parallel to the collectors, which are tilted at 45 degrees with respect to horizontal. Both instantaneous and integrated values of solar radiation are included in the data set.

5.2.2 Temperature and Temperature Differences

Copper-constantan (Type T) thermocouples are used to measure temperatures of both air and water. Sheathed thermocouples are used to measure water temperatures. Reference junction compensation and linearization is provided in the data logging unit to an accuracy of $\pm 0.11^{\circ}\text{C}$ (Ref. 1).

Temperature differences are measured with multiple-junction thermopiles and electrical output is converted to temperature differences using standard procedures (Ref. 2, 3, 4). A typical thermopile arrangement is shown in Figure 5-2. Because air velocities are low, the dynamic heating effect is negligible. Also, the effect of radiative heat transfer between the duct walls and thermocouple junction is negligible.

Table 5-1. Transducers and Specifications

FUNCTION	INSTRUMENT TYPE	MANUFACTURER, DESCRIPTION	QUANTITY	INSTRUMENT/ DATA RANGE	ACCURACY (1)	COMMENTS
Temperature measurement (2)	Thermocouple Type T	Leeds and Northrup, Omega, ThermoElectric: 22 and 26 gage	67	-184 to +390°C -40 to +150°C	±.4°C	Consider: Temperature gradients, heat transfer to and from the measuring junctions, thermoelectric homogeneity of wire, reference junction calibration, linearization errors, use of extension wire and connections, mechanical integrity, grounding, common mode voltage sources (including lightning).
		ThermoElectric, sheathed: Grounded (3) Ungrounded (3)	2 2			
Differential temperature measurement (2), (4)	Thermopile, Type T	Leeds and Northrup, Omega 26 gage	7	-184 to + 370°C ±100°C diff.	±(1XR+.05°C)	
Outside ambient Aspirator temperature and humidity		Modified Cambridge Systems, Inc., Model #1105 - contains 1 T.C. and 1 R.H. sensor	1			
Air flow measurement (velocity pressure)	Total/static pressure tap array	Air Monitor Corp., and Cambridge Filter Corp. duct air monitor devices	7	+1. to +20 m/sec	±(1.0XR+.02 N/m²), after calibration	More uniform pressure tap geometry and placement w.r.t. air straightener, more taps and better pneumatic averaging should give more uniform pitot coefficients between units. Suitability of materials for high temperatures should be checked.
			6	+1 to +3 m/sec		
Pneumatic multiplexer	Ganged wafer valves, actuator and electrical driver	Scanivalve, Inc. Fluid Wafer Switch SCANO Actuator: LEDEX S2 Controller: CTLRP10/S2-56	4	10000 N/m² max operating pressure	N/A	Dessicant needed to prevent condensation of water vapor inside tabulation, wafer valve, and differential pressure transducer.
			2			
Differential pressure	Variable capacitance diaphragm type	Datametrics (Gould) Transducer: 5700-IT-2C1-V1 Signal Conditioner: 1173-A1A-10A1-D1 Thermal Base: Model 525	2	+133 N/m² 0 to +4N/m²		RC-5 seconds filter inserted to mask turbulence induced fluctuations. Controlled temperature transducer environment essential to maintaining quoted error limits.
			2			
Mode/air-flow-multiplexer encoder/controller		Locally made by SEAL	2	Digital	±0.1 LSB	Digital filter needed to reject transients. A resettable clock to indicate exact time of mode change between scans would be useful.
Solar flux measurement on 45° tilt	Pyranometer	Eppley precision pyranometer Model PSP	1	0 to 2800 w/m² 0 to 1200 w/m²	±(1.5XR+.5% F)	Both instantaneous and integrated values of pyranometer output are logged. A "double-glazed" pyranometer with axially symmetric black and white sensing surfaces is required to maintain accuracy when measuring global radiation on a tilt.
Electric power transducers	Current coil and hall effect transducer	F.W. Bell, Inc., PX-22028 Ohio Semitronics, PC5	6	±1KW or ±2KW	±(.25XR+.25XF)	Models offered by Ohio Semitronics are available with offset, scale factor adjustments and in a greater range of capacities.
			5	0 to 800 w		
Water flow	Rotameter		1	0.1 to 1.02/sec	±.5XF	Sensitive to damage or error from excessive flow, passage of entrained air or dirt.
			1	0.1 to 0.32/sec .015 to .152/sec .03 to .062/sec	±.5XR	
Integrators Pulse counters		AGM Electronics EA-4011-5	12	Unipolar input/output range specified per individual module	±(.25XR+.25XF)	Pick range carefully. Large accumulated errors due to effect avoiding by setting offsets slightly negative and rejecting negative values during data processing
		AGM Electronics EA-4050-2	4			
Barometric Pressure	Variable capacitance diaphragm; vacuum reference	Rosemont 1332A	1	0 to 15 psia .73 to .83 atm	±0.2XR	
		Mercury Weathertronics 7420	1	508-790 mmkg	±0.1 mm	
Relative humidity	Brady Array (AC excited solid state sensor)	Thunder Scientific PC-200	3		±.5XF	Individual calibrations required. Calibration not consistent.
A/D data logging	µP controlled analog multiplexing; dual slope digitizer	Doric 220-160-05-34-61-K5-TK1 KK1-31-53-4K-43-73	1	±11.0 VDC; -165 to +435°C	±(.03XR+.005% F +1.5uv)	Integration of computer and D/A functions should be considered now that such equipment is increasingly available. Provision for digital inputs would be helpful.
				±1.0 VDC; -40 to 150°C	Thermocouple conversion ±0.3°C	
Wind speed and direction	Cup anemometer separate wind vane	Weathertronics Inc. Anemometer 2030	2	0.11 to 45 m/s	±1% or ±0.07 m/s	Experience has shown that the photon chopper in anemometer is subject to failure. However light chopper concept assures micro response.
	Wind vane	Wind vane 2020	1	0.360°	±2°	
Btu domestic hot water to load	Accumulated Btu flow	Conserdyne Inc.	1			Water flow meter subject to failure

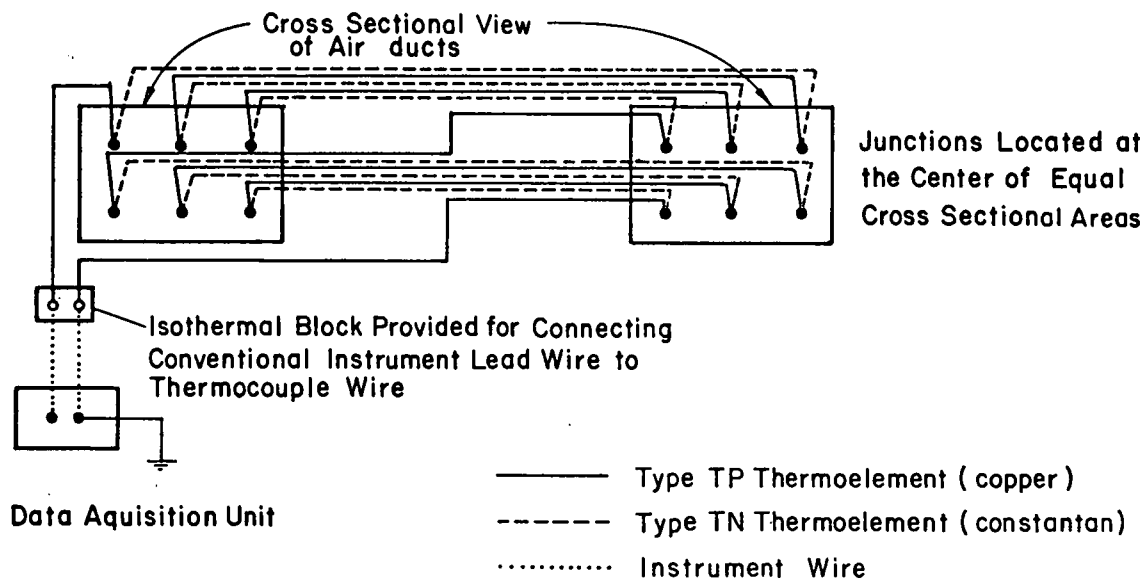


Figure 5-2. Thermopile Arrangement Used to Measure Temperature Differences

The locations of the thermocouples and thermopiles are shown in Figures 5-3 through 5-7. All instruments monitored by the data acquisition unit are listed in Table 5-2.

5.2.3 Pressure and Pressure Differences

Barometric pressure is measured with a Rosemont Series 1332 pressure transducer, the output of which is periodically checked against a standard mercury barometer. Differential pressures for the air flow monitors are measured with a Datametrics Model 570D-IT-2C1-V1 Barocel Electronic Manometer. The pressure range of the Barocel is $\pm 133 \text{ N/m}^2$ with an accuracy of 0.2 percent in the operating range from 0 to 4 N/m^2 and a full-scale accuracy of 0.02 percent. The thirteen flow monitors are multiplexed to the two differential pressure transducers through Scanivalves. One set of ports on each of the Scanivalves is short circuited so that a zero differential pressure reading is obtained for the Barocel, sequentially in the rotation of the Scanivalve.

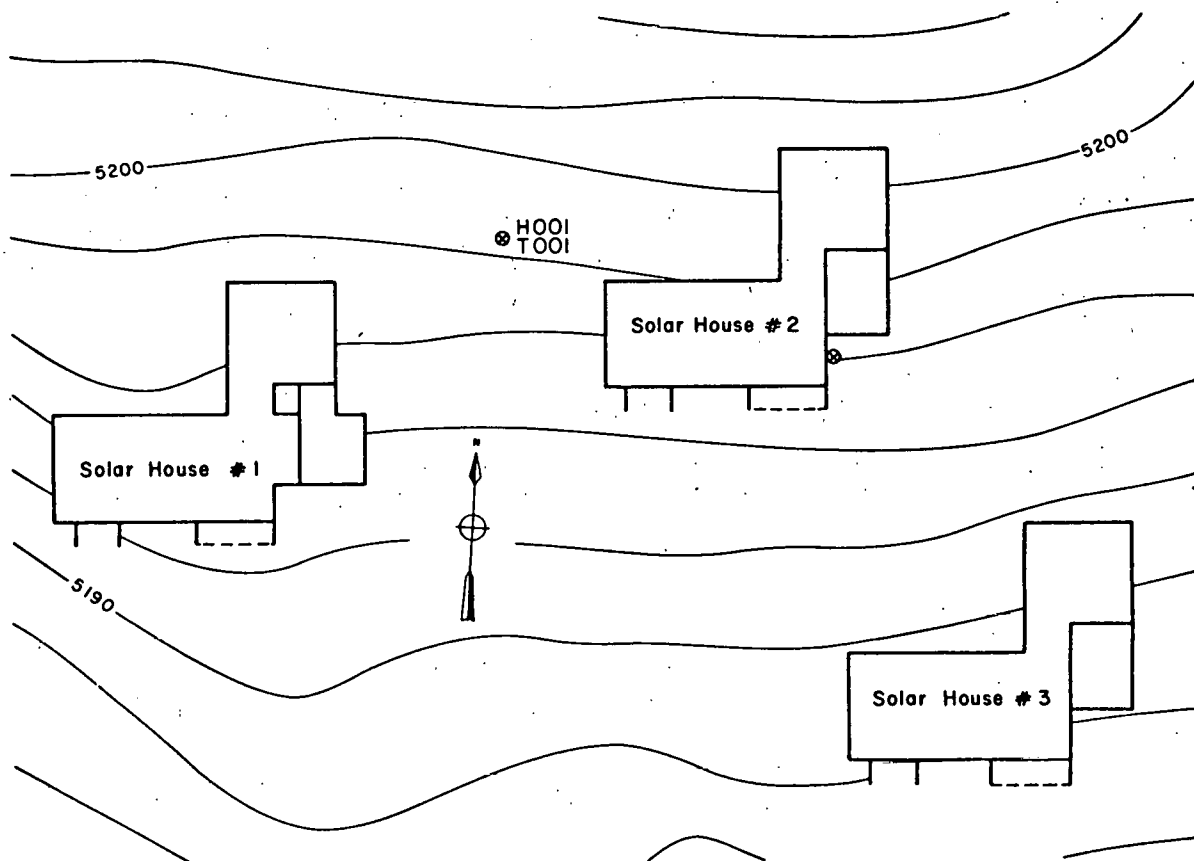


Figure 5-3. Weather Station and Pyranometer Locations. Sensor Location Numbered According to DAU Channel (Table 5-2)

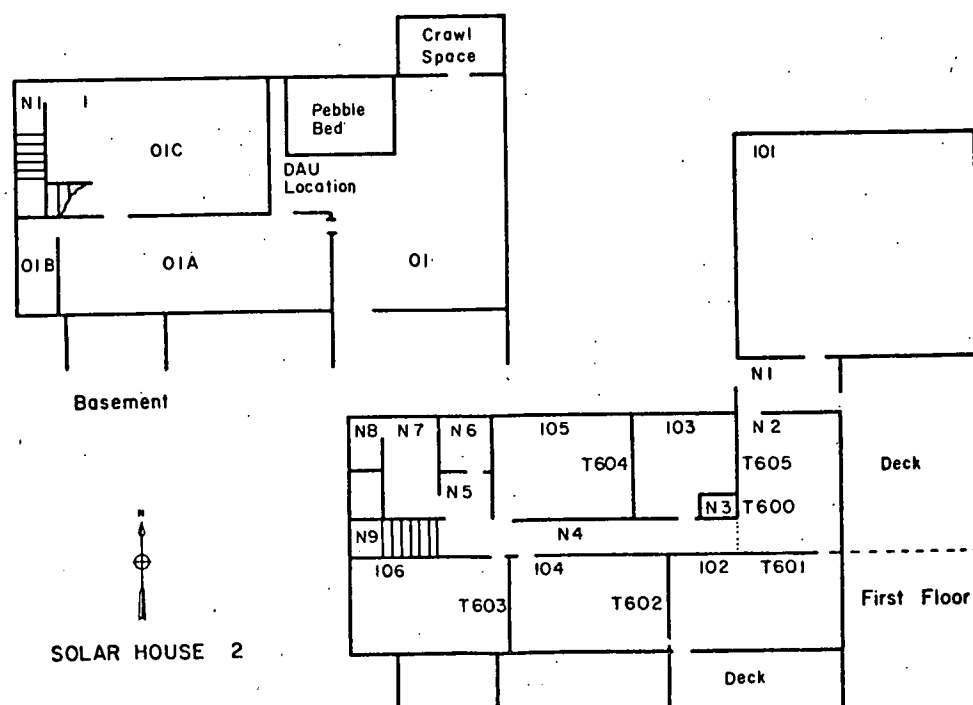


Figure 5-4. Temperature and Humidity Sensor Locations and Designations for House and Ambient Conditions (see Table 5-2).

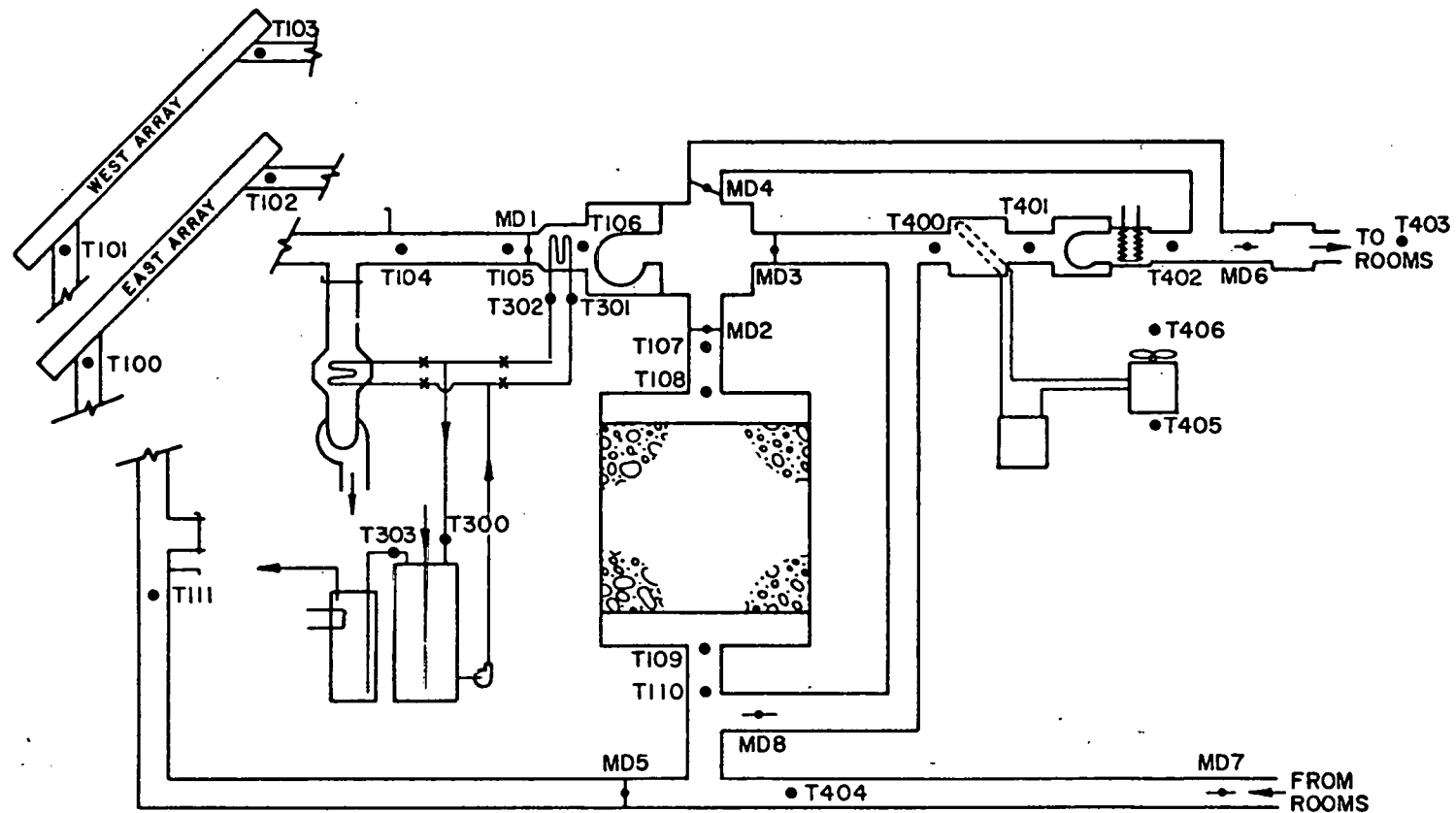


Figure 5-5. Temperature Sensor (Thermocouple) Locations and Designations

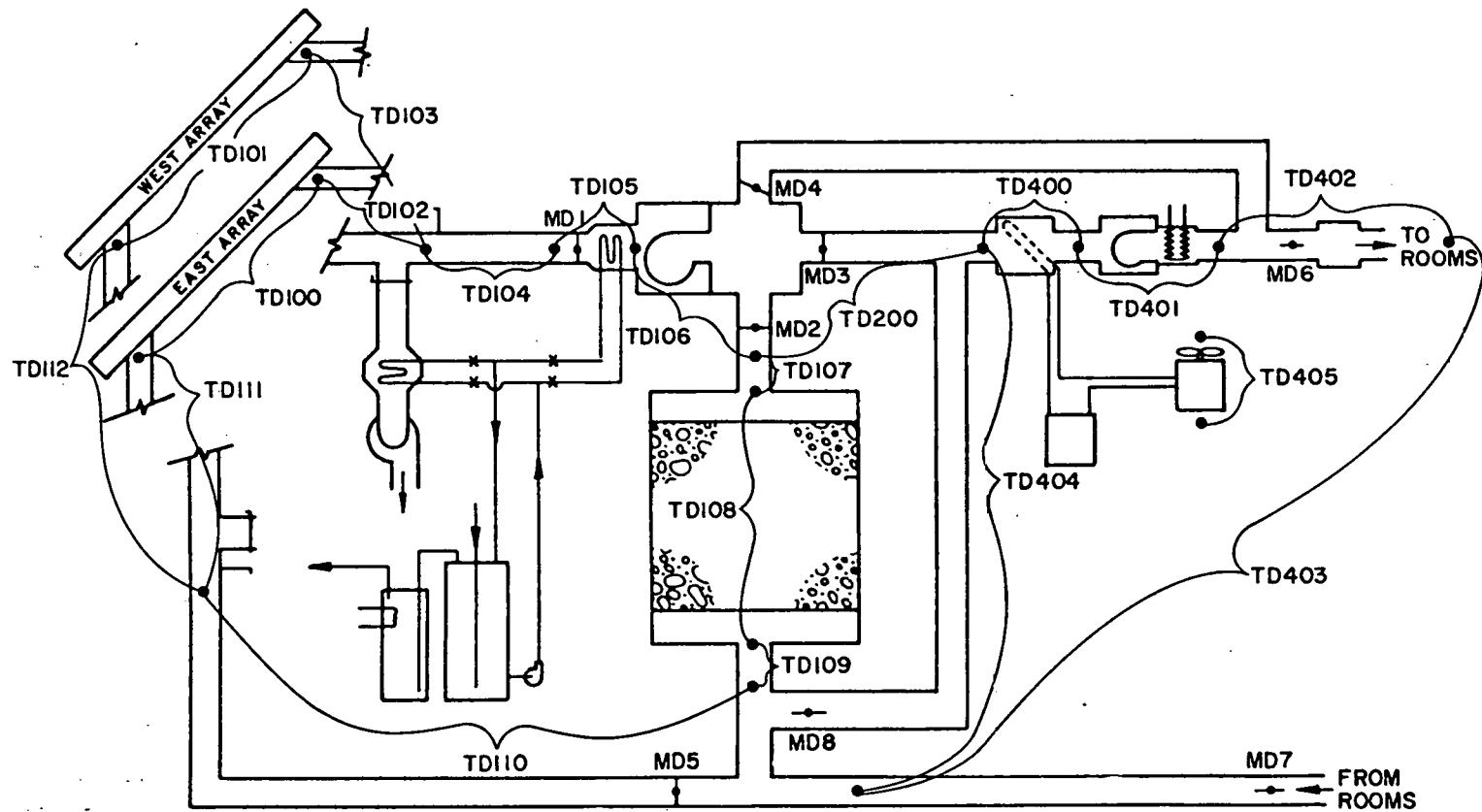


Figure 5-6. Temperature Differential (Thermopile) Sensor Locations and Designations

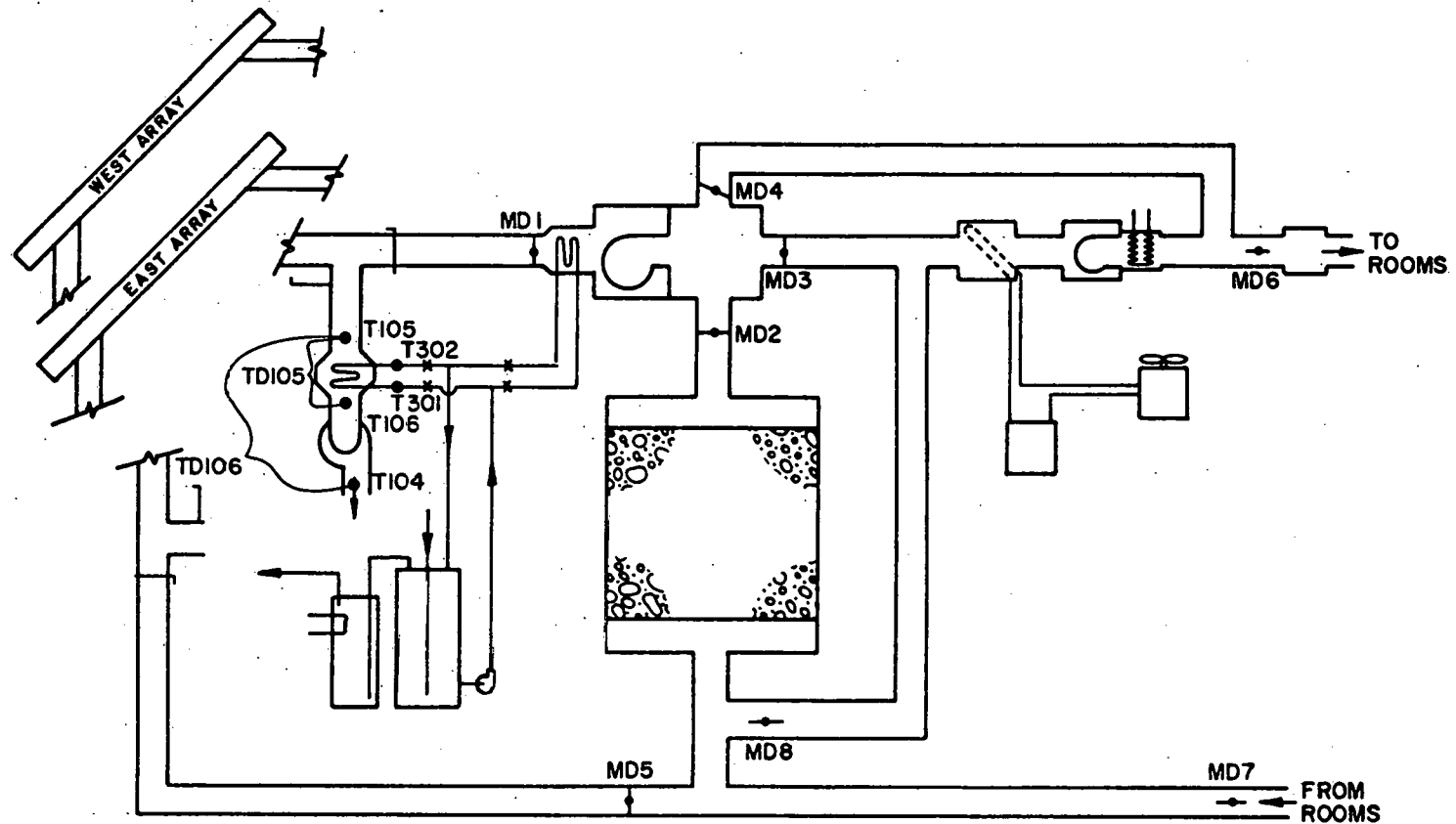


Figure 5-7. Separate Summer DHW Preheat Temperature Sensors and Designations

Table 5-2. Instruments Monitored by the Data Acquisition Unit

Doric Chain	Function No.	Range	Description	Sensor No.
00	F01S		Reference Voltage	Intern.
01	F03	1.000V	Int Horiz Wind Speed	V001
02	F03		Int. 45° Wind Speed	V002
03	F03		Wind Direction	D001
04	F04	10.000V	Humidity at Wx Stat	H001
05	F04		Rel Humid Indoor Coil Exit	H400
06	F04		Rel Humid After Humidifier	H401
07	F04		Rel Humid at Thermostat	H600
08	F07	T2202C0.1°	Temp Room Air S.E. Office	T601
09	F07		Temp Room Air S. Cent. Office	T602
10	F07		Temp Room Air S.W. Office	T603
11	F07		Temp Room Air N. Cent. Office	T604
12	F07		Temp Near Thermostat	T605
13	F07		Temp Stor Top Plenum	T200
14	F07		Temp Stor Rock Top 5.5 ft	T201
15	F07		Temp Stor Rock 5.0 ft	T202
16	F07		Temp Stor Rock 4.0 ft	T203
17	F07		Temp Stor Rock 3.0 ft	T204
18	F07		Temp Stor Rock 2.0 ft	T205
19	F07		Temp Stor Rock 1.0 ft	T206
20	F07		Temp Stor Rock Btm 0.0 ft	T207
21	F07		Temp Stor Btm Plen	T208
22	F07		Temp Stor Top N.W. Mid Diag 5.5 ft	T250
23	F07		Temp Stor Top S.E. Mid Diag 5.5 ft	T251
24	F07		Temp Stor N.W. Corner 3 ft	T252
25	F07		Temp Stor N.W. Mid Diag 3 ft	T254
26	F07		Temp Stor S.E. Mid Diag 3 ft	T255
27	F07		Temp Stor S.E. Corner 3 ft	T256
28	F07		Temp Stor N.W. Corner 1 ft	T257
29	F07		Temp Stor N.W. Mid Diag 1 ft	T258
30	F07		Temp Stor S.E. Mid Diag 1 ft	T259
31	F07		Temp Stor S.E. Corner 1 ft	T260
32	F07		Temp Dry Bulb-Ambient Wx Stat	T001
33	F07		Temp Array 1 Inlet	T100
34	F07		Temp Array 2 Inlet	T101
35	F07		Temp Array 1 Outlet	T102
36	F07		Temp Array 2 Outlet	T103
37	F07		Temp Collector Top Jct Return Duct	T104
38	F07		Temp Collect. Return above Hx	T105
39	F07		Temp. Collect. Return below Hx	T106
40	F07		Temp Air After B1 to Stor	T107
41	F07		Temp Air in Duct-Top of Stor	T108
42	F07		Temp Air in Duct-Btm of Stor	T109
43	F07		Temp Air in Duct-Btm before Monitor	T110
44	F07		Temp-Supply to Collect at Jct.	T111
45	F07		Temp Before Indoor Coil	T400
46	F07		Temp Before Blower B2 (H/P)	T401
47	F07		Temp After Aux Heater	T402
48	F07		Temp in Dist Duct	T403
49	F07	T2202C0.1°	Temp in Room Return Duct	T404

Table 5-2. (continued)

Doric Chain	Function No.	Range	Description	Sensor No.
50	F07	T2202C0.1°	Temp Stor Outside Wall	T261
51	F07		Temp DHW Inlet-Cold Water	T300
52	F07		Temp Hx Inlet	T301
53	F07		Temp Hx Outlet	T302
54	F07		Temp Preheat Outlet	T303
55	F07		Temp Aux Heater Outlet	T304
56	F07		Temp Outdoor Coil Inlet	T405
57	F07		Temp Outdoor Coil Outlet	T406
58	F02	100.00 MV	ΔT Across Collect Array 1	TD100
59	F02		ΔT Across Collect Array 2	TD101
60	F02		ΔT Across Outlet Manifold Array 1	TD102
61	F02		ΔT Across Outlet Manifold Array 2	TD103
62	F02		ΔT In Downcomer Duct	TD104
63	F02		ΔT Across Hx	TD105
64	F02		ΔT Across B1 to Storage	TD106
65	F02		ΔT Across Storage Top Duct	TD107
66	F02		ΔT Across Storage	TD108
67	F02		ΔT Across Storage Btm Duct	TD109
68	F02		ΔT Across Collect Upper Duct	TD110
69	F02		ΔT Inlet Manifold to Array 1	TD111
70	F02		ΔT Inlet Manifold to Array 2	TD112
71	F02		ΔT From Stor Btm to Indoor Coil	TD200
72	F02		ΔT Across Indoor Coil	TD400
73	F02		ΔT Across B2 and AH	TD401
74	F02		ΔT Across Humidifier	TD402
75	F02		ΔT Room Supply to Room Return	TD403
76	F02		ΔT Room Return to Indoor Coil	TD404
77	F02		ΔT Across Outdoor Coil	TD405
78	F02		ΔT Across Wall of Storage	TD201
79	F03		Mode	
80	F04		Barometric Pressure-Basement	
81	F03		Air Monitor Barocell #1 Position	
82	F02		Δp From Barocell for Unit #1	
83	F03		Air Monitor Barocell #2	
84	F02		Δp From Barocell for Unit #2	
85	F03		Total DHW Used Integrat.	W300
86	F03		DHW Preheater Circulation Int.	W301
87	F03		Aux DHW Elect Energy Int.	EP300
88	F03		Circulating DHW Elect. Energy Int.	EP301
89	F03		Blower B1 (Sularon) Int.	EP200
90	F03		Integ. Blower B2(H/P) Elect.	EP400
91	F03		Integ. Aux Heater Elect.	EP401
92	F03		Integ. Compressor Elect.	EP402
93	F03		Integ. Outdoor Fan (H/P) Elect	EP493
94	F03		Integ. Controller Elect. Energy	EP404
95	F03		Integ. Attic and Ceiling Fan Elect	EP601
96	F03		Integ. Instrumentation Elect.	EP700
97	F03		Integ. Total House Elect.	EP600
98	F02		Instantant Pyranometer	I001
99	F03		Integ. 45° Pyranometer	I001

In addition to barometric pressures, gage pressures and pressure differences along the air flow circuit were measured with a sloping water manometer. The locations in the circuit where pressure measurements were recorded are shown on Figure 5-8.

5.2.4 Air Flow Rates

Air flow rates are measured at various locations by determining an average velocity at a duct cross-section with an array of pitot tubes and static pressure probes. Because the pitot tubes are interconnected, as are the static probes, pneumatic averages are obtained for the dynamic and static pressures. The velocities are normally less than 4 m/sec, and the pressure differences are small at all the flow monitoring stations.

There are thirteen air flow monitoring stations in the system as shown on Figure 5-9. All air monitors were calibrated with an ASME standard nozzle in a wind tunnel with the entrance to the air monitor configured with duct pieces similar to the installed configuration.

5.2.5 Water Flow Rates

The recirculating volumetric water flow rate through the preheater coils and the hot water delivery volume were measured with a Rotameter[®]. Rotameter readings were taken at various temperature readings so that flow rates could be assigned by temperature measurements when normal rotameter readings were not taken.

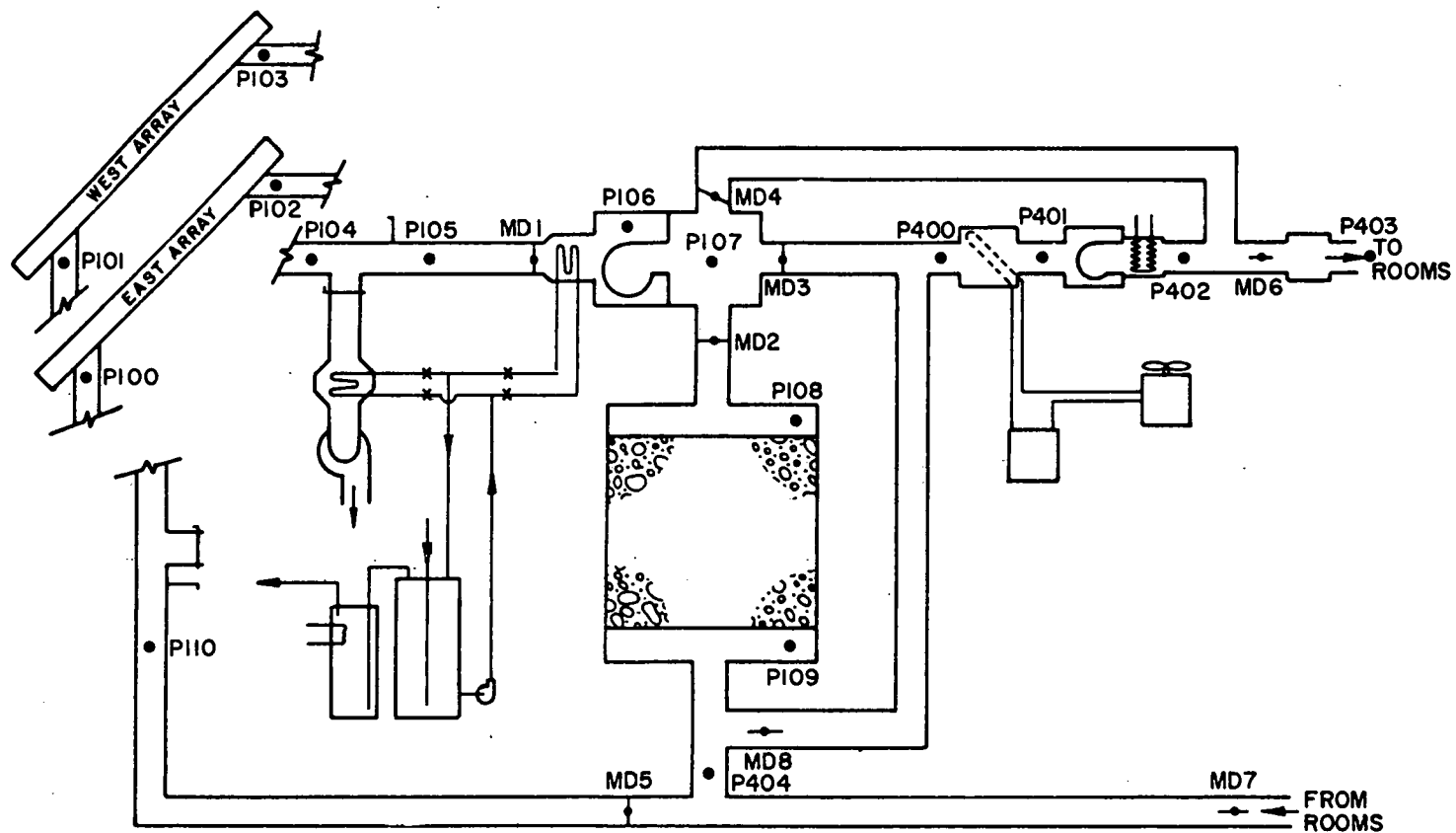


Figure 5-8. Location and Designation of Static Pressure Taps

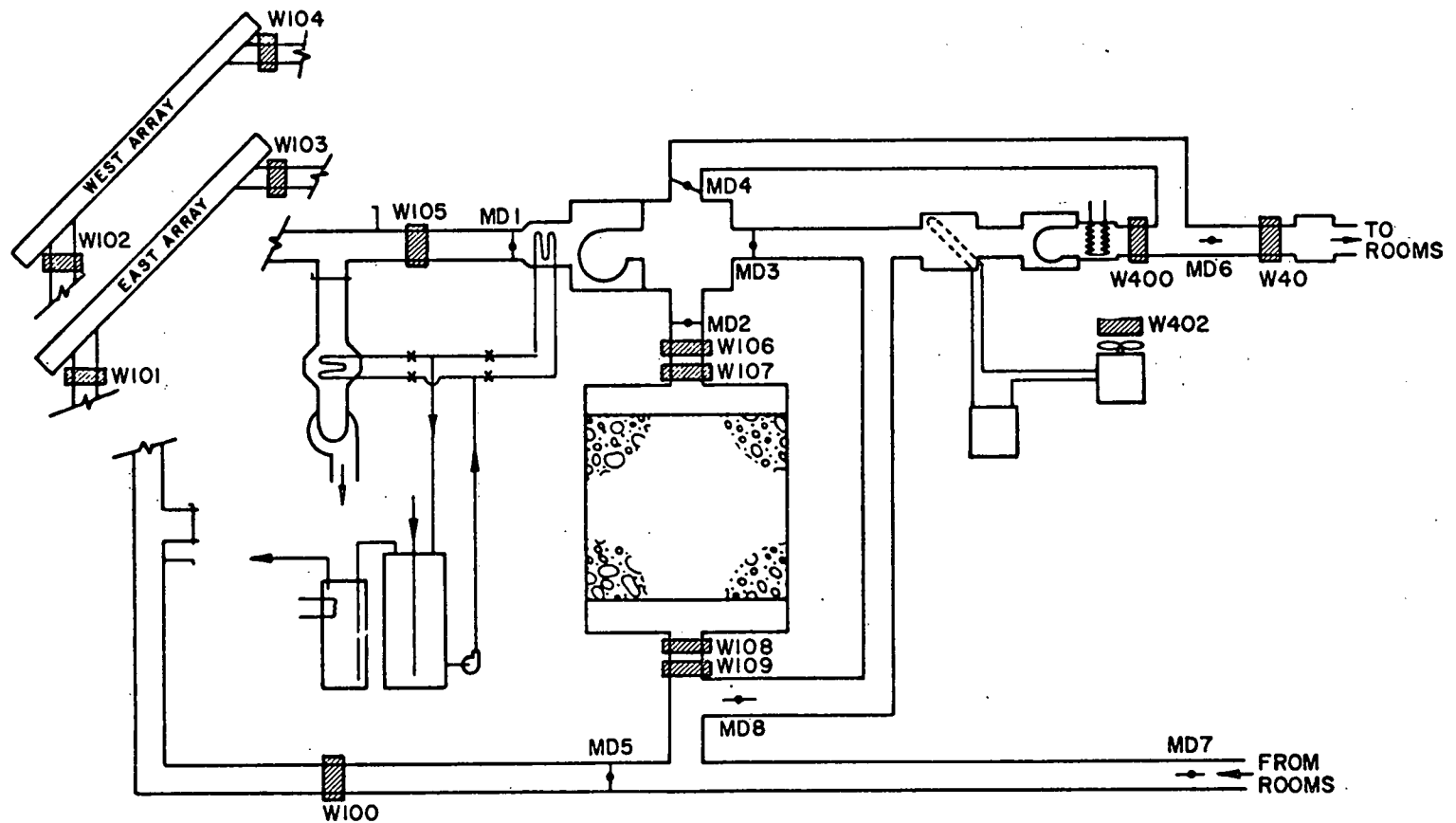


Figure 5-9. Duct Air Flow Monitor Stations

5.2.6 Relative Humidity

Relative humidity was measured at selected locations with Thunder Scientific Model PC-2000 humidity sensors. The active element is a thin-film that changes its electromechanical properties with changes in humidity. One unit is located outdoors at the "weather station", another is in the room near the thermostat and a third was in the duct on the suction side of the main blower.

5.2.7 Electric Power Meters

Eleven watt transducers of different ratings were used to record the electric power requirements of various components in the solar system and the building as well as various instrumentation load. The watt transducers consist of an isolated potential input transformer, a current sensing magnetic circuit, and a Hall generator. The Hall generator is a magnet-sensitive semi-conductor which generates a voltage that is proportional to the power through the circuits. The output of the watt transducers is integrated during the period between scans to obtain total energy consumed between scans.

House power is measured with two 20-kW power transducers (one for each of two incoming legs of the nominal 220 V system. Each consists of a 20:1 current transformer driving a 1000-watt power transducer. The outputs of the two transducers are connected in series to give the total power required in the building for lights, appliances and machinery other than the solar system.

5.2.8 Weather Station

A "weather station" was set up between Solar Houses I and II (see Figure 5-3 for location). The "station" is a Cambridge Model 410S Temperature/Dewpoint Measuring System, with an aspirator and radiation shield as shown in the diagram of Figure 5-10. The aspirator fan circulates air upward through concentric tubes that forms the radiation shield. A type T thermocouple and a humidity sensor were placed within the housing to measure the dry-bulb temperature and relative humidity of the ambient air.

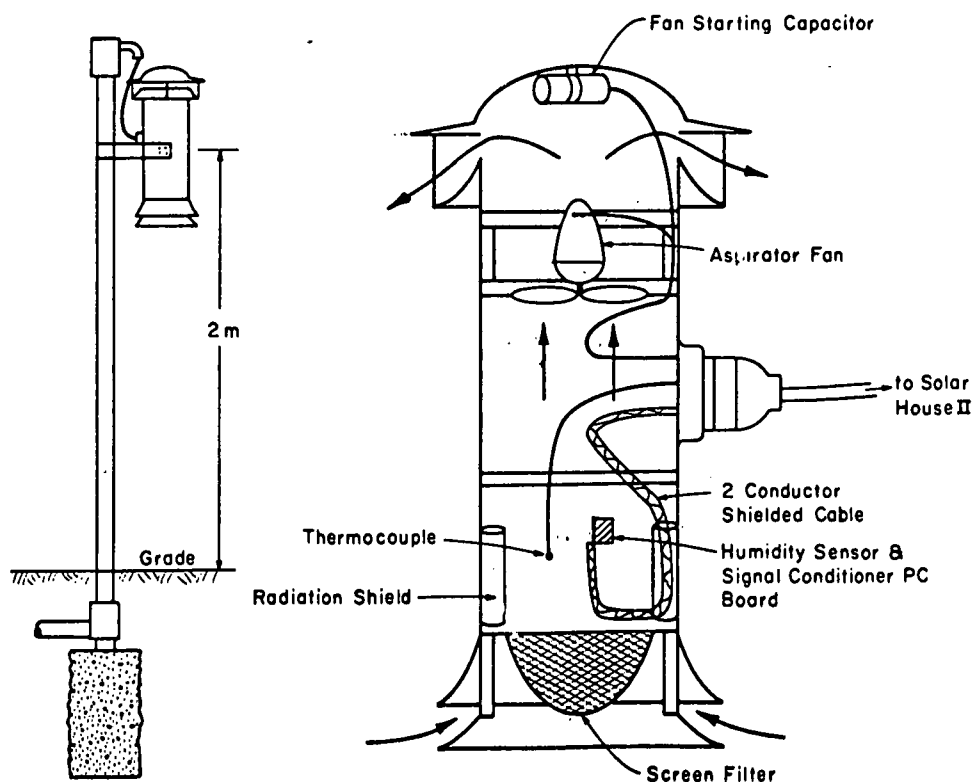


Figure 5-10. Weather Station

5.2.9 Mode Indicator

A basic need for system monitoring is determination of the mode, or state of the system devices, so that appropriate mass and heat flow rates can be determined. The mode indicator coupled with an air monitor position controller is illustrated in Figure 5-11.

There are 11 heating modes, and 13 cooling modes of the system; as shown on Table 4-1. When a system device malfunctions, the system state is identified as being in an "illegal" submode so that erroneous heat flow quantities are not included in the calculations.

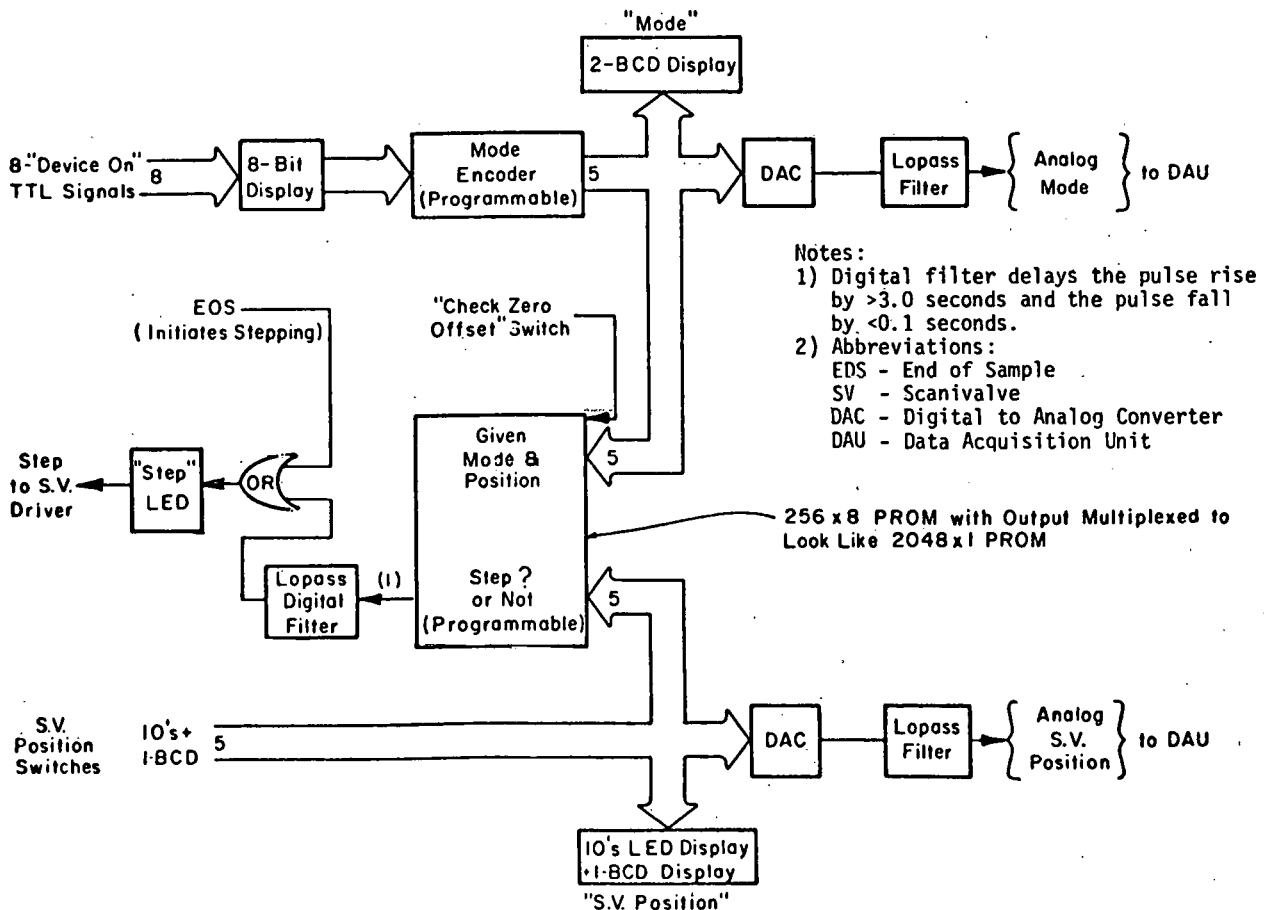


Figure 5-11. Block Diagram of Mode Indicator and Air Flow Measurement Station Controller

5.2.10 Air Monitor Controller

With two differential pressure transducers to measure the air velocities at thirteen air flow monitoring stations, an air monitor controller was needed to switch the two Scanivalves through appropriate air monitors for each system mode. For a short duty cycle all of the appropriate monitors may not be sampled and monitors that are scanned provide point differential pressure readings. Penumatic filters, electronic filters and integrators were considered to enable measurement of average velocities. Penumatic filtering is accomplished by the interconnected probes in the air monitor and the long pressure leads to the Scanivalve. An electronic filter is provided as part of the pressure instrument, and integrators were discarded because transients in the instruments and system could not be differentiated.

A block diagram of the air monitor controller, Scanivalve position indicator and mode encoder is shown in Figure 5-11. From the combination of the states of system devices, i.e., "on" or "off", one of the modes is identified and for every mode the applicable air monitors are identified in a pre-programmed logic. At the end of a data scan (EOS) the Scanivalve receives a signal to step to the next position. If that position is not the appropriate air monitor in the set, another "step" signal is generated. Stepping continues until a proper position is achieved. Visual display of modes and air monitor numbers are provided for monitoring purposes.

5.2.11 Integrators

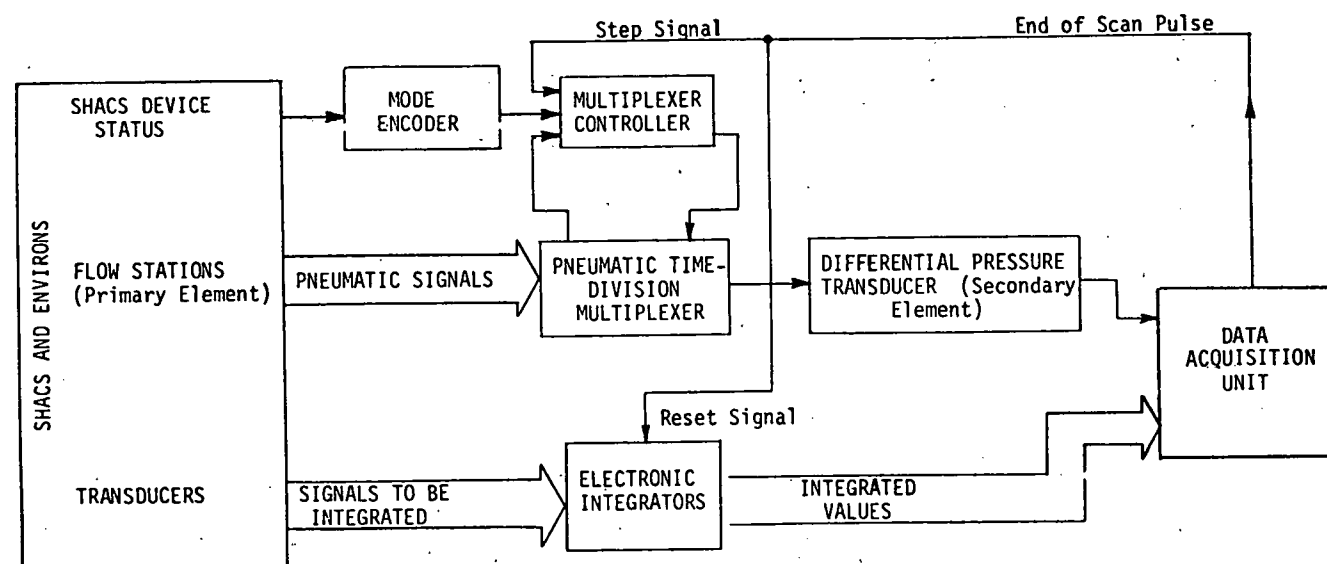
Analog signals from selected transducers and sensors are integrated during the interval between scans. The integrators used are AGM

Electronics Series 4000 Resetable Integrators. Signals for the pyranometer, wind speed anemometers, watt meters and water flow meters are integrated. The anemometers and water flow meters are pulse accumulators. All integrators are reset at the end of each scan.

5.3 DATA ACQUISITION UNIT

The Data Acquisition Unit (DAU) is a Doric Scientific Model Digitrand 220 which consists of a scanner, multiplexer, analog-to-digital converter, and printer. Interfacing capability with several peripheral units are possible. Presently a Kennedy tape deck and a Wang desk-top computer are interfaced with the DAU.

The analog-to-digital (A/D) converter produces 16-bit information with one microvolt resolution and has a normal sampling rate of about 10 channels per second. The interval between scans is selectable in discrete time increments, and a 5-minute interval was used. A separate and different time interval between scans can be initiated by the desk-top computer with data stored in computer memory. A one-minute interval is used and the data were analyzed in "real-time". The data collection process is depicted by the block diagram of Figure 5-12. Sampling can begin at any channel and end with any channel, provided that the beginning channel number is less than the ending channel number. An alarm system is incorporated with the DAU which is triggered by over ranges of sensors and power failure. Data sampled by the DAU are accumulated in a read buffer after being multiplexed and digitized and after checking the status of the output peripherals, data is transmitted according to the available output peripheral (printer magnetic tape, or desk-top computer).



TWO SETS OF INSTRUMENTS REQUIRE EXTERNAL CONTROL SIGNALS:

1. Air flow measurement system requires SHACS mode and end-of-scan signals.
2. Integrators require end-of-scan signal to reset immediately after each scan.

Figure 5-12. Block Diagram of Data Collection Process

6. DATA PROCESSING

6.1 GENERAL PROCEDURE

The on-line mini-computer was primarily used to monitor the instrumentation system, to calibrate instruments in the system, and to check specific channels of information while the system was adjusted or changed. The data used to determine system performance were recorded on the 7-track Kennedy tape recorder.

The general procedure for processing data tapes is as follows:

1. The source tape is removed weekly (on Monday morning).
2. A diagnostic program is used to scan the source tape for irregularities (parity errors, etc.) primarily to identify persistent instrument problems.
3. The source tape is copied onto a "working" master tape and a "back-up" master tape.
4. The "working" master tape is preprocessed to remove irregularities (parity errors) in the records and convert voltages into physical quantities using calibration constants. The physical quantities and temperatures are then "written" on a binary tape. A back-up binary master is also produced.
5. The binary tape is then processed to produce volumetric flow rates, heat fluxes, electrical energy quantities, collector performance parameters, heat pump performance parameters, component thermal energy balances and system thermal energy balances.
6. Detailed scan-wise data are written on a binary tape, and a limited amount of scan-wise data are printed on hard copy.

Hourly, daily and monthly summaries are also printed on hard copy for scrutiny in evaluating system performance.

7. All tapes except the working master and binary results are recycled.

The data handling and processing procedure is depicted in the block diagram of Figure 6-1.

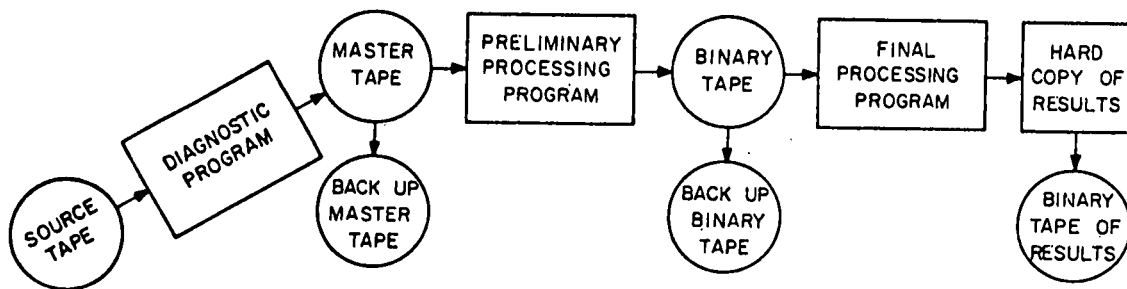


Figure 6-1. General Procedure for Data Processing

A flow chart which shows the on-line data processing procedure with the minicomputer is shown on Figure 6-2. The minicomputer is used to record one-minute scans of the data logger for selected channels and copies of the records are made on cassette tapes. The records include histories of modes, air flow rates and heat fluxes.

6.2 CONVERSIONS

Data which require conversion from voltages to physical quantities are:

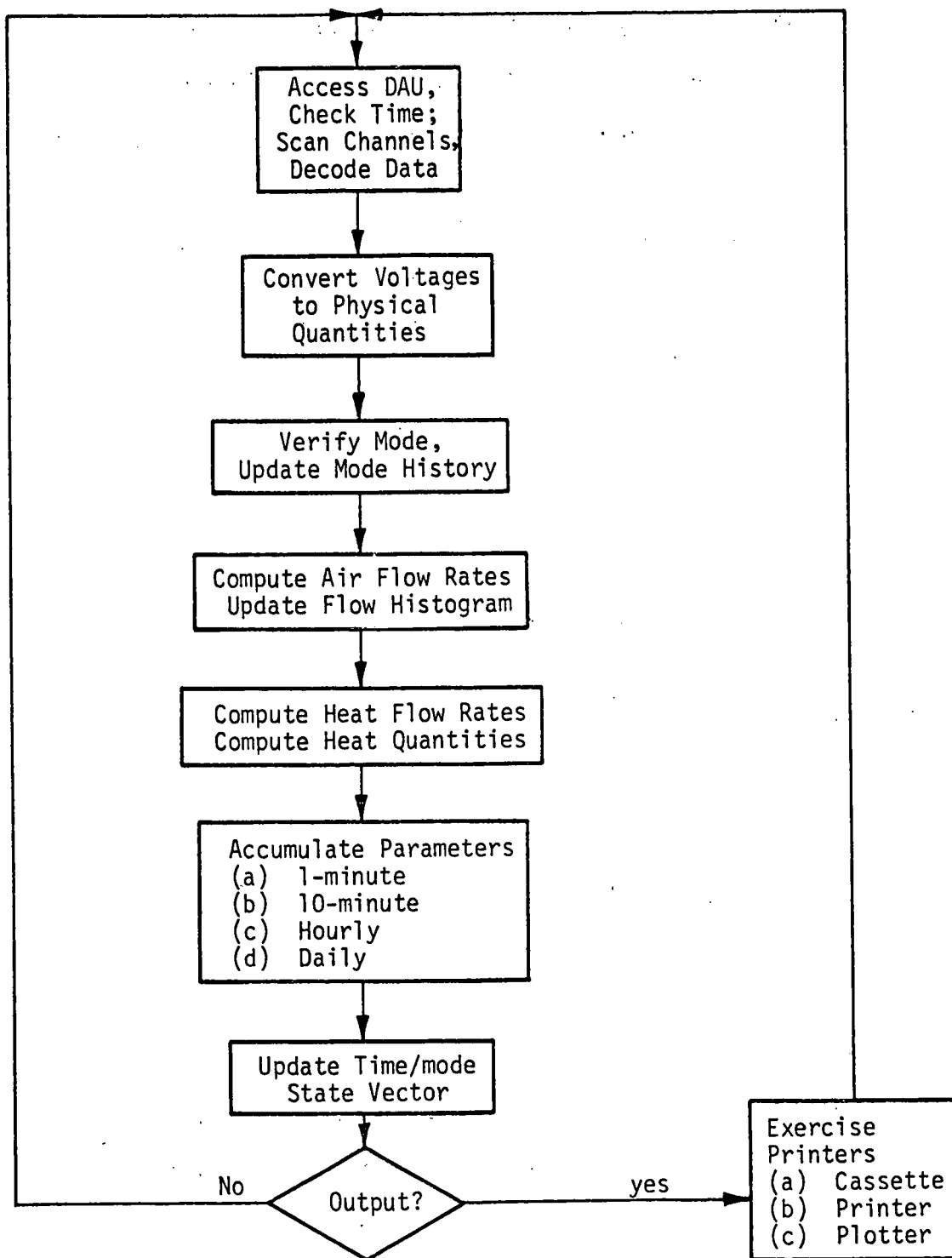


Figure 6-2. Flow Chart for On-Line Data Processing

1. Solar flux
2. System operating modes
3. Air monitor identification
4. Atmospheric pressure
5. Wind speed
6. Wind direction
7. Pressure differences for flow rate determination
8. Condensate from the indoor coil (cooling mode)
9. Electrical energy consumption
10. Relative humidity
11. Temperature differences from thermopiles

All instruments except the last were calibrated and conversion constants or curves were determined. Individual thermocouples and thermopiles are made with precision copper-constantan wires and randomly selected thermocouples were spot checked using a constant temperature bath and were found to coincide with standard Type T thermocouple conversion tables provided by the manufacturer (Omega). Volumetric and mass flow rates are calculated from pressure differences, atmospheric pressure and measured temperatures. Temperatures are converted by the data acquisition unit (DAU) prior to recording, and the DAU is calibrated (and adjusted if found necessary). The DAU is also calibrated with precision input voltages and adjusted so that the output are identical with the inputs.

6.2.1 Temperature Differences

Thermopile outputs (Δe) in microvolts are converted to temperature differences (ΔT) by polynomial representation of the Type T thermocouple

curve. Because the curve of temperature vs. emf is nonlinear, temperature difference determination is dependent on Δe and a reference temperature on the curve. The reference temperature can be at either end of the thermopile. With the reference temperature (T_1) known, the procedure to calculate ΔT is as follows:

1. Calculate e_1 corresponding to reference temperature T_1 using Equation (6-1).
2. Determine e_2 by adding Δe to e_1 ($e_2 = e_1 + \Delta e$)
3. Convert e_2 to T_2 using Equation (6-2).
4. Calculate ΔT ($\Delta T = T_2 - T_1$)

The polynomials for converting e to T and T to e are:

$$e = \sum_{i=1}^3 a_i T^i \quad (6-1)$$

and

$$T = \sum_{i=1}^3 b_i e^i \quad (6-2)$$

Coefficients a_i and b_i are listed in Table 6-1.

Table 6-1. Polynomial Coefficients for Equation

Temperature Range	i	a_i		b_i	
		Value	Exponent	Value	Exponent
-50°C to 0°C	1	3.87408	1	2.58126	- 2
	2	3.84373	-2	-7.39074	- 7
	3	2.06663	-5	1.02788	-10
0 to 120°C	1	3.85972	1	2.58126	- 2
	2	4.28044	-2	-6.53650	- 7
	3	-9.96760	-6	1.94253	-11

6.2.2 Volumetric Air Flow Rate

It is normal procedure in HVAC practice to correct locally measured air flow rates to standard (sea level) conditions. However, since mass flow rates are finally needed to calculate heat fluxes, use of any reference condition will be satisfactory provided the reference conditions are established. In this study, local conditions at the blower outlet were selected, principally because use of this reference resulted in narrower histograms with smaller standard deviations than histograms of flow rates converted to standard conditions. Examples are shown in Table 6-2.

Table 6-2. Example Mean and Standard Deviation of Flow Rates Corrected to Reference Blower Outlet Conditions and Standard Conditions

Flow Monitor No.	Local Reference		Standard Reference	
	Mean	St. Dev.	Mean	Std. Dev.
W101	13.91	0.24	10.74	0.26
W103	16.23	0.41	12.53	0.51
W102	15.51	0.14	11.91	0.30
W104	16.52	0.14	12.61	0.39
W401	40.50	0.32	32.38	0.51

The procedure followed to calculate volumetric flow rates were:

1. Determine pressure differences from the differential pressure transducers (Barocel) output by Equation (6-3).

Conversion of voltage to pressure difference is:

$$\Delta p = k_B(E_1 - E_2) \quad (6-3)$$

where k_B is the calibration constant

E_1 is the output voltage

E_2 is the output voltage for zero pressure difference measured by a pneumatic short circuit created with the Scanivalve.

2. Determine the instantaneous air velocity averaged over the cross-section of the air monitor by Equation (6-4).

Air velocity is calculated by:

$$V = k_v \sqrt{\frac{2\Delta p}{\rho}} \quad (6-4)$$

where k_v is the velocity coefficient for the air monitor determined by calibration with upstream duct configuration representing the actual installation.

Δp is calculated from Equation (6-3)

ρ is air density calculated from the equation of state with measured barometric pressure and temperature at the air monitor.

Because pressure differences in the system are small (less than 1.5 mm of Hg above and below ambient barometric pressure), ambient barometric pressure was not corrected for pressure rise or drop at the air monitor.

3. Determine local volumetric air flow rate using Equation (6-5).

"Local" volumetric air flow rate is calculated as:

$$\dot{V}_L = AV \quad (6-5)$$

Where A is the cross-sectional area of the air flow monitor

V is determined from Equation (6-4).

4. Convert local volumetric air flow rate to reference conditions using Equation (6-6),

$$\dot{V}_r = \dot{V}_\ell \left\{ \frac{p_\ell T_r}{p_r T_\ell} \right\} \quad (6-6)$$

Subscripts r and ℓ denote reference and local conditions respectively. Because $p_\ell/p_r \approx 1$ (within 0.25 percent), Equation (6-6) can be simplified to

$$\dot{V}_r \approx \dot{V}_\ell (T_r/T_\ell) \quad (6-7)$$

and $\dot{V}_r$ is within accuracies of pressure difference measurements.

5. Determine average volumetric flow rates for each air monitor. This step is superior to using instantaneous Δp measurements to calculate mass flow rates and heat fluxes because turbulent fluctuations are reflected in instantaneous samples of Δp even after pneumatic and electronic filtering. To obtain steady Δp readings from the air monitor a filter with a long time constant is needed (over one minute), which is undesirable because scan intervals are 5 minutes and mode changes within scans can bias the data. The alternative approach of multiple samples to establish mean and standard deviations using the minicomputer to scan at one minute intervals was adopted.

6.3 THERMAL ENERGY CALCULATIONS

Thermal energy added to the system, transported within the system from one component to another, stored in the system and delivered by the system are calculated using the relationships explained below.

6.3.1 Solar Energy

Solar energy incident at the outer cover of the collectors during a time interval Δt is calculated from

$$Q_s = A_c k_e k_p \int_0^{\Delta t} (v) dt \quad (6-8)$$

where A_c is the gross area of the collectors including the perimeter insulation strip, 57.9 m^2 .

k_e is the integrator constant determined by calibration
(mv/mv)

k_p is the pyranometer constant determined by calibration
at NOAA (Boulder, Colorado) ($\text{MJ} \cdot \text{m}^{-2} \cdot \text{min}^{-1} / \text{mv}$)

Δt is the time interval between integrator resets (5 minutes)

v is emf input into the integrator (millivolts)

6.3.2 Heat from the Collectors

Thermal energy delivered from the collector in time interval Δt is calculated from

$$Q_c = \{\dot{m}_o c_p (T_o - T_i) + \dot{m}_l c_p (T_i - T_a)\} \Delta t \quad (6-9)$$

where $\dot{m}_o$ is mass flow rate calculated at the collector outlet (kg/min)

c_p is specific heat of air [$\text{MJ}/(\text{kg} \cdot ^\circ\text{C})$]

T_o is air temperature at the outlet ($^\circ\text{C}$)

T_i is air temperature at the inlet ($^\circ\text{C}$)

$(T_o - T_i)$ is determined by a multijunction thermopile

$\dot{m}_l, (\dot{m}_o - \dot{m}_i)$ is the air mass leakage rate into the collector determined by measuring $\dot{m}_i$ as well as $\dot{m}_o$ (kg/min)

T_a is ambient air temperature ($^{\circ}\text{C}$)

Δt is sampling interval (5 min)

The change in enthalpy of the air which enters the collector is always positive (during the heating season) because T_a is always less than T_o . The system is also designed so that $\dot{m}_o$ is greater than $\dot{m}_i$ and $\dot{m}_l$ is positive. Thus air leakage into the collector adds thermal energy to the system.

6.3.3 Heat Losses in Ducts

As shown in Figure 6-3 thermopiles are provided completely around a ducting circuit and air flow rates in the ducts are measured into and out of each system component. Thus heat losses from the ducts are calculated from measured mass flow rates and enthalpy changes, from one section to another, in straightforward manner. Thermopiles are situated so that heat losses from ducts in the attic are separately calculated from heat losses from ducts within the heated envelope of the building. Heat losses from ducts within the heated envelope adds to useful heating, provided the temperature rise in the building is not measurably large and does not render the rooms to be uncomfortably warm.

6.3.4 Thermal Energy Storage and Discharge

The most direct method of measuring the quantity of thermal energy stored is to measure the change in average temperature of the storage medium. While this is relatively simple for a mixed water tank, it is impractical in pebble beds because of stratification, channeling of air streams, and non-uniform temperatures of each pebble. Calcula-

tions for the quantity of heat stored is therefore made on the basis of a control volume, using the outside walls of the container as the control surface. Air leakage into or out of the container is calculated as the difference in measured air flow rates in the ducts connected to the top and bottom plenums. Calculation for change in heat storage is performed as follows:

$$\Delta Q_{ST} = \{ \dot{m}_i c_p (T_i - T_o) - \dot{m}_l c_p (\bar{T}_s - T_o) - (UA)_j \Delta T_j \} \Delta t \quad (6-10)$$

where $\dot{m}_i$ is mass flow rate into the control volume (top duct) (kg/min)

c_p is specific heat of the air [MJ/(kg·°C)]

T_i is inflow air temperature at the control surface (°C)

T_o is outflow air temperature at the control surface (°C)

$T_i - T_o$ is measured by a thermopile

$\dot{m}_l$ is air mass leakage out of the container (container is above ambient pressure of the room during storage) (°C)

$\bar{T}_s$ is average storage temperature estimated from mass average of thermocouples distributed on the pebble bed

$(UA)_j$ is the thermal property of the container walls calculated from known construction materials (MJ/(min·m²·°C))

$(\Delta T)_j$ is the estimated temperature differences from the inside wall of the container to the room air or to ground. (One side of the container is against the basement wall and the bottom is resting on the concrete floor)

Δt is the sampling interval (5 min)

Thermal conductance losses to the ground and to the rooms are poorly determined and are least satisfactorily calculated quantities. Fortunately, heat losses are relatively small (but not negligible) compared to transported quantities of thermal energy. (See Appendix A for tabulated quantities of daily heat losses from storage).

Calculation of change in thermal energy during heat delivery from storage is performed as follows:

$$\Delta Q_{ST} = \{\dot{m}_o c_p (T_o - T_i) + (UA)_i \Delta T_i\} \Delta t \quad (6-11)$$

The container is under subatmospheric pressure during discharge mode and air leaks into the container from the room, which is at temperature T_i . Thus the change in enthalpy of the leaking air is reflected in the first term to the right of the equal sign in Equation (6-11).

6.3.5 Heat Pump

Thermal energy delivered and removed by the heat pump is calculated from the temperature difference measured across the indoor coil. Heat extracted or rejected to the outdoor air is also calculated directly with measured temperature difference.

6.3.6 DHW Preheater

Heat extracted from the air to preheat domestic water is calculated from measured temperature difference of the air stream across the air-water heat exchanger. As a check, the circulation rate and temperature difference of the water are used to calculate the thermal energy transferred to water from the hot air stream.

6.3.7 Solar Space Heating

The sum of solar thermal energy delivered by the system and heat conducted through ducts and storage walls plus transport of thermal energy by air leakage into the heated building envelope is the total contribution of solar energy to space heating.

6.3.8 Auxiliary Heating

The sum of thermal energy transferred through the indoor coil, electrical resistance duct heating and electrical energy to operate the motors and heat pump compressor is the auxiliary thermal energy supplied to the building.

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7. THERMAL PERFORMANCE

7.1 ENERGY FLOW DIAGRAMS

Energy flow diagrams which show thermal and electrical energy quantities included in the calculations of system performance are shown in Figures 7-1 and 7-2. For clarity, the winter and summer seasons are shown separately. Included in the energy flow calculations are heat flows and heat losses from conduits, and components as described in Section 6.

7.2 HEATING SEASON

7.2.1 Air Flow Rates

Air flow rates measured at each monitor will vary with changes in modes of operation because of changes in total pressure drops in the flow circuits. For purposes of processing the data it is convenient to assign unique identification numbers (indices) to each monitor for each mode. The indices are listed in Table 7-1.

The average air flow rates for each air monitor, for 6 (approximately) monthly periods through the heating season are listed in Table 7-2. The flow rates are referenced to blower outlet air temperature and pressure rather than standard conditions because the standard deviations of the samples were smaller. There are three distinct periods for the 1978-79 heating season for which air flow rates through the collectors were deliberately changed. The first period is from December 1, 1978 through January 6, 1979, during which the total air flow rate out of the collector array was about $13.1 \text{ l}/(\text{sec} \cdot \text{m}^2)$ [$10.01 \text{ l}/(\text{sec} \cdot \text{m}^2)$ standard flow rate]. On January 7, the air flow rate

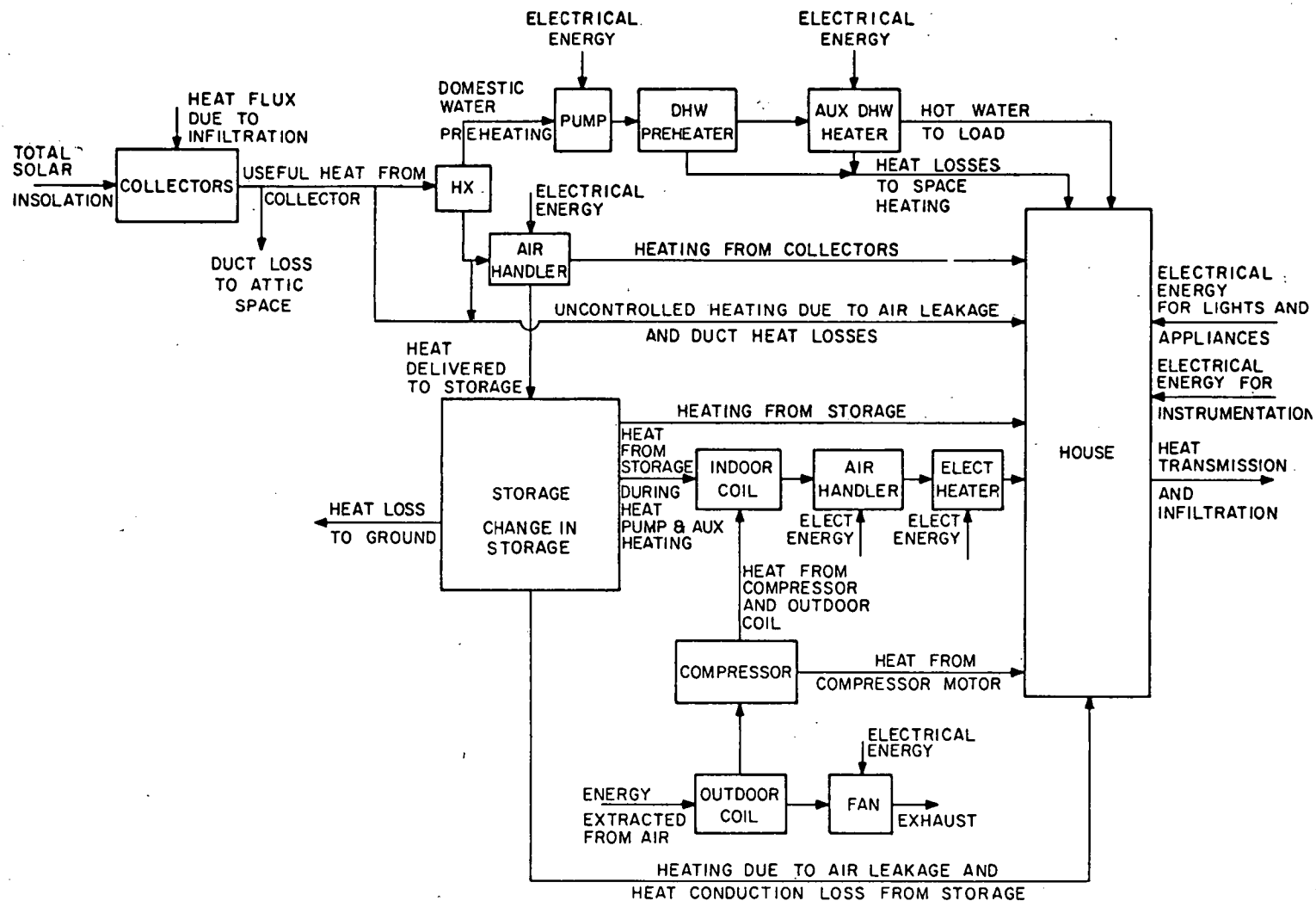


Figure 7-1. Energy Flow Diagram for Heating Season

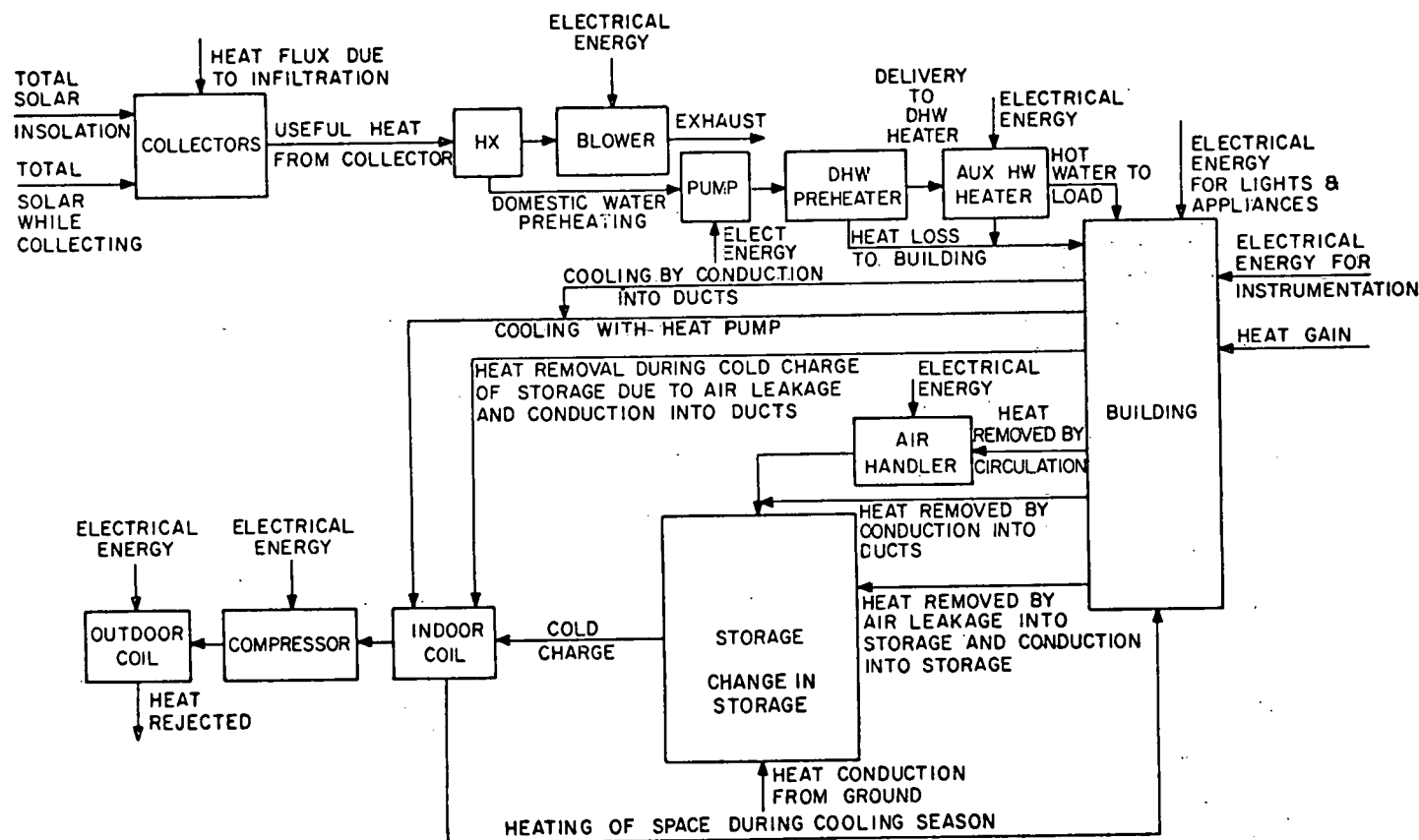


Figure 7-2. Energy Flow Diagram for Cooling Season

Table 7-1. Flow Monitor Index

Mode of Operation	East Collector Supply W101	East Collector Return W103	West Collector Supply W102	West Collector Return W104	Storage Top In W107	Storage Bottom Out W109	Storage Bottom In W108	Storage Top Out W106	Indoor Blower W400	Room Supply W401	Outdoor Fan W402	Pneumatic Short Circuit
1. DN	3	3	3	3	3	3	3	3	3	3	3	1
2. HFC	4	5	6	7	0	0	0	0	0	8	0	1
3. HFC + HP	9	10	11	12	0	0	0	0	13	14	15	1
4. HFC + HP + AUX	9	10	11	12	0	0	0	0	13	14	15	1
5. HFS	0	0	0	0	0	0	16	17	18	19	0	1
6. HFC + HP	0	0	0	0	0	0	16	17	18	19	15	1
7. HFC + HP + AUX	0	0	0	0	0	0	16	17	18	19	15	1
8. C/S (Start)	20	21	22	23	24	25	0	0	0	0	0	1
9. C/S + HN	20	21	22	23	24	25	0	0	0	0	0	1
10. FP	0	0	0	0	0	0	0	0	0	0	0	1
11. C/S	20	21	22	23	24	25	0	0	0	0	0	1

Mode Abbreviations

HFC - Heating from Collector
 HP - Heat Pump
 AUX - Auxiliary (Electric Resistance) Heating
 HFS - Heating from Storage
 C/S - Collector to Storage
 FP - Freeze Protection
 DN - Do Nothing
 HW - Hot Water Preheating

Table 7-2. Average Volumetric Air Flow Rates (m³/min)

Index No.	Air Monitor	Dec 1- Jan 6	Jan 7- Jan 31	Feb	Mar	Apr 1- Apr 26	Apr 27- May 11
1	-	0.00	0.00	0.00	0.00	0.00	0.00
2	-	0.00	0.00	0.00	0.00	0.00	0.00
3	-	0.00	0.00	0.00	0.00	0.00	0.00
4	W101	19.36	14.00	13.90	14.10	14.10	17.38
5	W103	23.84	16.54	16.20	16.39	16.27	21.87
6	W102	19.69	15.69	15.58	15.70	15.60	3.50
7	W104	21.79	16.72	16.70	16.63	16.68	6.73
8	W401	44.35	33.42	32.30	32.40	31.75	27.78
9	W101	18.76	15.31	15.36	15.56	15.33	20.15
10	W103	23.07	18.38	18.06	18.21	18.51	25.84
11	W102	19.18	17.01	17.00	17.02	16.90	5.94
12	W104	21.18	18.58	18.53	18.52	18.49	9.38
13	W400	49.07	43.43	43.75	43.38	43.00	41.22
14	W401	45.93	41.00	41.50	40.63	40.31	38.20
15	W402	95.79	95.35	93.85	95.28	91.80	89.65
16	W108	28.12	27.80	27.70	27.68	27.79	27.63
17	W106	32.85	32.55	32.37	32.95	33.13	33.29
18	W400	37.11	35.86	35.86	36.67	36.59	36.48
19	W401	34.71	34.60	34.13	34.01	34.03	33.96
20	W101	21.02	15.30	15.28	15.31	15.17	18.84
21	W103	24.11	16.14	15.97	16.09	15.89	21.04
22	W102	21.17	16.17	16.64	16.70	16.55	3.22
23	W104	22.68	17.12	16.90	16.97	16.78	6.51
24	W107	47.20	34.71	34.37	34.66	34.20	28.40
25	W109	47.00	31.88	32.26	32.67	31.86	25.50

Table 7-3. Air Leakages

MODE OF OPERATION	COLLECTORS				COLLECTOR TO ROOM		COLLECTOR TO HEAT PUMP OUTLET		COLLECTOR TO STORAGE		STORAGE		STORAGE TO HEAT PUMP		HEAT PUMP TO ROOM	
	EAST ARRAY		WEST ARRAY		m ³ /min	Percent of Delivery	m ³ /min	Percent of Delivery	m ³ /min	Percent of Delivery	m ³ /min	Percent of Delivery	m ³ /min	Percent of Delivery	m ³ /min	Percent of Delivery
	m ³ /min	Percent of Outflow	m ³ /min	Percent of Outflow												
Dec 1 - Jan 6																
2 HFC	4.48	18.8	2.10	9.6	-1.28	2.9	--	--	--	--	--	--				
3 HFC + HP	4.31	18.7	2.00	9.4			4.82	9.8							-3.14	6.8
5 HFS	--	--	--	--							4.73	14.4	4.26	11.5	-2.40	6.9
11 C/S	3.09	12.8	1.51	6.7					0.41	0.9	-0.20	0.4				
Jan 7 - April 26																
2 HFC	2.32	14.2	1.04	6.2	-0.56	1.7	--	--								
3 HFC + HP	2.90	15.9	1.55	8.4			6.57	15.1							-2.53	6.2
5 HFS											4.97	15.2	3.54	9.8	-2.06	6.0
11 C/S	0.75	4.7	0.42	2.5					1.53	4.4	-2.32	7.2				
April 27 - May 11																
2 HFC	4.49	20.5	3.23	48.0	-0.82	3.0										
3 HFC + HP	5.69	22.0	3.34	36.7			6.00	14.6							-3.02	7.9
5 HFS											5.66	17.0	3.19	8.7	-2.52	7.4
11 C/S	2.20	10.5	3.29	50.5					0.85	3.0	-2.90	11.4				

- Note: 1. Negative signs indicate leakage out of circuit or component.
 2. Non-negative numbers are leakage into circuit or component.
 3. Leakages occur primarily through closed dampers.
 4. Leakage into collector arrays is assumed to occur at gaskets between modules.
 5. Leakage out of storage occurs because of a crack at the junction between walls.

was reduced to 9.6 liters/(sec·m²)[7.05 l/(sec·m²) standard flow rate] to raise the air temperature at the collector exit and also the maximum temperature in storage. The second period is from Jan 7 through April 26. During the third period, from April 27 through May 11 the flow was unbalanced in the east and west arrays, with more air flow through the east than the west. The east half had an air flow rate of approximately 12.6 l/(sec·m²)[9.03 l/(sec·m²) standard] while the west was reduced to 3.75 l/(sec·m²)[2.78 l/(sec·m²) standard].

7.2.2 Air Leakage Rate

Air leakage rates from components and circuits are shown in Table 7-3, which are calculated from the air flow rates listed in Table 7-2. Air flow out of a flow circuit is designated by a negative number while flow into a circuit or component is designated as a positive number. Because all flow rates are referenced to blower outlet conditions leakages may be calculated from volumetric flow rates.

Leakage rates of air into the collectors varies with mode of operation because of pressure changes, with the smallest amount of leakage occurring during the collector to storage mode, which is the predominant mode of operation during the day. In addition to collector leakage, there is air leakage into and out of storage through a small crack in one corner of the box. (The crack was located after the pebbles in the bed were removed in October 1979). There are various leakage rates through dampers, which vary from 2 to 15 percent. Larger amounts of leakage occur in bidirectional ducts when the

"wrong" side of the damper is pressurized. For example damper MD8 (See Figure 3-1) is positioned to prevent flow when the storage side is pressurized. In Mode 3 the opposite side of MD8 is pressurized and leakage is 10 to 15 percent of flow measured at W400. Similarly when MD4 is pressurized on the "wrong" side, 6 to 8 percent leakage occurs. For the types of dampers used in the system (standard Honeywell two blade damper) when the correct side of the damper is pressurized, leakage appears to be about 2 to 3 percent. In Mode 5 the cumulative leakage across 3 dampers, MD1, MD4 and MD8 adds to about 10 percent of the amount measured at W400.

7.2.3 Space and Water Heating

The computed and measured daily totals of energy flows through the heating system from 1 December 1978 through 11 May 1979 are listed in the tables in Appendix A. For each month the data are tabulated in the following order:

1. Energy Flows for Space and Water Heating
2. Thermal Energy Transport From Collectors and through Storage
3. Collector Performance
4. Auxiliary Heating, Electrical Energy Requirements and Coefficients of Performance.

The month of November was excluded because of the intermittent and incomplete nature of data collection due to experimentation and adjustments of a new system controller. Data are missing for January 31 and February 28. Daily totals are the sums of calculated quantities at each 5-minute interval from 99 channels of information, some of which are integrated values and others which are instantaneous values as

listed in Section 5. The calculations are explained in Section 6. There were days when one or more scans are missing in the data. For such days adjustments are made to the data for the missing scans and the adjusted data are identified by an asterisk (*). Totals for the month and monthly mean values are calculated at the bottom of the tables. A summary of key monthly mean daily quantities and performance figures are presented in Table 7-4 and graphical presentations of performance are shown in Figures 7-3 through 7-9.

Monthly mean solar insolation, insolation while system was collecting heat and thermal energy collected, (the top 3 items in Table 7-4), are shown graphically in Figure 7-3. For the season 87 percent of the measured insolation was incident on the collectors while the system was operating with a mean daily collection efficiency of 33 percent, based upon total insolation and 38 percent based on insolation while collecting. During 160 days when data were taken, there were 162.6 GJ of total solar radiation incident on the collectors, 141.6 GJ of which was recorded during collector operation and 53.5 GJ of thermal energy was collected. Collection efficiency was high in December because of the high rate of air flow through the collectors [$13.1 \text{ l}/(\text{sec} \cdot \text{m}^2)$] but reduced by 3 to 4 percentage points in January and February when air flow was reduced to $9.6 \text{ l}/(\text{sec} \cdot \text{m}^2)$. Further reductions in collector efficiency in March and April are due to warm air returning to the collector from the bottom of storage, at temperatures between 60 and 70°C, on many days when storage was "full" following successive sunny days and heating requirements in the house were low. The unbalanced collector operation during the last 4 days in April and 11

Table 7-4. Summary of Key Monthly Mean Daily Quantities and Performance Measures

NUMBER	ITEM	UNITS	DEC	JAN	FEB	MAR	APR	MAY	SEASON
1	Total Incident Solar Insolation	(MJ/m ² ·day)	16.74	15.96	18.71	17.77	20.56	12.51	17.55
2	Insolation Solar While Collecting	(MJ/m ² ·day)	14.16	14.30	16.52	15.28	18.32	9.84	15.28
3	Thermal Energy Collected	(MJ/m ² ·day)	6.31	5.57	6.25	5.61	5.87	3.86	5.77
3a	Thermal Energy Collected	MJ/day	365.29	322.52	362.18	324.86	340.11	223.33	334.43
4	Collector Operating Efficiency	3/2	0.45	0.39	0.38	0.37	0.32	0.39	0.38
5	Collector Daily Efficiency	3/1	0.38	0.35	0.33	0.32	0.29	0.31	0.33
6	Total Heating Load	MJ/day	594.00	614.78	447.03	377.81	265.12	337.33	451.90
6a	Space Heating Load	MJ/day	551.19	557.70	382.20	306.57	193.43	280.72	390.82
6b	DHW Load	MJ/day	42.81	57.08	64.83	71.24	71.69	56.61	61.08
7	Solar Energy Utilized	MJ/day	353.53	297.91	340.06	285.79	223.60	223.65	294.42
7a	Space Heating	MJ/day	331.68	271.91	300.96	247.82	176.59	203.60	261.16
7b	DHW Preheating	MJ/day	21.85	26.00	39.10	37.97	47.01	20.05	33.26
8	Auxiliary Thermal Energy	MJ/day	240.47	316.87	106.97	92.02	41.52	113.67	157.49
8a	Heat Pump Space	MJ/day	74.28	129.42	51.40	48.40	15.09	51.91	63.11
8b	Elec. Resistance Space	MJ/day	145.23	156.37	29.84	10.35	1.75	25.21	66.56
8c	Elec. Resistance, DHW	MJ/day	20.96	31.08	25.73	33.27	24.68	36.55	27.82
9	Elec. Energy to Collect	MJ/day	17.70	12.32	12.04	11.19	13.11	8.11	12.95
10	Elec. Energy to Dist. Solar	MJ/day	12.77	10.75	10.10	9.12	3.57	11.75	9.42
11	Elec. Energy for Heat Pump	MJ/day	50.70	84.88	27.33	22.35	7.88	24.38	37.83
12	Elec. Energy for H.P. Blower	MJ/day	8.59	13.13	3.91	2.86	1.03	3.15	5.75
13	Solar System Efficiency	7/(1-A _c)	0.36	0.32	0.31	0.28	0.19	0.31	0.29
14	COP to Collect Solar	3a/9	20.64	26.18	30.09	29.03	25.94	27.50	26.36
15	COP to Distribute Solar	7/10	27.69	27.71	33.67	31.34	62.63	19.03	31.25
16	COP Overall Solar	7/(9+10)	11.60	12.91	15.36	14.07	13.41	11.26	13.78
17	COP Heat Pump	8a/11	1.47	1.52	1.88	2.17	1.91	2.13	1.67
18	COP Auxiliary Heating	8a+8b/(8b+11+12)	1.07	1.12	1.33	1.65	1.58	1.46	1.18
19	COP Overall Heating	6/(8b+8c+9+10+11+12)	2.32	1.99	4.10	4.24	5.09	3.09	2.82
20	Number of Day of Measurement		31	30	27	31	30	11	160
21	Solar Fraction Total	7/6	0.60	0.48	0.76	0.76	0.85	0.66	0.65
22	Solar Fraction Space	7a/6a	0.60	0.49	0.79	0.81	0.91	0.73	0.67
23	Solar Fraction, DHW	7b/6b	0.51	0.46	0.60	0.53	0.66	0.35	0.54
24	F-Chart Fraction		0.55	0.45	0.72	0.78	1.00	0.61	0.64
25	Difference (percent)	(24-21)/21	-8.3	-6.2	-5.2	2.4	17.6	-7.9	-1.5

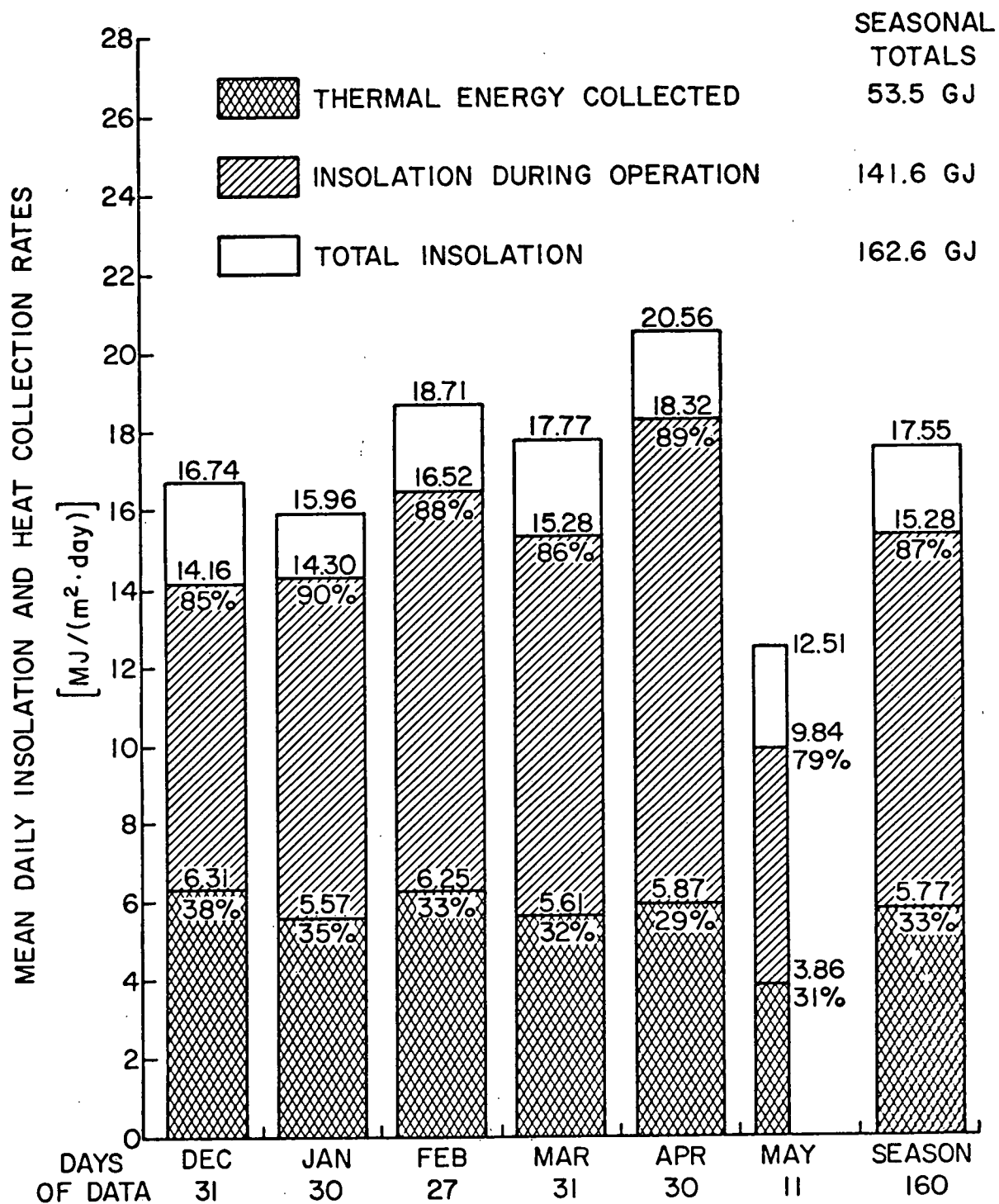


Figure 7-3. Solar Insolation and Thermal Energy Collected

days in May did not noticeably reduce collection efficiency. Collection efficiencies for the east and west arrays during that period are shown in Section 8.

The mean daily energy quantities supplied to the load in terms of solar and auxiliary sources are shown in Figure 7-4 (Items 7 and 8 in Table 7-4). As expected, the total load is highest in January and reduces each month into spring. The mean daily load for May is higher than April because it is an average of only the first 11 days of the month. Data collection was terminated when it was thought that little heating would be required for the balance of the month. Had data been taken throughout May undoubtedly the mean load could have been less than during April. The mean daily seasonal space and water heating loads totaled 452 MJ/day and 72.3 GJ for the season, of which 65 percent, 293 MJ/day or 46.9 GJ, was supplied from the solar system. Since 53.5 GJ was collected, 6.6 GJ or 12 percent was lost from the system through duct losses in the attic and heat losses from storage to the ground. The monthly solar contribution to the load varied from a low of 48 percent in January to a high of 85 percent in April. The first 11 days in May was dominated by cold cloudy days and the solar contribution was low. (Mean daily solar insolation was only 61 percent of that in April).

The monthly average daily space heating load is shown in Figure 7-5, separated in terms of the solar heat pump and electrical resistance heating contributions. The seasonal space heating load was 62.5 GJ of which 67 percent was supplied by the solar system. The heat pump accounted for 16 percent or 10 GJ and the balance, 10.6 GJ, or 17 percent, was supplied by electrical resistance back-up provided with the heat pump.

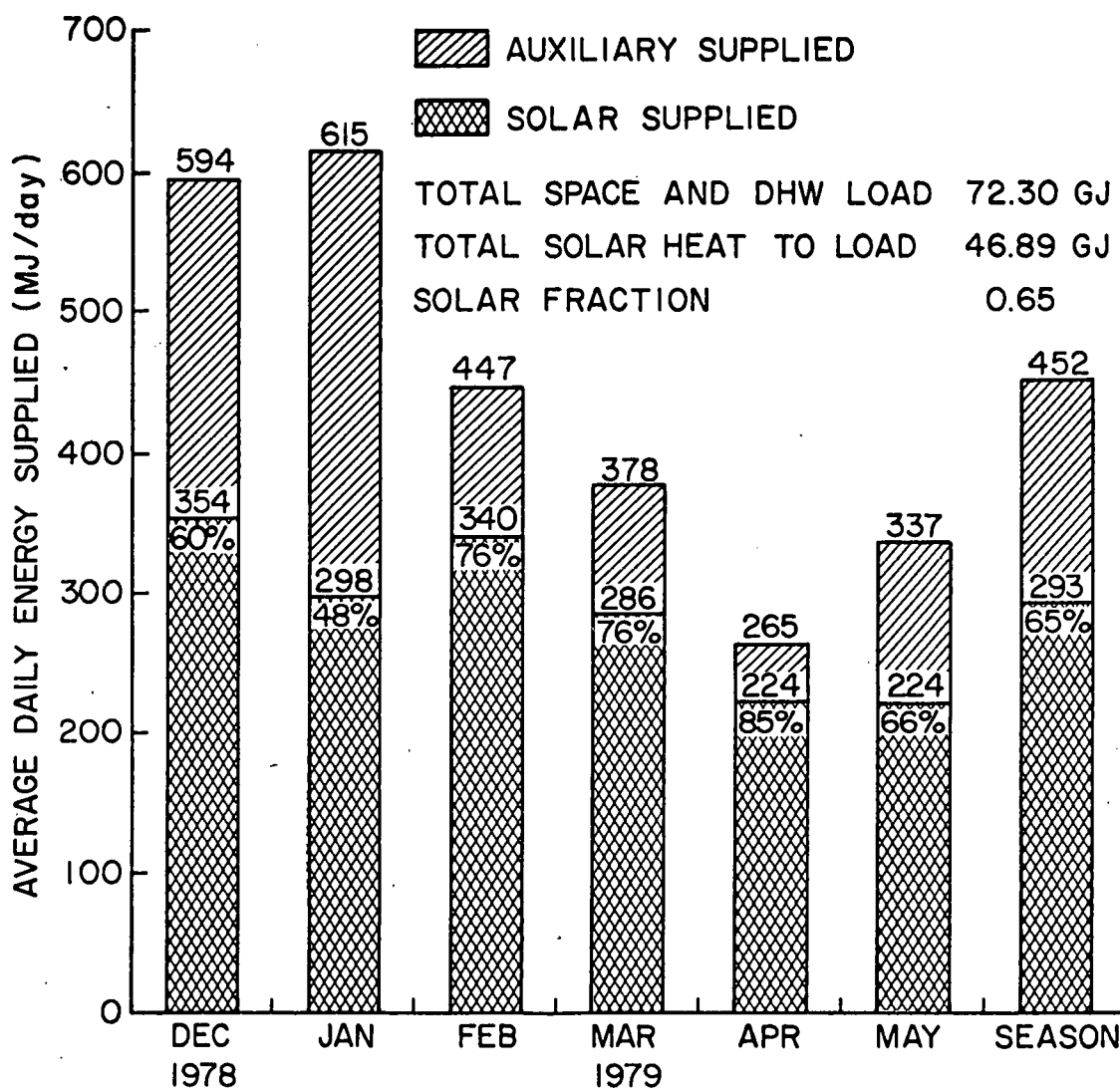


Figure 7-4. Mean Daily Energy Supplied to the Load

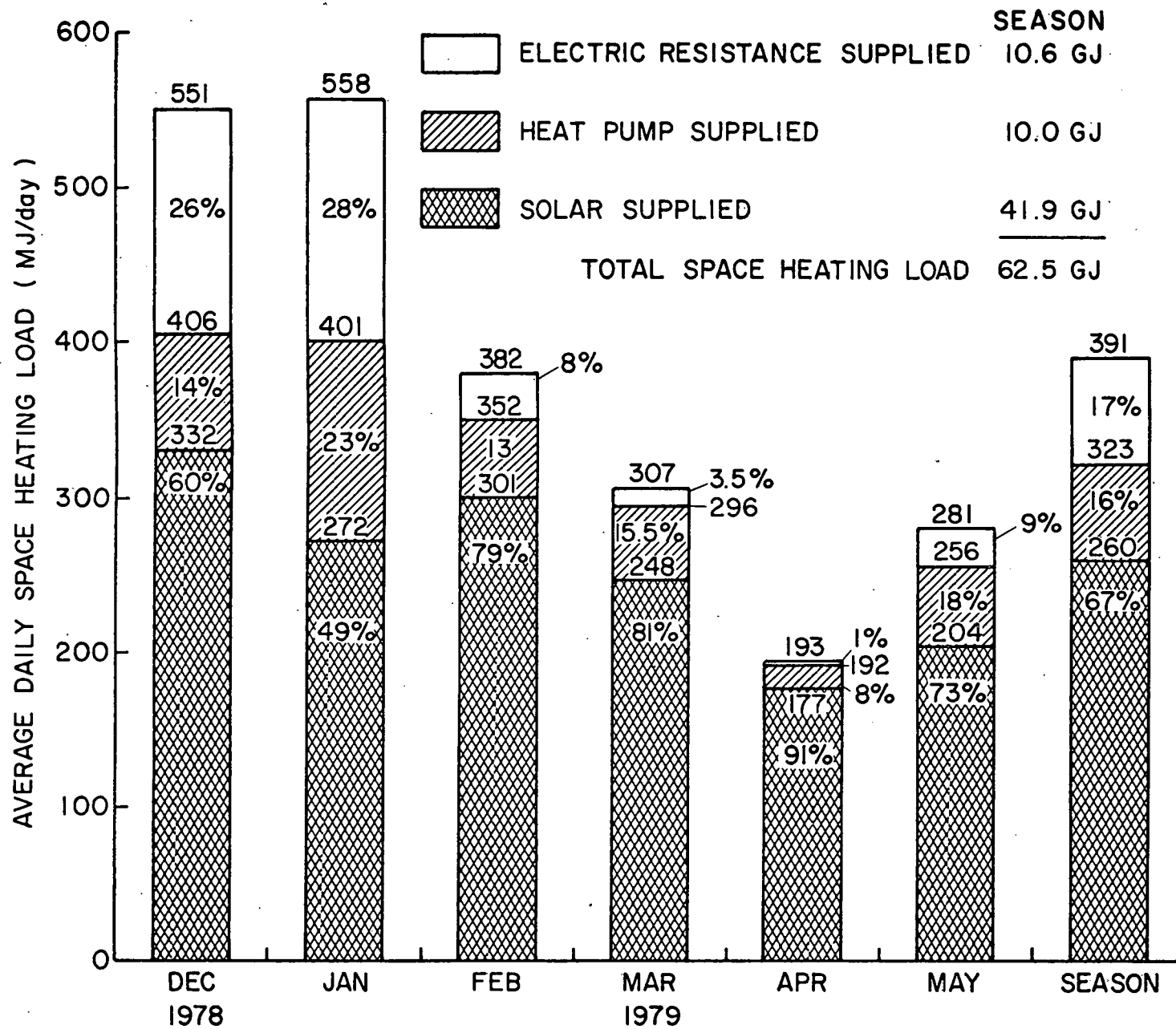


Figure 7-5. Monthly Average Daily Space Heating Load

The overall seasonal performance of the heat pump is low with a mean daily COP of 1.67 (See item 17 in Table 7-4) and varies from 1.47 in December to a high of 2.17 in March. The low COP results from the use of a heat pump as an auxiliary unit in this system and generally operates under adverse conditions when solar heat has been depleted and ambient air temperatures are low. The measured performance of the heat pump as a function of ambient air temperature is shown in Figure 7-6. The COP varies from slightly greater than one at -20°C to about 2.5 at 3°C . When combined with electrical resistance heating, which was about equal to the thermal energy provided by the heat pump, the COP for auxiliary heating for the season was 1.18 (see item 18 of Table 7-4). The overall heating COP for the solar and auxiliary heating system was 2.82, varying from a low of 1.99 in January to a high of 5.09 in April.

The monthly mean daily domestic hot water load and the solar contributions are shown in Figure 7-7. In the air heating system for Solar House II with the placement of the air-to-water heat exchanger and the control strategy used, domestic water preheating will be limited because (1) preheating occurs only during the day when solar energy is being collected and (2) priority is given to space heating. When solar heat is being delivered from the collectors to the rooms, preheating of water is not permitted according to the control program adopted. The energy required for DHW increased from December through April as generally did the solar contribution. The seasonal solar contribution to the DHW load was 5.32 GJ or 54 percent, and the DHW load was 13.5 percent of the total load.

The net system efficiency for the season (item 13 in Table 7-4) was 29 percent, varying from 36 percent in December to 19 percent in

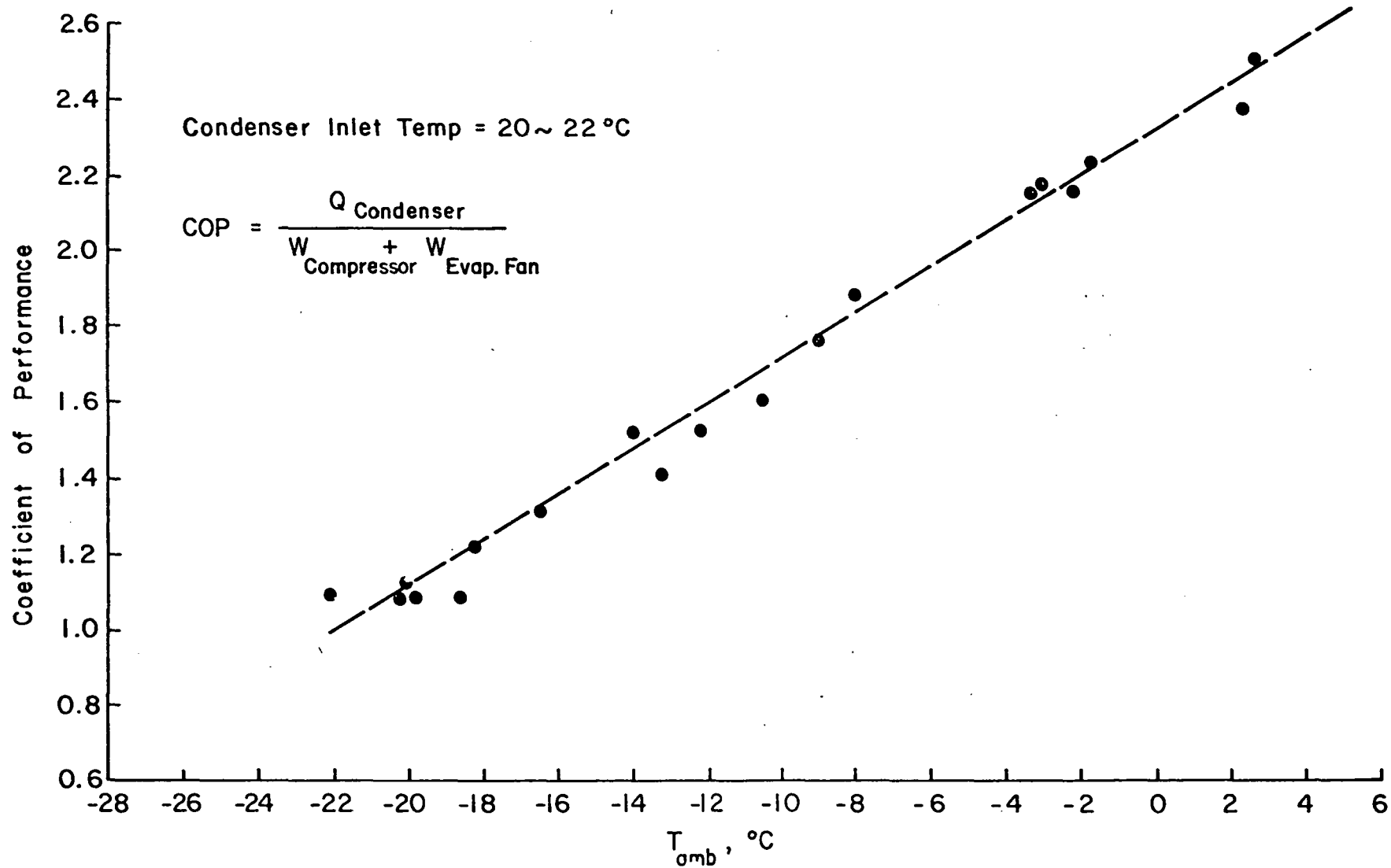


Figure 7-6. Heat Pump COP as a Function of Ambient Air Temperature

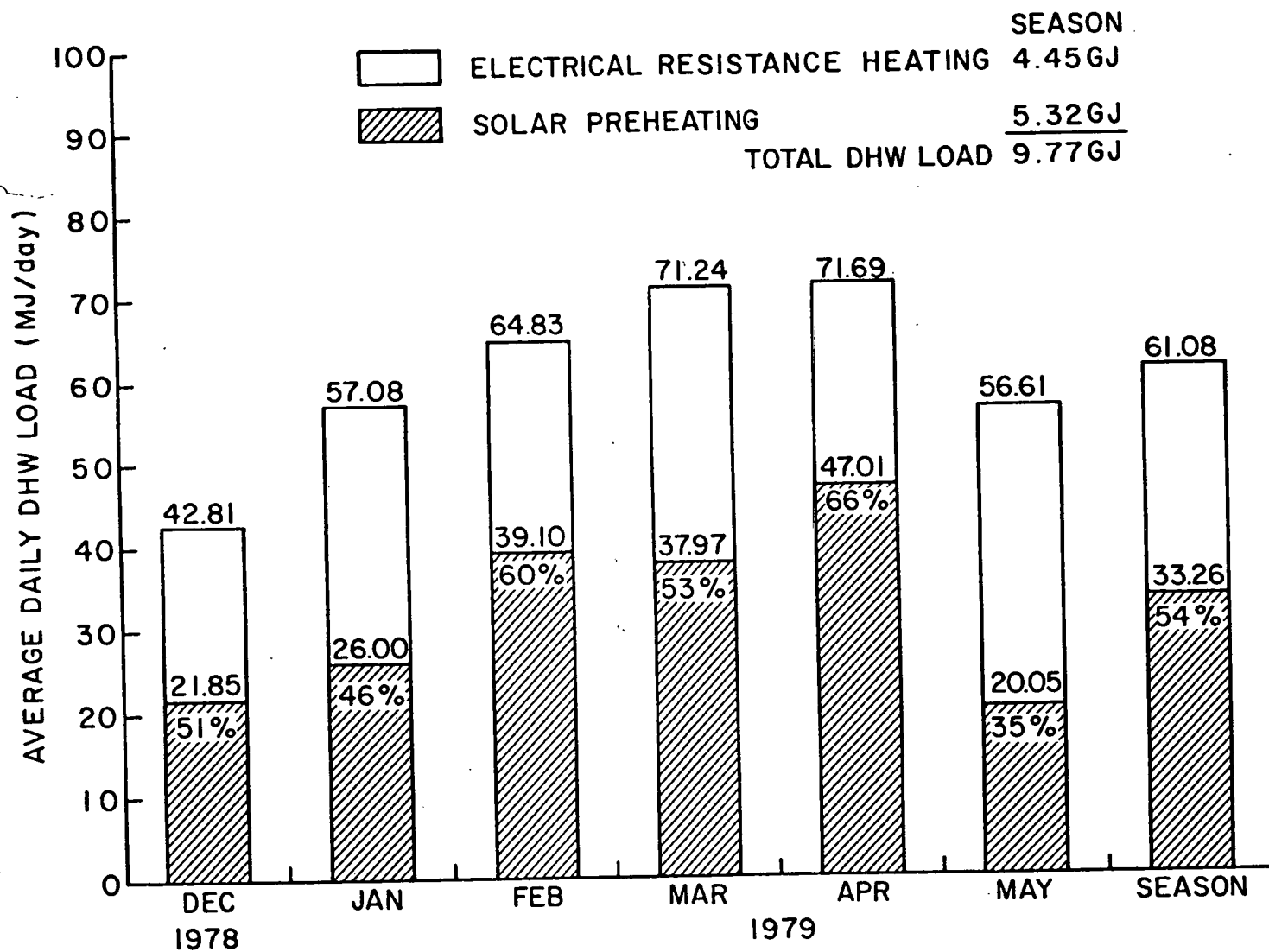


Figure 7-7. Monthly Average Daily DHW Load

April. During the cold winter months collection efficiency is high, despite cold ambient air conditions, because the inlet air temperature to the collector is nearly always at room temperature. During the warmer months when storage is "full" for a significant number of days the temperature of the return air to the collector is high and collection efficiency decreases. Heat losses from ducts in the attic and from storage also increases during the warmer months.

The ratio of solar energy collection to electrical energy required by the blower (i.e. collection COP) averages 26.36 for the season, which means that 3.8 percent in blower energy is required for collection. Another 3.2 percent is required over the season to distribute the stored solar heat. In terms of the total solar energy utilized for space and water heating 7.3 percent electrical energy was required for an overall solar COP of 13.78. The range in COP was 11.26 in May to 15.36 in February. It will be noted in Table 7-4 that the COP to distribute solar heat to the rooms varied from 19 in May to 62.6 in April. Since April was a warm month and the heating load was small while solar radiation levels were high, a large portion of the load was satisfied by heat losses from the ducts and from storage during collection so that only small amounts of air circulation through storage was necessary.

7.2.4 Comparisons with Previous Years

The solar air heating system described in this report is a state-of-the-art system, the components of which are available commercially. The performance of this state-of-the-art system is compared with the previous site-built system (Ref. 6) in Figures 7-8 through 7-10. In terms of daily and operating efficiencies the commercial collector

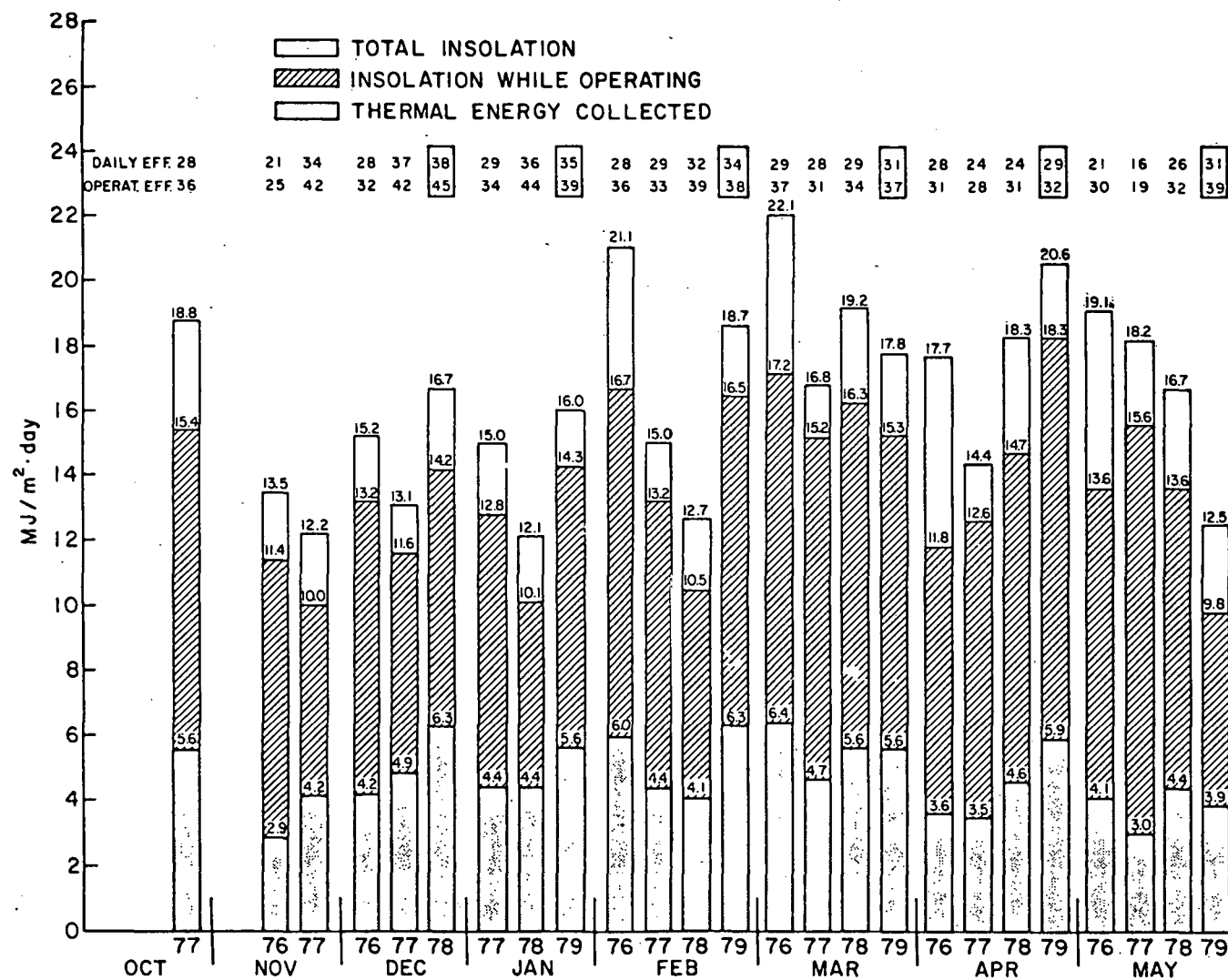


Figure 7-8. Mean Daily Solar Insolation and Heat Collection.
Solar House II, 1 Feb 1976 - 11 May 1979.

subsystem performance is only slightly better than the improved site-built system which was operated during the 1977-78 heating season. The monthly and seasonal efficiencies of systems for all the years of operation are shown in Figure 7-9. Seasonal and overall efficiencies of the present system are only fractionally better than for the 1977-78 season and may be due in part to the smaller collector area (57.9 m^2 vs. 67.1 m^2) of the new system and smaller (except February) solar fractions which are shown in Figure 7-10.

7.2.5 Comparisons of Calculated and Measured Solar Fractions

Predictions of monthly and seasonal solar fractions of the total load using the f-chart method are compared to measured solar fractions in Table 7-5 and shown graphically in Figure 7-11. There is reasonably good correspondence between calculated and measured solar fractions and the seasonal comparison differs by only 1 percentage point. The procedure of f-chart tends to underpredict performance during the cold months and overpredict during the warm months and May is an exception because of the limited days of data.

Also shown on Figure 7-11 are the calculated solar fractions using average solar radiation and heating degree-days in Fort Collins (Ref. 7). The calculated UA of the building is $36.2 \text{ MJ}/(^{\circ}\text{C-day})$ and the degree days are based on 12.8°C rather than 18.3°C to account for internal heat generation. Monthly comparisons vary from good to poor; but for the season the calculated seasonal fraction of 0.67 and measured fraction of 0.65 compare very well.

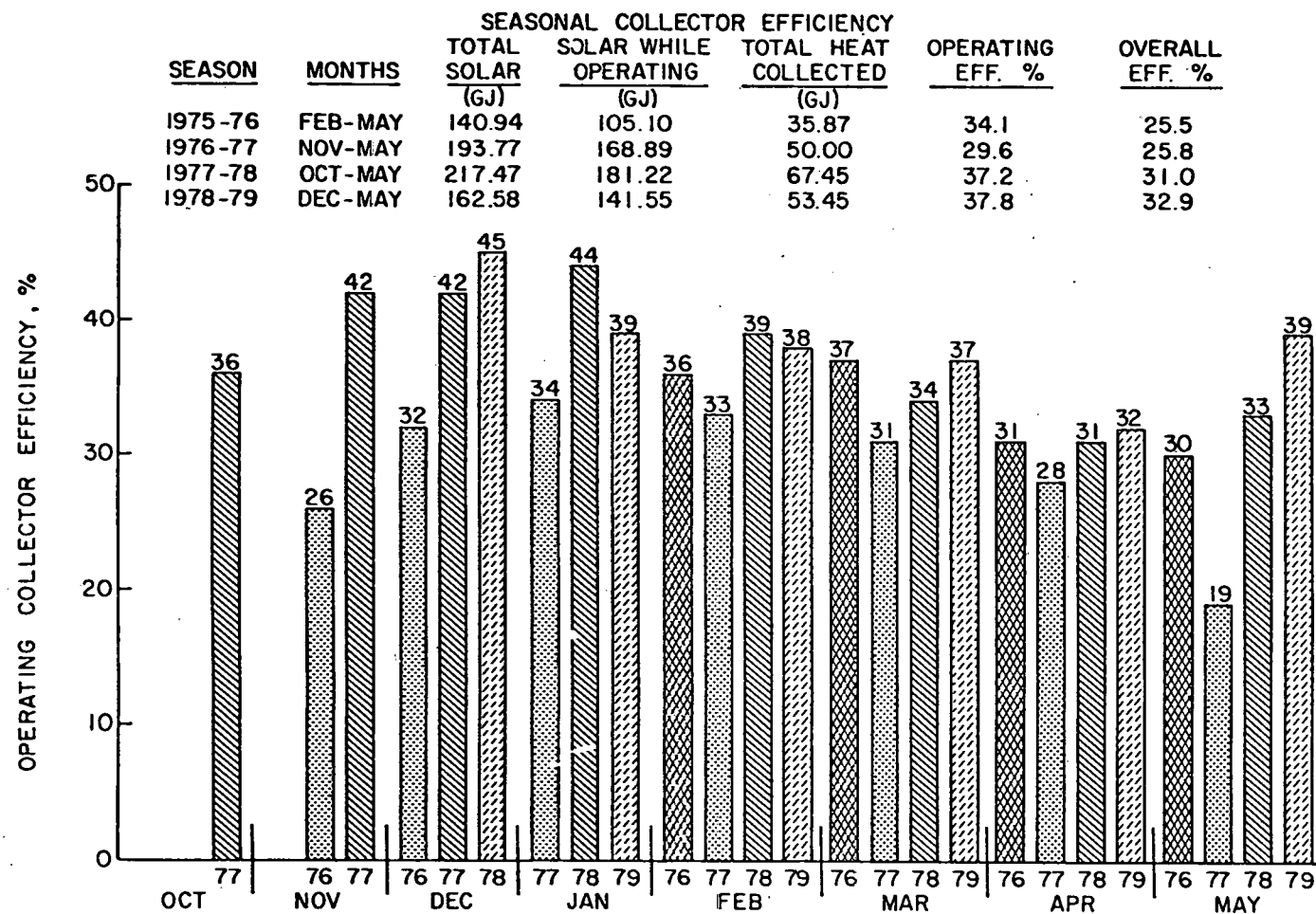


Figure 7-9. Comparisons of Monthly and Seasonal Collector Efficiencies

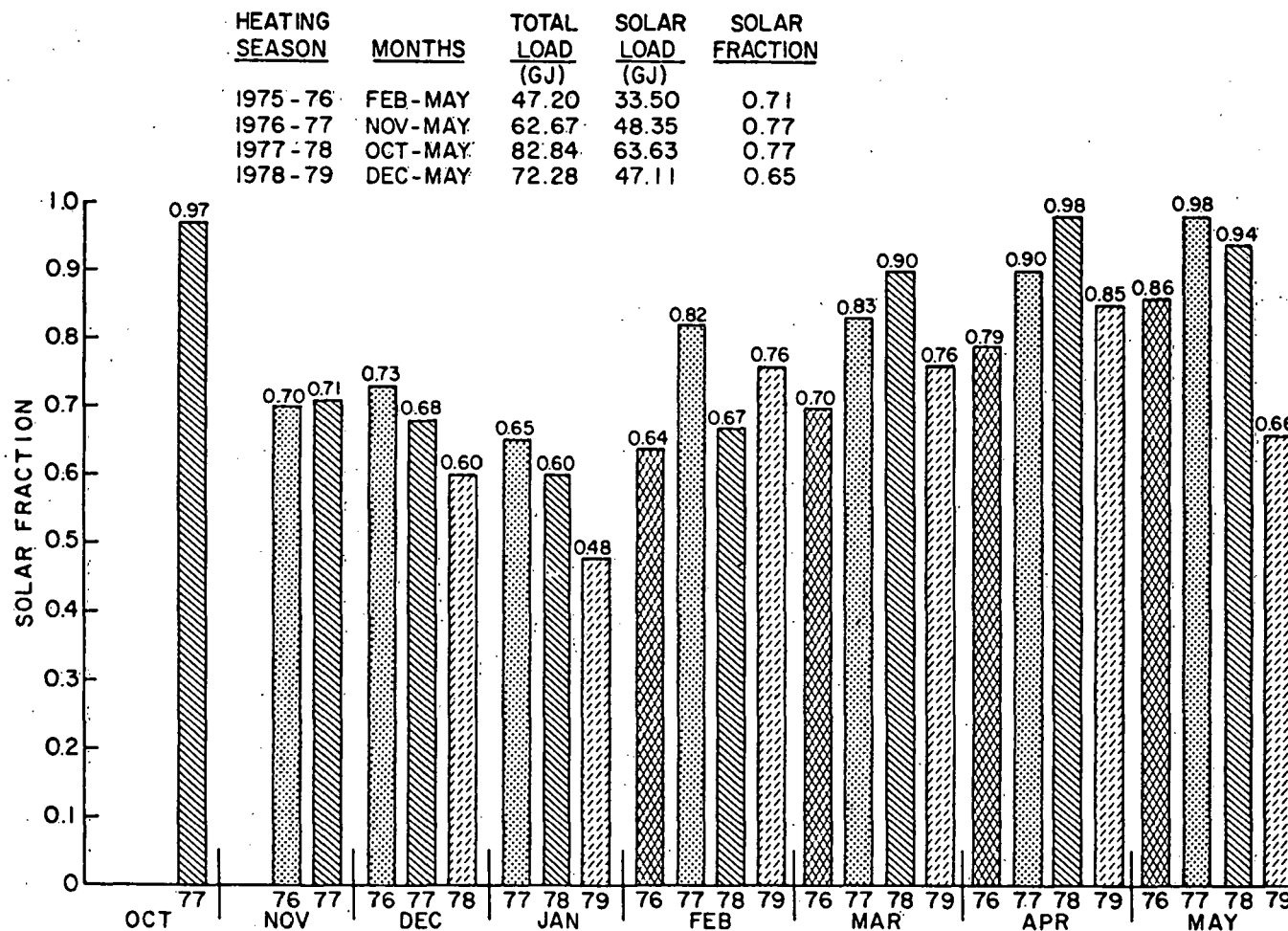


Figure 7-10. Monthly and Seasonal Solar Fractions

Table 7-5. Comparisons of Predicted and Measured Solar Fractions of Monthly and Seasonal Total Loads for the 1978-79 Season.

MONTH	DATA BASE	TOTAL MO. SOLAR RADIATION MJ/mo·m ²	TOTAL HEATING LOAD MJ/mo	T _a °C	f-CHART COORDINATES		CALC. MO. SOLAR FRACTION	MEAS. MO. SOLAR FRACTION	PERCENT DIFFERENCE
					x ⁴	y ⁵			
DEC	Measured	518.7	18414	-5.7	5.31	0.96	0.55	.60	-8.3
	Average	491.0	15345 ⁶	-1.0	6.08	1.09	0.61		
JAN ¹	Measured	478.7	18443	-8.2	4.09	0.75	0.45	.48	-6.2
	Average	518.4	16601	-2.5	5.03	0.90	0.52		
FEB ²	Measured	505.0	12070	-0.2	5.21	1.21	0.72	.76	-5.2
	Average	447.1	12819	-0.3	5.74	1.01	0.57		
MAR	Measured	550.4	11712	4.2	5.89	1.36	0.78	.76	+2.4
	Average	680.8	1222.8	1.9	6.76	1.61	0.87		
APR	Measured	616.4	7954	9.5	7.93	2.24	1.00	.85	+17.6
	Average	561.6	5370	7.8	14.0	3.03	1.00		
MAY ³	Measured	137.5	3711 ⁷	7.0	6.67	1.13	0.61	.66	-7.9
	Average	205.9	2011	13.5	12.6	3.11	1.00		
SEASON	Measured	2806.7	72304				.64	.65	-7.9
	Average	2904.8	64374				.60		

1. 30 days or 720 hours

2. 27 days or 648 hours

3. 11 days or 264 hours

4. $x = F_{R,L} A_c (T_{ref} - T_a) K_1 K_2 t / L$

5. $y = F_R (\tau \alpha) A_c S / L$

6. 12.8°C Base for Heating Degree Days

7. Estimate of 55.6°C Days for first 11 days of May

$$A_c = 57.93 \text{ m}^2$$

$$F_{R\tau\alpha} = 0.59(\text{Dec}).50(\text{Jan-April}).525(\text{May})$$

$$F_{R,L} = 19.09 \text{ KJ}/(\text{m}^2 \cdot ^\circ\text{C} \cdot \text{hr})(\text{Dec})1633(\text{Jan-April})17.0(\text{May})$$

$$K_1 = 1.07(\text{DEC}, \text{MAY})0.975(\text{Jan-April})$$

$$K_2 = 1.05$$

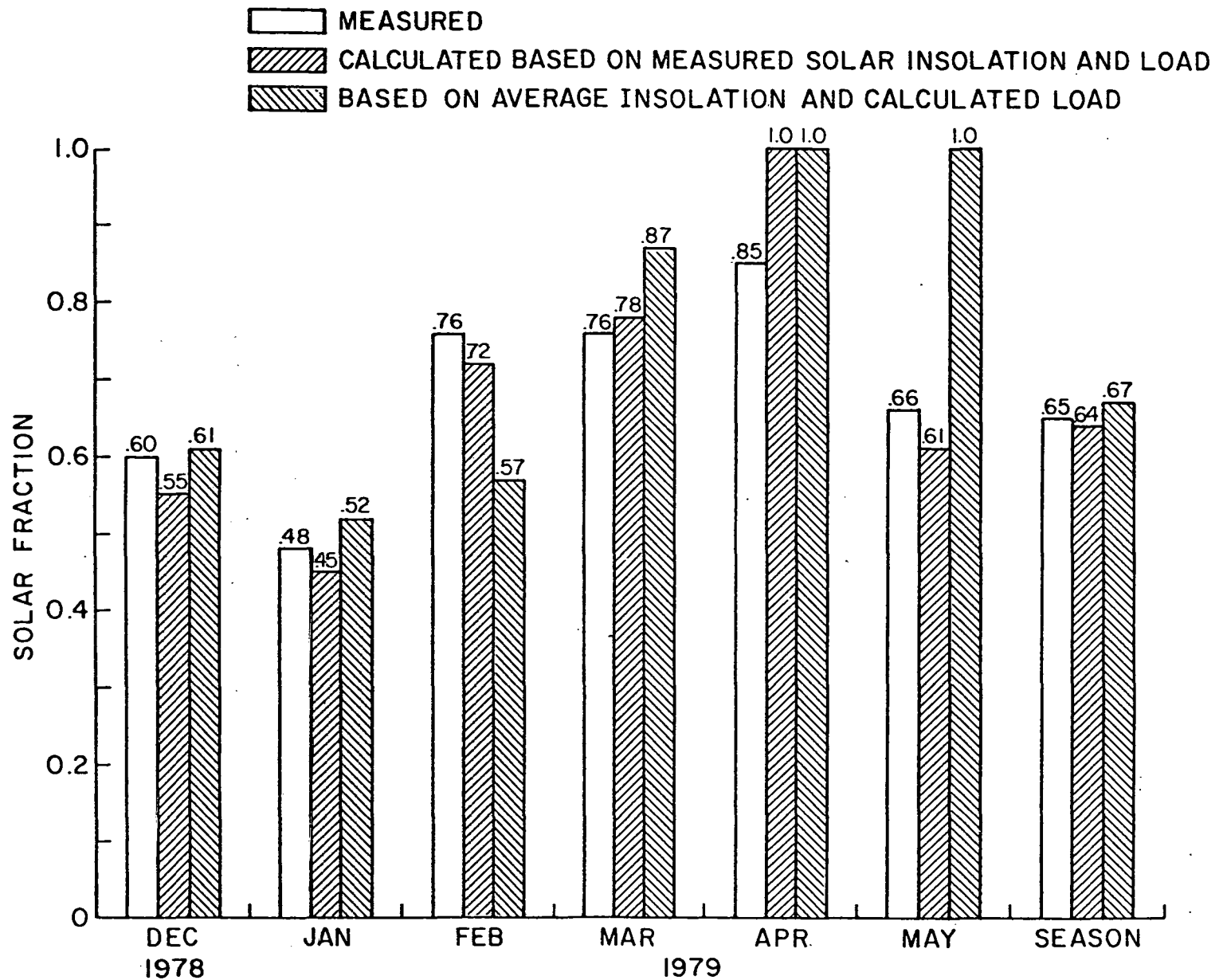


Figure 7-11. Comparisons of Measured and Predicted Monthly and Seasonal Solar Fractions of the Total Heating Load

7.3 COOLING SEASON

7.3.1 Air Flow Rates

A second Barocel differential pressure transducer and Scanivalve multiplexer was added to the instrumentation complex before the summer season and a flow monitor index was reassigned as shown in Table 7-6. The average volumetric flow rates for three periods through the summer are listed in Table 7-7, where the air flow rates are referenced to blower outlet air temperature and pressure. The periods are approximately for the months of June, July and August/September and the largest differences occur in the reduction of air flow rates through the collector, which for the summer was used only to preheat domestic water.

7.3.2 Air Leakage Rates

Air leakage rates from or into components and between components are shown in Table 7-8. Air flow out of a flow circuit is assigned a negative sign while flow into a component or circuit is positive. As is evident from the table, air leakage into the east array is significantly greater than air leakage into the west array and leakages through closed dampers vary from 4 to almost 11 percent.

7.3.3 Space Cooling

Space cooling is provided primarily by cool storage in the pebble bed. Heat is removed from the pebble bed during the off-peak hours (00 to 0800 hours in this study but is applicable for any 8 hour period) and only blower energy is used during the peak electrical demand periods to circulate room air through the pebble bed.

Table 7-6. Flow Monitor Index

Mode	SCANIVALVE A								SCANIVALVE B				
	Indoor Blower W400	Storage Top In W107	Storage Bottom Out W109	Outdoor Fan W402	Storage Bottom In W108	Storage Top Out W106	Room Supply W101	Pneumatic Short Circuit	East Collector Supply W101	East Collector Return W103	West Collector Supply W103	West Collector Return W104	Pneumatic Short Circuit
0 Illegal	2	2	2	2	2	2	3	1	19	19	19	19	18
1 DN	3	3	3	3	3	3	3	1	20	20	20	20	18
2 CCh	4	5	6	7	0	0	0	1	20	20	20	20	18
3 CFS	8	0	0	0	9	10	11	1	20	20	20	20	18
4 CFS+HW	8	0	0	0	9	10	11	1	21	22	23	24	18
5 CFS+CC	8	0	0	0	9	10	11	1	21	22	23	24	18
6 CHP	12	0	0	13	0	0	14	1	20	20	20	20	18
7 CHP+HW	12	0	0	13	0	0	14	1	21	22	23	24	18
8 CHP+CC	12	0	0	13	0	0	14	1	21	22	23	24	18
9 HN	3	3	3	3	3	3	3	1	21	22	23	24	18
10 CC	3	3	3	3	3	3	3	1	21	22	23	24	18
11 HS	15	0	0	16	0	0	17	1	20	20	20	20	18
12 HS+HN	15	0	0	16	0	0	17	1	21	22	23	24	18
13 HS+CC	15	0	0	16	0	0	17	1	21	22	23	24	18

Mode Abbreviations:

- DN - Do Nothing
- CCh - Cold Charging Storage
- CFS - Cooling from Storage
- HW - Hot Water Preheating
- CC - Cooling the Collectors
- CHP - Cooling with Heat Pump
- HS - Heating Space
- CCh

Table 7-7. Average Volumetric Air Flow Rates
Summer 1979 (m³/min)

Index	June 11-June 29	June 30-Aug 3	Aug 4-Sept 9
1	0	0	0
2	0	0	0
3	0	0	0
4	37.24	36.99	36.75
5	33.87	33.77	34.14
6	33.51	33.55	34.22
7	94.24	94.11	94.17
8	36.58	36.03	34.99
9	30.00	30.00	27.17
10	32.72	32.80	34.13
11	34.03	33.66	33.70
12	39.97	38.97	38.08
13	93.80	93.18	93.17
14	37.31	36.35	35.93
15			
16			
17			
18	0	0	0
19	0	0	0
20	0	0	0
21	16.14	13.02	11.97
22	20.02	14.92	13.86
23	21.51	14.16	13.23
24	23.24	14.96	13.84

Table 7-8. Air Leakages

MODE OF OPERATION	COLLECTORS				HEAT PUMP TO STORAGE		STORAGE		STORAGE TO HEAT PUMP BLOWER		HEAT PUMP TO ROOMS	
	EAST ARRAY		WEST ARRAY									
	Percent of m ³ /min Outflow		Percent of m ³ /min Outflow		Percent of m ³ /min Delivery		Percent of m ³ /min Delivery		Percent of m ³ /min Delivery		Percent of m ³ /min Delivery	
June 11-June 29												
2 CCh	-	-	-	-	-3.37	9.9	-0.36	1.1	-	-	-	-
3 CFS	-	-	-	-	-	-	2.72	8.3	3.86	10.6	-2.55	7.5
4 CFS+HW	3.88	19.4	1.73	7.4	-	-	2.72	8.3	3.86	10.6	-2.55	7.5
6 CHP	-	-	-	-	-	-	-	-	-	-	-2.66	7.1
June 30-Aug 3												
2 CCh	-	-	-	-	-3.22	9.5	-0.22	0.7	-	-	-	-
3 CFS	-	-	-	-	-	-	2.80	8.5	3.23	9.0	-2.37	7.0
4 CFS+HW	1.90	12.7	0.80	5.3	-	-	2.80	8.5	3.23	9.0	-2.37	7.0
6 CHP	-	-	-	-	-	-	-	-	-	-	-2.62	7.2
Aug 4-Sept 9												
2 CCh	-	-	-	-	-2.61	7.6	.08	0.2	-	-	-	-
3 CFS	-	-	-	-	-	-	6.96	20.4	0.86	2.5	1.29	3.8
4 CFS+HW	1.89	13.6	0.61	4.4	-	-	6.96	20.4	0.86	2.5	1.29	3.8
6 CHP	-	-	-	-	-	-	-	-	-	-	-2.15	6.0

The measured and computed daily total energy flows are provided in the tables of Appendix B. For each month the following data tables are provided:

1. Cooling performance, cold charge, and storage
2. Environmental conditions, collector performance and electrical energy requirements.

The tabulated values for cooling are for sensible heat only because reliable data for calculating latent heat removal were not available. Semiconductor sensors to measure relative humidity at different points in the air flow stream did not perform as expected. By not including latent heat removal, the error is largest in calculating the quantity of heat removed by the heat pump since the evaporator coil is sometimes at a temperature low enough to condense water from the air. Based on measurements made of the quantity of condensate collected at the indoor coil, late in the cooling season, the error is estimated to be about 5 to 7 percent of the sensible heat removed.

The pebble bed is sufficiently cooled at the top of the bed during the latter part of the cold charge period, to cause condensation at the beginning of the room cooling period. However, because the dew point is normally low during the summer (in Colorado) condensation can occur only during a short period of time. The amount of latent heat removed from the air in the pebble bed is estimated to be about 5 percent of the sensible heat removed, but the latent heat quantity is not included in the calculations.

A summary of monthly average daily cooling performance is tabulated in Table 7-9 and mean daily cooling rates are plotted on Figure 7-12.

Table 7-9. Monthly Average Daily Cooling Performance

Number	Item	Units	June	July	Aug	Sept	Season
1	Number of Days of Data		20	31	31	9	91
2	Heat Removed by Heat Pump during Cold Charge	MJ/day	156.28	200.52	143.95	205.26	171.99
3	Cold Charging of Pebble Bed	MJ/day	108.99	153.48	110.56	162.71	129.99
4	Room Cooling through Pebble Bed	MJ/day	110.78	146.61	101.64	155.41	124.28
5	Storage Efficiency	4/3	1.02	0.95	0.92	0.96	0.96
6	Cold Charge Efficiency	3/2	0.70	0.77	0.77	0.79	0.76
7	Direct Heat Pump Cooling	MJ/day	2.26	14.14	16.73	12.38	12.24
8	Total Room Cooling Including Cooling from Losses	MJ/day	138.69	189.40	137.51	190.70	160.71
9	Electrical Energy for Heat Pump during Cold Charge	MJ/day	64.96	84.22	61.46	84.53	72.27
10	Electrical Energy for Blower during Cold Charge	MJ/day	9.58	12.02	8.81	11.99	10.38
11	Electrical Energy for Heat Pump during Direct Cooling	MJ/day	0.81	5.72	6.80	4.68	4.91
12	Electrical Energy in Blower during Direct Cooling	MJ/day	0.12	0.74	0.88	0.63	0.64
13	Electrical Energy to Blower for Storage Discharge	MJ/day	6.33	10.01	6.17	9.90	7.88
14	Heat Pump COP for Cold Charge	2/9	2.41	2.38	2.34	2.43	2.38
15	Heat Pump COP for Direct Cooling	7/11	2.79	2.47	2.46	2.65	2.49
16	Cooling COP from Cold Charge	$4/(9)+(10)+(13)$	1.37	1.38	1.33	1.46	1.37
17	Average Daily COP for Cooling	$8/(9)+(10)+(11)+(12)+(13)$	1.70	1.68	1.63	1.71	1.67

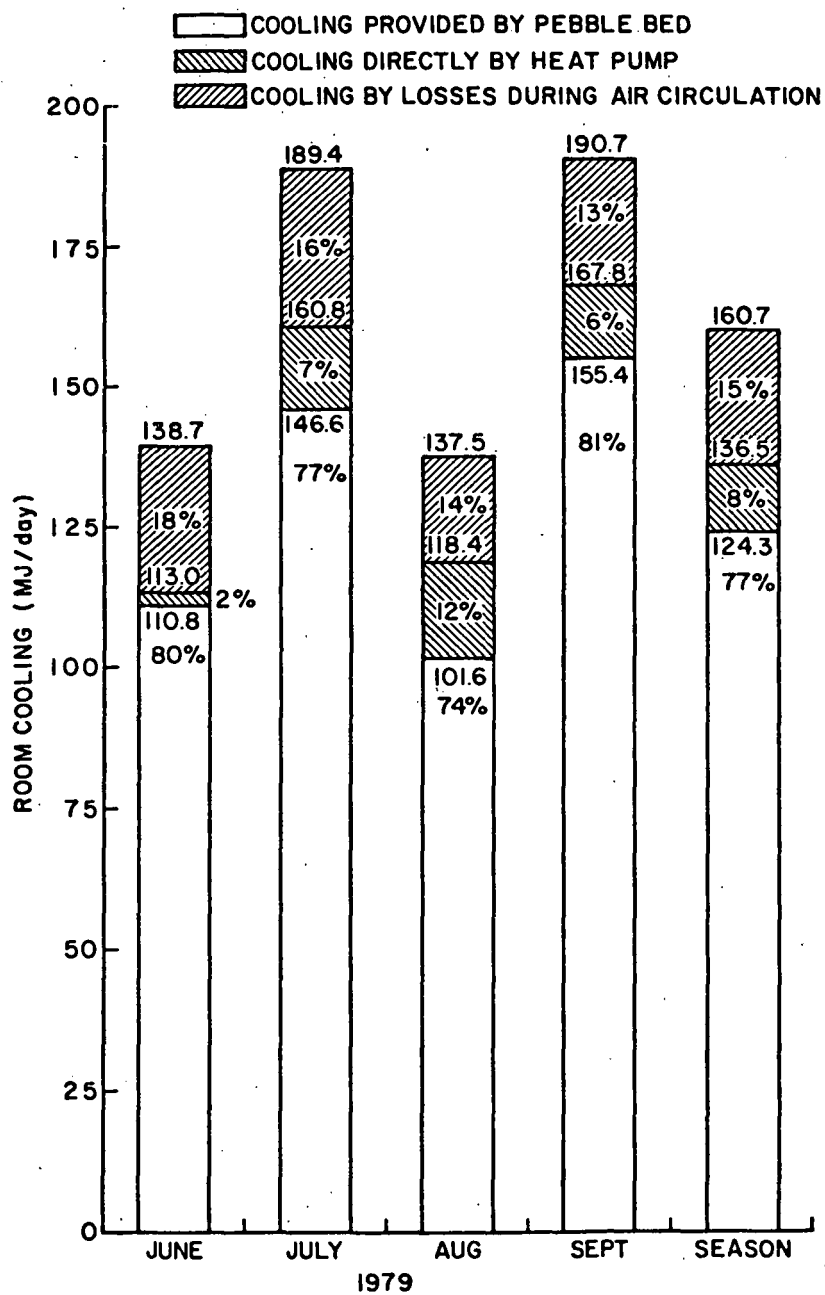


Figure 7-12. Monthly Average Daily Cooling Performance

During the season 77 percent of an average daily cooling demand of 160.7 MJ was provided by cold charge in storage during the off peak hours with an additional 15 percent provided by "losses" in the ducts during cold charge and discharge modes and including conduction through the pebble bed container. By cold charging the pebble bed electrical energy requirement increases by 30 percent, which is the energy required for the blower during cold charge plus a small amount to overcome additional pressure drop through the rock bed during discharge and room cooling.

The heat pump COP for cold charge is less than the COP for direct cooling because the air temperature to the indoor coil is colder than for direct cooling of room air. The COP of the heat pump for direct cooling is 2.49 while the COP for cooling from storage is about 1.37 for the season. The overall cooling COP with the system was about 1.7, the increase resulting from the higher COP of the heat pump during direct cooling periods.

7.3.4 Solar Preheating of Domestic Water During Summer

Preheating of domestic water with the air system in Solar House II is limited to daytime periods. For the summer attic air is drawn through the collectors, is heated, and flows across an air-to-water heat exchanger. The hot air is discharged out of the attic space. The heat exchanger is a 0.6 m x 0.6 m single loop cross-flow unit with fin widths of 10 cm. The water circulation pump was changed from the winter season to a Grundfos adjustable flow rate pump.

The 1979 summer season is divided into 3 experimental periods. In Period 1, from 11 June to 29 June, the air flow rate through the

collector is high ($12.45 \text{ l}(\text{s}\cdot\text{m}^2)$) and water circulation rate is low (about 4 l/min). In Period 2, from 30 June through 3 August, air flow rate was reduced to $8.61 \text{ l}(\text{s}\cdot\text{m}^2)$ and water circulation rate remained the same. In Period 3, from 4 August to 9 September the air flow rate changed slightly to $7.97 \text{ l}(\text{s}\cdot\text{m}^2)$ and water circulation rate was increased to about 6 l/min .

The performance results are summarized in Table 7-10. As a consequence of reducing the air flow rate through the collector, the air temperature increased and the effectiveness of the heat exchanger increased from 0.24 during Period 1 to 0.32 during Period 2. The collector efficiency reduced from 61 percent to 51 percent but the reduction is not important to domestic water preheating since the entire 57.9 m^2 of collector area is available for water heating. Electrical energy requirement for preheating water reduced as a consequence of the change in flow rate and the solar COP increased from 3.36 in Period 1 to 4.36 in Period 2.

There was little change from Period 2 to Period 3 except that further reduction in air flow rate increased the solar COP to 5.63. The change in water flow rate did not affect heat exchanger performance because the capacitance rate of the air and physical size of the heat exchanger are the limiting factors. The solar system provided 83 percent of the seasonal water heating load with a COP of 5.1 and the heat exchanger size needs to be increased to attain a higher solar fraction. Overall COP for domestic water heating for the summer was 2.7.

Table 7-10. Domestic Water Heating, Summer 1979

Number	Item Calendar Dates	Units	Period 1 11-June- 29 June	Period 2 30 June- 3 Aug	Period 3 4 Aug- 9 Sept	Season 11 June- 9 Sept
1	No. of Days of Data		19	35	37	91
2	Total Solar Insolation	MJ/(m ² ·day)	18.85	19.72	19.00	19.24
3	Insolation While Collecting	MJ/(m ² ·day)	15.57	16.74	16.40	16.36
4	Total Thermal Energy Collected	MJ/(m ² ·day)	9.45	8.62	8.01	8.54
4a	East Array	MJ/(m ² ·day)	9.36	8.63	8.03	8.54
4b	West Array	MJ/(m ² ·day)	9.54	8.60	7.99	8.55
4c	Total Thermal Energy Collected	MJ/day	547.38	499.1	464.09	494.96
5	Collection Operating Efficiency	4/3	0.61	0.51	0.49	0.52
5a	East Array	4a/3	0.60	0.52	0.49	0.52
5b	West Array	4b/3	0.61	0.51	0.49	0.52
6	Daily Collector Efficiency	4/2	0.50	0.44	0.42	0.44
7	Total Domestic HW Load	MJ/day	80.70	85.84	84.68	84.30
7a	Solar Preheating	MJ/day	61.36	73.72	70.85	69.97
7b	Auxiliary Heating	MJ/day	19.34	12.12	13.83	14.33
7c	Solar Fraction		0.76	0.86	0.84	0.83
8	Electrical Energy for Collector Blower	MJ/day	18.98	12.05	8.14	11.91
9	Electrical Energy for Water Circulation Pump	MJ/day	5.04	4.84	4.44	4.72
10	Solar COP for Preheating	7a/(8+9)	3.36	4.36	5.63	5.07
11	Overall COP for DHW	7/(7b+8+9)	1.86	2.96	3.21	2.72

8. COLLECTOR PERFORMANCE

The Solaron Series 3000 collectors installed on Solar House II were described in Section 2 of this report. From independent test results of the same collector series, performed by the Desert Sunshine Exposure Test Center (DSETC), Solaron published a chart which depicts the performance characteristics of the collector. A portion of the chart is reproduced in Figure 8-1 (converted to SI units by the authors).

Measured collector efficiencies during the heating season are shown on Figure 8-2, using data on clear days between the hours of 1130 and 1230. The triangles are for December days with a relatively high air flow rate and the circles are for days in the period 7 January through 26 April when air flow rate was reduced. The two lines represent the collector efficiencies predicted by Solaron for the flow rates used in December and beyond 7 January, with the volumetric flow rates listed in Table 7-2 (corrected to standard conditions) and the collector characteristics shown in Figure 8-1 used to define the bias.

Evidently, collector efficiency curves provided by the manufacturer and based on steady state tests at DSETC under-predicts measured performance. The difference, at least in part, is due to higher efficiency resulting from air leaks into the collector, as shown by Close and Yusoff (Ref. 8), where the lines do not include leakage effects. However it is thought that not all of the apparent differences can be attributed to leakage effects and that the collectors in the system operate more efficiently than is depicted by the steady-state test data.

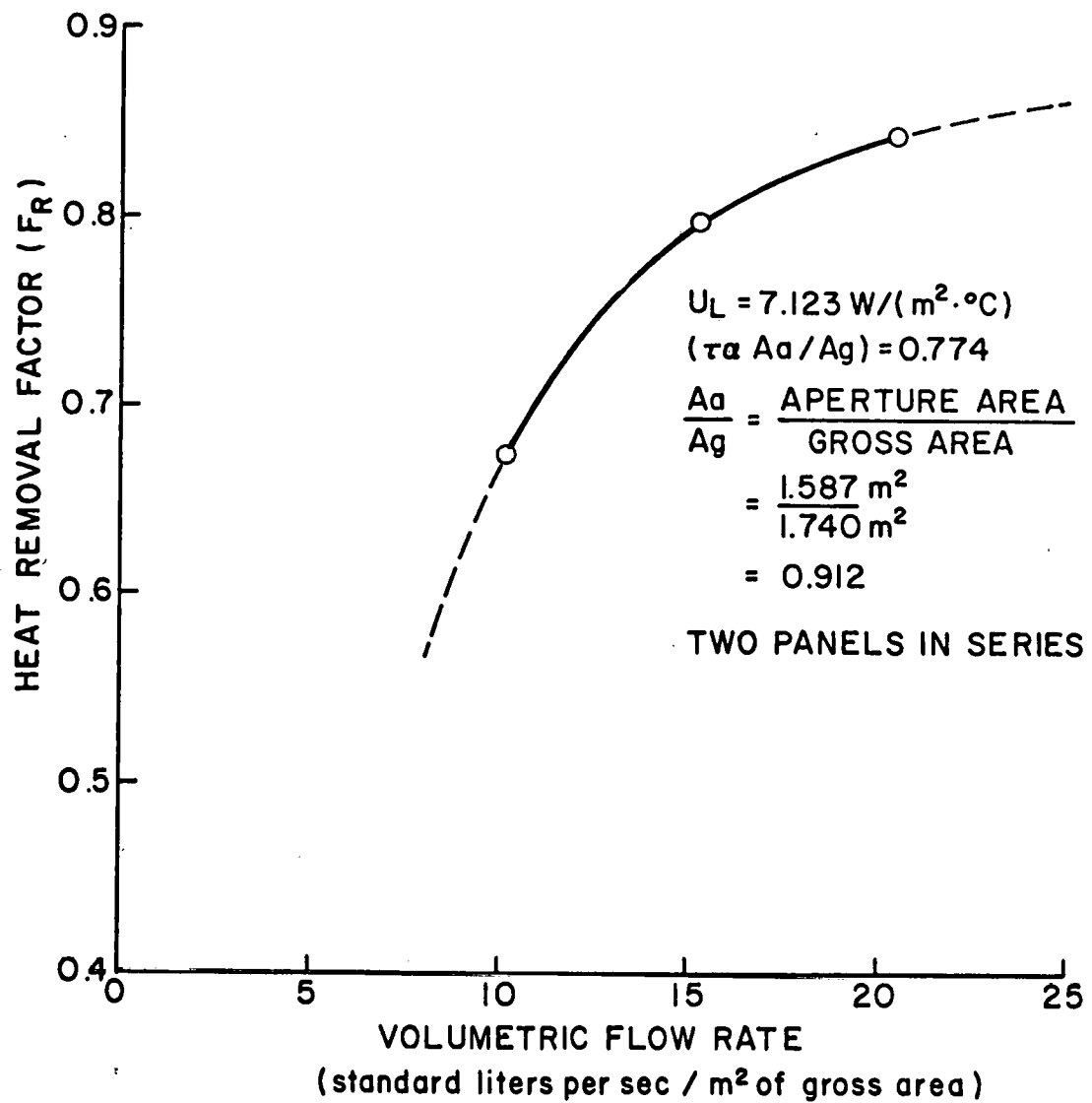


Figure 8-1. Solaron Series 3000 Collector Characteristics

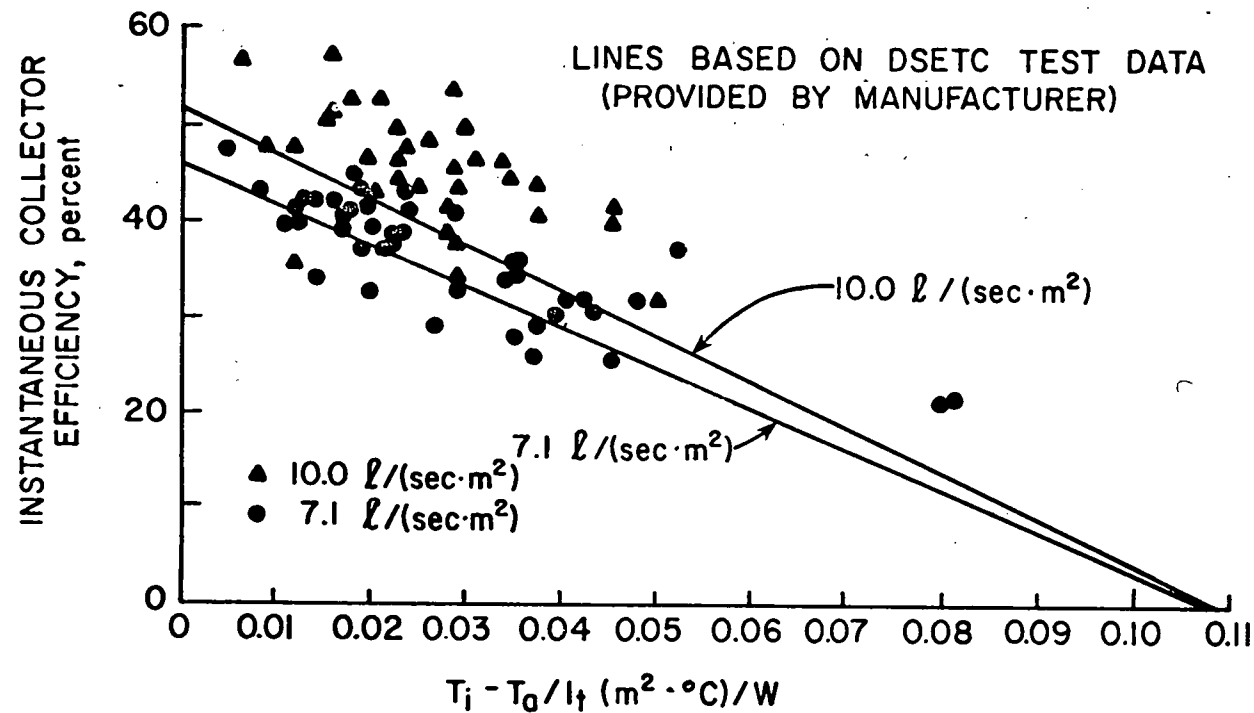


Figure 8-2. Measured Instantaneous Collector Efficiencies Near Solar Noon

When the local air flow rates of $13.1 \text{ l}/(\text{sec}\cdot\text{m}^2)$ and $9.6 \text{ l}/(\text{sec}\cdot\text{m}^2)$ are used to determine values of F_R from Figure 8-1, assuming the abscissa to be local flow rates, a "better" correspondence between data points and the line results as shown in Figure 8-3. The measured performance of the collector array is about 10 percent higher in efficiency than predicted by the manufacturer's curves.

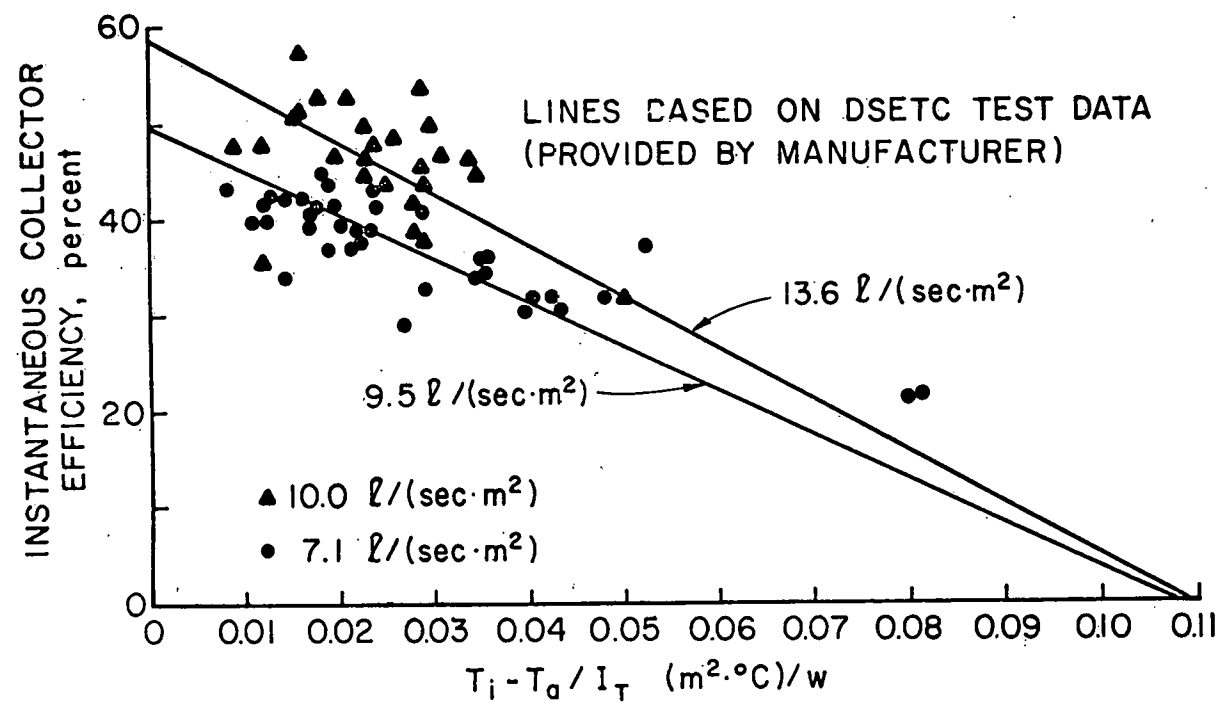


Figure 8-3. Measured Instantaneous Collector Efficiencies Near Solar Noon

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9. STORAGE PERFORMANCE

9.1 HEATING SEASON

Temperature profiles along the vertical centerline of the pebble bed are shown in Figures 9-1 and 9-2 for typical winter days when all the thermal energy stored during the day is used to heat the rooms during the night. For the December day shown in Figure 9-1 the air flow rate to charge storage was $47.20 \text{ m}^3/\text{min}$ and superficial velocity through storage was 7.69 m/min with an overall pressure head drop of 4.6 mm of water. The flow rate while discharging was less, at $32.85 \text{ m}^3/\text{min}$, superficial velocity was 5.35 m/min and pressure head drop was 2.0 mm of water. The maximum temperature of the air during storage charge was about 60°C with peak rock temperature of about 57°C . During discharge the maximum temperature of the air delivered to the rooms was about 44°C .

After reducing the air flow rate through the collector in January the air flow rate through storage during the charging cycle was about $34.5 \text{ m}^3/\text{min}$, superficial velocity was 5.62 m/min and pressure head drop was 2.5 mm water. Flow rate during discharge was the same as in December, with higher max mean storage temperature and delivery temperature to the rooms by about 10°C as shown in Figure 9-2.

Calculation of storage efficiency for each month and for the season evidences errors in either or both inflow and outflow energy rates. More energy is shown to flow out of storage than to flow into storage by 6 percent for the season. It is likely that both the inflow and outflow rates are in error, with the inflow rate being too small and outflow rates being too large. As shown in the tables

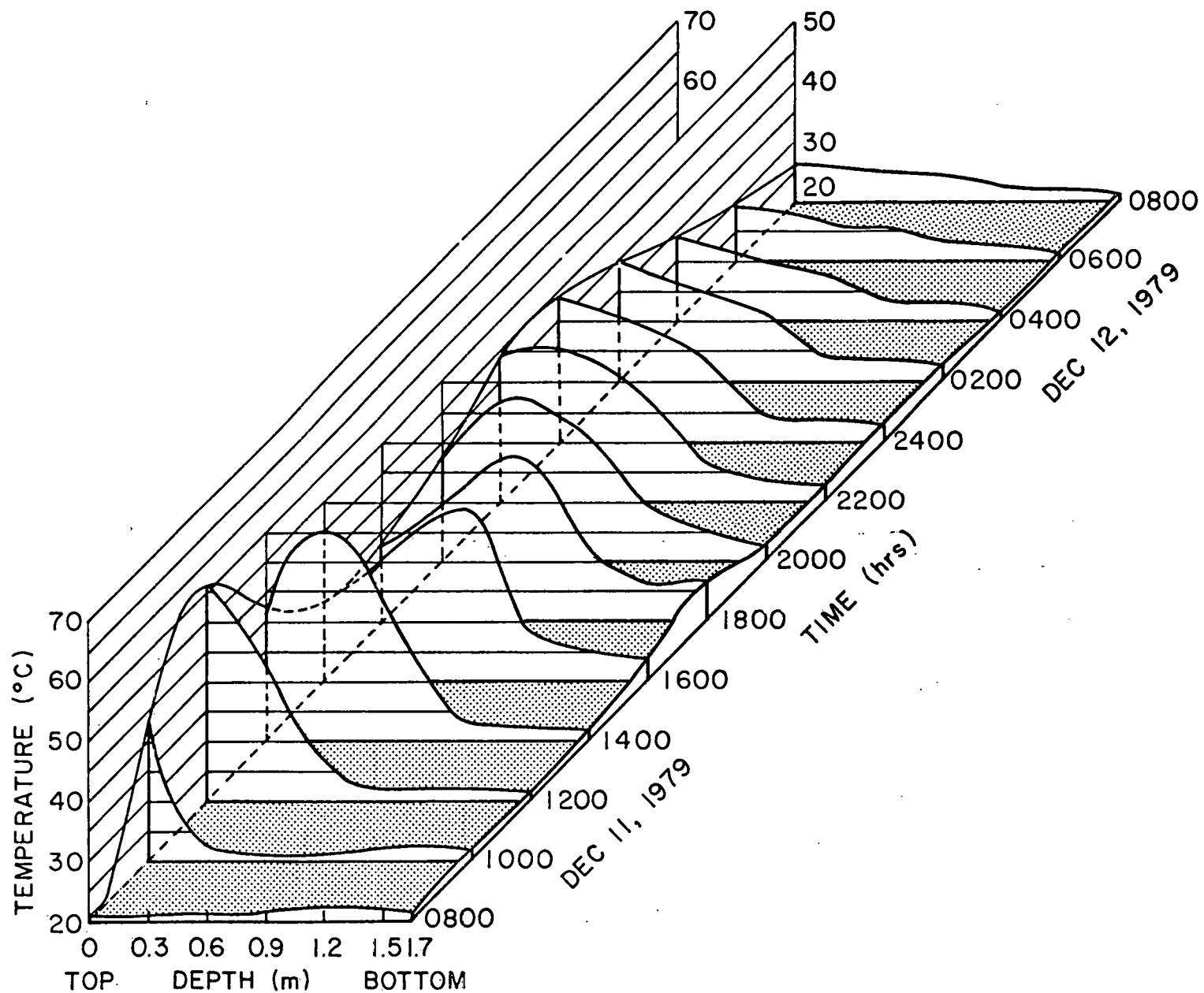


Figure 9-1. Temperature Profiles in the Pebble Bed During Charge/Discharge Cycle
Air Flow Rate $13.6 \text{ L}/(\text{sec} \cdot \text{m}^2)$

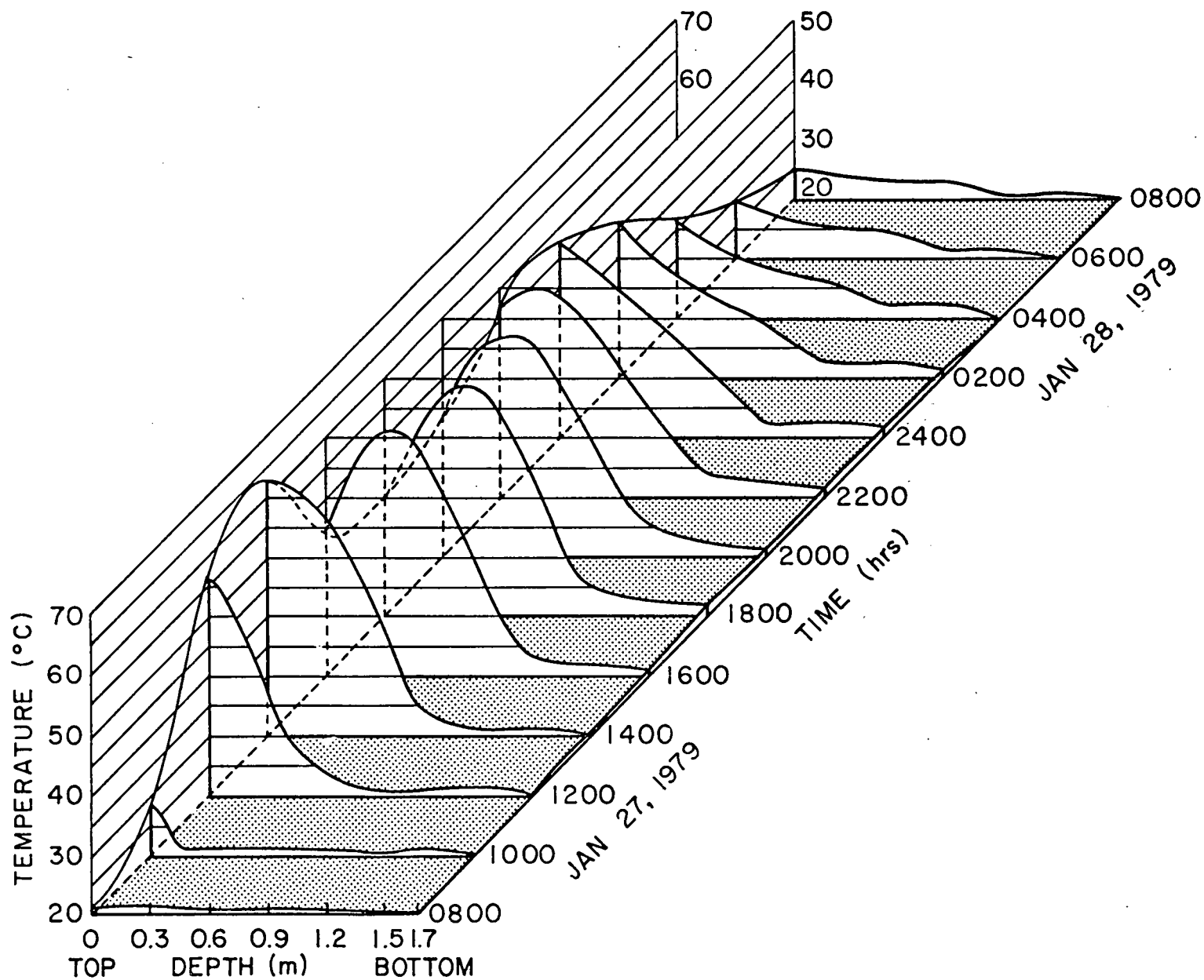


Figure 9-2. Temperature Profiles in the Pebble Bed During Charge/Discharge Cycle Air Flow Rate $9.5 \text{ l}/(\text{sec} \cdot \text{m}^2)$

of data in Appendix A the resulting changes of energy in storage for several months are cumulatively negative. Although corrections to data can be made artificially through monthly energy balances, such corrections were not made and the inflows and outflows shown are based on measured air flow rates into and out from storage. Errors of ± 3 percent are likely in the air flow rate measurements.

9.2 COOLING SEASON

After the cooling season was over (on September 9, 1979) experiments were conducted to compare air flow rates, measured by various air monitors in the system, with the air monitors in place. Various branches in the ducts and dampers were blocked and taped to make comparison air flow measurements. Of particular interest were the air monitors which measured air flow rates into and out from storage. Based upon these comparison measurements, differences of 5 percent from calibrated air monitor coefficients were found. The energy flow rates into and out of storage during the cooling season (shown in the tables in Appendix B) have been adjusted in accordance with the comparison measurements and better storage balance is the result. The storage efficiency (discharge divided by the charge) is 0.95.

Temperature profiles along the storage centerline during a typical cold charge and discharge cycle is shown in Figure 9-3, with cold charge beginning at 0000 hours and ending at 0800 hours. Discharge cycle begins at 0800 hours and ends at 1600 hours on the day shown. The particular day was chosen to show the changes in temperature of the rock bed during cold charge, during discharge and while no

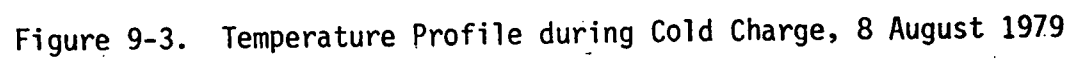


Figure 9-3. Temperature Profile during Cold Charge, 8 August 1979

air flows through the rock bed. It will be noted that the top of the rock bed is warmer than the rocks a few pebble layers beneath the surface. Heat "losses" through ducts and the storage container must warm the air in the upper plenum and radiative exchange with the rocks evidently warms the top layer of rocks.

The distribution of air flow through the pebble bed is non-uniform as evidenced by horizontal temperature profiles in Figure 9-4 which are based on thermocouples located across diagonals in the pebble bed at the top, 0.76 m and 1.4 m depths. Evidently air flow through the center of the pebble bed is less than along the "sides". During the charging cycle the centerline temperature remains high at about midnight, 1.4 m depth, indicating non-uniform porosity of the bed. During the discharge cycle the temperature at 1.4 m depth is fairly uniform but at 0.76 m depth the rocks remain colder at the centerline by 4°C. The pebbles at the top are uniform in temperature during the charging cycle but is non-uniform by as much as 6°C during discharge.

At the end of the cooling season, the end of the pebble bed container was opened along the top plenum as shown in Figure 9-5 to examine the pebble bed. As shown in Figure 9-6 a visible amount of fine material was evident over the east end of the pebble bed (which is the opposite end from the duct connection to the top plenum). As the pebble bed was explored further, layers of fine material were discovered throughout the pebble bed as shown on Figures 9-7. The quantity of fine material in the pebble bed is illustrated in Figure 9-8. The accumulation is a result of raking off the layer pebbles which leaves the fines behind. The pebbles were completely removed and the pebble bed was reconstructed for the 1979-1980 heating season.

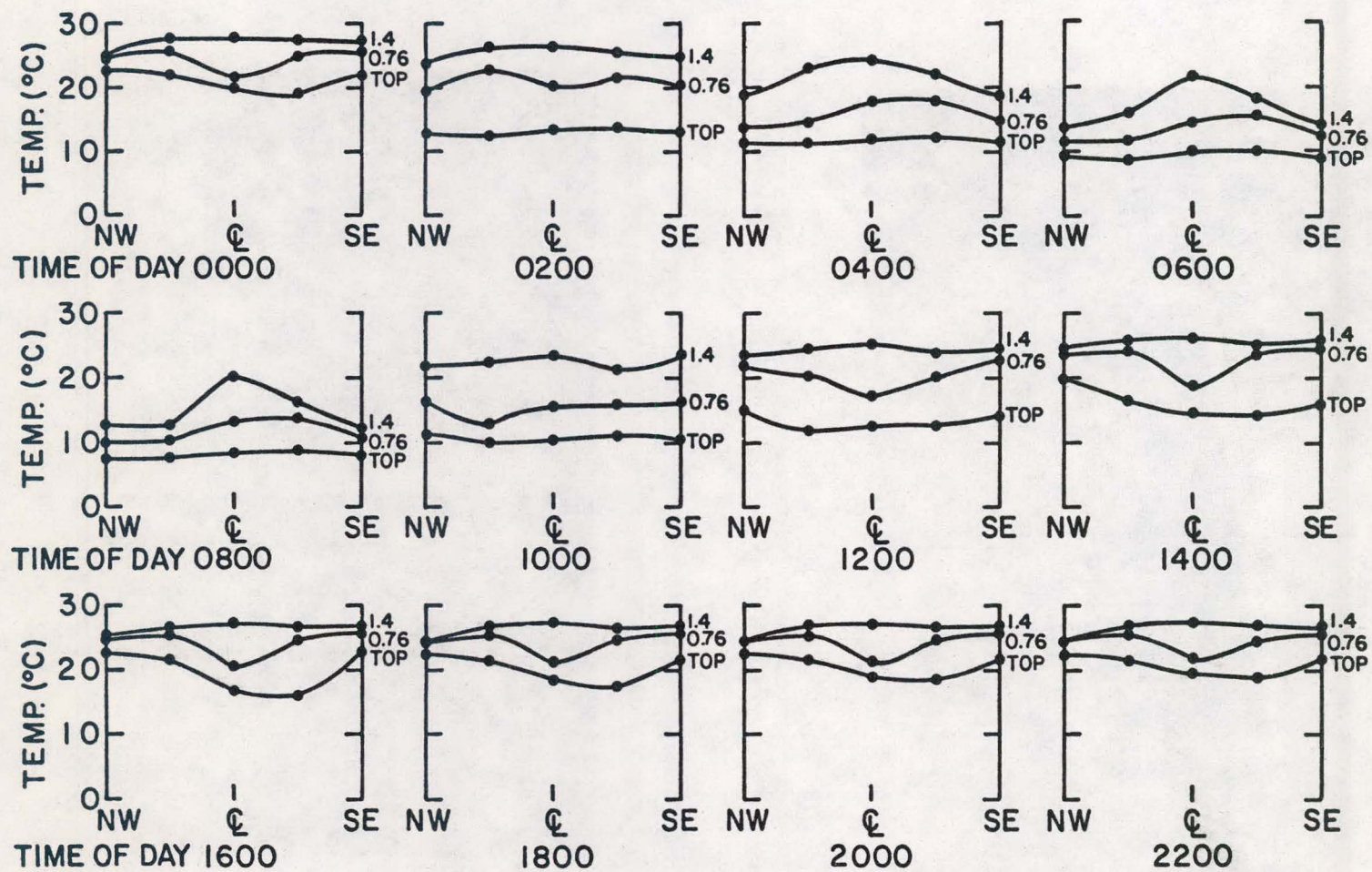


Figure 9-4. Horizontal Temperature Profiles in the Pebble Bed, 8 August 1979

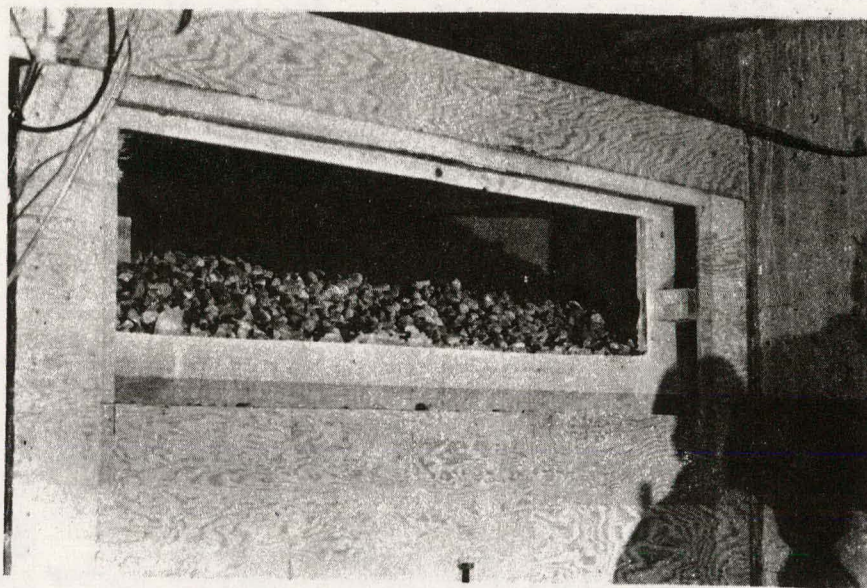


Figure 9-5. Opening of the East End of the Pebble Bed

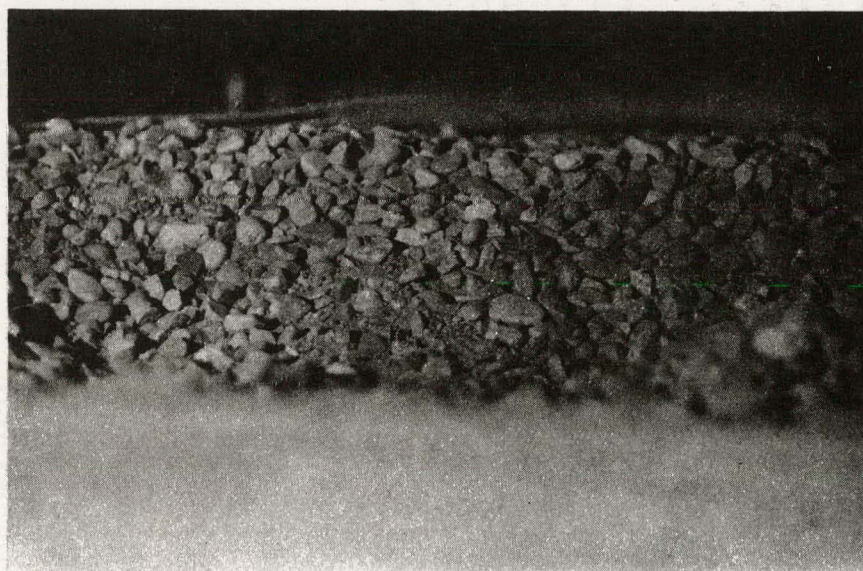


Figure 9-6. Fine Material is Evident along the Top Layer of Pebbles



Figure 9-7. Fine Material within the Pebble Bed



Figure 9-8. Accumulation of Fines (During removal of the rocks the fine material accumulated as the larger material was raked off leaving the fines)

9.3 CONDENSATION IN THE PEBBLE BED

When the pebble bed is cooled to temperatures below dew point, condensation will take place. During cold charge, condensation does not occur because there is dehumidification of the air stream at the indoor coil and the air stream is colder than the pebbles. However, during the discharge cycle warm room air is circulated through a cold pebble bed and condensation can take place, at least initially and until the pebbles are warmer than dew point temperatures.

The occurrence of condensation is illustrated on a sketch of a psychrometric chart in Figure 9-9. Point 1 is the room air state.

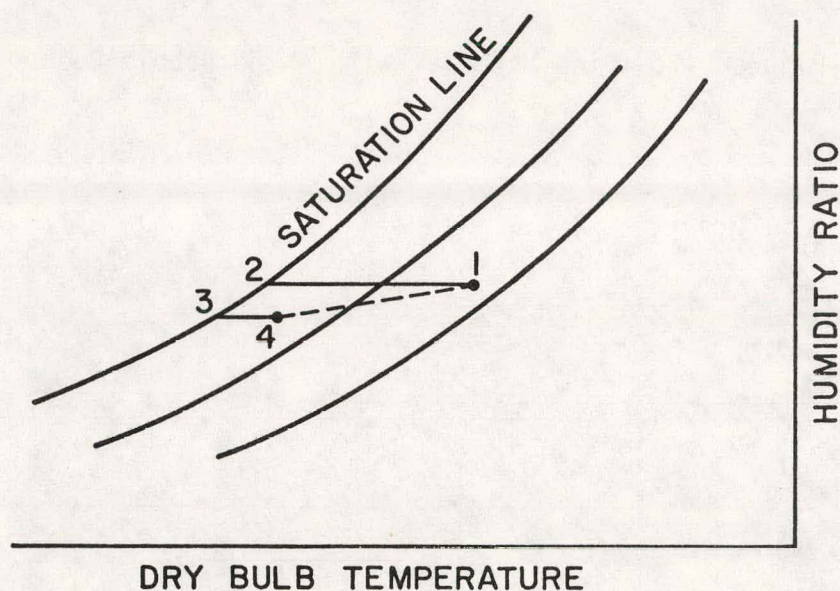


Figure 9-9. Cooling of Room Air in the Pebble Bed

As room air flows through the pebble bed it is sensibly cooled until state 2 is reached. In cooling from state 2 to state 3 moisture is condensed, near the top of the pebble bed, and as the air flows from the pebble bed through the ducts to the rooms heat is absorbed and the temperature increases from state 3 to state 4. There is

further warming of the air in the rooms from state 4 to state 1. When the pebble bed becomes warmer than dew point throughout, condensation can no longer take place but since there is moisture on the surface of the pebbles, the air is humidified and the humidity ratio of the room air increases.

Time histories of the inlet and outlet dry bulb temperatures of the air stream and the dew points are shown in Figures 9-10 and 9-11. The dew point, which is a function of the moisture content in the air, is changed little as the air passes through the pebble bed (see Figure 9-11). The relationship between relative humidity and dew point at 25°C and 84.29 kPa atmospheric pressure is shown in Figure 9-12.

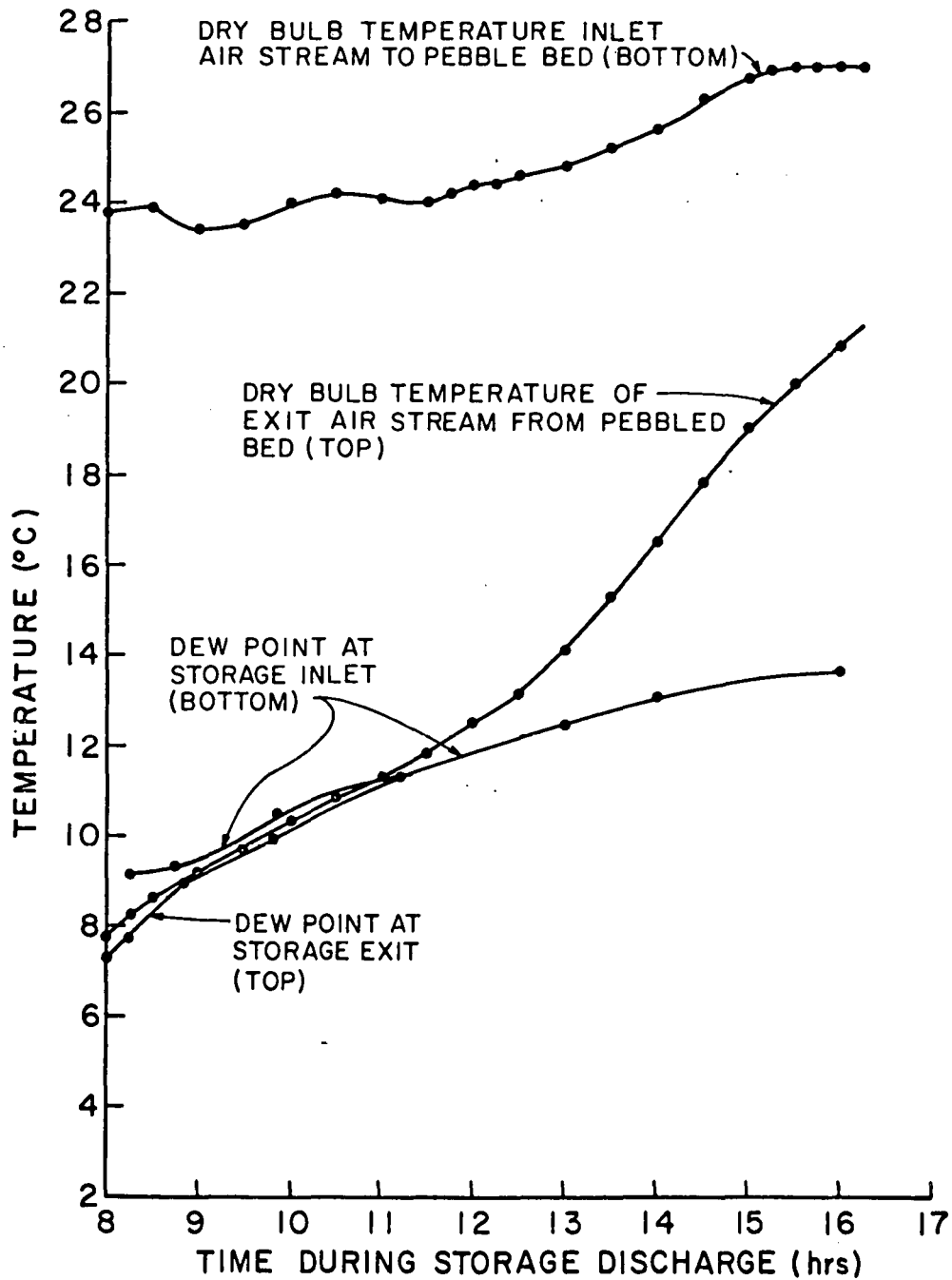


Figure 9-10. Time Heating of Air Stream Temperatures, 8 August 1979

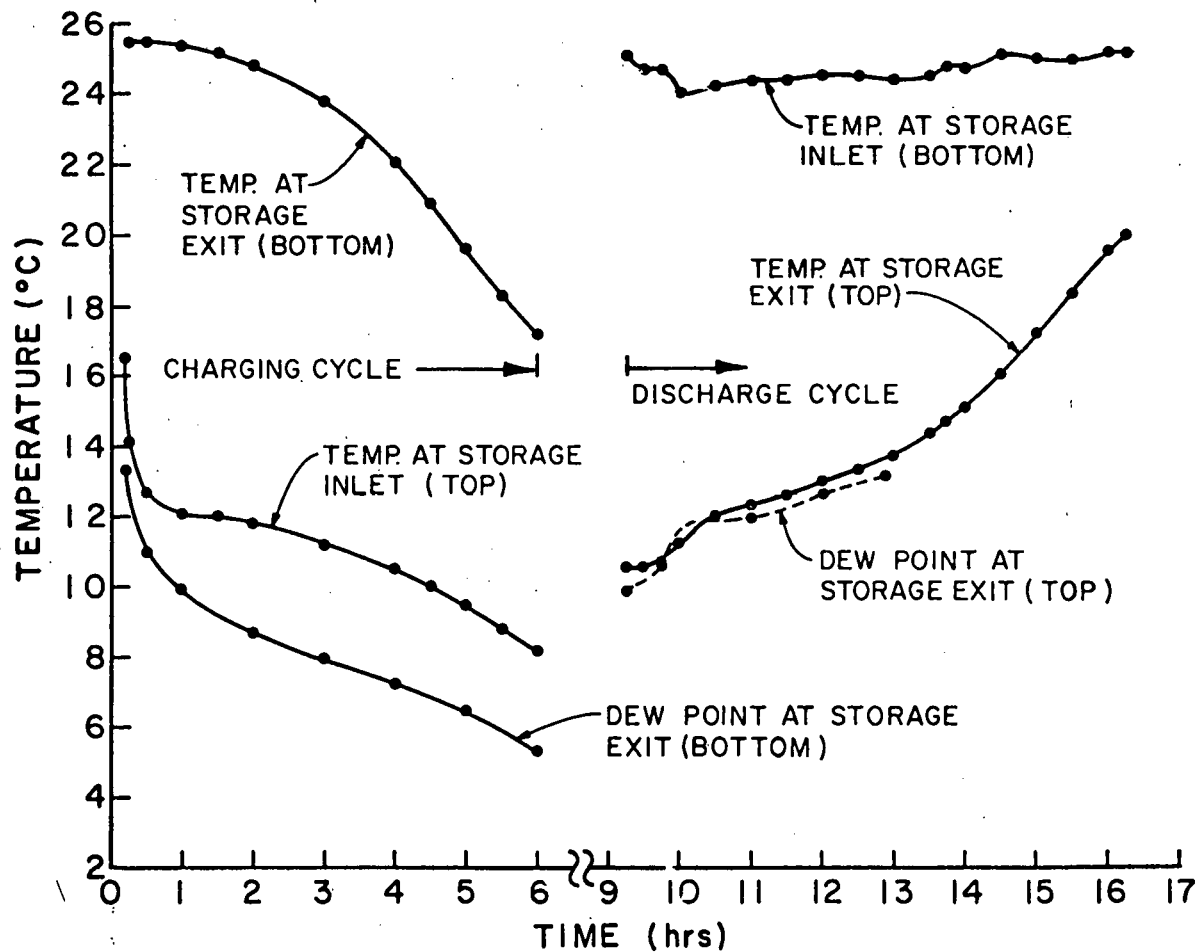


Figure 9-11. Time Heating of Air Stream Temperatures, 9 August 1979

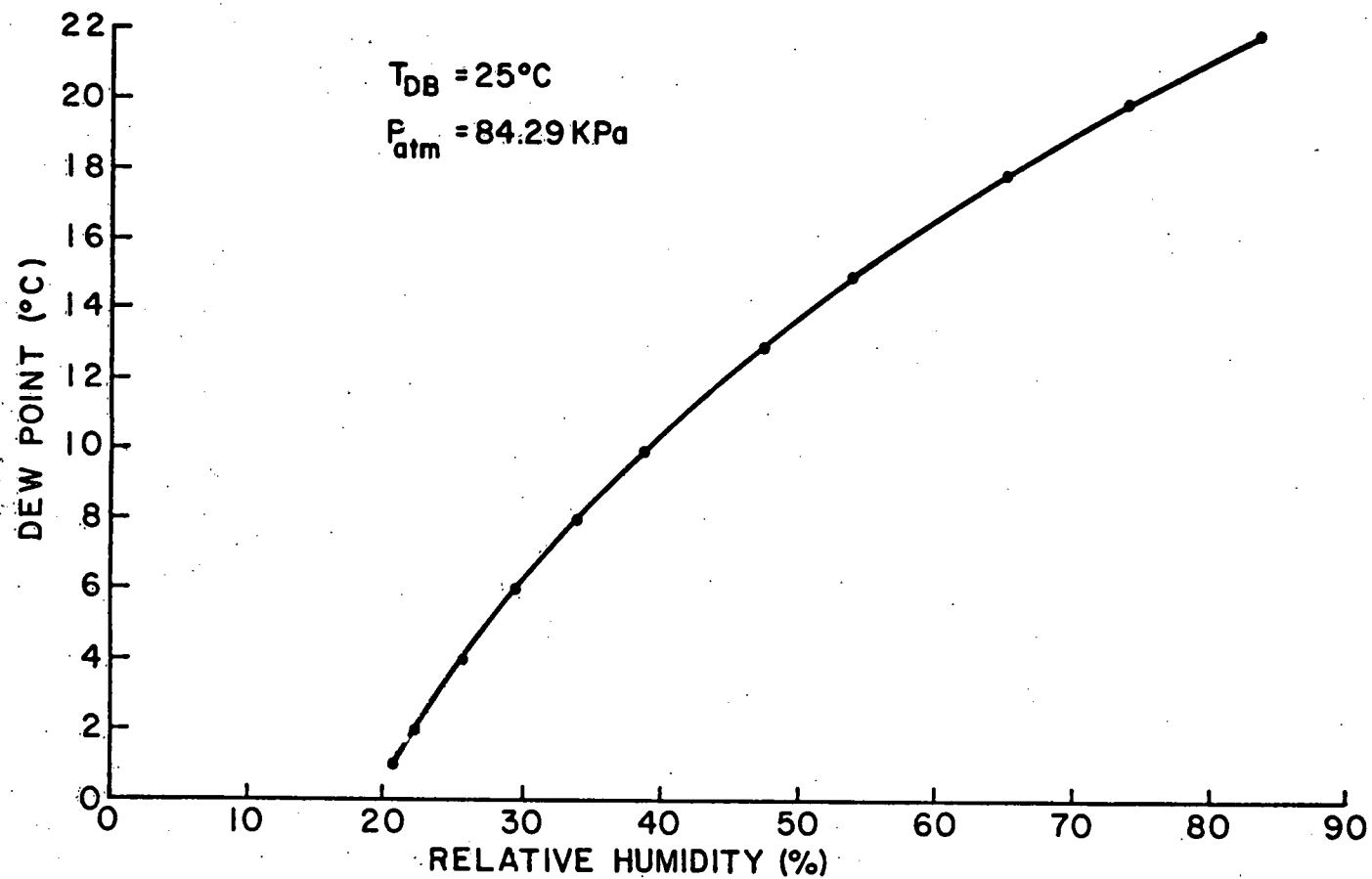


Figure 9-12. Relationship between Dew Point and Relative Humidity

10. HEAT PUMP PERFORMANCE

10.1 HEATING SEASON

The Carrier Weathermaster III, 3-ton, air-to-air heat pump with back-up resistance heating was the auxiliary heater in Solar House II. As indicated in Table 7-4 and Figure 7-5 the auxiliary heating COP was only 1.18 for the season while providing 33 percent of the space heating requirements. The heat pump operating COP averaged 1.67 and is low because in the auxiliary heating mode the heat pump is required after solar heat has been depleted from storage and generally the outdoor air temperature is low. From experimental data, the change in COP of the heat pump as a function of ambient air temperature is shown in Figure 10-1. The COP varies from slightly greater than 1 at -22°C to 2.5 at 3°C . With higher ambient temperatures the COP will be larger, probably achieving a magnitude of about 3 at 10°C , but with a solar system the heat pump would rarely operate at such favorable conditions because there will generally be sufficient solar heat storage to meet the light heating load requirements.

10.2 COOLING SEASON

When the heat pump is used to cold charge storage in a closed circulation system; the circulating air temperature through the evaporator coil is lower than normal room temperature by 10°C to 15°C . As a consequence the COP reduces. The variations in COP for the heat pump in the cooling mode, as a function of air temperatures at both the evaporator and condensor are shown in

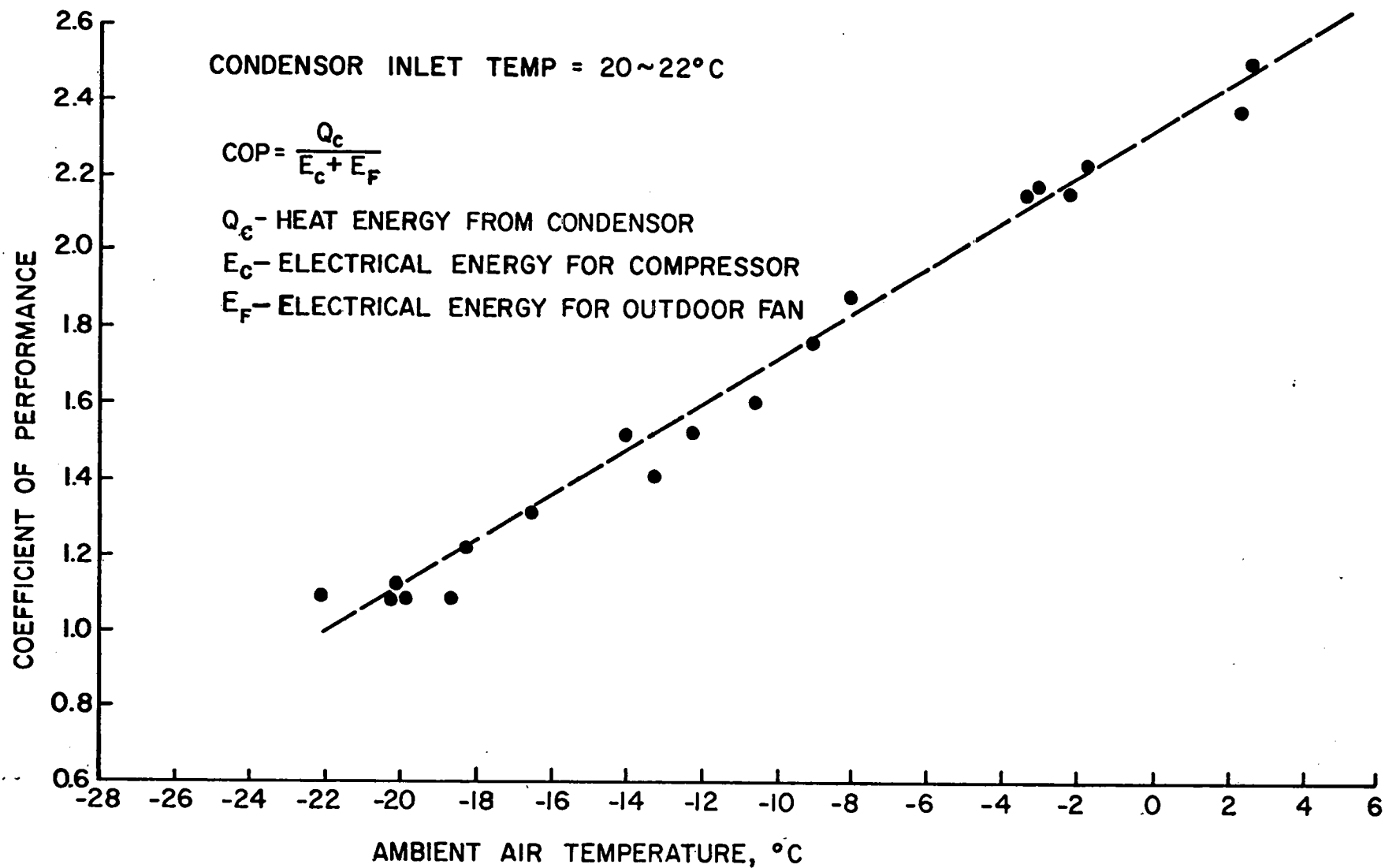


Figure 10-1. COP of the Carrier Heat Pump in Solar House II

Figure 10-2. Time histories of COP and air temperatures during a cold charge cycle on 4 August 1979 are shown in Figure 10-3. The COP varies from 2.45 at the start to about 1.9 at the end of the charge cycle as evaporator temperature drops and ambient air temperature rises.

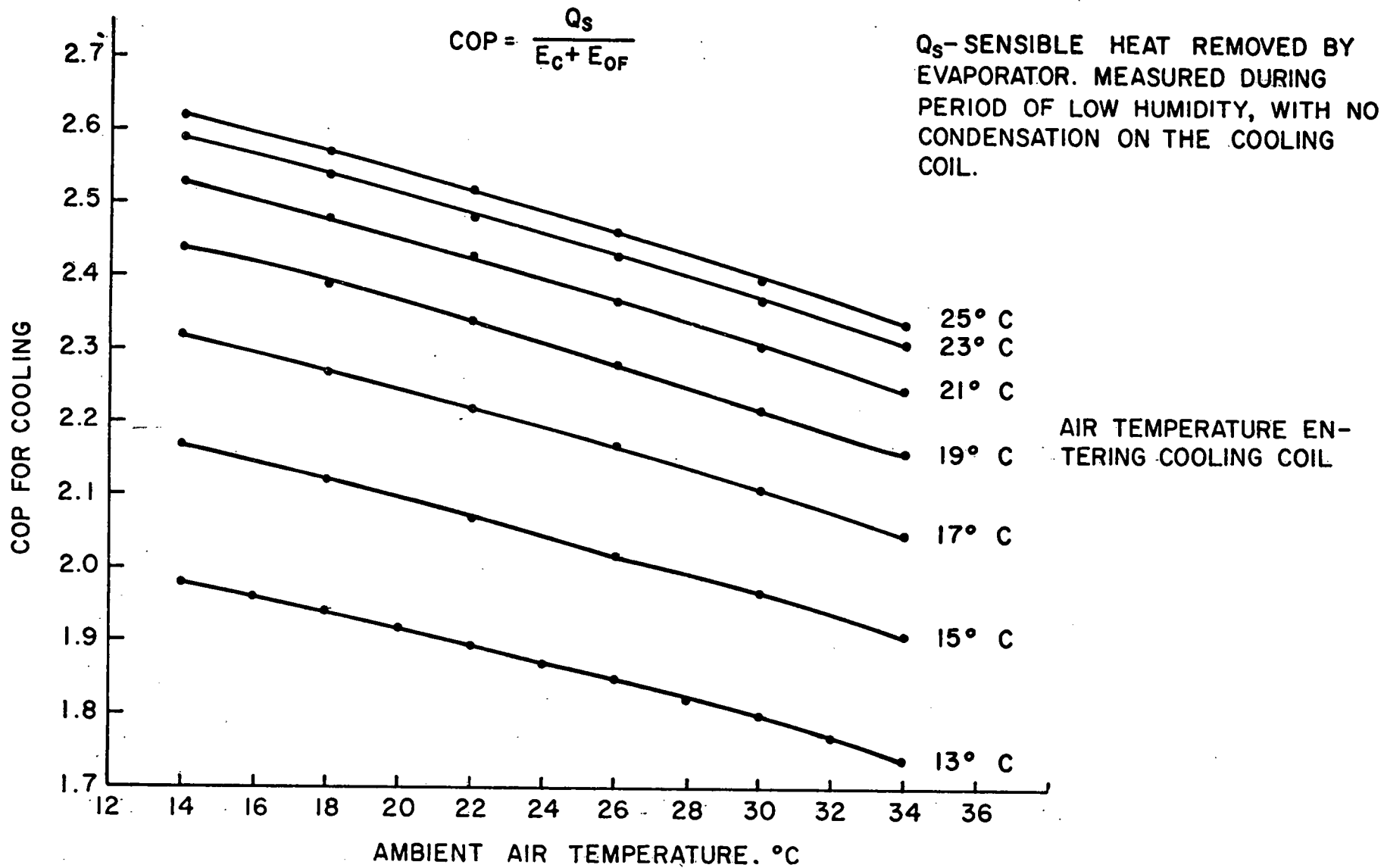


Figure 10-2. COP of the Carrier Heat Pump in Solar House II as a Function of Air Temperatures at Evaporator and Condensor

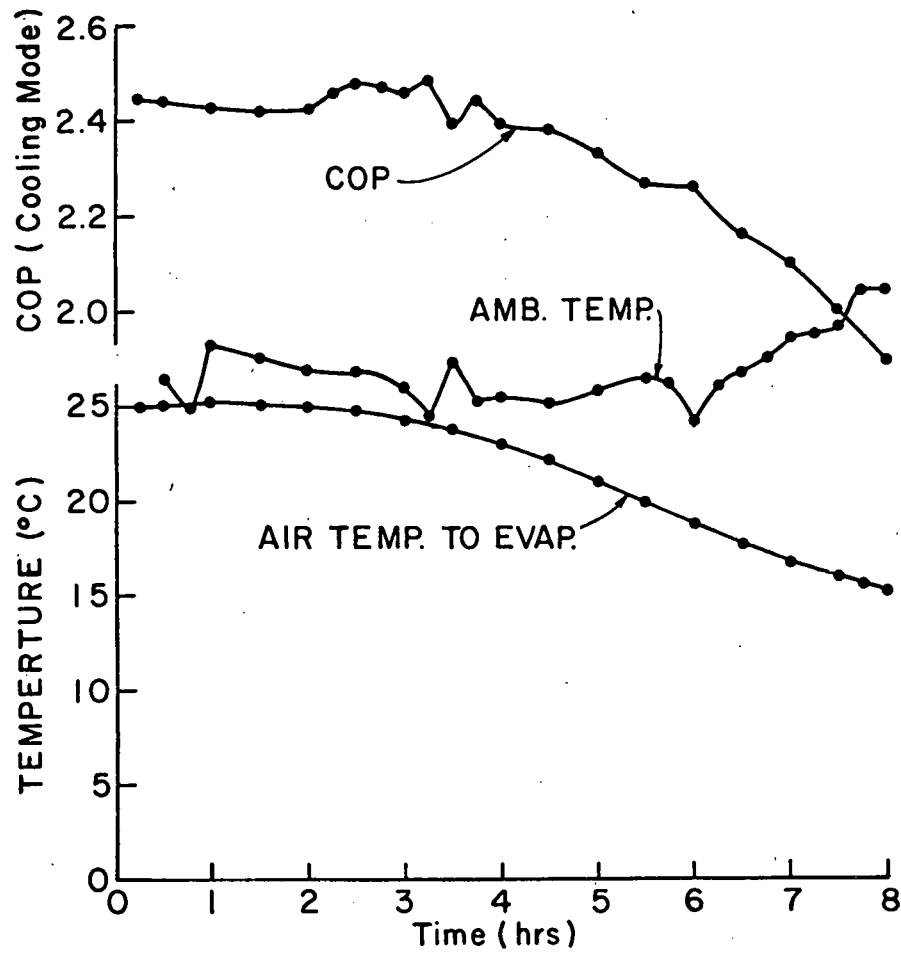


Figure 10-3. Time Histories of Heat Pump COP and Air Temperatures, 4 August 1979

11. DISCUSSION AND RECOMMENDATIONS

11.1 COLLECTOR EFFICIENCIES

Monthly average daily collection efficiencies for the Solaron Series 3000 collectors were only slightly better than efficiencies of the site-built double-glazed collectors used the preceding year but it is shown that the "steady-state" collector efficiencies are greater than predicted by the manufacturer. The site-built collectors were double glazed and had a non-selective absorber coating while the new collectors are single glazed and the absorber is coated with a selective coating. In terms of installation the new collectors require less time for mounting than the site-built collectors and internal manifolding within the collector results in less ductwork to interconnect collectors and to connect the collectors to the balance of the system.

11.2 AIR LEAKAGE INTO COLLECTOR ARRAYS

Air leaks into the collector array were at different rates for the east and west halves, with leakage into the east being greater probably because of different procedures used in the assembly process. Air flow rates into the collectors, out of the collectors, and energy delivered from the two collector sections are listed in Table 11-1.

With a lower air inflow rate, but higher outflow rate than the west array, the east half collected 10 percent greater thermal energy for 1 Dec-6 January period. Leakage into the east side was 15 percent of inflow and leakage into the west side was 7 percent.

Table 11-1. Air and Energy Flow Rates for the Collector Array

PERIOD	AIR FLOW RATES (m ² /min)				HEAT FLOW RATE (MJ/MO)	
	EAST ARRAY		WEST ARRAY		EAST ARRAY	WEST ARRAY
	Inflow	Outflow	Inflow	Outflow		
1 Dec-6 Jan	21.02	24.11	21.17	22.68	6874.6	6246.0
7 Jan-30 Jan	15.30	16.14	16.17	17.12	3937.9	3941.0
1 Feb-27 Feb	15.28	15.97	16.64	16.90	4893.7	4885.2
1 Mar-31 Mar	15.31	16.09	16.70	16.97	5041.2	5029.4
1 Apr-26 Apr	15.17	15.89	16.55	16.78	4369.1	4327.2
27 April-11 May	18.84	21.04	3.22	6.51	2315.0	1648.5

During the succeeding period energy delivered from the collectors were virtually identical even though the east half had 6 percent less volumetric air flow rate than the leaky west side. Similar results are noted for February through 26 April. In the latter part of April and data through 11 May, the air flow rates were purposely unbalanced.

The experimental data indicate that air leaks into the collector array increases energy collection. With air leakage by as much as 15 percent over the inflow rate, there was 10 percent greater energy collection than the array with a leakage rate of 7 percent. Leakages of 5 to 15 percent in the Solaron Series 3000 collector array may be expected as a consequence of normal installation practices. The larger air leakage rate into the collector, in fact increases the quantity of energy delivered from the collectors compared to a smaller air leakage rate. Although it is not our recommendation to purposely create air leaks in the system, neither is it necessary to be so overly concerned with air leaks as to unduly increase the cost for installation.

11.3 AIR LEAKAGE FROM STORAGE

Air leakages in the storage container, on the other hand, are detrimental to system performance because warm air leaks out into the rooms when heating is not required (i.e. in the heat storage mode). The $2.5 \text{ m}^3/\text{min}$ (approximately 7 percent) air leakage out of storage slightly reduced the overall available heat in storage. Assuming an average temperature difference of 20° between leakage air temperature and room air temperature and seasonal average of 4 hours collection per day, 12.5 MJ/day or about 5 percent less energy was stored because of the air leakage. Air leaks from storage boxes can be controlled by

good construction. In the case of the Solar House II system, the storage container is constructed on the basement slab which lies over a foundation of bentonite clay, and over the past 5 years the clay has expanded and raised the floor slab by 6 to 8 cm, raising the storage box with it, and a crack in the container box resulted from the gradual movement. The storage box has been reconstructed prior to the 1979-80 heating season.

11.4 AIR LEAKAGES ACROSS DAMPERS

The effect of air leakages across dampers on system performance depends upon the ultimate egress of the air and whether warm or cold air is being discharged. If cold air is leaked into the circulating system, there is a positive change in enthalpy of the cold air and degradation of temperature, but thermal energy delivery is not reduced. (In some circumstances energy delivery is increased as in the collectors). When warm air leaks out of a circulating system performance may be degraded if the warm air outlet is outside the building envelope. This can happen if warm air leaks to the collectors during heat delivery from storage. However if the leakage is within the building envelope the thermal energy is not lost and the net result is greater use of electrical energy for the blower to recirculate the air. With the arrangement of the dampers in the Solar House II system little air was egressed outside the building envelope because of the location of motorized dampers MD1 and MD5. Although system cost increases with the addition of each motorized damper, it is recommended that such dampers be used in ducts which extend outside the heated envelope.

11.5 HEAT PUMP AS AN AUXILIARY UNIT

The overall COP of the heat pump for the season was low with considerable heating provided from electrical resistance strips so that the seasonal auxiliary heating COP was 1.18. The principal reason for the low heat pump COP is attributable to unfavorable operating conditions. Only after solar heat in storage has been nearly exhausted is the heat pump called to provide heating and generally the ambient air temperature is very low so that low performance is the result.

In view of the low auxiliary heating COP, an off-peak electric heat storage unit combined with the solar system could result in lower auxiliary heating cost (where off-peak electrical energy rates with a cost differential of more than about 1.5 is available). Experimental data is needed to verify this observation however, because with a parallel auxiliary off-peak heating unit the contribution of solar heating could be reduced and greater amounts of thermal energy would be provided from electricity.

11.6 ECONOMIC ASSESSMENT OF COOL STORAGE WITH THE HEAT PUMP

The heat pump in the heating system is used as an air conditioner during the cooling season and operated during the off-peak hours to cool down the pebble bed. With a seasonal COP of 2.38 for the heat pump during cold charge, compared to 2.49 in the direct cooling mode, there is a slight penalty (4 percent) for operation during the cool night hours. Because of some losses in storage and ducts during circulation of cool air, plus electrical energy to discharge storage, the overall cooling COP using the cold charged pebble bed is

about 1.37 for the season. Assuming all of the cooling to be provided by the pebble bed and compared to direct cooling with the heat pump, the cost for cooling would be the same if the ratio of cost for electrical energy between peak hours and off-peak hours is 1.86. In sampling a few utility companies in the eastern states that have adopted off-peak rates, there is a minimum of 8 hours of off-peak rates available with a cost ratio typically of 3. Although there are relatively few utility companies that have adopted time-of-day pricing, in regions served by such companies off-peak operation of the heat pump and cool storage in the pebble bed is economically viable for the homeowner (with a solar heating system) and would aid the utility company to levelize the electrical load.

If the solar/auxiliary heating system is configured similar to the Solar House II system no additional capital expenditure is necessary to take advantage of the off-peak rates for cooling.

After the cooling season, when the pebble bed storage was reconstructed, 9 samples of the pebbles were taken at all levels across the storage unit and the samples were sent to the Microbiology laboratory at Colorado State University for detailed analysis. The pebble bed had been used with the nocturnal evaporative cooler during the summers of 1976 and 1977 (Ref. 6) and as a cold charge reservoir for the heat pump in 1978 and 1979. The analysis of all samples indicated that the pebbles were devoid of any biological growth and unusually free of bacteriological species. The bacteriological count on the pebbles were less than that prevalent on normally exposed surfaces in the house.

12. CONCLUSIONS

A commercial, state-of-the-art, air-heating solar system was thoroughly monitored in the CSU Solar House II. The commercial system consisted of Solaron Series 3000 collectors and Solaron air handler, pebble bed storage that had been in the building for the previous 4 years, Carrier Weathermaster III air-to-air, split system, 3-ton heat pump as an auxiliary heater, and an "on-off" controller that was specially assembled to facilitate monitoring and computer data analysis. As a result of the performance evaluation it is concluded that:

1. The specific solar system tested has an overall system efficiency of 29 percent (solar energy utilized divided by the total insolation on the gross area of the collector).
2. Collector efficiency is greater for an array with 15 percent air leakage than an array with 5 percent air leakage into the array. Thermal energy collected is 10 percent greater for the array with 15 percent leakage, based on a unit outflow air rate of $13.1 \text{ l}/(\text{sec} \cdot \text{m}^2)$. The amount of additional energy collected reduces as air leakage rate reduces.
3. Overall COP of the solar system was 13.8 for useful solar heat delivered to the space and used to heat domestic water. The COP for solar energy collection was 26.4 and 31.2 for solar heat distribution to the rooms.

4. An air-to-air heat pump used as an auxiliary heater for a solar system that supplies a substantial fraction of the heating load will have a low seasonal COP because operation is under unfavorable conditions for the heat pump. Approximately equal amounts of auxiliary heating was provided by the heat pump and electrical resistance heating systems.
5. The performance of the solar system, in terms of the seasonal fraction of total load, can be predicted using the f-chart procedure developed by the University of Wisconsin. The prediction was based on measured solar insolation, measured heating load and measured steady-state collector efficiencies. The monthly predictions of solar fractions are lower than the measured fractions for the cold months of December, January, and February, and higher for the warmer months of March and April.
6. Use of the heat pump in the off-peak hours to cold charge the pebble bed and cooling the rooms from storage during the day is a viable mode of operation where off-peak electrical energy rates are available and the rates of peak rates to off-peak rates is greater than about 2.
7. No unusual biological or bacteriological growth was found on the pebbles in the pebble bed as a consequence of operating the unit in a cool storage mode where condensation occurred at least in parts of the pebble bed.

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14. ACKNOWLEDGEMENTS

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APPENDIX A

Summary tables of daily data and energy flow for the 1978-79 heating season are assembled in Appendix A. The daily totals are for a 24-hour period from 8 a.m. of the day to 8 a.m. the following day which represents a solar heating day, i.e., a solar collection and storage period followed by discharge of storage until the beginning of a normal collection period of the following day. The daily solar insolation, however, includes the solar insolation measured during the particular day from sunrise to sunset.

There are 4 tables for each month. The tables include the following data:

First Table of Monthly Set - Total energy required for space and water heating, separated into solar, and auxiliary contributions. Daily solar fractions of the loads are calculated.

Second Table - Energy flow balances from collectors to storage and storage balances. The useful solar energy delivered to the load, including heat losses during transport, is the sum of thermal energies delivered from collectors to the rooms, to DHW preheating, loss from ducts, delivery from storage, and loss of heat from storage to the rooms.

Third Table - Auxiliary heat pump energy and electrical energies supplied to resistance heaters and mechanical devices in the system are listed. Coefficients of performance as defined below are calculated:

COP for solar collection - Thermal energy measured at the collector outlet divided by electrical energy to operate the collection blower.

COP of solar distribution - Thermal energy delivered from storage divided by electrical energy required for blower operation.

COP for overall solar utilization - Solar thermal energy utilized to meet the load divided by the electrical energy for collection and distribution.

COP for heat pump - Thermal energy delivered by the indoor coil divided by the electrical energy utilized for the compressor and outdoor fan.

COP for heat pump and distribution - Thermal energy delivered by the indoor coil divided by the electrical energy utilized for the compressor, outdoor fan, and the blower.

COP for auxiliary heating - Thermal energy provided by the heat pump and resistance heating strips divided by the electrical energy utilized by the heat pump, outdoor fan, indoor blower and resistance strips.

COP for overall heating - Thermal energy delivered to the load divided by the electrical energy utilized by the system to meet the load.

Base house load - is the load of lights and appliances in the building, not including the electrical load for the solar heating system.

Fourth Table - Collector performance of the east and west arrays and the total collector array.

Table A1. Space and DHW Heating for the Month of December 1978

Day	ENERGY FOR HEATING AND DHW				ENERGY FOR SPACE HEATING				ENERGY FOR DHW			
	Solar MJ	Aux MJ	Total MJ	Solar Fraction	Solar MJ	Aux MJ	Total MJ	Solar Fraction	Solar MJ	Aux MJ	Total MJ	Solar Fraction
1	481.3	9.4	490.7	0.98	461.5	6.7	468.2	0.99	19.8	2.7	22.5	0.88
2	111.5	588.5*	700.0*	0.81	111.5	588.5*	700.0*	0.16	0.0	0.0	0.0	----
3	424.6	11.6	436.2	0.97	407.6	11.6	419.2	0.97	17.0	0.0	17.0	1.00
4	362.5	15.3	377.8	0.96	337.0	15.3	352.3	0.96	25.5	0.0	25.5	1.00
5	158.9	466.6*	625.5*	0.62	158.9	461.1*	620.0*	0.26	0.0	5.5	5.5	0.00
6	-8.6	721.9*	713.3*	----	-8.6	708.6*	700.0*	----	0.0	13.3	13.3	0.00
7	109.2	705.7*	814.9*	0.36	109.2	690.8*	800.0*	0.14	0.0	14.9	14.9	0.00
8	505.3	335.3	840.6	0.60	479.0	325.8	804.8	0.60	26.3	9.5	35.8	0.73
9	473.4	43.5	516.9	0.92	461.3	34.6	495.9	0.93	12.1	8.9	21.0	0.58
10	31.7	610.8	642.5	0.05	31.7	599.1	630.8	0.05	0.0	11.7	11.7	0.00
11	421.7	83.3	505.0	0.84	397.3	72.6	469.9	0.85	24.4	10.7	35.1	0.70
12	445.3	47.3	492.6	0.90	426.1	36.5	462.6	0.92	19.2	10.8	30.0	0.64
13	504.4	20.0	524.4	0.96	482.0	9.5	491.5	0.98	22.4	10.5	32.9	0.68
14	366.2	17.3	383.5	0.95	341.7	6.2	347.9	0.98	24.5	11.1	35.6	0.69
15	600.5	12.8	613.3	0.98	582.9	1.9	584.8	1.00	17.6	10.9	28.5	0.62
16	652.9	26.7	679.6	0.96	626.4	16.8	643.2	0.97	26.5	9.9	36.4	0.73
17	56.2	572.8	629.0	0.09	56.2	562.4	618.6	0.09	0.0	10.4	10.4	0.00
18	138.4	123.2	261.6	0.53	183.4	109.3	292.7	0.56	0.0	13.9	13.9	0.00
19	399.6	18.2	417.8	0.96	367.4	8.1	375.5	0.98	32.2	10.1	42.3	0.76
20	506.0	21.6	527.6	0.96	466.7	3.9	470.6	0.99	39.3	17.7	57.0	0.69
21	467.8	49.0	516.8	0.91	408.9	0.0	408.9	1.00	58.9	49.0*	107.9	0.55
22	498.8	38.3	537.1	0.93	443.6	7.4	451.0	0.98	55.2	30.9	86.1	0.64
23	495.2	85.3	580.5	0.85	461.1	46.9	508.0	0.91	34.1	38.4	72.5	0.47
24	523.6	41.6	565.2	0.93	480.5	10.6	491.1	0.98	43.1	31.0	74.1	0.58
25	44.3	574.4	618.7	0.07	44.3	523.3	567.6	0.08	0.0	51.1	51.1	0.00
26	406.3	268.8	675.1	0.60	375.3	221.5	596.8	0.63	31.0	47.3	78.3	0.40
27	332.9	190.4	523.3	0.64	308.5	145.3	453.8	0.68	24.4	45.1	69.5	0.35
28	535.7	62.7	598.4	0.90	489.4	32.5	521.9	0.94	46.3	30.2	76.5	0.61
29	41.8	778.0	819.8	0.05	41.8	722.7	764.5	0.05	0.0	55.3	55.3	0.00
30	435.9	417.9	853.8	0.51	397.2	370.1	767.3	0.52	38.7	47.8	86.5	0.45
31	436.3	496.2	932.5	0.47	397.5	455.0	852.5	0.47	38.8	41.2	80.0	0.49
Total	10959.16	7454.4	18414.0		10282.3	6804.6	17086.9		677.3	649.8	1327.1	
Mean	353.5	240.5	594.0	0.60	331.7	219.5	551.2	0.60	21.8	21.0	42.8	0.51

*Calculated values

+Stated HW dump

Table A2. Solar Thermal Energy Transport for the Month of December 1978

Day	FROM COLLECTORS						STORAGE PERFORMANCE				
	Coll. Deliv.	To Storage	To Rooms	To DHW	Loss to Rooms	Loss to Outdoors	Charge	Discharge	Loss to Rooms	Loss to Outdoors	Change In Storage
1	333.9	224.2	7.1	19.8	55.3	27.5	224.2	384.6	14.5	14.0	-188.9
2	69.6	0.0	55.8	0.0	0.9	12.9	0.0	56.0	-1.2	2.3	-57.1
3	464.7	231.0	143.6	17.0	33.9	39.2	231.0	230.7	-0.6	4.3	-3.4
4	571.1	403.5	18.8	25.5	73.3	50.0	403.5	232.0	12.9	13.7	144.9
5	0.9	4.0	0.0	0.0	-2.5	-0.6	4.0	156.6	4.8	6.2	-163.6
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-9.0	0.3	1.8	6.9
7	144.0	16.8	93.0	0.0	7.6	26.6	16.8	8.0	0.6	2.0	6.2
8	526.7	262.2	127.9	26.3	4.4	105.9	262.2	306.6	4.4	6.7	-55.5
9	506.9	234.1	181.8	12.1	37.1	41.8	234.1	240.4	2.0	5.7	-14.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.6	5.1	2.1	-33.8
11	479.4	295.4	45.0	24.4	54.6	60.0	295.4	292.1	5.7	7.8	-10.2
12	455.8	320.9	36.2	19.2	43.9	35.6	320.9	339.2	6.8	8.9	-34.0
13	586.3	395.5	28.6	22.4	67.2	72.6	395.5	373.2	12.9	13.0	-3.6
14	610.5	428.8	1.6	24.5	83.1	72.5	428.8	238.8	18.2	17.4	154.4
15	506.5	326.3	0.0	17.6	91.3	71.3	326.3	467.8	23.8	20.2	-185.5
16	551.7	327.8	38.0	26.5	75.3	84.1	327.8	492.3	20.9	15.9	-201.3
17	31.0	0.0	21.0	0.0	1.2	8.8	0.0	30.5	3.6	3.1	-37.2
18	111.9	61.5	14.9	0.0	25.9	9.6	61.5	93.5	4.1	3.9	-40.0
19	543.3	388.8	0.0	32.2	70.5	351.8	388.8	280.9	16.0	13.0	78.9
20	548.8	325.6	32.2	39.3	75.0	76.7	325.6	340.8	18.7	15.5	-49.4
21	541.2	323.3	9.7	59.8	77.4	71.0	323.3	304.0	17.8	16.0	-14.5
22	560.5	337.5	3.8	55.2	82.8	81.2	337.5	337.5	19.5	17.5	-37.0
23	311.3	179.6	14.3	34.1	42.3	41.0	179.6	391.8	12.6	11.7	-236.5
24	530.5	350.0	24.2	43.1	64.0	49.2	350.0	382.9	9.3	10.4	-52.6
25	19.0	0.0	11.0	0.0	0.0	8.0	0.0	35.3	-2.0	1.8	-35.1
26	446.2	223.5	108.9	31.0	35.2	47.6	223.5	230.6	0.6	4.3	-12.0
27	356.0	203.1	40.0	24.4	45.7	42.8	203.1	220.8	2.1	4.9	-24.7
28	569.1	391.3	17.4	46.3	62.4	51.7	391.3	402.2	7.4	6.6	-24.9
29	18.3	0.0	31.8	0.0	0.1	-13.6	0.0	31.8	-0.8	1.7	-32.7
30	482.5	279.3	43.2	38.7	44.6	76.7	279.3	305.5	4.0	5.4	-35.6
31	446.4	247.3	80.1	38.8	35.6	44.6	247.3	283.5	-1.6	4.0	-38.6
Total	11324.0	6781.3	1229.9	678.2	1288.1	1346.5	6781.3	7507.5	242.4	261.8	-1230.4
Mean	365.3	218.8	39.7	21.9	41.6	43.4	218.8	242.2	7.8	8.4	-39.7

Table A3. Heat Pump Performance for the Month of December 1978

AUX ENERGY				ELECTRICAL ENERGY FOR BLOWERS, PUMPS, CONTROLS, ETC.										COEFFICIENT OF PERFORMANCE							
Day	Heat Pump	Resist. Pump	Total Aux	Compressor	Outdoor Fan	Indoor Blower for HP Aux	Indoor Blower for Solar	Collector Blower	Direct Collector Blower	Controls	Instr.	Base House Load	Total House Electric	Solar Collection	Solar Distr.	Overall Solar	Heat Pump	HP & Distr.	Aux Heating	Overall Heat	Degree Days
1	6.7	0.0	6.7	2.7*	0.2	0.4	14.6	19.5	1.1	----	46.2	239.3*	276.0*	17.1	26.34	14.11	2.31	2.03	2.03	12.23	20.7
2	25.9	562.6*	588.5*	16.2*	1.2*	3.8	34.3	7.4	7.0	----	55.0	295.1	916.2	9.4	1.63	2.67	1.49	1.22	1.01	1.12	32.1
3	11.6	0.0	11.6	6.3*	0.6*	1.2	22.7	17.3	6.2	----	53.8	354.2	400.4	26.9	10.16	10.62	1.68	1.43	1.43	9.07	23.2
4	15.3	0.0	15.3	5.9*	0.5	1.2	7.2	26.2	2.7	----	53.8	287.9	327.2	21.8	32.22	10.85	2.39	2.01	2.01	9.21	15.7
5	93.2	367.9*	461.1*	75.4	8.3	10.2	15.1	0.5	0.0	----	33.8	124.0	578.0	1.8	10.37	10.19	1.11	.99	1.00	1.30	27.7
6	283.1	425.5*	708.6*	180.9	21.3	35.0	0.0	0.0	0.0	----	32.9	291.2	896.4	----	----	----	1.40	1.19	1.07	1.06	33.4
7	177.2	513.6*	690.8*	183.6	23.1	28.1*	1.6*	11.6	9.5	----	33.9	286.5	988.3	12.4	5.0*	8.27	.86	.75	.92	1.05	38.1
8	2.9	322.9	325.8	59.0†	6.4†	3.6	20.7	19.6	6.8	----	29.2	188.3	613.7*	26.9	14.81	12.54	-----	-----	-----	1.90	37.2
9	-1.1	35.7	34.6	-----	0.0	0.9	12.8	18.9	7.8	----	34.5	77.3	145.6	26.8	18.78	14.93	-----	-----	.95*	6.70	26.4
10	-7.9	607.0	599.1	0.0	0.0	20.4*	4.1*	0.0	0.0	----	34.5	88.8	720.3	-----	6.49*	7.73	-----	-----	.95*	1.00	23.0
11	2.0	70.6	72.6	0.0	0.0	1.8*	20.5*	22.6	3.5	7.1	33.2	204.6	297.8	21.2	14.25*	9.78	-----	-----	1.00*	4.00	20.4
12	10.6	25.9	36.5	5.8	0.7	1.3	21.2	24.7	7.6	9.6	33.2	229.6	307.3	18.5	16.00	9.70	1.63	1.36	1.08	5.45	17.0
13	9.5	0.0	9.5	3.8	0.4	1.1	13.7	25.3	3.0	8.9	33.3	234.4	277.5	23.2	27.24	12.93	2.26	1.79	1.79	9.57	22.8
14	6.2	0.0	6.2	1.8	0.2	0.6	6.2	25.3	0.5	7.8	34.0	242.5	276.0	24.1	38.52	11.63	3.10	2.38	2.38	8.48	14.8
15	1.9	0.0	1.9	0.4	0.1	0.2	10.4	21.5	0.0	8.3	34.2	213.5	245.9	23.6	44.98	18.82	3.80	2.71	2.71	14.10	20.0
16	3.9	12.9	16.8	3.3	0.3	0.5	16.8	22.9	2.4	9.5	34.4	135.0	190.7	24.1	29.30	16.45	1.08	.95	.99	10.20	24.1
17	522.8	39.6	562.4	206.8	18.4	31.6	4.2	7.1	5.9	10.9	34.5	171.3	419.2	4.4	7.26	4.97	2.32	2.04	1.90	1.98	19.4
18	97.7	11.6	109.3	36.5	3.2	6.6	11.0	23.2	1.9	9.2	34.0	254.0	335.6	4.8	8.50	4.05	2.46	2.11	1.89	2.47	15.6
19	8.1	0.0	8.1	3.1	0.3	0.4	9.1	23.7	0.0	8.3	34.3	214.8	250.5	22.9	30.87	12.18	2.38	2.13	2.13	8.95	19.4
20	3.9	0.0	3.9	1.7	0.2	0.4	10.1	24.3	2.4	8.5	34.4	277.2	263.4	22.6	33.74	14.71	2.05	1.70	1.70	9.70	23.1
21	0.0	0.0	0.0	0.0	0.0	0.0	8.8	24.8	0.8	8.4	33.5	263.5	297.1	21.8	34.55	13.92	-----	-----	-----	6.26	19.2
22	7.4	0.0	7.4	3.2	0.4	0.8	8.3	23.8	1.1	8.4	34.0	215.4	250.9	23.6	40.66	15.54	2.06	1.68	1.68	7.97	19.4
23	26.5	20.4	46.9	10.8	1.0	1.8	18.2	18.1	2.4	9.5	34.5	163.6	230.7	17.2	21.53	13.64	2.25	1.95	1.38	5.34	21.9
24	10.6	0.0	10.6	4.7	0.5	1.0	16.8	25.8	3.0	9.8	34.5	143.2	190.6	20.6	22.79	12.29	2.04	1.71	1.71	7.08	16.6
25	368.7	154.6	523.3	179.3	18.2	30.7	7.6	2.6	2.2	11.4	34.6	227.5	566.4	7.3	4.64	4.34	1.87	1.62	1.37	1.39	25.0
26	115.8	105.7	221.5	62.7	6.7	10.8	15.2	21.1	5.7	10.9	34.5	170.0	373.0	21.1	15.17	11.19	1.67	1.44	1.19	2.50	26.1
27	77.4	67.9	145.3	32.8	3.2	5.1	19.1	24.4	3.5	10.6	34.4	169.2	311.9	14.6	11.56	7.65	2.15	1.88	1.33	2.65	20.9
28	17.9	14.6	32.5	10.0	1.0	1.8	14.9	24.2	2.2	9.3	33.8	245.1	308.6	23.5	26.99	13.70	1.63	1.40	1.19	6.19	23.0
29	229.4	493.3	722.7	161.6	19.4	32.7	5.8	3.3	3.3	11.7	34.8	305.7	970.1	5.5	5.48	4.59	1.27	1.07	1.02	1.06	37.0
30	73.3	296.8	370.1	70.0	8.7	14.2	12.9	20.3	3.0	11.1	34.6	212.2	612.4	23.8	23.68	13.13	0.93	0.79	.95	1.81	37.4
31	102.1	352.9	455.0	87.9	10.9	18.2	12.0	18.6	6.2	11.4	34.7	156.9	628.9	24.0	23.63	14.26	1.03	0.87	.97	1.72	37.1
Total	2302.6	4502.0	6304.6	1416.2	155.4	266.4*	395.9*	548.6	101.7	200.6*	1125.0	6540.2	13466.6		27.69*		1.47	1.25			757.7
Mean	74.3	145.2	219.5	45.7	5.0	8.6	12.8	17.7	3.3	9.6	36.3	211.0	434.4	20.6		11.60			1.07	2.32	24.4

*Calculated values
 †Averaged over 21 days
 ‡Heat pump malfunction

Table A4. Collector Performance for the Month of December 1978

Day	ENVIRONMENT					EAST ARRAY			WEST ARRAY			TOTAL ARRAY		
	Total Incident	Solar While Collecting	Average Ambient Temp	Wind Speed	Direction+ Degrees	T.E. Energy Collected	Avg % Eff.(1)	Avg % Eff.(2)	T.E. Collected	Avg % Eff.(1)	Avg % Eff.(2)	T.E. Collected	Avg % Eff.(1)	Avg % Eff.(2)
1	726.0	701.0	-4.3	----	225.0	173.7	49.6	47.9	160.2	45.7	44.1	333.9	47.7	46.0
2	377.0*	170.0*	-13.8	----	359.0	42.2	49.6*	22.4*	27.4	32.2*	14.5*	69.6	40.9*	18.5*
3	1415.0*	874.0*	-8.0	----	298.0	243.6	55.7*	34.4*	221.1	50.6*	31.3*	464.7	53.2*	32.8
4	1111.0	1104.0	6.5	----	195.0	294.3	53.3	48.6	276.8	50.1	48.6	571.1	51.7	48.2
5	87.0	1.0	-9.9	----	239.0	0.6	----	1.4	0.3	60.0	0.7	0.9	----	1.0
6	84.0	0.0	-14.8	----	340.0	0.0	----	----	0.0	----	----	0.0	----	----
7	988.0	471.0	-19.3	----	319.0	86.3	36.7	17.5	57.7	24.5	11.7	144.0	30.6	14.6
8	1573.0	1440.0	-18.5	----	310.0	281.7	39.1	35.8	245.0	34.0	31.2	526.7	36.6	33.5
9	1384.0	1019.0	-7.3	----	213.0	266.1	52.2	38.4	240.8	47.2	34.8	506.9	49.7	36.6
10	751.0	0.0	-4.5	----	229.0	0.0	----	----	0.0	----	----	0.0	----	----
11	1117.0	940.0	-0.3	----	315.0	250.6	53.3	44.9	228.9	48.7	41.0	479.4	51.0	42.9
12	1018.0	976.0	0.1	----	185.0	236.2	48.4	46.4	219.5	45.0	43.1	455.8	46.7	44.8
13	1265.0	1200.0	-3.7	----	----	305.0	50.9	48.2	281.3	46.9	44.5	586.3	48.9	46.4
14	1394.0	1345.0	1.9	1.16	140.0	34.9	46.8	45.2	295.6	43.9	42.4	610.5	45.4	43.8
15	1197.0	1133.0	0.3	2.81	131.0	262.7	46.4	43.9	243.8	43.0	40.7	506.5	44.7	42.7
16	1346.0	1293.0	-5.6	1.95	166.0	285.8	44.2	42.5	265.9	41.1	39.5	551.7	42.7	41.0
17	251.0	79.0	-0.2	1.63	182.0	17.6	44.7	14.0	13.4	34.2	10.7	31.0	39.4	12.4
18	360.0	272.0	2.7	1.27	140.0	60.8	44.7	33.8	51.1	37.5	28.4	111.9	41.1	31.1
19	1151.0	1100.0	0.6	1.32	97.0	281.6	51.2	48.9	261.8	47.6	45.5	543.3	49.4	47.2
20	1374.0	1334.0	-3.8	2.89	136.0	286.3	43.0	41.8	261.9	393.0	38.1	548.8	41.2	39.9
21	1314.0	1263.0	0.1	2.48	103.0	280.5	44.4	42.7	260.7	41.3	39.7	541.2	42.8	41.2
22	1310.0	1253.0	0.4	2.75	108.0	291.7	46.6	44.5	268.8	42.9	41.0	560.5	44.7	42.8
23	760.0	709.0	-3.3	2.27	143.0	162.9	46.0	42.9	148.4	41.9	39.1	311.3	43.9	41.0
24	1300.0	1256.0	4.0	7.73	196.0	274.4	43.7	42.2	256.1	40.8	39.4	530.5	42.2	40.8
25	263.0	56.0	-6.0	3.75	174.0	10.1	36.4	7.7	8.8	31.8	6.7	19.0	34.1	7.2
26	1048.0	980.0	-7.8	1.90	169.0	232.4	47.5	44.4	213.8	43.6	40.8	446.2	45.6	42.6
27	883.0	811.0	-0.9	1.77	183.0	186.7	46.0	42.3	169.3	41.7	38.3	356.0	43.9	40.3
28	1245.0	1206.0	-5.9	2.62	114.0	294.5	48.8	47.3	274.6	45.6	44.1	569.1	47.2	45.7
29	318.0	54.0	-17.7	2.17	130.0	107.0	40.0	6.7	7.6	28.1	4.8	18.3	34.0	5.8
30	1450.0	1295.0	-19.5	1.05	208.0	253.9	39.2	35.0	228.6	35.3	31.5	482.5	37.3	33.3
31	1188.0	1089.0	-18.0	1.11	158.0	234.7	41.7	39.5	211.7	38.9	35.6	446.4	41.0	37.6
Total	30043.0	25424.0				5923.1			5400.9			11324.0		
Mean	969.3	820.1	- 5.7	2.37	----	191.1	46.6	39.4	174.2	42.5	35.9	365.3	44.5	37.7

*Calculated values

*North = 0, 360° East = 90°

Table A5. Space and DHW Heating for the Month of January 1979

Day	ENERGY FOR HEATING AND DHW				ENERGY FOR SPACE HEATING				ENERGY FOR DHW			
	Solar MJ	Aux MJ	Total MJ	Solar Fraction	Solar MJ	Aux MJ	Total MJ	Solar Fraction	Solar MJ	Aux MJ	Total MJ	Solar Fraction
1	472.3	507.6	979.9	.47	450.5	456.9	907.4	.50	21.8	50.7	72.5	.30
2	114.8	511.7	626.5	.18	105.5	454.9	560.4	.19	9.3	56.8	66.1	.14
3	164.0	437.9	601.9	.27	148.0	389.5	537.5	.28	16.0	48.4	64.4	.25
4	272.1	472.4	744.5	.37	250.7	440.2	690.9	.36	21.4	32.2	53.6	.40
5	421.1	268.2	689.3	.61	399.6	258.5	658.1	.61	21.5	9.7	31.2	.69
6	131.1	597.6	728.7	.18	131.1	583.9	715.0	.18	0.0	13.7	13.7	0.00
7	512.4	268.5	780.9	.66	479.3	258.4	737.7	.65	33.1	10.1	43.2	.77
8	340.6	232.3	572.9	.59	303.3	212.0	515.3	.59	37.3	20.3	57.6	.65
9	235.1	230.6	465.7	.50	226.3	195.0	421.3	.54	8.8	35.6	44.4	.20
10	364.9	212.2	577.1	.63	327.1	182.8	509.9	.64	37.8	29.4	67.2	.56
11	29.7	472.7	502.4	.06	18.7	414.2	432.9	.04	11.0	58.5	69.5	.16
12	38.6	708.8	747.4	.05	36.7	663.3	700.0	.05	1.9	45.5	47.4	.04
13	428.3	365.9	794.2	.54	386.7	337.0	723.7	.53	41.6	28.9	70.5	.59
14	313.9	311.3	625.2	.50	285.6	284.7	570.3	.50	28.3	26.6	54.9	.52
15	398.8	36.3	435.1	.92	350.1	17.8	367.9	.95	48.7	18.5	67.2	.72
16	164.3	301.9	466.2	.35	157.7	264.0	421.7	.37	6.6	37.9	44.5	.15
17	266.0	211.2	477.2	.56	239.4	174.7	414.1	.58	26.6	36.5	63.1	.42
18	86.2	372.2	458.2	.19	75.8	335.4	411.2	.18	10.4	36.8	47.2	.22
19	454.6	58.9	513.5	.89	405.2	37.2	442.4	.92	49.4	21.7	71.1	.69
20	549.4	28.2	577.6	.95	507.5	11.8	519.3	.98	41.9	16.4	58.3	.72
21	447.2	38.4	485.6	.92	411.9	21.2	433.1	.95	35.3	17.2	52.5	.67
22	121.0	479.2	600.2	.20	110.1	442.3	552.4	.20	10.9	36.9	47.8	.23
23	413.4	156.9	570.3	.72	368.3	129.1	492.4	.74	45.1	27.8	72.9	.62
24	412.4	41.4	453.8	.91	364.4	21.4	385.8	.94	48.0	20.0	68.0	.71
25	107.6	295.4	403.0	.27	105.9	258.4	364.3	.29	1.7	37.0	38.7	.04
26	273.3	292.9	566.2	.48	241.7	259.0	500.7	.48	31.6	33.9	65.5	.48
27	568.0	123.3	691.3	.82	514.8	104.0	618.8	.83	53.2	19.3	72.5	.73
28	461.9	343.5	805.4	.57	426.8	318.4	745.2	.57	35.1	25.1	60.2	.58
29	-17.0	803.4	786.4	----	-17.0	757.0*	740.0	----	0.0	46.4	46.4	0.00
30	391.3	325.4	716.7	.55	345.6	290.7	636.3	.54	45.7	34.7	80.4	.57
31												
Total	8937.3	9506.2	18443.5		8157.3	8573.7	16731.0		780.0	932.5	1712.5	
Mean	297.9	316.9	614.8	.48	271.9	285.8	557.7	.49	26.0	31.1	57.1	.46

Table A6. Solar Thermal Energy Transport for the Month of January 1979

Day	FROM COLLECTORS						STORAGE PERFORMANCE				
	Coll. Deliv.	To Storage	To Rooms	To DHW	Loss to Rooms	Loss to Outdoors	Charge	Discharge	Loss to Rooms	Loss to Outdoors	Change In Storage
1	509.4	146.0	254.6	21.8	31.1	55.9	146.0	171.1	-6.2	2.7	-21.6
2	151.7	57.5	48.5	9.3	10.5	25.9	57.5	46.8	-0.3	1.4	9.6
3	214.3	97.2	31.3	16.0	26.6	43.2	97.2	89.6	0.5	3.1	4.0
4	304.4	159.8	53.0	21.4	27.2	43.0	159.8	170.2	0.4	3.3	-14.1
5	473.9	287.7	42.1	21.5	45.4	77.2	287.7	308.3	3.7	6.6	-31.9
6	142.9	0.0	114.4	0.0	0.2	28.3	0.0	18.4	-1.9	1.5	-18.0
7	528.5	327.2	84.3	33.1	33.9	50.0	327.2	350.6	10.5	5.6	-39.5
8	558.5	382.9	49.5	37.3	32.9	55.9	382.9	198.1	22.8	10.4	151.6
9	106.6	25.3	13.8	8.8	5.3	53.4	25.3	196.8	10.5	6.8	-188.8
10	388.8	244.5	40.5	37.8	23.3	42.7	244.5	252.1	11.2	5.3	-24.1
11	60.6	27.2	10.8	11.0	0.3	11.3	27.2	7.2	0.4	1.8	17.8
12	53.7	6.0	25.5	1.9	-0.7	21.0	6.0	10.2	1.6	1.6	-7.4
13	451.4	254.2	86.7	41.6	24.7	44.2	254.2	267.1	8.2	4.8	-25.9
14	344.5	198.3	50.8	28.3	16.4	50.7	198.3	207.0	11.4	4.3	-24.4
15	508.9	366.8	15.0	48.7	29.0	49.4	366.8	282.8	23.4	10.6	50.0
16	83.5	43.2	5.9	6.6	2.0	25.8	43.2	142.7	7.1	4.4	-111.0
17	292.1	172.9	42.7	26.6	9.8	40.1	172.9	175.4	11.5	4.6	-18.6
18	107.5	67.2	7.1	10.4	3.0	19.8	67.2	61.5	4.2	2.4	-0.9
19	507.6	355.7	25.9	49.4	29.4	47.2	355.7	327.3	22.6	9.6	-3.8
20	557.5	338.0	94.1	41.9	30.9	52.6	338.0	359.8	22.7	9.9	-54.4
21	452.3	275.6	81.1	35.3	25.2	35.1	275.6	286.8	18.9	8.7	-38.8
22	98.3	57.2	11.9	10.9	4.1	14.2	57.2	87.9	6.1	2.8	-39.6
23	443.6	289.8	30.7	45.1	25.1	52.9	289.8	294.1	18.4	6.5	-29.2
24	512.9	349.7	37.5	48.0	28.5	49.2	349.7	274.8	23.6	10.2	41.1
25	38.6	9.8	4.0	1.7	-7	23.8	9.8	94.9	7.8	3.8	-96.7
26	295.0	199.5	10.9	31.6	12.8	40.2	199.5	204.9	13.2	4.4	-23.0
27	595.4	393.5	46.7	53.2	37.3	64.7	393.5	406.5	24.3	8.6	-45.9
28	469.7	233.6	134.2	35.1	23.2	43.6	233.6	259.3	10.0	5.3	-41.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-20.0	3.0	1.4	15.6
30	423.4	268.8	36.3	45.7	24.8	47.8	268.8	270.1	14.4	5.3	-21.0
31											
Total	9675.5	5635.1	1489.8	780.0	561.5	1209.1	5635.1	5802.3	304.0	157.7	-628.9
Mean	322.5	187.8	49.7	26.0	18.7	40.3	187.8	193.4	10.1	5.3	21.0

Table A7. Heat Pump Performance for the Month of January 1979

Day	AUX ENERGY			ELECTRICAL ENERGY FOR BLOWERS, PUMPS, CONTROLS, ETC.										COEFFICIENT OF PERFORMANCE							
	Heat Pump	Resist. Pump	Total Aux	Compressor	Outdoor Fan	Indoor Blower for HP Aux	Indoor Blower for Solar	Collector Blower	Direct Collector Blower	Controls	Instr.	Base House Load	Total House Electric	Solar Collection	Solar Distr.	Overall Solar	Heat Pump	HP & Distr.	Aux Heating	Overall Heat	Degree Days
1	119.6	337.3	456.9	101.0	12.0	20.3	7.8	23.0	13.8	11.7	34.7	173.9	643.1	22.15	21.94	15.33	1.06	.90	.97	1.77	36.1
2	241.3	213.6	454.9	144.3	15.8	26.7	5.7	12.1	6.2	11.0	34.6	329.8	703.3	12.53	8.21	6.45	1.51	1.29	1.14	1.32	31.4
3	147.0	242.5	389.5	94.4	10.2	16.6	11.7	20.7	3.5	11.1	34.7	284.7	651.7	10.35	7.66	5.06	1.41	1.21	1.07	1.35	27.2
4	137.3	302.9	440.2	108.9	12.4	20.3	10.9	19.0	5.4	11.4	33.8	290.1	710.3	16.02	15.61	9.10	1.13	1.00	.99	1.47	33.2
5	82.2	176.3	258.5	52.1	5.5	9.9	15.7	21.7	3.8	10.6	34.5	234.2	499.5	21.83	19.64	11.26	1.43	1.22	1.06	2.37	29.9
6	327.5	256.4	583.9	180.1	19.5	30.7*	2.0*	9.2	9.2	11.8	34.5	197.5	639.9	15.53	9.24	11.71	1.64	1.42*	1.20*	1.42	30.5
7	85.0	173.4	258.4	61.0	7.0	10.9	12.7	12.3	3.6	10.7*	34.5	138.6	396.7	42.56	27.61	20.50	1.25	1.08	1.02	1.57	32.2
8	50.9	161.1	212.0	50.5	5.0	7.9*	-----*	13.3	2.7	8.4	34.2	291.8	514.5	41.99	-----	25.60	.92*	.80*	.94*	2.22*	26.4
9	55.6	139.4	195.0	34.9	3.9	6.2	16.3	11.3	1.5	10.1	34.3	293.3	494.4	9.43	12.07	8.52	1.43	1.24	1.06	1.88	25.9
10	97.6	85.2	182.8	55.7	5.9	9.1	13.6	11.0	2.0	10.2	34.6	293.5	457.0	35.34	18.54	14.83	1.58	1.38	1.17	2.75	26.3
11	343.1	71.1	414.2	154.2	13.9	23.2	3.8	5.8	1.2	10.1	34.4	297.2	524.6	10.45	1.89	3.09	2.04	1.79	1.58	1.52	19.8
12	297.2	366.1	663.3	182.1	19.3	26.6*	5.4*	9.1	3.5	11.5	34.6	263.7	816.6	5.90	1.89*	2.66	1.48	1.30*	1.12*	1.14	25.4
13	112.5	224.5	337.0	78.2	8.9	14.0	12.3	12.2	3.9	11.2	34.6	148.1	473.7	37.00	21.72	17.48	1.29	1.11	1.04	2.10	30.0
14	163.7	121.0	284.7	77.2	7.5	12.1	14.5	13.1	2.9	11.0	34.5	200.0	422.5	26.30	14.28	11.37	1.93	1.69	1.31	2.30	25.8
15	16.3	1.5	17.8	6.4	0.5	.8	9.4	14.2	1.1	8.6	34.3	240.4	271.4	35.84	30.09	16.90	2.36	2.12	1.93	8.48	17.5
16	125.5	138.5	264.0	60.9	5.9	9.4	16.6	9.4	.8	10.4	34.5	248.8	471.3	8.88	8.60	6.32	1.88	1.65	1.23	1.67	20.0
17	112.7	62.0	174.7	50.0	4.7	7.2	15.6	13.5	2.6	10.4	34.5	217.4	355.7	21.64	11.24	9.14	2.06	1.82	1.41	2.52	19.4
18	305.9	29.5	335.4	125.8	11.1	18.8	7.3	10.1	1.2	10.5	34.5	245.7	412.0	10.64	8.42	4.95	2.23	1.96	1.81	1.91	17.6
19	35.5	1.7	37.2	15.7	1.4	2.5	13.5	13.3	1.5	9.4	34.1	192.1	235.7	38.17	24.24	16.96	2.08	1.81	1.75	7.36	19.1
20	11.8	0.0	11.8	4.7	.5	.7	15.3	14.5	4.1	9.7	34.4	106.8	141.1	38.45	23.52	18.44	2.27	2.00	2.00	11.09	18.1
21	19.9	1.3	21.2	7.5	.7	1.1	15.4	12.4	4.1	9.4	34.4	140.5	176.7	36.48	18.62	16.09	2.43	2.14	2.00	8.73	15.9
22	213.7	228.6	442.3	121.8	12.9	22.6	6.5	5.0	1.4	10.5	33.9	324.9	185.0	19.66	13.52	10.52	1.59	1.36	1.15	1.38	25.5
23	58.0	71.1	129.1	35.7	3.9	6.0	15.0	12.7	1.8	10.1	34.3	263.5	396.9	34.93	19.61	14.92	1.46	1.27	1.11	3.31	26.8
24	21.4	0.0	21.4	11.4	1.2	1.9	9.8	13.6	2.3	8.8	34.4	252.2	286.6	37.71	28.04	17.62	1.70	1.47	1.47	7.84	22.0
25	99.6	158.8	258.4	58.8	6.1	9.1	14.3	7.6	.6	9.8	34.6	266.9	503.7	5.08	6.64	4.91	1.53	1.35	1.11	1.37	26.5
26	114.8	144.2	259.0	72.0	8.0	12.4	12.7	10.6	.6	10.5	34.6	256.1	493.6	27.83	16.13	11.73	1.44	1.24	1.09	1.74	30.5
27	29.2	74.8	104.0	23.4	2.7	4.1	15.5	14.0	2.6	10.1	34.6	167.5	294.6	42.55	26.23	19.25	1.11	.97	.99	4.49	31.2
28	93.7	224.7	318.4	64.3	7.1	11.4	10.4	13.3	5.4	10.6	34.6	202.1	513.3	35.32	24.93	19.49	1.31	1.13	1.04	2.26	30.1
29	280.0	477.0*	757.0*	201.9	22.8	37.1	0.0	.2	-----	11.4	34.6	226.8	902.6	0.0	-----	-----	1.25	1.07	1.02	1.00	34.2
30	84.0	206.7	290.7	67.3	7.9	12.2	12.8	11.5	2.3	10.7	34.7	303.2	600.2	36.82	21.10	16.10	1.12	.96	.99	2.03	34.3
31																					
Total	3882.5	4691.2	8573.7	2302.2	244.2	391.8*	322.5*	369.7	95.6	311.7	1033.5	7071.4	14688.2								788.8
Mean	129.4	156.4	285.8	76.7	8.1	13.1	10.8	12.3	3.2	10.4	34.5	235.7	489.6	26.17	17.99	12.91	1.52	1.32	1.12		26.3

Table A8. Collector Performance for the Month of January 1979.

Day	ENVIRONMENT					EAST ARRAY			WEST ARRAY			TOTAL ARRAY		
	Total Incident	Solar While Collecting	Average Ambient Temp	Wind Speed	Direction+ Degrees	T.E. Energy Collected	Avg % Eff.(1)	Avg % Eff.(2)	T.E. Collected	Avg % Eff.(1)	Avg % Eff.(2)	T.E. Collected	Avg % Eff.(1)	Avg % Eff.(2)
1	1530	1406	-16.9	3.48	204	262.8	37.4	34.4	246.6	35.1	32.2	509.4	36.2	33.3
2	529	360	-11.3	1.54	159	79.6	44.2	30.0	72.1	40.1	27.3	151.7	42.1	28.7
3	576	495	-9.5	1.78	144	114.2	46.2	39.7	100.1	40.5	34.8	214.3	43.3	37.2
4	814	717	-15.6	2.12	118	167.0	46.6	41.0	137.4	38.3	33.8	304.4	42.5	37.4
5	1242	1154	-12.1	1.60	190	249.0	43.1	40.1	224.9	39.0	36.2	473.9	41.1	38.2
6	517	302	-11.3	1.85	176	78.9	52.3	30.5	64.0	42.4	24.8	142.9	47.4	27.6
7	1407	1333	-14.0	1.64	212	263.5	39.5	37.5	265.0	39.8	37.7	528.5	39.7	37.6
8	1430	1357	-7.7	.78	107	280.5	41.3	39.2	278.0	41.0	38.9	558.5	41.1	39.1
9	488	406	-7.6	2.12	137	50.2	24.8	20.6	56.4	27.8	23.1	106.6	26.3	21.8
10	1112	1033	-11.0	1.96	152	192.3	37.2	34.6	196.5	38.0	35.3	388.8	37.6	35.0
11	310	164	-0.6	1.60	178	29.8	36.4	19.2	30.8	37.6	19.9	60.6	37.0	19.5
12	303	216	-11.0	3.45	168	26.9	24.9	17.8	26.8	24.8	17.7	53.7	24.9	17.7
13	1248	1151	-11.9	1.92	161	225.7	39.2	36.2	225.7	39.2	36.2	451.4	39.2	36.2
14	1068	964	-9.3	2.61	167	171.5	35.6	31.8	173.0	35.9	32.4	344.5	35.7	32.3
15	1298	1269	0.1	2.93	131	251.7	39.7	38.8	257.2	40.5	39.6	508.9	40.1	39.2
16	348	261	-0.8	3.03	211	40.6	31.1	23.3	42.9	32.9	24.7	83.5	32.0	24.0
17	785	728	-1.7	1.54	189	145.1	39.9	37.0	147.0	40.4	37.5	292.1	40.1	37.2
18	330	280	1.5	2.06	200	52.6	37.6	31.9	58.9	39.2	33.3	107.5	38.4	32.6
19	1252	1204	0.5	2.76	139	252.1	41.9	40.3	255.5	42.4	40.8	507.6	42.2	40.5
20	1403	1366	1.5	3.14	140	278.2	40.7	40.0	279.3	40.9	39.8	557.5	40.8	39.7
21	1140	1076	2.1	1.80	138	225.8	42.0	39.6	226.5	42.1	39.7	452.3	42.0	39.7
22	368	272	-8.7	3.22	151	49.0	36.0	26.6	49.3	36.3	26.8	98.3	36.1	26.7
23	1291	1217	-8.0	2.56	182	219.1	36.0	33.9	224.5	36.9	34.8	443.6	36.5	34.4
24	1280	1217	-2.0	1.44	108	255.8	42.0	40.0	257.1	42.3	40.2	512.9	42.1	40.1
25	315	182	-7.6	1.41	107	19.5	21.4	12.4	19.1	21.0	12.1	38.6	21.2	12.3
26	933	822	-11.8	1.33	228	165.1	40.2	35.4	129.9	31.6	27.8	295.0	35.9	31.6
27	1513	1446	-12.6	1.80	204	297.6	41.2	39.3	297.8	41.2	39.4	595.4	41.2	39.3
28	1250	1154	-12.3	1.18	156	236.1	40.9	37.8	233.6	40.5	37.4	469.7	40.7	37.6
29	215	0	-15.6	2.15	138	0.0	----	----	0.0	----	----	0.0	----	----
30	1434	1289	-16.6	1.99	208	209.2	32.5	29.2	214.2	33.2	29.9	403.4	32.8	29.5
31														
Total	27729	24841				4889.4			4786.1			9675.5		
Mean	924	828	-8.1	2.09	----	163.0	39.4	35.3	159.5	38.5	34.5	322.5	38.9	34.9

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Table A9. Space and DHW Heating for the Month of February 1979

Day	ENERGY FOR HEATING AND DHW				ENERGY FOR SPACE HEATING				ENERGY FOR DHW			
	Solar MJ	Aux MJ	Total MJ	Solar Fraction	Solar MJ	Aux MJ	Total MJ	Solar Fraction	Solar MJ	Aux MJ	Total MJ	Solar Fraction
1	557.0	72.1	629.1	.89	509.4	53.1	562.5	.91	47.6	19.0	66.6	.71
2	262.1	333.8	595.9	.44	241.7	301.1	542.8	.45	20.4	32.7	53.1	.38
3	585.4	73.8	659.2	.89	532.6	52.2	584.8	.91	52.8	21.6	74.4	.71
4	435.5	190.2	625.7	.70	398.1	171.0	569.1	.70	37.4	19.2	56.6	.66
5	396.5	30.7	427.2	.93	339.3	12.1	351.4	.97	57.2	18.6	75.8	.75
6	457.1	18.1	475.2	.96	407.8	0.1	407.9	1.00	49.3	18.0	67.3	.73
7	419.4	51.3	470.7	.89	419.4	38.7	458.1	.92	0.0	12.6	12.6	.0
8	460.7	20.9	481.6	.96	420.6	8.8	429.4	.98	40.1	12.1	52.2	.77
9	354.7	12.5	367.2	.97	324.9	0.2	325.1	1.0	29.8	12.3	42.1	.71
10	392.3	25.4	417.7	.94	349.7	0.0	349.7	1.0	42.6	25.4	68.0	.63
11	315.9	19.9	335.8	.94	260.2	3.3	263.5	.99	55.7	16.6	72.3	.77
12	250.2	25.9	276.1	.91	207.5	0.0	207.5	1.0	42.7	25.9	68.6	.62
13	280.1	21.1	301.2	.93	220.0*	0.0	220.0	1.0	60.1	21.1	81.2	.74
14	281.7	13.9	295.6	.95	236.0	0.4	236.4	1.0	45.7	13.5	59.2	.77
15	589.7	31.5	621.2	.95	547.7	8.6	556.3	.98	42.0	22.9	64.9	.65
16	75.5	524.8	600.3	.13	73.1	489.7	562.8	.13	2.4	35.1	37.5	.06
17	453.0	39.1	492.1	.92	390.8	15.8	406.6	.96	62.2	23.3	85.5	.73
18	392.4	22.5	414.9	.95	347.1	8.9	356.0	.98	45.3	13.6	58.9	.77
19	209.9	20.8	230.7	.91	160.2	5.0	165.2	.97	49.7	15.8	65.5	.76
20	386.2	23.4	409.6	.94	327.4	0.0	327.4	1.00	58.8	23.4	82.2	.72
21	355.3	51.7	407.0	.87	298.2	23.9	322.1	.93	57.1	27.8	84.9	.67
22	431.0	21.1	452.1	.95	378.2	0.0	378.2	1.0	52.8	21.1	73.9	.71
23	241.5	134.2	375.7	.64	223.0	85.3	308.3	.72	18.5	48.9	67.4	.27
24	-8.7	440.4	431.7	----	-8.7	383.4	374.7	----	0.0	57.0	57.0	.0
25	300.7	160.3	461.0	.65	264.2	113.9	378.1	.70	36.5	46.4	82.9	.44
26	194.6	184.3	378.9	.51	166.2	142.8	309.0	.54	28.4	41.5	69.9	.41
27	111.9	324.3	436.2	.27	91.4	275.0	366.4	.25	20.5	49.3	69.8	.29
28												
29												
30												
31												
Total	9181.6	2888.0	12069.6		8126.0	2193.3	10319.3		1055.6	694.7	1750.3	
Mean	340.1	106.9	447.0	0.76	301.0	81.2	382.2	0.79	39.1	25.7	64.8	0.60

*Est. with 9.8 degree days

Table A10. Solar Thermal Energy Transport for the Month of February 1979

Day	FROM COLLECTORS						STORAGE PERFORMANCE				
	Coll. Deliv.	To Storage	To Rooms	To DHW	Loss to Rooms	Loss to Outdoors	Charge	Discharge	Loss to Rooms	Loss to Outdoors	Change In Storage
1	572.9	401.2	35.2	47.6	34.9	54.0	401.2	417.6	21.7	10.7	-48.8
2	260.5	132.1	56.7	20.4	9.3	42.0	132.1	165.3	10.3	4.3	-47.8
3	621.2	387.2	88.8	52.8	39.2	53.2	387.2	384.2	20.4	9.3	-26.7
4	420.2	265.4	44.2	37.4	25.7	47.5	265.4	312.2	16.1	6.3	-69.2
5	582.1	405.4	32.5	57.2	35.5	51.5	405.4	248.0	23.4	11.7	122.3
6	481.5	315.0	13.7	49.3	36.9	66.6	315.0	328.1	29.1	15.5	-57.7
7	292.5	238.8	7.6	0.0	20.1	26.0	238.8	372.1	19.7	10.5	-163.5
8	559.1	402.7	27.8	40.1	34.0	54.5	402.7	332.6	26.2	12.5	31.4
9	431.2	331.0	0.0	29.8	28.0	42.4	331.0	271.0	25.9	13.7	20.4
10	311.6	192.7	12.6	42.0	18.5	45.8	192.7	294.6	23.9	13.0	138.8
11	534.8	375.1	15.3	55.7	35.7	49.0	375.1	175.4	29.8	15.8	154.1
12	269.4	146.3	13.6	42.7	23.9	42.9	146.3	146.2	23.9	16.2	-40.0
13	376.7	236.5	0.0	60.1	32.6	47.5	236.5	161.9*	25.5*	17.8**	31.3
14	350.2	184.9	0.0	45.7	53.4	66.2	184.9	156.1	26.5	20.5	-18.2
15	282.8	134.2	20.5	42.0	22.7	63.4	134.2	475.7	28.9	15.2	-385.6
16	53.8	6.1	28.7	2.4	.1	16.5	6.1	39.1	5.3	3.0	-41.3
17	596.9	385.8	62.3	62.2	36.5	50.1	385.8	269.3	22.7	11.2	82.6
18	537.7	364.4	34.9	45.3	37.6	55.5	364.4	244.7	29.9	16.2	73.6
19	413.7	263.2	.9	49.7	35.9	64.0	263.2	93.4	30.0	19.1	120.7
20	485.6	273.4	0.0	58.8	66.2	87.2	273.4	227.5	33.7	23.3	-11.1
21	255.8	82.9	15.1	57.1	32.2	68.5	82.9	224.0	26.8	19.4	-187.3
22	372.8	241.7	0.0	52.8	32.7	45.6	241.7	315.8	29.7	17.5	-121.3
23	75.9	31.9	1.3	18.5	1.3	22.9	31.9	208.1	12.2	8.0	-196.4
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-10.0	1.3	1.9	6.8
25	333.4	190.5	47.2	36.5	18.7	40.5	190.5	188.5	9.9	5.7	-13.6
26	197.4	146.8	0.7	28.4	12.4	9.1	146.8	148.8	4.3	4.9	-11.2
27	109.2	72.6	0.0	20.5	5.3	10.8	72.6	84.7	1.4	3.0	-16.5
28											
29											
30											
31											
Total	9778.9	6207.8	563.6	1055.0	729.3	1223.2	6207.8	6274.9	558.5	326.2	-951.80
Mean	362.2	229.9	20.9	39.1	27.0	45.3	229.9	232.4	20.7	12.1	35.3

*Est. from total load

**Calc. value to include missing data for 7 hr. period

Table A11. Heat Pump Performance for the Month of February 1979

	AUX ENERGY			ELECTRICAL ENERGY FOR BLOWERS, PUMPS, CONTROLS, ETC.									COEFFICIENT OF PERFORMANCE								
Day	Heat Pump	Resist. Pump	Total Aux	Compressor	Outdoor Fan	Indoor Blower for HP Aux	Indoor Blower for Solar	Collector Blower	Direct Collector Blower	Controls	Instr.	Base House Load	Total House Electric	Solar Collection	Solar Distr.	Overall Solar	Heat Pump	HP & Distr.	Aux Heating	Overall Heat	Degree Days
1	17.0	36.1	53.1	10.4	1.1	2.1	14.9	13.9	1.8	9.7	34.5	217.4	292.7	41.21	28.03	19.34	1.48	1.25	1.07	6.45	26.0
2	113.1	188.0	301.1	69.8	7.3	11.3	13.6	14.7	3.4	11.0	34.6	223.7	507.1	17.72	12.15	9.26	1.47	1.28	1.09	1.77	27.9
3	20.8	31.4	52.2	11.1	1.2	1.7	15.3	14.8	3.5	9.9	34.5	125.2	198.3	41.97	25.11	19.45	1.69	1.49	1.15	6.79	26.1
4	72.6	98.4	171.0	47.3	5.2	8.2	16.9	13.4	2.2	10.9	34.6	153.1	327.8	31.36	18.47	14.37	1.38	1.20	1.07	3.00	25.9
5	10.2	1.9	12.1	8.3	.9	1.4	7.4	14.3	2.0	8.5	34.2	251.8	283.4	40.71	33.51	18.27	1.11	.96	.97	8.09	23.9
6	0.0	.1	.1	0.0	0.0	0.0	9.2	14.3	.8	8.6	34.3	208.8	232.4	33.68	35.66	19.45	0.0	----	1.00	11.42	21.1
7	18.4	20.3	38.7	9.5	.9	1.2	18.0	10.7	.8	9.5	34.2	229.6	287.4	27.34	20.67	14.61	1.76	1.59	1.21	6.43	17.8
8	7.1	1.7	8.8	4.0	.4	.6	10.3	13.8	1.7	8.8	34.3	210.4	240.0	40.51	32.29	19.12	1.61	1.42	1.31	11.23	23.5
9	0.0	0.2	0.2	0.0	0.0	0.0	8.8	11.8	0.0	8.1	34.1	202.8	223.6	36.54	30.80	17.22	0.0	----	1.00	11.09	14.6
10	0.0	0.0	0.0	0.0	0.0	0.0	11.4	11.3	.6	8.6	34.3	136.9	159.6	27.58	25.84	17.28	0.0	----	----	8.68	14.3
11	3.2	0.1	3.3	1.4	0.2	.2	5.6	14.5	1.0	8.4	34.3	121.3	143.0	36.88	31.32	15.72	2.0	1.78	1.74	8.70	11.3
12	0.0	0.0	0.0	0.0	0.0	0.0	5.1	10.5	.3	7.6	34.0	256.9	272.5	25.66	28.67	16.04	0.0	----	----	6.65	9.8
13	0.0	0.0	0.0	0.0	0.0	0.0	5.4+	12.6	0.0	7.8*	34.0*	----	----	29.90	29.98	15.56	0.0	----	----	7.70	----
14	0.0	0.4	0.4	0.0	0.0	0.0	3.6	14.0	0.0	7.8	33.9	187.5	205.5	25.01	43.36	16.01	0.0	----	1.00	9.38	14.5
15	8.4	0.2	8.6	4.9	0.6	.9	17.5	10.5	1.3	9.3	34.6	214.8	247.8	26.93	27.18	21.06	1.53	1.31	1.30	10.80	27.3
16	303.6	186.1	489.7	160.5	15.9	27.1	10.0	6.6	4.6	11.4	34.6	269.3	627.5	8.15	3.91	4.55	1.72	1.49	1.26	1.36	25.6
17	10.7	5.1	15.8	8.1	.8	1.1	8.6	14.7	2.7	8.8	34.5	148.2	184.2	40.60	31.31	19.44	1.20	1.07	1.05	7.98	18.5
18	8.8	.1	8.9	4.2	.5	.7	5.9	13.9	1.4	8.2	34.4	122.8	146.8	38.68	41.47	19.82	1.87	1.63	1.62	10.67	15.3
19	5.0	0.0	5.0	1.7	.2	.3	2.6	13.0	.3	7.4	33.8	244.4	261.7	31.82	35.42	13.46	2.63	2.27	2.27	6.87	12.1
20	0.0	0.0	0.0	0.0	0.0	0.0	4.5	14.2	0.0	8.0	34.1	222.6	241.3	34.20	50.56	20.65	0.0	----	----	9.73	15.6
21	22.6	1.3	23.9	10.5	0.9	1.7	6.3	13.0	2.0	8.1	34.4	264.5	295.2	19.68	35.56	18.41	1.98	1.73	1.66	6.62	19.2
22	0.0	0.0	0.0	0.0	0.0	0.0	8.6	9.8	0.0	7.9	34.0	234.7	253.1	38.04	36.72	23.42	0.0	----	----	11.45	16.6
23	30.6	54.7	85.3	17.4	1.7	2.4	20.0	8.9	.4	9.6	34.4	257.4	357.3	8.53	10.41	8.36	1.60	1.42	1.12	2.44	22.2
24	325.1	58.3	383.4	136.9	13.0	20.8	2.8	0.0	0.0	11.7	34.5	233.7	425.1	0.0	----	----	2.17	1.90	1.67	1.49	18.3
25	68.2	45.7	113.9	25.7	2.3	3.5	17.7	16.2	2.7	10.6	34.4	188.6	292.3	20.58	10.65	8.87	2.44	2.17	1.48	2.93	15.6
26	114.1	28.7	142.8	45.2	3.7	5.8	14.2	9.8	.3	9.8	34.4	264.2	362.0	20.14	10.48	8.11	2.33	2.09	1.71	2.54	12.0
27	228.2	46.8	275.0	95.5	8.8	14.6	8.5	9.8	0.0	10.1	34.3	280.3	436.4	11.14	9.96	6.11	2.19	1.92	1.66	1.87	17.7
28																					
Total	1387.7	805.6	2193.3	672.4	65.6	105.6	272.7	325.0	33.8	246.1	962.2	5471.9	7504.0								491.7
Mean	51.4	29.8	81.2	24.9	2.4	3.9	10.1	12.0	1.2	9.1	34.3	210.5	288.6	30.09	23.01	15.36	1.88	1.64	1.33	4.10	18.9

Table A12. Collector Performance for the Month of February 1979

Day	ENVIRONMENT					EAST ARRAY			WEST ARRAY			TOTAL ARRAY		
	Total Incident	Solar While Collecting	Average Ambient Temp	Wind Speed	Direction+ Degrees	T.E. Energy Collected	Avg % Eff.(1)	Avg % Eff.(2)	T.E. Collected	Avg % Eff.(1)	Avg % Eff.(2)	T.E. Collected	Avg % Eff.(1)	Avg % Eff.(2)
1	1470	1413	-8.5	1.75	164	286.8	40.6	39.0	286.1	40.5	38.9	572.9	40.5	39.0
2	838	781	-9.3	2.48	193	131.1	33.6	31.3	129.4	33.1	30.9	260.5	33.4	31.0
3	1591	1534	-7.1	1.66	156	312.1	40.7	39.2	309.1	40.3	38.9	621.2	40.5	39.0
4	1231	1162	-8.0	3.68	213	209.8	36.1	34.1	210.4	36.2	34.2	420.2	36.2	34.1
5	1499	1421	-2.1	1.33	104	292.2	41.1	39.0	289.9	40.8	38.7	582.1	41.0	38.8
6	1320	1284	-2.9	2.05	107	241.9	37.7	36.7	239.6	37.3	36.3	481.5	37.5	36.5
7	916	822	1.1	6.30	172	146.2	35.6	31.9	146.3	35.6	31.9	292.5	35.6	31.9
8	1543	1464	-5.0	1.97	114	279.7	38.2	36.3	279.4	38.2	36.2	559.1	38.2	36.2
9	1118	1058	3.9	1.61	111	214.7	40.6	38.4	216.5	40.9	38.7	431.2	40.8	38.6
10	868	781	2.7	0.93	120	156.3	40.0	36.0	155.3	39.8	35.8	311.6	39.9	35.9
11	1373	1346	7.6	3.10	117	267.8	39.8	39.0	266.8	39.6	38.9	534.8	39.7	39.0
12	831	746	8.5	1.82	98	135.1	36.2	32.5	134.3	36.0	32.3	269.4	36.1	32.4
13	1114†	1010†	---	0.89	87	188.2	37.3	33.8	188.5	37.3	33.8	376.7	37.3	33.8
14	816	804	8.2	2.63	92	173.6	43.2	42.5	176.6	43.9	43.3	350.2	43.6	42.9
15	1029	938	-8.4	3.37	105	140.5	30.0	27.3	142.3	30.3	27.7	282.8	30.1	27.5
16	294	161	-6.9	1.83	162	27.9	34.7	19.0	25.9	32.2	17.6	53.8	33.4	18.3
17	1590	1520	1.0	2.79	139	300.8	40.0	37.8	296.1	39.0	37.2	596.9	39.3	37.5
18	1422	1358	3.0	1.45	98	268.8	39.6	37.8	268.9	39.6	37.8	537.7	40.0	37.8
19	1192	1144	5.6	1.46	61	205.6	35.9	34.5	208.1	36.4	34.9	413.7	36.1	34.7
20	1523	1475	2.7	2.22	96	242.5	32.9	31.8	243.1	33.0	31.9	485.6	32.9	31.9
21	661	644	0.1	1.17	61	128.8	40.0	39.0	127.1	39.5	38.5	255.8	39.7	38.7
22	1095	1000	-0.5	1.11	88	185.5	37.1	33.9	187.3	37.5	34.2	372.8	37.3	34.0
23	490	307	-3.5	0.14	114	37.5	24.4	15.3	38.4	25.0	15.7	75.9	24.7	15.5
24	1485	0	-1.0	0.60	136	0.0	Faulty controller		0.0	----	----	0.0	----	----
25	912	892	3.3	0.16	200	166.3	39.5	36.5	167.2	39.7	36.7	333.4	37.4	36.6
26	613*	428*	6.3	0.11	151	99.3	46.4	32.4	98.1	45.8	32.0	197.4	46.1	32.2
27	418	326	0.6	0.13	203	54.7	33.6	26.1	54.5	33.4	26.1	109.2	33.5	26.1
28														
Total	29252	25819				4893.7			4885.2			9778.9		
Mean	1083	956	-0.3	1.81	---	181.3	37.9	33.5	180.9	38.8	33.4	362.2	37.9	33.4

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Table A13. Space and DHW Heating for the Month of March 1979

Day	ENERGY FOR HEATING AND DHW				ENERGY FOR SPACE HEATING				ENERGY FOR DHW			
	Solar MJ	Aux MJ	Total MJ	Solar Fraction	Solar MJ	Aux MJ	Total MJ	Solar Fraction	Solar MJ	Aux MJ	Total MJ	Solar Fraction
1	420.4	29.0	449.4	.94	363.9	7.1	371.0	.98	56.5	21.9	78.4	.72
2	194.2	210.4	404.6	.48	177.8	169.5	342.3	.52	16.4	45.9	62.3	.26
3	457.6	212.2	669.8	.68	411.8	181.2	593.0	.69	45.8	31.0	76.8	.60
4	557.9	30.5	588.4	.95	498.3	11.8	510.1	.98	59.6	18.7	78.3	.76
5	284.6	26.4	311.0	.92	232.0	7.4	239.4	.97	52.6	19.0	71.6	.73
6	216.7	47.9	264.6	.82	174.5	8.2	182.7	.96	42.2	39.7	81.9	.52
7	213.7	17.6	231.3	.92	160.8	0.0	160.8	1.00	52.9	17.6	70.5	.75
8	417.2	51.7	462.9	.90	417.2	0.0	417.2	1.00	0.0	51.7	51.7	0
9	464.5	44.7	508.9	.91	405.9	11.4	417.3	.97	58.6	33.3	91.9	.64
10	445.9	34.5	480.4	.93	394.9	16.6	411.3	.96	51.0	17.9	68.9	.74
11	328.4	18.2	346.6	.95	276.5	0.0	275.5	1.00	52.9	18.2	71.1	.74
12	284.5	16.8	301.3	.94	231.6	0.0	231.6	1.00	52.9	16.8	69.7	.76
13	252.3	20.6	272.9	.92	198.2	0.0	198.2	1.00	54.1	20.6	74.7	.72
14	175.6	20.1	195.7	.90	122.4	0.0	122.4	1.00	53.2	20.1	73.3	.73
15	305.2	36.2	341.4	.89	251.2	15.4	266.6	.94	54.0	20.8	74.8	.72
16	233.6	21.7	255.3	.92	180.7	0.0	180.7	1.00	52.9	21.7	74.6	.71
17	208.1	18.6	326.7	.94	256.8	0.0	256.8	1.00	51.3	18.6	69.9	.73
18	553.8	45.8	599.6	.92	553.8	0.0	553.8	.00	0.0	45.8	45.8	0
19	234.9	49.7	284.6	.83	192.7	7.3	200.0	.96	42.2	42.4	84.6	.50
20	135.8	100.9	236.7	.57	123.0	45.8	168.8	.73	12.8	55.1	67.9	.19
21	148.2	138.6	286.8	.52	128.8	91.8	220.6	.58	19.4	46.8	66.2	.29
22	110.5	368.3	478.8	.23	88.4	318.7	407.1	.22	22.1	49.6	71.7	.31
23	-19.5	461.6	442.1	----	-19.5	407.9	388.4	----	0.0	53.7	53.7	0
24	380.8	23.9	404.7	.94	320.3	0.0	320.3	1.00	60.5	23.9	84.4	.72
25	231.5	18.3	249.8	.93	178.6	0.0	178.6	1.00	52.9	18.3	71.2	.74
26	337.9	72.3	410.2	.82	332.6	16.5	349.1	.95	5.3	55.8	61.1	.09
27	269.2	68.0	337.2	.80	229.2	24.2	253.4	.90	40.0	43.8	83.8	.48
28	353.1	31.4	384.5	.92	304.1	.3	304.4	1.00	49.0	31.1	80.1	.61
29	176.0	172.9	348.9	.50	175.2	127.3	284.5	.55	18.8	45.6	64.4	.29
30	290.4	41.1	331.5	.88	254.8	2.8	257.6	.99	35.6	38.3	71.2	.48
31	96.3	402.9	499.2	.19	84.9	355.1	440.0	.19	11.4	47.8	59.2	.19
Total	8859.3	2852.8	11712.1		7682.4	1821.3	9503.7		1176.9	1031.5	2208.4	
Mean	285.8	92.0	377.8	.76	247.8	58.8	306.6	.81	37.9	33.3	71.2	.53

Table A14. Solar Thermal Energy Transport for the Month of March 1979

Day	FROM COLLECTORS						STORAGE PERFORMANCE				
	Coll. Deliv.	To Storage	To Rooms	To DHW	Loss to Rooms	Loss to Outdoors	Charge	Discharge	Loss to Rooms	Loss to Outdoors	Change In Storage
1	468.0	328.8	5.9	56.5	33.0	43.8	328.8	303.8	21.2	12.0	-8.2
2	104.5	66.1	4.0	16.4	4.5	13.5	66.1	162.1	7.2	5.8	-109.0
3	477.5	238.3	133.0	45.8	25.1	35.3	238.3	242.7	11.0	5.9	-21.3
4	652.4	400.8	99.1	59.6	39.3	53.6	400.8	337.8	22.2	10.9	29.9
5	579.1	428.2	2.1	52.6	43.9	52.3	428.2	156.7	29.2	16.4	225.9
6	177.4	71.2	0.0	42.2	21.5	42.5	71.2	128.9	21.8	16.3	-95.8
7	479.7	318.7	2.7	52.9	52.8	52.6	318.7	73.7	31.4	21.2	192.4
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	398.6	18.6	15.9	-433.1
9	467.0	317.1	7.1	58.6	31.2	53.0	317.1	343.4	24.2	11.6	-62.1
10	643.7	432.1	55.5	51.0	43.1	62.0	432.1	266.1	30.2	14.7	121.1
11	609.8	426.9	0.0	52.9	58.8	71.2	426.9	178.1	38.6	21.3	188.9
12	557.7	335.2	0.0	52.9	78.9	90.7	335.2	114.0	38.6	27.1	155.5
13	275.8	88.5	0.0	54.1	53.0	80.2	88.5	112.1	33.1	25.4	-82.1
14	519.1	307.1	0.0	53.2	70.7	88.1	307.1	13.5	38.3	26.9	228.4
15	443.9	178.9	22.0	54.0	87.9	101.1	178.9	104.8	36.5	29.9	7.7
16	264.2	73.4	0.0	52.9	57.7	80.2	73.4	90.3	32.7	27.5	-77.1
17	397.8	190.3	9.8	51.3	68.7	77.7	190.3	142.4	36.0	28.0	-16.1
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	529.4	24.0	18.4	-571.8
19	302.2	209.8	.2	42.2	18.4	31.6	209.8	154.2	19.9	10.9	24.8
20	48.4	10.1	3.9	12.8	1.5	20.1	10.1	108.2	9.3	3.9	-113.3
21	139.1	88.7	15.6	19.4	6.9	8.5	88.7	100.4	5.8	3.7	-21.2
22	144.6	83.4	17.1	22.1	6.0	16.0	83.4	61.1	4.2	2.7	15.4
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-20.7	1.2	2.1	17.4
24	656.0	460.9	33.1	60.5	47.0	54.5	460.9	213.2	27.0	14.6	206.1
25	451.3	316.0	0.0	52.9	40.5	41.9	316.0	106.6	31.6	20.9	156.9
26	11.7	-2.0	0.0	5.3	.3	8.1	-2.0	315.4	16.9	12.6	-346.9
27	280.0	179.7	25.7	40.0	19.6	15.0	179.7	174.1	9.8	7.3	-11.5
28	435.1	276.2	47.2	49.0	29.1	33.6	276.2	211.5	16.2	10.4	38.1
29	82.2	47.2	4.2	17.5	2.3	11.0	47.2	142.4	6.4	5.6	-107.2
30	315.9	197.2	41.5	35.6	20.7	20.9	197.2	181.8	10.8	7.1	-2.5
31	87.5	41.1	23.0	11.4	3.2	8.8	41.1	55.1	3.6	2.6	-20.2
Total	10071.6	6109.9	552.7	1175.6	965.6	1267.8	6109.9	5501.7	657.5	441.6	-490.9
Mean	324.9	197.1	17.8	37.9	31.1	40.9	197.1	177.5	21.2	14.2	-15.8

Table A15. Heat Pump Performance for the Month of March 1979

Day	AUX. ENERGY			ELECTRICAL ENERGY FOR BLOWERS, PUMPS, CONTROLS, ETC.										COEFFICIENT OF PERFORMANCE							
	Heat Pump	Resist. Pump	Total Aux	Compressor	Outdoor Fan	Indoor Blower for HP Aux	Indoor Blower for Solar	Collector Blower	Direct Collector Blower	Controls	Instr.	Base House Load	Total House Electric	Solar Collection	Solar Distr.	Overall Solar	Heat Pump	HP & Distr.	Aux Heating	Overall Heat	Degree Days
1	7.1	0.0	7.1	3.3	.3	.5	11.7	14.9	.6	9.1	34.3	179.6	209.3	31.41	25.97	11.13	1.97	1.73	1.73	8.54	12.6
2	66.5	98.0	164.5	34.6	3.5	4.4	19.0	9.9	.6	10.1	34.5	255.2	414.2	10.56	8.53	6.72	1.75	1.56	1.17	1.88	17.4
3	143.6	37.6	181.2	63.1	6.1	9.7	14.2	15.2	6.3	10.9	34.4	140.3	267.5	31.41	17.09	15.56	2.08	1.82	1.56	3.79	20.3
4	10.7	1.1	11.8	5.4	.5	.9	11.9	16.5	3.8	9.6	34.3	112.0	146.7	39.54	28.39	19.64	1.81	1.57	1.49	10.70	16.0
5	7.4	0.0	7.4	2.6	.3	.3	4.8	15.1	.2	8.1	34.1	191.1	213.4	38.35	32.65	14.30	2.55	2.31	2.31	7.39	11.8
6	8.2	0.0	8.2	4.6	.4	.4	4.9	10.2	0.0	7.4	34.3	211.5	230.4	17.39	26.31	14.36	1.64	1.52	1.52	4.40	10.3
7	0.0	0.0	0.0	0.0	0.0	.1	1.9	12.9	.2	7.4	32.4	202.3	217.2	37.19	38.79	14.44	----	----	----	7.12	9.1
8	0.0	0.0	0.0	0.0	0.0	0.0	13.6	.3	0.0	7.3	34.5	248.7	262.6	----	29.31	30.01	----	----	----	7.06	20.4
9	11.4	0.0	11.4	5.2	.5	.9	15.2	15.0	1.4	9.6	34.5	203.3	238.5	31.13	22.59	15.38	2.00	1.73	1.73	7.26	21.2
10	15.4	1.2	16.6	6.9	.6	1.1	7.6	17.0	2.2	9.0	34.4	94.6	127.0	37.86	35.01	18.13	2.05	1.79	1.69	9.19	14.9
11	0.0	0.0	0.0	0.0	0.0	0.0	4.0	16.3	0.0	8.3	34.2	93.3	113.6	37.41	44.53	16.18	----	----	----	9.00	8.4
12	0.0	0.0	0.0	0.0	0.0	0.0	2.4	14.6	0.0	7.8	33.2	129.9	146.9	38.20	47.50	16.74	----	----	----	8.91	8.7
13	0.0	0.0	0.0	0.0	0.0	0.0	4.4	11.0	0.0	7.6	34.1	275.1	290.5	25.07	25.48	16.38	----	----	----	7.58	16.0
14	0.0	0.0	0.0	0.0	0.0	0.0	.6	14.2	0.0	7.4	32.6	293.2	308.0	35.56	22.50	11.86	----	----	----	5.61	13.3
15	6.6	8.8	15.4	2.8	.3	.5	2.0	13.9	1.4	7.7	34.0	255.6	283.1	31.94	52.40	19.19	2.13	1.83	1.24	6.95	11.7
16	0.0	0.0	0.0	0.0	0.0	0.0	1.6	11.2	0.0	7.2	34.1	233.5	246.3	23.59	56.44	18.25	----	----	----	7.40	8.9
17	0.0	0.0	0.0	0.0	0.0	0.0	2.6	13.0	.8	7.7	34.1	170.3	185.9	30.60	54.77	19.75	----	----	----	9.55	10.0
18	0.0	0.0	0.0	0.0	0.0	2.0	13.9	.3	0.0	7.4	34.1	134.8	149.0	----	38.07	39.00	----	----	----	9.99	17.8
19	7.3	0.0	7.3	3.3	.3	.5	8.1	13.6	.4	8.3	34.2	313.1	337.9	22.22	19.04	10.82	2.03	1.78	1.78	4.17	17.2
20	23.4	22.4	45.8	10.3	1.0	1.2	16.4	9.4	.6	8.9	34.4	274.8	332.5	5.15	6.60	5.26	2.07	1.87	1.31	2.04	19.4
21	73.2	18.6	91.8	34.8	3.8	4.2	15.3	8.0	1.4	9.0	34.3	296.7	370.7	9.09	6.56	6.36	1.90	1.71	1.50	2.18	16.0
22	280.0	38.7	318.7	111.5	10.7	15.4	11.3	13.0	2.0	10.9	34.4	266.7	434.3	12.80	5.41	4.55	2.29	2.03	1.81	1.91	17.8
23	402.9	5.0	407.9	148.6	12.2	20.2	0.0	.3	0.0	11.2	34.3	265.0	409.4	----	----	----	2.51	2.23	2.19	1.84	15.2
24	0.0	0.0	0.0	0.0	0.0	0.0	6.6	16.5	1.3	8.9	34.2	150.4	173.5	39.76	32.30	16.48	----	----	----	8.61	9.7
25	0.0	0.0	0.0	0.0	0.0	0.0	3.0	9.7	0.0	8.4	34.3	157.7	188.4	46.53	35.53	18.09	----	----	----	8.03	12.7
26	0.0	16.5	16.5	0.0	0.0	0.0	19.5	2.9	0.0	8.5	33.7	246.9	285.8	4.03	16.17	15.08	----	----	1.00	4.33	20.3
27	19.1	5.1	24.2	13.4	1.2	1.6	13.2	9.7	2.5	9.4	34.2	252.1	292.4	28.87	13.19	11.76	1.30	1.18	1.14	3.83	11.5
28	0.0	.3	.3	0.0	0.0	0.0	9.5	14.9	2.2	8.8	33.5	232.3	257.0	29.20	22.26	14.47	----	----	1.00	6.89	8.4
29	70.7	56.6	127.3	25.9	2.2	3.3	21.0	8.8	1.0	10.0	34.4	246.8	357.2	9.34	6.78	5.91	2.52	2.25	1.45	2.14	12.0
30	2.3	.5	2.8	.7	.1	.1	13.9	11.0	1.8	8.7	34.5	231.5	257.5	28.72	13.08	11.66	2.88	2.56	2.00	5.13	12.5
31	344.5	10.6	355.1	157.8	14.0	23.5	8.6	7.6	2.7	11.1	34.5	164.4	372.5	11.51	6.41	5.94	2.01	1.76	1.72	1.85	15.7
Total	1500.3	321.0	1821.3	634.8	58.0	88.8	282.7	346.9	33.4	271.7	1057.0	6540.7	8119.2								437.2
Mean	48.4	10.4	58.8	20.5	1.9	2.9	9.1	11.2	1.1	8.8	34.1	211.0	261.9	29.03	19.46	14.07	2.17	1.92	1.65	4.24	14.1

Table A16. Collector Performance for the Month of March 1979

Day	ENVIRONMENT					EAST ARRAY			WEST ARRAY			TOTAL ARRAY		
	Total Incident	Solar While Collecting	Average Ambient Temp	Wind Speed	Direction+ Degrees	T.E. Energy Collected	Avg % Eff.(1)	Avg % Eff.(2)	T.E. Collected	Avg % Eff.(1)	Avg % Eff.(2)	T.E. Collected	Avg % Eff.(1)	Avg % Eff.(2)
1	1245	1203	5.4		131	234.3	39.0	37.6	233.7	38.9	37.5	468.0	38.9	37.6
2	363	292	.1		135	52.8	36.2	29.1	51.8	35.5	28.5	104.5	35.8	28.8
3	1344	1215	-2.5		169	239.8	39.5	35.7	237.7	39.1	35.4	477.5	39.3	35.5
4	1662	1599	2.6		139	324.5	40.6	39.0	327.9	41.0	39.5	652.4	40.8	39.3
5	1478	1434	7.9		101	290.9	40.6	39.4	288.2	40.2	39.0	579.1	40.4	39.2
6	718	559	8.9		84	88.8	31.8	24.7	88.6	31.7	24.7	177.4	31.7	24.7
7	1368	1265	10.8		64	239.6	37.9	35.0	240.1	38.0	35.1	479.7	37.9	35.1
8	127	0	-1.3		91	0.0	----	----	0.0	----	----	0.0	----	----
9	1471	1531	-2.4		140	231.2	34.2	31.4	235.9	34.9	32.1	467.0	34.6	31.7
10	1690	1621	4.7		116	323.5	39.9	38.3	320.2	39.5	37.9	643.7	39.7	38.1
11	1679	1628	9.6		95	303.7	37.3	36.2	305.1	37.5	36.3	608.8	37.4	36.3
12	1674	1608	10.3		77	278.1	34.6	33.2	279.6	34.8	33.4	557.7	34.7	33.3
13	1072	971	2.0		61	136.8	28.2	25.4	139.0	28.6	25.9	275.8	28.4	25.6
14	1657	1549	5.4		52	258.3	33.3	31.2	260.8	33.7	31.5	519.1	33.5	31.3
15	1603	1491	5.9		64	221.4	29.7	27.6	222.5	29.8	27.8	443.9	29.8	27.7
16	1106	961	9.0		46	130.5	27.2	23.6	133.6	27.8	24.2	264.2	27.5	23.9
17	1314	1231	7.3		53	199.4	32.4	30.4	198.4	32.2	30.2	397.8	32.3	30.3
18	227	0	0.6		97	0.0	----	----	0.0	----	----	0.0	----	----
19	904	755	0.9		78	150.0	39.7	33.2	152.2	40.3	33.7	302.2	40.0	33.4
20	350	222	-0.7		113	24.2	21.8	13.8	24.2	21.8	13.8	48.4	21.8	13.8
21	461	353	1.7		125	71.1	40.3	30.8	68.0	38.5	29.5	139.1	39.4	30.2
22	536	450	1.0		169	72.6	32.3	27.1	72.0	32.0	26.9	144.6	32.1	27.0
23	1133	0	3.7		147	0.0	----	----	0.0	----	----	0.0	----	----
24	1721	1615	9.4		154	332.0	41.1	38.6	324.0	40.1	37.7	656.0	40.6	38.1
25	1292	1055	5.4		74	226.4	42.9	35.0	224.9	42.6	34.8	451.3	42.8	34.9
26	167	34	-0.8		82	7.8	45.9	9.3	3.9	22.9	4.7	11.7	34.4	7.0
27	793	641	8.6		106	141.0	44.0	35.6	139.0	43.4	35.0	280.0	43.7	35.3
28	1159	1036	9.4		115	218.1	42.1	37.6	216.9	41.9	37.4	435.1	42.0	37.5
29	345	234	7.1		208	41.7	35.6	24.2	40.5	34.6	23.5	82.2	35.1	23.8
30	932	815	4.7		82	157.9	38.7	33.9	158.0	38.8	33.9	315.9	38.8	33.9
31	291	230	0.8		175	44.8	39.0	30.8	42.7	37.1	29.3	87.5	38.0	30.1
Total	31887	27418				5041.2			5029.4			10070.6		
Mean	1029	884	4.4	---	---	162.6	36.8	31.6	162.2	36.7	31.5	324.8	36.7	31.6

Table A17. Space and DHW Heating for the Month of April 1979

Day	ENERGY FOR HEATING AND DHW				ENERGY FOR SPACE HEATING				ENERGY FOR DHW			
	Solar MJ	Aux MJ	Total MJ	Solar Fraction	Solar MJ	Aux MJ	Total MJ	Solar Fraction	Solar MJ	Aux MJ	Total MJ	Solar Fraction
1	152.5	315.6	468.1	.33	134.5	267.0	401.5	.33	18.0	48.6	66.6	.27
2	355.7	42.8	398.5	.89	312.2	8.4	320.6	.97	43.5	34.4	77.9	.56
3	306.1	174.1	480.2	.64	272.3	137.2	409.5	.66	33.8	36.9	70.7	.48
4	284.5	33.6	318.1	.89	235.9	0.1	236.0	1.00	48.6	33.5	82.1	.59
5	227.0	17.2	244.2	.93	175.2	0.0	175.2	1.00	51.8	17.2	69.0	.75
6	297.1	22.6	319.7	.93	242.7	0.0	242.7	1.00	54.4	22.6	77.0	.71
7	229.4	21.0	250.4	.92	179.2	0.0	179.2	1.00	50.2	21.0	71.2	.71
8	190.6	18.4	209.0	.91	140.6	0.0	140.6	1.00	50.0	18.4	68.4	.73
9	152.5	22.7	175.2	.87	102.2	0.0	102.2	1.00	50.3	22.7	73.0	.69
10	457.2	49.0	506.2	.90	454.9	2.3	457.2	.99	2.3	46.7	49.0	.05
11	196.9	84.8	281.7	.70	180.2	34.5	214.7	.84	16.7	50.3	67.0	.25
12	320.6	68.5	389.1	.82	272.7	36.7	309.4	.88	47.9	31.8	79.7	.60
13	239.4	28.4	267.8	.89	188.7	0.0	188.7	1.00	50.7	28.4	79.1	.64
14	179.6	16.7	196.3	.91	131.6	0.0	131.6	1.00	48.0	16.7	64.7	.74
15	161.6	16.8	178.4	.91	109.9	0.0	109.9	1.00	51.7	16.8	68.5	.75
16	180.0	17.2	197.2	.91	124.7	0.0	124.7	1.00	55.3	17.2	72.5	.76
17	183.1	24.9	208.0	.88	130.3	3.1	133.4	.98	52.8	21.8	74.6	.71
18	175.8	21.0	196.8	.89	122.9	0.0	122.9	1.00	52.9	21.0	73.9	.72
19	153.3	19.2	172.5	.89	101.6	0.0	101.6	1.00	51.7	19.2	70.9	.73
20	146.7	21.1	167.8	.87	92.4	0.0	92.4	1.00	54.3	21.1	75.4	.72
21	155.7	18.9	174.6	.89	103.4	0.0	103.4	1.00	52.3	18.9	71.2	.73
22	129.9	17.7	147.6	.88	74.3	0.0	74.3	1.00	55.6	17.7	73.3	.76
23	137.2	14.9	152.1	.90	87.3	0.0	87.3	1.00	49.9	14.9	64.8	.77
24	102.6	25.8	128.4	.80	59.0	0.0	59.0	1.00	43.6	25.8	69.4	.63
25	196.7	34.7	231.4	.85	139.5	16.1	155.6	.90	57.2	18.6	75.8	.75
26	230.4	18.3	248.7	.93	182.1	0.0	182.1	1.00	48.3	18.3	66.6	.73
27	295.4	18.9	314.3	.94	239.6	0.0	239.6	1.00	55.8	18.9	74.7	.75
28	271.6	18.0	289.6	.94	217.5	0.0	217.5	1.00	54.1	18.0	72.1	.75
29	336.7	14.7	351.4	.96	282.4	0.0	282.4	1.00	54.3	14.7	69.0	.79
30	262.0	28.4	290.4	.90	207.8	0.0	207.8	1.00	54.2	28.4	82.6	.66
Total	6707.8	1245.9	7953.7		5297.6	505.4	5803.0		1410.2	740.5	2150.7	
Mean	223.6	41.5	265.1	.84	176.6	16.8	193.4	.91	47.0	24.7	71.7	.66

Table A18. Solar Thermal Energy Transport for the Month of April 1979

Day	FROM COLLECTORS						STORAGE PERFORMANCE				
	Coll. Deliv.	To Storage	To Rooms	To DHW	Loss to Rooms	Loss to Outdoors	Charge	Discharge	Loss to Rooms	Loss to Outdoors	Change In Storage
1	154.9	83.5	30.9	18.0	5.1	17.4	83.5	94.4	4.1	2.7	-17.7
2	381.4	285.6	5.0	43.5	21.7	25.6	285.6	269.0	16.5	8.0	-7.9
3	316.4	177.9	59.0	33.8	15.8	29.9	177.9	186.4	11.1	5.3	-24.9
4	392.7	280.0	0.0	48.6	21.0	43.1	280.0	193.7	16.7	9.0	60.6
5	579.4	419.6	0.0	51.8	40.3	67.7	419.6	102.2	32.1	17.9	267.4
6	483.3	277.7	0.0	54.4	63.7	87.5	277.7	143.2	36.1	24.1	74.3
7	343.6	153.8	0.0	50.2	56.2	83.4	153.8	90.2	32.8	24.6	6.2
8	475.5	251.1	0.0	50.0	71.3	102.8	251.4	31.0	38.3	27.0	155.1
9	420.1	204.1	0.0	50.3	66.1	99.6	204.1	0.0	36.0	29.0	139.1
10	4.2	-1.6	0.0	2.3	.1	3.4	-1.6	428.3	26.5	23.3	-479.7
11	59.0	22.7	0.0	16.7	-.6	20.2	22.7	165.5	15.1	10.8	-168.7
12	483.3	323.7	43.3	47.9	23.8	44.6	323.7	183.5	22.1	11.6	106.5
13	356.8	209.7	6.5	50.7	28.2	61.7	209.7	129.2	24.8	14.6	41.1
14	542.8	353.8	0.0	48.0	54.6	86.4	353.8	41.2	35.8	21.1	255.7
15	447.4	224.9	0.0	51.7	77.2	93.6	224.9	0.0	32.6	26.7	165.6
16	462.1	215.1	0.0	55.3	89.0	102.7	215.1	0.0	35.7	31.2	148.2
17	387.6	136.5	0.0	52.6	88.6	109.9	136.5	7.2	34.5	33.2	61.6
18	390.0	136.7	0.0	52.9	85.0	115.4	136.7	0.0	37.9	34.5	64.3
19	244.5	24.1	0.0	51.7	68.4	100.3	24.1	0.0	33.2	32.6	-41.7
20	197.2	-13.9	0.0	54.3	63.5	93.3	-13.8	0.0	28.8	29.0	-71.7
21	294.6	76.3	0.0	52.3	73.6	92.4	76.3	0.0	29.8	27.6	18.9
22	140.6	-25.4	0.0	55.6	52.3	58.1	-25.4	0.0	24.3	22.0	-71.7
23	297.8	108.4	0.0	49.9	61.5	78.0	108.4	0.0	25.8	24.4	58.2
24	119.8	-8.4	0.0	43.6	36.1	48.5	-8.4	0.0	21.7	22.9	-53.0
25	359.4	154.0	15.0	57.2	64.6	68.6	154.0	32.4	27.5	24.6	69.5
26	361.9	68.3	8.5	48.3	144.4	92.4	68.3	0.0	29.1	24.9	114.3
27	410.3	96.0	0.0	55.8	149.8	108.7	96.0	61.1	28.7	25.4	-19.2
28	388.6	108.9	0.0	54.1	134.9	90.7	108.9	49.8	32.8	24.7	1.6
29	476.1	160.8	28.2	54.3	132.2	100.6	160.8	83.8	38.2	26.1	12.7
30	231.9	-32.6	0.0	54.2	114.5	95.8	-32.6	67.2	25.4	22.0	-147.2
Total	10203.2	4471.6	196.4	1410.0	1902.9	2222.3	4471.6	2359.3	834.0	660.8	617.5
Mean	340.1	149.0	6.6	47.0	63.4	74.1	149.0	78.6	27.8	22.0	20.6

Table A19. Heat Pump Performance for the Month of April 1979

AUX ENERGY				ELECTRICAL ENERGY FOR BLOWERS, PUMPS, CONTROLS, ETC.										COEFFICIENT OF PERFORMANCE								
Day	Heat Pump	Resist. Pump	Total Aux	Compressor	Outdoor Fan	Indoor Blower for HP Aux	Indoor Blower for Solar	Collector Blower	Direct Collector Blower	Controls	Instr.	Base House Load	Total House Electric	Solar Collection	Solar Distr.	Overall Solar	Heat Pump	HP & Distr.	Aux Heating	Overall Heat	Degree Days	
1	260.3	6.7	267.0	124.8	12.2	18.8	9.9	9.6	1.8	11.0	34.6	204.1	348.9	16.14	9.54	7.82	1.90	1.67	1.64	2.03	21.5	
2	8.0	.4	8.4	5.9	.5	.9	14.2	10.8	.7	8.9	34.0	250.5	281.5	35.31	18.94	14.23	1.25	1.13	1.09	5.94	18.2	
3	119.3	17.9	137.2	54.7	5.1	7.3	17.2	13.5	3.9	10.7	34.7	227.2	326.9	23.44	10.84	9.97	1.99	1.78	1.61	3.15	17.9	
4	0.0	0.1	0.1	0.0	0.0	0.0	7.0	16.3	0.0	8.5	34.1	237.3	260.7	24.09	27.67	12.21	----	----	1.00	5.59	12.1	
5	0.0	0.0	0.0	0.0	0.0	0.0	2.9	16.0	0.0	7.9	33.7	195.7	214.6	36.21	35.24	12.01	----	----	----	6.76	9.0	
6	0.0	0.0	0.0	0.0	0.0	0.0	3.0	16.9	0.0	8.0	34.5	193.2	213.1	28.60	47.73	14.93	----	----	----	7.52	8.3	
7	0.0	0.0	0.0	0.0	0.0	0.0	2.1	15.2	0.0	7.8	34.6	135.9	153.2	22.61	42.95	13.26	----	----	----	6.54	8.3	
8	0.0	0.0	0.0	0.0	0.0	0.0	2.6	16.0	0.0	8.1	34.6	114.8	133.4	29.72	11.92	10.25	----	----	----	5.65	9.5	
9	0.0	0.0	0.0	0.0	0.0	0.0	.6	14.3	0.0	7.3	33.9	211.9	226.8	29.38	----	10.23	----	----	----	4.66	6.1	
10	-.3	2.6	2.3	.1	.1	0.0	9.3	1.2	0.0	6.9	34.5	264.0	277.2	3.50	46.05	43.54	----	----	0.82	8.44	15.0	
11	21.7	12.8	34.5	8.5	.9	1.3	18.7	6.7	0.0	9.1	33.9	238.3	284.6	8.81	8.85	7.75	2.31	2.03	1.47	2.84	17.8	
12	26.4	10.3	36.7	14.8	1.2	1.9	6.5	15.8	2.8	8.5	34.6	206.5	252.9	30.59	28.23	14.38	1.65	1.47	1.30	4.73	15.7	
13	0.0	0.0	0.0	0.0	0.0	0.0	4.0	15.8	.8	8.1	34.6	178.3	198.1	22.58	32.30	12.09	----	----	----	5.56	11.3	
14	0.0	0.0	0.0	0.0	0.0	0.0	1.2	16.5	0.0	7.9	34.6	108.4	126.1	32.90	34.33	10.15	----	----	----	5.71	8.5	
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.7	0.0	7.6	34.4	118.3	134.0	28.50	----	10.29	----	----	----	5.49	2.7	
16	0.0	0.0	0.0	0.0	0.0	0.0	.1	14.2	0.0	7.4	34.0	190.1	204.4	32.54	----	12.59	----	----	----	6.26	2.7	
17	1.3	1.8	3.1	1.5	.1	.1	0.0	14.2	0.0	8.2	32.7	212.4	229.7	27.30	----	12.89	0.81	0.76	0.89	5.27	2.7	
18	0.0	0.0	0.0	0.0	0.0	0.0	.1	12.7	0.0	7.3	33.8	224.4	237.2	30.71	----	13.73	----	----	----	5.82	0.8	
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	0.0	6.9	34.1	177.3	187.8	23.29	----	14.60	----	----	----	5.81	6.5	
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.2	0.0	7.0	34.4	192.6	203.8	17.63	----	13.10	----	----	----	5.20	10.0	
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0	0.0	7.4	34.3	106.6	120.6	21.04	----	11.12	----	----	----	5.31	5.7	
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.4	0.0	7.1	34.2	109.8	121.2	12.33	----	11.39	----	----	----	5.07	3.5	
23	0.0	0.0	0.0	0.0	0.0	0.0	.1	14.5	0.0	7.4	34.1	179.0	193.6	20.54	----	9.40	----	----	----	5.16	1.1	
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.4	0.0	6.5	34.2	196.5	204.9	14.26	----	12.21	----	----	----	3.75	5.9	
25	16.1	0.0	16.1	5.7	.4	.7	0.8	13.1	1.5	7.6	34.3	220.1	239.3	27.44	40.50	14.15	2.64	2.37	2.37	5.89	9.7	
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.4	1.0	7.4	34.3	249.8	265.2	23.50	----	14.96	----	----	----	7.38	8.4	
27	0.0	0.0	0.0	0.0	0.0	0.0	1.9	12.6	0.0	7.6	34.4	200.9	215.4	32.56	32.16	20.37	----	----	----	9.41	9.6	
28	0.0	0.0	0.0	0.0	0.0	0.0	1.3	13.9	0.0	7.9	34.3	99.8	115.0	27.96	38.31	17.87	----	----	----	8.72	8.8	
29	0.0	0.0	0.0	0.0	0.0	0.0	1.6	14.4	2.0	7.9	34.2	98.3	114.3	33.06	52.38	21.04	----	----	----	11.45	8.2	
30	0.0	0.0	0.0	0.0	0.0	0.0	2.1	12.5	0.0	7.5	34.3	203.5	218.1	18.55	32.00	17.95	----	----	----	6.75	8.7	
Total	452.8	52.6	505.4	216.0	20.5	31.0	107.2	393.3	14.5	237.4	1026.9	5545.3	6302.5								294.2	
Mean	15.1	1.7	16.8	7.2	0.7	1.0	3.6	13.1	0.5	7.9	34.2	184.9	210.1	25.94	22.01	13.41	1.91	1.69	1.58	5.04	9.1	

Table A20. Collector Performance for the Month of April 1979

Day	ENVIRONMENT					EAST ARRAY			WEST ARRAY			TOTAL ARRAY		
	Total Incident	Solar While Collecting	Average Ambient Temp	Wind Speed	Direction+ Degrees	T.E. Energy Collected	Avg % Eff.(1)	Avg % Eff.(2)	T.E. Collected	Avg % Eff.(1)	Avg % Eff.(2)	T.E. Collected	Avg % Eff.(1)	Avg % Eff.(2)
1	637	457	-2.5	.70	167	81.6	35.7	25.6	73.3	32.1	23.0	154.9	33.9	24.3
2	1093	965	-0.9	.64	156	192.2	39.8	35.2	189.2	39.2	34.6	381.4	39.5	34.9
3	1002	848	.8	.48	190	159.7	37.7	31.9	156.7	37.0	31.3	316.4	37.3	31.6
4	1141	1047	6.5	2.14	124	197.0	37.6	34.5	195.7	37.4	34.3	392.7	37.5	34.4
5	1502	1439	8.7	1.40	76	289.3	40.2	38.5	290.1	40.3	38.6	579.4	40.3	38.6
6	1463	1408	11.8	1.75	85	240.2	34.1	32.8	243.1	34.5	33.2	483.3	34.3	33.0
7	1310	1189	10.5	2.75	110	171.3	28.8	26.2	172.3	29.0	26.3	343.6	28.9	26.2
8	1639	1553	9.0	1.92	69	235.9	30.4	28.8	239.6	30.9	29.2	475.5	30.6	29.0
9	1441	1365	10.9	1.21	52	208.1	30.5	28.9	212.0	31.1	29.4	420.1	30.8	29.2
10	157	21	2.8	.65	42	2.1	20.0	2.7	2.1	20.0	2.7	4.2	20.0	2.7
11	493	263	1.0	1.61	104	28.5	21.7	11.6	30.5	23.2	12.4	59.0	22.4	12.0
12	1333	1195	2.2	1.41	104	243.2	40.7	36.5	240.1	40.2	36.0	483.3	40.4	36.3
13	1117	1017	7.4	1.81	86	178.4	35.1	31.9	178.4	35.1	31.9	356.8	35.1	31.9
14	1562	1498	9.9	1.41	73	270.5	36.1	34.6	272.3	36.4	34.9	542.8	36.2	34.8
15	1444	1377	16.3	1.34	51	222.2	32.3	30.8	225.2	32.7	31.2	447.4	32.5	31.0
16	1613	1484	16.4	1.70	52	228.6	30.8	28.3	233.5	31.5	29.0	462.1	31.1	28.6
17	1455	1324	15.5	.83	61	192.6	29.1	26.5	195.0	29.5	26.8	387.6	29.3	26.6
18	1461	1321	17.2	1.31	51	193.7	29.3	26.5	196.3	29.7	26.9	390.0	29.5	26.7
19	1189	996	11.6	1.29	47	120.3	24.2	20.2	124.2	24.9	20.9	244.5	24.5	20.6
20	1164	916	8.8	1.33	42	96.1	21.0	16.5	101.1	22.0	17.4	197.2	21.5	16.9
21	1200	1069	13.1	.83	49	145.7	27.3	24.3	148.9	27.9	24.8	294.6	27.6	24.6
22	826	578	14.8	.39	38	69.4	24.0	16.8	71.2	24.6	17.2	140.6	24.3	17.0
23	1113	1026	17.5	1.33	55	147.1	28.7	26.4	150.7	29.4	27.1	297.8	29.0	26.8
24	705	501	12.5	1.12	37	59.1	23.6	16.8	60.7	24.2	17.2	119.8	23.9	17.0
25	1284	1141	8.9	1.86	79	180.6	31.7	28.0	178.8	31.3	27.9	359.4	31.5	28.0
26	1278	1192	8.9	2.00	89	215.7	36.2	33.8	146.2	24.5	22.9	361.9	30.4	28.3
27	1410	1296	9.4	1.96	73	231.3	35.7	32.8	179.0	27.6	25.4	410.3	31.7	29.1
28	1245	1171	9.9	2.23	97	223.2	38.1	35.9	165.4	28.2	26.6	388.6	33.2	31.2
29	1476	1838	10.4	1.43	71	276.5	40.0	37.5	199.6	28.9	27.0	476.1	34.4	32.3
30	954	789	9.3	.89	61	120.2	30.5	25.2	111.7	28.3	23.4	231.9	29.4	24.3
Total	35707	31829				5220.3			4982.9			10203.2		
Mean	1190	1061	9.3	1.37	--	174.0	32.8	29.2	166.1	31.3	27.9	340.1	32.1	28.6

Table A21. Space and DHW Heating for the Month of May 1979

	ENERGY FOR HEATING AND DHW				ENERGY FOR SPACE HEATING				ENERGY FOR DHW			
Day	Solar MJ	Aux MJ	Total MJ	Solar Fraction	Solar MJ	Aux MJ	Total MJ	Solar Fraction	Solar MJ	Aux MJ	Total MJ	Solar Fraction
1	303.6	29.2	332.8	.91	271.3	.3	271.6	1.00	32.3	28.9	61.9	.52
2	237.5	126.5	364.0	.65	235.3	72.5	308.8	.76	2.2	54.0	56.2	.04
3	7.5	343.8	351.3	.02	7.5	283.9	291.4	.03	0.0	59.9	59.9	.00
4	211.2	32.6	243.8	.87	164.0	0.0	164.0	1.00	47.2	32.6	79.8	.59
5	206.5	15.2	221.7	.93	150.6	0.0	150.6	1.00	55.9	15.2	71.1	.79
6	232.7	16.5	249.2	.93	175.1	0.0	175.1	1.00	57.6	16.5	74.1	.78
7	332.4	55.2	387.6	.86	332.4	6.1	338.5	.98	0.0	49.1	49.1	.00
8	256.7	122.5	379.2	.68	255.2	63.6	318.8	.80	1.5	58.9	60.4	.02
9	6.1	458.4	464.5	.01	6.1	398.0	404.1	.02	0.0	60.4	60.4	.00
10	324.4	45.1	369.5	.88	309.1	20.3	329.4	.94	15.3	24.8	40.1	.38
11	341.6	5.4	347.0	.98	333.0	3.6	336.6	.99	8.6	11.8	20.4	.42
Total	2460.2	1250.4	3710.6		2239.6	848.3	3087.9		220.6	402.1	622.7	
Mean	223.6	113.7	337.3	0.66	203.6	77.1	280.7	0.73	20.0	36.6	56.6	0.35

Table A22. Solar Thermal Energy Transport for the Month of May 1979

Day	FROM COLLECTORS						STORAGE PERFORMANCE				
	Coll. Deliv.	To Storage	To Rooms	To DHW	Loss to Rooms	Loss to Outdoors	Charge	Discharge	Loss to Rooms	Loss to Outdoors	Change In Storage
1	153.5	19.2	0.0	32.3	55.5	46.5	19.2	198.8	17.0	18.4	-215.0
2	8.4	-2.5	0.0	2.2	4.0	4.7	-2.5	222.8	8.5	10.1	-243.9
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7	-2.2	1.7	-9.2
4	467.2	325.5	0.0	47.2	55.0	39.5	325.5	79.7	29.4	12.5	203.9
5	484.2	221.6	0.0	55.9	121.5	85.2	221.6	0.0	29.1	19.4	173.1
6	480.8	183.7	0.0	57.6	150.2	89.3	183.7	0.0	25.0	20.1	138.6
7	1.6	0.0	-0.4	0.0	0.0	2.0	0.0	311.7	21.2	20.7	-353.6
8	6.0	-2.1	0.0	1.5	2.1	4.5	-2.1	244.0	9.2	10.6	-265.9
9	13.8	0.0	-1.6	0.0	-0.2	15.6	0.0	12.3	-4.5	1.7	-9.5
10	429.9	260.1	-4.4	15.3	58.9	100.0	260.1	239.9	14.7	6.8	-1.3
11	411.2	204.6	60.7	8.6	55.8	81.5	204.6	203.5	13.1	6.7	-18.7
Total	2456.6	1210.1	54.3	220.6	502.8	468.8	1210.1	1522.4	160.5	128.7	-601.5
Mean	223.3	110.0	4.9	20.1	45.7	42.6	110.0	138.4	14.6	11.7	-54.7

Table A23. Heat Pump Performance for the Month of May 1979

Day	AUX ENERGY			ELECTRICAL ENERGY FOR BLOWERS, PUMPS, CONTROLS, ETC.										COEFFICIENT OF PERFORMANCE							
	Heat Pump	Resist. Pump	Total Aux	Compressor	Outdoor Fan	Indoor Blower for HP Aux	Indoor Blower for Solar	Collector Blower	Direct Collector Blower	Controls	Instr.	Base House Load	Total House Electric	Solar Collection	Solar Distr.	Overall Solar	Heat Pump	HP & Distr.	Aux Heating	Overall Heat	Degree Days
1	0.0	0.3	0.3	0.0	0.0	0.0	6.4	7.7	0.0	7.3	34.2	219.9	234.3	19.74	31.06	21.53	----	----	1.00	7.69	7.3
2	31.3	41.2	72.5	11.1	1.1	1.6	18.7	2.1	0.0	8.6	34.4	241.1	313.6	4.00	11.91	11.42	2.57	2.27	1.32	2.80	16.2
3	206.9	77.0	283.9	86.2	7.6	11.3	23.6	0.3	0.0	10.6	34.5	297.3	478.4	----	.41	.31	2.21	1.97	1.56	1.32	15.5
4	0.0	0.0	0.0	0.0	0.0	0.0	3.0	12.6	0.0	8.4	34.0	214.5	230.1	37.08	26.57	13.54	----	----	----	5.06	6.5
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.9	0.0	7.7	34.1	132.6	148.5	30.45	----	12.99	----	----	----	7.13	.3
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.5	0.0	7.5	33.9	103.8	118.3	33.16	----	16.05	----	----	----	8.04	3.4
7	6.1	0.0	6.1	2.4	.2	.3	7.2	.7	0.0	6.5	34.4	251.3	261.4	2.29	43.29	42.08	2.35	2.10	2.10	6.47	13.7
8	23.2	40.4	63.6	10.8	1.0	1.6	17.4	1.3	0.0	8.3	34.5	265.8	335.2	4.62	14.02	13.73	1.97	1.73	1.18	2.89	16.6
9	280.7	117.3	398.0	124.0	12.3	18.5*	19.5*	1.9	0.0	11.2	34.6	279.8	528.2	7.26	.63*	.29	2.06	1.81*	1.46*	1.32	19.6
10	19.8	.5	20.3	8.5	.9	1.2	16.6	15.3	0.0	10.2	34.5	190.0	230.4	28.10	14.45	10.17	2.11	1.87	1.83	5.45	14.4
11	23.0	.6	3.6	1.9	.2	.1	16.9	17.0	3.6	10.5	34.5	160.8	196.9	24.19	12.04	10.08	1.43	1.36	1.29	9.01	10.0
Total	571.0	277.3	848.3	244.9	23.3	34.6	129.3	89.3	3.6	96.8	377.6	2356.9	3075.3								123.5
Mean	51.9	25.2	77.1	22.3	2.1	3.2	10.0	8.1	0.3	8.8	34.3	214.3	279.6	27.51	11.77*	11.26	2.13	1.89*	1.46*	3.09	11.2

Table A24. Collector Performance for the Month of May 1979

	ENVIRONMENT					EAST ARRAY			WEST ARRAY			TOTAL ARRAY		
Day	Total Incident	Solar While Collecting	Average Ambient Temp	Wind Speed	Direction+ Degrees	T.E. Energy Collected	Avg % Eff.(1)	Avg % Eff.(2)	T.E. Collected	Avg % Eff.(1)	Avg % Eff.(2)	T.E. Collected	Avg % Eff.(1)	Avg % Eff.(2)
1	632	471	10.3	1.17	72	80.3	34.1	25.4	73.2	31.1	23.2	153.5	32.6	24.3
2	156	30	0.9	1.34	92	3.4	22.7	4.4	5.0	33.3	6.4	8.4	28.0	5.4
3	156	0	2.1	1.39	225	0.0	----	----	0.0	----	----	0.0	----	----
4	1596	1177	12.8	2.22	157	341.4	58.0	42.3	125.8	21.4	15.8	467.2	39.7	29.3
5	1298	1237	19.9	2.18	156	278.1	45.0	42.9	206.1	33.3	31.8	484.2	39.1	37.3
6	1407	1323	15.0	2.59	131	274.5	41.5	39.0	206.3	31.1	29.3	480.8	36.3	34.2
7	187	2	4.4	0.63	74	.3	----	----	1.3	----	----	1.6	----	----
8	156	19	0.8	0.39	193	2.2	23.2	2.8	3.8	40.0	4.9	6.0	31.6	3.8
9	272	29	-1.1	1.47	358	7.8	53.8	5.7	6.0	41.4	4.4	13.8	47.5	5.1
10	1054	991	3.7	1.86	308	240.8	48.6	45.7	189.1	38.2	35.9	429.9	43.4	40.8
11	1052	989	8.2	2.87	313	235.0	47.5	44.7	176.2	35.6	33.5	411.2	41.6	39.1
Total	7966	6268				1463.8			992.8			2456.6		
Mean	724	570	7.0	1.65	---	133.1	46.7	36.8	90.3	31.7	24.9	223.3	39.2	30.8

APPENDIX B

Summary tables of daily data and energy flows for the 1979 cooling season are provided in this Appendix. The daily totals are from midnight to midnight, with cold charge of storage controlled by a clock to begin shortly after midnight. There are two tables for each month, the first table of the set is for cooling performance and the second table gives environmental data, collector performance and domestic water heating information. Explanations for calculation of the various coefficients of performance are provided below:

Average Daily COP - Total useful cooling supplied divided by the total electrical energies utilized to provide cooling.

Heat Pump COP - Heat removed by the heat pump divided by the electrical energy for heat pump operation (compressor plus outdoor fan).

Hot Water Heating COP - Solar thermal energy provided to DHW preheating divided by electrical energy to operate the air blower and hot water circulating pump.

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Table B1. Cooling Performance for the Month of June 1979

Day	Total Cooling Supplied MJ	Average Daily COP	COLD CHARGE				DIRECT COOLING				STORAGE AND DISCHARGE PERFORMANCE						
			Heat Removed by Heat Pump MJ	Circulation Blower Energy MJ	Heat Pump Oper. Energy MJ	Heat Pump COP	Heat Removed by Heat Pump MJ	Circulation Blower Energy MJ	Heat Pump Oper. Energy MJ	Heat Pump COP	Charge MJ	Discharge MJ	Loss to Outdoors MJ	Loss to House MJ	Change in Storage MJ	Average Storage Temp °C	Blower Energy During Storage Discharge MJ
11	9.6	0.69	29.8	2.0	12.0	2.49	0.0	0.0	0.0	0.00	16.0	0.0	3.1	7.8	-5.2	9.7	0.0
12	211.8	4.59	47.4	3.4	21.1	2.24	26.2	1.4	10.0	2.61	26.6	176.2	2.2	8.3	160.1	12.3	10.3
13	257.4	2.00	238.2	14.1	98.0	2.43	11.1	0.6	3.6	3.06	170.5	210.0	1.3	6.4	47.2	15.0	12.1
14	205.2	1.64	244.8	14.2	99.8	2.45	8.0	0.4	2.6	3.06	178.5	162.8	1.3	5.8	-8.6	15.1	8.0
15	160.0	1.38	236.5	14.1	96.2	2.46	0.0	0.0	0.0	0.00	166.3	122.4	2.1	7.2	-34.6	12.5	6.0
16	53.0	0.52	207.5	13.3	87.9	2.36	0.0	0.0	0.0	0.00	140.9	14.6	3.3	8.2	-114.8	8.9	0.7
17	15.8	0.57	52.4	3.8	24.2	2.17	0.0	0.0	0.0	0.00	29.4	0.0	3.6	8.6	-17.3	8.1	0.0
18	10.2	0.86	21.1	1.7	10.2	2.07	0.0	0.0	0.0	0.00	11.1	0.0	3.4	8.2	0.5	8.5	0.0
19	8.5	0.66	26.1	1.8	11.1	2.35	0.0	0.0	0.0	0.00	10.9	0.0	3.3	7.8	0.3	9.0	0.0
20	97.2	3.99	37.9	2.8	17.2	2.21	0.0	0.0	0.0	0.00	19.7	85.8	2.8	7.9	76.8	10.4	4.4
21	200.1	2.29	164.8	10.6	68.6	2.40	0.0	0.0	0.0	0.00	110.7	172.3	2.6	8.0	72.2	11.1	8.2
22	199.9	1.78	222.7	13.7	90.8	2.45	0.0	0.0	0.0	0.00	156.0	163.7	2.3	6.6	16.6	12.1	7.5
23	40.2	0.37	224.8	14.2	94.2	2.39	0.0	0.0	0.0	0.00	154.3	0.0	3.4	7.7	-143.2	8.8	0.0
24	142.1	6.95	24.2	1.8	11.3	2.15	0.0	0.0	0.0	0.00	11.6	131.6	2.8	7.8	130.6	10.6	7.3
25	193.6	1.94	187.6	12.0	79.1	2.37	0.0	0.0	0.0	0.00	129.1	163.6	2.0	6.8	43.2	13.0	9.0
26	252.5	2.11	222.1	13.6	93.0	2.39	0.0	0.0	0.0	0.00	158.6	220.4	1.5	6.0	69.4	14.6	13.3
27	232.4	1.87	231.9	13.6	96.0	2.42	0.0	0.0	0.0	0.00	168.8	201.4	0.7	4.7	37.9	16.8	14.5
28	224.1	1.80	237.0	13.7	96.9	2.45	0.0	0.0	0.0	0.00	174.8	194.4	0.6	4.4	24.6	17.1	14.1
29	194.3	1.64	240.2	13.6	95.0	2.53	0.0	0.0	0.0	0.00	178.1	165.0	1.0	4.8	-7.4	16.0	9.9
30	65.7	0.59	228.6	13.7	96.6	2.37	0.0	0.0	0.0	0.00	167.6	31.2	2.2	6.9	-127.3	12.3	1.3
Total	2773.8		3125.6	191.7	1299.2		45.3	2.4	16.2		2179.5	2215.4	45.5	139.9	221.0		126.6
Mean	138.7	1.70	156.3	9.6	65.0	2.41	2.3	0.1	0.8	2.80	109.0	110.8	2.3	7.0		11.9	6.3

Table B2. Environmental Conditions, Collector Performance and Electrical Energy Requirements for the Month of June 1979

	ENVIRONMENTAL CONDITIONS		ELECTRICAL ENERGY REQUIREMENTS			ENVIRONMENTAL CONDITIONS WHILE COLLECTOR OPERATING						EAST ARRAY		WEST ARRAY		DOMESTIC HOT WATER					
Day	Ambient Temp °C	Indoor Temp °C	Total House Load MJ	Base House Load MJ	Instrumentation MJ	Total Incident Solar MJ	Incident Solar MJ	Horizontal Wind Speed (m/sec)	Wind Speed on Collector (m/sec)	Ambient Temp °C	Collector Inlet Temp °C	Energy Collected MJ	Efficiency	Energy Collected	Efficiency	Solar Heat to DHW MJ	Collector Blower Electricity MJ	Auxiliary Energy to DHW MJ	Hot Water Pump Electricity MJ	Fraction DHW	COP Heat Hot Water
11	19.3	23.4	234.9	183.7	34.2	1356.1	1198.4	3.71	2.41	24.0	26.2	350.9	58.6	357.0	59.6	71.1	23.1	15.5	6.0	.82	2.44
12	23.3	24.7	259.8	172.9	34.2	1411.9	1264.5	2.88	1.78	28.1	30.5	377.6	59.7	380.2	60.1	78.7	23.1	11.7	6.1	.87	2.69
13	24.0	25.4	327.8	161.2	34.2	1194.2	1045.6	2.91	1.87	27.9	31.2	307.7	58.9	311.5	59.6	70.4	21.1	10.3	5.6	.87	2.64
14	23.6	25.4	326.0	161.9	34.1	867.8	695.6	4.02	2.50	26.9	29.4	211.5	60.8	211.8	60.9	48.9	23.0	23.2	6.0	.68	1.69
15	20.6	25.1	326.2	176.9	33.8	940.0	730.4	3.80	2.30	23.7	26.6	222.0	60.8	228.4	62.5	52.7	18.7	22.5	4.9	.70	2.23
16	18.2	24.2	246.0	107.6	34.0	976.2	810.6	3.40	2.20	20.7	25.1	247.1	61.0	247.3	61.0	50.8	22.7	23.6	5.8	.68	1.78
17	15.8	23.2	163.3	108.9	34.3	878.7	720.9	4.77	3.41	19.2	21.7	206.1	57.2	209.9	58.2	46.3	15.8	23.9	4.0	.66	2.33
18	15.7	22.9	237.7	193.6	34.4	790.0	680.3	2.84	1.81	18.6	21.1	214.2	63.0	215.6	63.4	43.5	20.5	30.3	5.3	.59	1.69
19	14.4	22.7	284.3	237.0	34.4	1147.9	959.4	9.55	7.26	16.3	18.9	270.7	56.4	274.2	57.2	49.5	21.1	30.0	5.4	.62	1.87
20	18.6	23.8	289.9	227.8	34.4	1399.6	1245.2	----	2.11	21.4	24.8	366.9	58.9	371.9	59.7	76.5	22.7	24.5	5.9	.76	2.67
21	20.8	24.2	315.8	192.7	34.3	1338.9	1201.1	----	2.08	25.1	28.1	350.4	58.3	355.1	59.1	74.9	21.3	12.4	5.6	.86	2.78
22	20.2	23.9	300.3	155.9	34.3	1303.2	1040.8	----	2.09	24.8	28.6	315.4	60.6	319.4	61.4	68.9	18.3	12.1	4.8	.85	2.98
23	17.2	23.4	241.4	108.7	34.2	449.8	258.9	----	1.68	18.3	22.7	90.8	70.2	90.1	69.6	22.3	12.8	30.9	3.3	.42	1.38
24	19.5	23.2	182.3	127.8	34.0	1280.5	1088.5	----	1.32	23.3	27.2	336.3	61.8	339.5	62.4	73.0	20.5	19.6	5.5	.79	2.80
25	20.6	24.3	320.6	191.6	34.3	977.4	734.1	----	2.05	23.3	26.0	213.5	58.2	218.7	59.6	53.6	14.8	18.5	3.8	.74	2.87
26	21.9	24.4	359.6	207.3	34.2	970.4	726.6	----	1.80	25.3	28.0	227.3	62.6	231.6	63.8	58.3	16.6	16.6	4.3	.78	2.80
27	21.4	24.9	355.3	201.8	34.0	1026.1	792.7	----	1.55	24.1	28.4	237.8	60.0	240.1	60.6	60.8	15.2	16.8	4.0	.78	3.16
28	21.3	24.7	377.5	220.8	33.9	1234.9	1030.7	----	2.06	25.2	28.4	303.4	58.9	309.2	60.0	73.0	16.9	12.2	4.8	.86	3.36
29	21.3	24.7	319.8	174.4	33.3	1204.0*	913.0	----	1.21	24.6	27.9	299.5	65.6	339.6	74.4	92.8	12.3	13.0	4.6	.88	5.52
30	20.9	24.9	232.4	96.4	34.3	753.6	613.8	----	1.60	25.5	26.9	169.0	55.1	166.9	54.4	52.0	10.4	19.1	4.9	.73	3.39
Totals			5700.9	3408.9	682.8	21501.2		2.30				5318.1		5418.0		1218.0	370.9	386.7	100.6		
Mean	19.9	23.7	285.0	170.4	34.1	1075.1	887.6	4.21		23.0	2.55	265.9	59.9	270.9	61.0	60.9	18.6	19.3	5.0	0.76	2.58

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Table B3. Cooling Performance for the Month of July 1979

Day	Total Cooling Supplied MJ	Average Daily COP	COLD CHARGE				DIRECT COOLING				STORAGE AND DISCHARGE PERFORMANCE						
			Heat Removed by Heat Pump MJ	Circulation Blower Energy MJ	Heat Pump Oper. Energy MJ	Heat Pump COP	Heat Removed by Heat Pump MJ	Circulation Blower Energy MJ	Heat Pump Oper. Energy MJ	Heat Pump COP	Charge MJ	Discharge MJ	Loss to Outdoors MJ	Loss to House MJ	Change in Storage MJ	Average Storage Temp °C	Blower Energy During Storage Discharge MJ
1	91.5	1.87	85.0	5.8	39.1	2.17	0.0	0.0	0.0	0.00	55.7	74.1	2.6	7.6	28.9	11.1	4.1
2	178.5	2.16	144.5	9.5	64.0	2.26	0.0	0.0	0.0	0.00	104.1	154.2	2.0	7.4	59.5	12.8	9.3
3	223.0	2.00	205.0	12.7	85.4	2.40	0.0	0.0	0.0	0.00	155.3	193.9	1.4	6.2	46.3	14.7	13.3
4	51.8	0.47	233.3	13.7	95.6	2.44	0.0	0.0	0.0	0.00	183.7	20.2	2.2	6.4	-154.8	12.2	1.0
5*	187.7	3.40	83.6	5.8	37.8	2.21	0.0	0.0	0.0	0.00	55.2	171.8	1.6	6.7	124.8	13.8	11.6
6	158.0	1.35	222.8	13.6	96.4	2.31	0.0	0.0	0.0	0.00	172.3	125.4	1.4	5.9	-39.6	14.7	7.3
7	109.8	1.18	191.5	1.6	77.6	2.47	0.0	0.0	0.0	0.00	146.8	80.5	2.5	7.2	-56.6	11.4	3.5
8	109.8	1.69	119.0	7.8	53.1	2.24	0.0	0.0	0.0	0.00	85.1	85.9	2.5	8.4	11.7	11.2	4.2
9	278.3	3.03	130.8	8.30	57.3	2.29	21.3	1.0	7.4	2.89	95.8	235.2	1.3	6.6	147.3	15.1	17.8
10	296.5	1.91	243.8	13.6	97.6	2.50	66.2	3.4	25.5	2.60	195.3	200.4	.2	4.3	9.6	18.4	15.1
11	317.0	1.89	240.2	13.5	98.3	2.44	95.5	4.7	37.2	2.57	192.3	193.0	.0	3.3	4.1	18.9	14.0
12	316.6	2.24	242.2	13.5	98.1	2.47	33.6	1.8	13.1	2.56	192.8	191.2	.1	3.6	2.5	18.7	14.6
13	287.2	1.51	239.3	13.4	98.7	2.42	137.7	7.3	57.9	2.21	188.9	181.9	.2	3.8	-3.0	18.5	12.6
14	277.0	1.76	243.4	13.6	97.3	2.50	66.4	3.7	28.6	2.32	191.2	180.1	.5	4.6	-6.0	17.5	13.9
15	51.6	0.47	240.0	13.7	95.8	2.50	0.0	0.0	0.0	0.00	189.1	19.7	1.9	6.2	-161.3	13.3	1.1
16	174.3	2.06	142.0	10.2	66.6	2.13	0.0	0.0	0.0	0.00	91.9	143.8	2.1	7.5	61.5	12.7	8.0
17	57.0	0.61	182.1	11.5	80.2	2.27	0.0	0.0	0.0	0.00	134.9	26.2	2.5	8.1	-98.2	11.3	1.1
18	165.4	2.84	90.4	6.5	42.9	2.11	0.0	0.0	0.0	0.00	58.7	144.9	2.0	7.7	95.9	13.0	8.8
19	241.8	2.09	203.5	12.6	85.7	2.37	0.0	0.0	0.0	0.00	153.9	213.2	1.4	6.1	66.7	14.9	17.3
20	240.5	1.88	236.7	13.7	95.3	2.48	5.2	.3	2.2	2.41	187.4	206.2	.8	4.7	24.2	16.7	16.8
21	177.1	1.49	240.9	13.5	96.1	2.51	0.0	0.0	0.0	0.00	191.5	147.5	.9	4.4	-38.8	16.4	9.0
22	157.4	1.37	227.2	13.6	95.2	2.39	0.0	0.0	0.0	0.00	174.0	124.2	1.6	6.2	-42.1	14.2	6.2
23	233.7	2.02	197.9	12.5	87.7	2.26	0.0	0.0	0.0	0.00	145.5	203.7	1.2	6.1	65.4	15.4	15.3
24	222.5	1.71	233.2	13.6	97.0	2.40	9.9	.5	4.5	2.18	182.2	182.7	.6	4.9	6.0	17.1	14.5
25	208.6	1.68	236.8	13.5	96.5	2.45	0.0	0.0	0.0	0.00	186.6	179.7	.5	4.3	-2.1	17.4	14.2
26	218.2	1.72	237.1	13.6	97.2	2.44	2.4	.1	.1	2.50	187.2	185.7	.4	4.2	3.0	17.8	14.8
27	201.1	1.67	236.9	13.4	95.4	2.48	0.0	0.0	0.0	0.00	188.5	171.2	.6	4.2	-12.6	17.3	11.4
28	174.8	1.46	232.8	13.6	97.4	2.39	0.0	0.0	0.0	0.00	181.4	143.7	1.3	6.1	-30.2	15.1	9.0
29	187.9	1.58	222.3	13.5	96.1	2.31	0.0	0.0	0.0	0.00	168.1	154.8	1.7	7.0	-4.7	13.9	9.0
30	146.6	1.23	219.1	13.6	98.0	2.24	0.0	0.0	0.0	0.00	165.2	113.0	1.5	6.5	-44.2	14.4	7.2
31	130.2	1.19	212.9	13.5	91.5	2.33	0.0	0.0	0.0	0.00	157.3	96.9	2.3	7.0	-51.0	12.0	4.4
Total	5871.3		6216.0	372.5	2610.9		438.2	22.9	177.4		8757.9	4544.8	41.6	183.7	12.2		310.2
Mean	189.4	1.68	200.5	12.0	84.2	2.38	14.1	0.7	5.7	2.47	153.5	146.6	1.3	5.9		14.9	10.0

*Gap from 0445-0650. System is in a do nothing mode. No corrections applied.

Table B4. Environmental Conditions, Collector Performance and Electrical Energy Requirements for the Month of July 1979

Day	ENVIRONMENTAL CONDITIONS		ELECTRICAL ENERGY REQUIREMENTS			ENVIRONMENTAL CONDITIONS WHILE COLLECTOR OPERATING						EAST ARRAY		WEST ARRAY		DOMESTIC HOT WATER					
	Ambient Temp °C	Indoor Temp °C	Total House Load MJ	Base House Load MJ	Instrumentation MJ	Total Incident Solar MJ	Incident Solar MJ	Horizontal Wind Speed (m/sec)	Wind Speed on Collector (m/sec)	Ambient Temp °C	Collector Inlet Temp °C	Energy Collected MJ	Efficiency	Energy Collected MJ	Efficiency	Solar Heat to DHW MJ	Collector Blower Electricity MJ	Auxiliary Energy to DHW MJ	Hot Water Pump Electricity MJ	Fraction DHW	COP Heat Hot Water
1	21.2	24.4	150.5	78.3	34.3	1134.9	955.6	----	2.89	25.5	26.5	237.3	49.7	236.2	49.4	72.6	9.5	12.1	4.6	0.86	5.18
2	20.7	24.4	269.7	163.2	33.5	948.8	761.1	----	1.52	24.3	26.8	208.3	54.7	206.4	54.3	65.4	10.2	17.0	5.0	0.79	4.31
3	21.2	24.4	305.0	166.3	34.1	1318.4	1184.9	----	1.69	26.9	29.7	305.0	51.5	303.7	51.3	79.4	11.6	11.3	5.2	0.88	4.74
4	20.0	24.2	207.2	72.6	34.1	1265.6	1138.1	----	1.81	23.4	25.5	299.4	52.6	297.3	52.2	80.0	10.9	0.34	5.20	0.90	4.96
5*	20.6	24.7	260.6	179.8	19.1	1249.3	1064.0	----	1.92	22.7	26.8	279.0	52.4	278.1	52.3	80.4	11.4	11.5	5.5	0.88	4.76
6	19.7	24.7	308.2	168.7	29.0	857.3	717.8	----	2.26	23.3	26.6	186.7	52.0	184.7	51.5	57.7	8.7	19.0	4.2	0.75	4.47
7	22.4	23.9	194.7	77.5	27.3	1409.9	1269.3	----	1.78	27.7	29.0	325.0	51.2	323.6	51.0	82.5	11.6	11.4	4.6	0.88	5.09
8	23.8	25.1	148.0	59.9	33.9	1150.5*	965.5	----	1.19	27.3	30.4	250.0	51.8	248.7	51.5	73.0	10.0	7.6	4.3	0.91	5.12
9	23.8	25.3	283.2	164.3	34.0	1380.3	1258.6	----	1.43	28.1	31.3	329.5	52.4	325.8	51.8	80.1	12.0	11.6	4.5	0.87	4.89
10	24.5	25.6	366.7	180.2	33.9	1299.4	1154.7	----	1.96	28.5	31.5	294.0	50.9	293.1	50.8	87.3	11.7	9.9	5.9	0.90	4.95
11	26.2	25.4	375.6	177.8	33.8	1293.9	1142.8	----	1.83	31.2	32.3	294.1	51.5	293.4	51.4	84.6	10.8	6.5	5.5	0.93	5.19
12	25.2	25.6	341.3	173.7	33.9	1219.3	1006.0	----	2.05	29.9	31.7	264.5	52.6	263.8	52.4	81.2	9.8	6.4	5.1	0.93	5.48
13	26.5	25.6	358.8	139.5	35.3	1412.2	1270.2	----	2.44	31.2	32.7	319.1	50.2	315.3	49.6	93.3	11.8	9.8	6.0	0.90	5.26
14	23.3	24.9	283.9	97.7	34.0	1391.0	1256.5	----	1.78	26.4	31.4	318.9	50.8	317.4	50.5	86.8	11.7	5.6	5.7	0.94	4.99
15	20.6	24.9	191.5	58.8	34.0	1220.0	983.3	----	2.81	22.7	26.9	246.2	50.1	245.1	49.8	71.3	9.3	6.1	4.5	0.92	5.16
16	21.3	25.1	240.4	134.2	33.8	1012.0	824.4	----	1.93	25.1	28.0	211.9	51.4	211.1	51.2	70.1	8.6	14.5	4.3	0.83	5.45
17	18.3	25.5	335.9	224.6	34.0	430.4	328.3	3.19	2.05	20.1	22.5	86.2	52.5	85.3	52.0	27.4	7.4	28.6	3.5	0.49	2.52
18	19.4	25.1	257.2	179.0	34.0	865.3	654.1	2.21	1.55	22.4	25.5	168.2	51.4	167.4	51.2	56.6	8.0	23.3	3.9	0.71	4.77
19	20.8	24.2	307.6	166.5	34.0	1235.5	1054.5	2.62	1.81	25.2	27.9	271.1	51.4	270.8	51.4	84.0	10.0	12.5	5.0	0.87	5.62
20	21.8	24.4	324.4	171.1	34.0	1162.5	961.5	3.68	2.71	25.4	28.0	241.9	50.3	241.9	50.3	73.5	9.3	9.0	4.7	0.89	5.25
21	22.6	24.4	265.1	123.9	34.0	798.6	609.4	3.52	2.29	26.9	28.9	158.4	52.0	158.0	51.9	51.1	8.9	19.3	4.3	0.73	3.88
22	22.3	24.8	248.0	107.0	34.0	1129.0	1034.0	2.50	1.64	26.0	28.7	262.4	50.8	261.5	50.6	80.4	10.8	11.6	5.3	.087	5.02
23	22.6	24.7	345.0	207.0	34.0	861.3	614.3	2.61	1.90	26.3	28.6	163.6	53.3	163.6	53.3	58.0	7.5	18.1	3.7	0.76	5.17
24	22.2	24.9	345.5	189.2	34.0	1217.3	1044.5	2.69	1.89	25.2	28.5	271.7	52.0	270.4	51.8	77.3	10.5	12.4	5.2	0.86	4.91
25	22.2	24.8	334.3	183.6	33.9	1420.1†	1239.5	3.28	2.41	26.3	29.6	315.8	51.0	315.6	50.9	90.0	11.0	10.4	5.6	0.90	5.42
26	22.4	25.1	314.3	164.5	34.0	967.5	733.6	3.29	2.30	27.8	29.2	193.2	52.7	193.2	52.7	62.8	8.4	9.6	4.2	0.87	4.99
27	21.2	24.8	329.7	186.7	33.9	1001.7	817.5	3.29	2.34	24.8	27.6	206.6	50.5	206.4	50.5	67.8	8.2	12.0	4.1	0.85	5.53
28	24.2	25.0	219.7	73.6	34.0	1223.7	1070.2	3.13	2.15	27.4	29.9	276.3	51.6	274.2	51.2	82 *	11.1	12.3	5.5	0.87	5.00
29	25.2	25.3	218.2	75.4	34.0	1099.5	877.9	2.83	1.89	29.6	30.6	230.7	52.6	230.0	52.4	72.1	9.9	6.7	4.9	0.92	4.71
30	20.0	25.2	330.4	190.3	34.0	833.3	706.7	4.11	2.86	23.1	26.9	182.4	51.6	181.3	51.3	57.1	8.1	13.2	4.0	0.81	4.71
31	18.2	24.4	329.9	195.4	34.1	1177.0	1028.7	2.77	1.97	20.9	24.5	259.7	50.5	258.5	50.3	73.7	10.4	13.4	5.1	0.85	4.78
Total	---	---	8790.3	4530.1	1027.5	34985.2	29727.5	---	---	---	---	7657.1	---	7621.7	---	2261.0	308.7	381.8	148.8	---	---
Mean	22.1	24.9	283.6	146.1	33.2	1128.6	959.0	3.05	2.02	26.0	28.7	247.0	51.5	245.9	51.3	72.9	10.0	12.3	4.8	0.86	4.94

*Gap from 0445-0650. System is in a do nothing mode. No corrections applied.

†Skipped record at 1310. Total solar collected.

‡Skipped record at 1430. Total solar collected.

Table B5. Cooling Performance for the Month of August 1979

			COLD CHARGE				DIRECT COOLING				STORAGE AND DISCHARGE PERFORMANCE						
Day	Total Cooling Supplied MJ	Average Daily COP	Heat Removed by Heat Pump MJ	Circulation Blower Energy MJ	Heat Pump Oper. Energy MJ	Heat Pump COP	Heat Removed by Heat Pump MJ	Circulation Blower Energy MJ	Heat Pump Oper. Energy MJ	Heat Pump COP	Charge MJ	Discharge MJ	Loss to Outdoors MJ	Loss to House MJ	Change in Storage MJ	Average Storage Temp °C	Blower Energy During Storage Discharge MJ
1	249.2	1.73	263.5	16.3	113.9	2.31	0.0	0.0	0.0	----	196.9	212.4	2.1	7.1	24.8	12.7	13.5
2	305.5	2.43	200.8	12.7	86.0	2.33	21.8	1.2	8.4	2.59	142.4	248.3	1.6	6.4	114.0	14.1	17.4
3*	305.3	1.87	251.3	14.3	101.7	2.47	75.5	3.8	29.4	2.57	199.0	197.8	0.3	3.7	2.7	18.0	13.7
4	251.3	1.69	241.7	14.1	103.8	2.33	39.6	2.0	15.1	2.63	197.2	188.7	0.6	8.5	0.6	17.2	13.5
5	259.9	1.75	243.9	14.2	102.8	2.37	39.7	2.2	15.8	2.52	195.5	196.6	0.7	8.5	10.3	16.9	13.7
6+	277.9	1.83	241.3	13.9	100.0	2.41	51.6	2.8	21.0	2.45	194.3	202.4	0.7	7.4	16.2	17.0	14.0
7	400.8	1.94	237.5	13.7	100.2	2.37	163.4	8.4	70.0	2.33	192.0	213.7	0.1	6.0	27.8	18.8	13.8
8	288.6	1.78	241.5	13.5	100.4	2.41	76.3	4.1	31.0	2.46	196.9	190.2	0.1	6.0	-0.8	19.3	13.5
9+	194.8	1.78	191.7	10.5	78.7	2.43	32.6	1.8	13.4	2.43	160.6	146.7	0.1	6.0	-8.0	19.3	5.1
10	50.1	1.92	35.9	1.8	13.2	2.73	18.2	1.0	6.8	2.68	30.6	30.6	1.0	2.2	1.1	22.2	3.3
11	96.6	0.88	246.2	13.7	93.0	2.65	0.0	0.0	0.0	----	201.6	72.1	1.5	6.4	-121.5	14.4	3.4
12	78.1	0.95	161.2	10.3	69.8	2.31	0.0	0.0	0.0	----	118.5	55.2	2.6	8.5	-52.3	11.1	2.6
13	17.8	0.32	108.1	7.1	48.9	2.21	0.0	0.0	0.0	----	73.1	0.0	3.0	8.3	-62.0	9.8	0.0
14++	7.0	----	0.0	0.0	0.0	----	0.0	0.0	0.0	----	0.0	0.0	2.7	7.0	10.0	10.9	0.0
15	6.9	0.47	29.4	2.0	12.8	2.30	0.0	0.0	0.0	----	20.3	0.0	2.7	6.6	-11.1	10.8	0.0
16	79.2	16.50	0.0	0.0	0.0	----	0.0	0.0	0.0	----	0.0	73.3	1.9	5.8	81.0	13.4	4.8
17	120.1	1.20	189.2	12.4	83.6	2.26	0.0	0.0	0.0	----	143.0	96.2	2.6	8.0	-36.3	11.2	4.4
18	26.5	0.30	166.9	11.4	77.7	2.15	0.0	0.0	0.0	----	118.2	0.0	3.4	8.7	-106.1	8.6	0.0
19	7.1	----	0.0	0.0	0.0	----	0.0	0.0	0.0	----	0.0	0.0	3.2	7.1	10.3	9.4	0.0
20	15.9	22.71	0.0	0.0	0.0	----	0.0	0.0	0.0	----	0.0	9.3	2.	6.7	18.7	10.7	0.7
21	53.6	1.17	80.5	5.8	38.2	2.11	0.0	0.0	0.0	----	55.1	40.2	3.2	8.8	-2.9	9.3	1.8
22	101.2	1.70	102.5	7.3	48.2	2.13	0.0	0.0	0.0	----	70.1	84.1	2.8	8.5	25.4	10.3	4.0
23	131.7	1.51	159.3	10.6	71.5	2.23	0.0	0.0	0.0	----	114.1	107.9	2.7	8.9	5.3	10.7	5.1
24	87.4	1.16	144.4	9.3	62.9	2.30	0.0	0.0	0.0	----	107.8	66.4	2.8	8.4	-30.3	10.5	2.9
25	40.9	0.72	110.9	7.3	48.5	2.29	0.0	0.0	0.0	----	80.2	21.7	3.2	8.3	-47.0	9.2	0.9
26	19.5	0.42	89.6	6.2	40.4	2.22	0.0	0.0	0.0	----	59.0	0.0	3.7	9.0	-46.2	7.6	0.0
27	51.0	22.17	0.0	0.0	0.0	----	0.0	0.0	0.0	----	0.0	43.6	3.0	8.2	54.8	9.9	2.3
28	144.4	2.13	114.7	8.0	53.3	2.15	0.0	0.0	0.0	----	81.1	128.4	2.7	9.3	59.3	10.7	6.6
29	225.5	2.41	158.0	10.1	70.1	2.25	0.0	0.0	0.0	----	120.6	205.6	1.5	7.9	94.3	14.4	13.4
30	180.1	1.56	227.3	13.2	93.8	2.42	0.0	0.0	0.0	----	182.9	156.5	1.3	6.2	-18.9	15.1	8.8
31	188.9	1.66	225.3	13.5	92.3	2.44	0.0	0.0	0.0	----	176.5	163.0	1.9	7.4	-4.3	13.3	8.1
Total	4262.9		4462.5	273.0	1905.4		518.6	27.3	210.9		3427.4	3150.7	59.8	225.7	8.8		191.3
Mean	137.5	1.63	144.0	8.8	61.5	2.34	16.7	0.9	6.8	2.46	110.6	101.6	1.9	7.3		13.1	6.2

* Gap from 0810-0930: Airflow to collectors adjusted total solar radiation corrected.

* Missed scan at 2040 Mode 3. No corrections applied.

* Missed scan at 2015 Mode 1. No corrections applied.

* Missed scan at 0710 Mode 1. No corrections applied.

Table B6. Environmental Conditions, Collector Performance and Electrical Energy Requirements for the Month of August 1979

Day	ENVIRONMENTAL CONDITIONS		ELECTRICAL ENERGY REQUIREMENTS			ENVIRONMENTAL CONDITIONS WHILE COLLECTOR OPERATING						EAST ARRAY		WEST ARRAY		DOMESTIC HOT WATER					
	Ambient Temp °C	Indoor Temp °C	Total House Load MJ	Base House Load MJ	Instrumentation MJ	Total Incident Solar MJ	Incident Solar MJ	Horizontal Wind Speed (m/sec)	Wind Speed on Collector (m/sec)	Ambient Temp °C	Collector Inlet Temp °C	Energy Collected MJ	Efficiency	Energy Collected MJ	Efficiency	Solar Heat to DHW MJ	Collector Blower Electricity MJ	Auxiliary Energy to DHW MJ	Hot Water Pump Electricity MJ	Fraction DHW	COP Heat Hot Water
1	22.7	24.6	387.2	216.5	34.0	1376.0	1227.0	2.95	2.15	27.2	29.0	309.8	50.4	309.6	50.5	86.4	10.9	11.2	5.5	0.89	5.28
2	23.8	24.8	361.4	207.5	33.7	1396.8	1258.2	3.47	2.32	29.0	30.7	319.6	50.8	319.4	50.8	88.2	10.9	6.4	5.6	0.93	5.34
3	25.4	25.3	361.9	175.2	32.0	1469.0*	1121.9	4.34	3.23	31.8	32.3	298.1	53.1	298.6	53.2	92.7	7.7	5.8	4.6	0.94	7.56
4	28.1	25.4	261.4	86.2	34.0	1494.4	1327.8	3.61	2.34	34.0	34.4	319.1	48.1	317.8	47.9	96.5	9.8	6.2	5.6	0.94	6.26
5	26.6	25.4	242.7	67.9	33.9	1498.5	1328.3	5.24	3.58	32.1	33.7	307.0	46.2	306.1	46.1	89.7	9.8	4.5	5.5	0.95	5.86
6†	26.6	25.2	272.9	94.4	33.9	1368.4	1155.0	2.27	1.72	32.2	34.6	285.0	49.4	284.9	49.3	92.6	9.0	4.9	5.3	0.95	6.48
7	27.1	26.2	443.4	207.9	33.9	1446.9	1316.0	2.29	1.61	31.1	35.2	316.9	48.2	316.8	48.1	95.8	10.1	5.1	5.9	0.95	6.01
8	23.1	25.8	384.5	198.2	33.9	1088.3	918.5	3.82	2.55	27.0	31.4	218.5	47.6	218.9	47.7	71.7	7.4	4.1	4.3	0.95	6.10
9†	21.1	25.5	276.2	139.0	27.6	502.4	369.1	3.88	1.30	25.9	27.2	136.5	74.0	133.4	72.3	50.2	3.9	13.0	1.4	0.79	9.54
10	14.6	24.9	260.9	216.8	34.1	629.7	542.0	2.82	2.00	16.0	20.6	135.9	50.2	134.3	49.6	21.0	7.2	33.5	2.0	0.39	2.27
11	19.4	24.0	268.3	133.4	34.1	1414.8	1277.6	3.72	2.56	23.5	25.1	309.6	48.4	307.3	48.1	88.4	10.3	16.4	5.7	0.84	5.52
12	21.5	24.6	209.3	107.9	34.1	812.5	606.8	2.13	1.49	26.0	27.6	158.4	52.2	157.4	51.9	54.6	7.0	14.6	3.8	0.79	5.05
13	16.8	24.0	283.5	209.9	34.1	219.4	160.9	2.26	1.59	17.2	21.2	44.7	55.6	43.5	54.1	11.9	6.4	42.9	1.6	0.22	1.47
14†	11.8	23.0	225.4	220.6	34.2	118.3	0.0	---	---	---	---	0.0	---	0.0	---	0.0	0.0	34.4	0.0	0.00	---
15	13.3	22.1	255.8	224.0	34.2	500.9	399.8	1.68	1.06	15.4	18.8	109.7	54.9	107.6	53.8	38.9	7.1	34.9	3.8	0.53	3.57
16	17.5	23.5	198.2	175.3	34.0	1053.8	876.2	3.29	2.23	22.3	23.7	213.7	48.8	212.9	48.6	69.4	7.6	15.9	4.2	0.81	5.89
17	19.4	23.7	322.4	199.0	34.0	1372.2	1245.4	3.41	2.33	23.1	25.0	299.5	48.1	297.7	47.8	86.2	9.2	13.8	5.2	0.86	5.99
18	17.0	23.5	171.0	64.4	34.0	827.6	757.5	0.36	1.40	21.3	24.6	183.5	48.5	181.7	48.0	63.7	6.1	8.8	3.4	0.88	6.73
19	14.8	21.8	112.7	100.2	34.1	491.2	395.4	2.14	1.62	18.3	19.9	100.0	50.4	99.4	50.3	37.1	4.7	24.6	2.5	0.60	5.11
20	15.3	22.3	206.8	189.1	34.0	824.0	662.8	1.74	1.19	17.9	20.9	172.3	52.0	170.4	51.4	54.2	7.6	27.3	4.2	0.66	4.59
21	17.6	23.9	268.5	201.5	34.0	945.2	811.4	2.64	1.87	20.5	22.9	205.5	50.6	203.8	50.2	62.0	9.1	18.3	5.0	0.77	4.41
22	18.7	24.2	260.9	179.5	34.0	1288.5	1103.4	1.90	1.3*	22.2	25.3	276.7	50.2	274.9	49.8	82.2	9.1	11.0	5.1	0.88	5.81
23	17.8	24.3	299.8	192.8	34.1	1149.7	940.5	3.45	2.41	21.0	24.6	225.1	47.9	224.4	47.7	72.0	7.5	9.7	4.2	0.88	6.17
24	17.9	23.8	283.6	189.9	34.0	967.6	778.6	4.07	2.83	22.7	24.3	183.0	47.0	182.1	46.8	65.6	6.9	14.7	3.8	0.82	6.10
25	15.8	23.4	198.2	121.8	34.0	1116.8	907.4	2.31	1.26	18.6	22.8	228.0	50.2	224.9	49.6	70.7	8.0	11.7	4.3	0.86	5.77
26	16.3	23.2	185.2	120.4	34.1	1013.7	782.0	3.39	2.39	19.5	23.0	189.9	48.6	188.8	48.3	62.0	7.6	17.5	4.1	0.78	5.32
27	16.7	23.5	221.0	200.2	33.8	1098.4	908.5	3.45	2.24	19.3	22.5	219.7	48.4	218.6	48.1	71.4	7.5	14.1	4.2	0.84	6.13
28	19.4	24.1	309.5	214.8	34.0	1128.1	1014.6	2.36	1.56	22.9	25.7	258.6	51.0	256.1	50.5	67.9	10.4	15.8	5.8	0.81	4.20
29	20.8	24.7	325.6	203.4	33.9	1491.8	1392.0	2.85	2.03	25.0	28.2	333.8	48.0	333.4	47.9	93.9	10.9	11.7	6.2	0.89	5.51
30	19.8	24.3	326.6	187.7	34.0	1050.8	899.6	2.34	1.43	24.7	27.3	226.7	50.4	224.9	50.0	71.1	7.9	6.4	4.5	0.92	5.75
31	21.1	24.1	315.3	177.4	33.9	1418.6	1267.0	3.30	1.70	26.8	27.4	315.1	49.7	311.1	49.1	93.8	9.6	11.8	5.5	0.89	6.24
Total			8499.5	5222.5	1045.3	32574.0	27751.0					6899.3		6860.3		2101.7	247.2	470.9	132.6		
Mean	19.6	24.2	274.2	168.5	33.7	1050.8	895.2	2.97	2.01	24.4	26.9	222.6	49.7	221.3	49.4	67.8	8.0	15.2	4.3	0.82	5.53

* Gap from 0810-0930. Airflow to collectors adjusted. Total Solar corrected.
 † Missed scan at 2040 Mode 3. No correction applied.
 ‡ Missed scan at 2015 Mode 1. No correction applied.
 ‡ Missed scan at 0710 Mode 1. No correction applied.

Table B7. Cooling Performance for the Month of September 1979

Day	COLD CHARGE						DIRECT COOLING				STORAGE AND DISCHARGE PERFORMANCE						
	Total Cooling Supplied MJ	Average Daily COP	Heat Removed by Heat Pump MJ	Circulation Blower Energy MJ	Heat Pump Oper. Energy MJ	Heat Pump COP	Heat Removed by Heat Pump MJ	Circulation Blower Energy MJ	Heat Pump Oper. Energy MJ	Heat Pump COP	Charge MJ	Discharge MJ	Loss to Outdoors MJ	Loss to House MJ	Change in Storage MJ	Average Storage Temp °C	Blower Energy During Storage Discharge MJ
1	119.3	1.15	210.9	12.6	86.4	2.44	0.0	0.0	0.0	0.00	163.4	92.3	2.5	8.2	-60.4	11.4	4.4
2	67.8	0.95	143.8	9.0	60.6	2.37	0.0	0.0	0.0	0.00	107.5	46.1	3.0	8.4	-50.0	9.9	2.2
3	224.6	4.40	73.1	4.8	32.7	2.24	0.0	0.0	0.0	0.00	51.7	212.4	1.8	7.1	169.5	13.6	13.6
4	251.5	1.94	237.3	13.5	95.7	2.48	10.6	0.6	4.4	2.41	191.7	217.1	0.8	6.7	-32.9	16.6	15.4
5	273.4	1.92	237.7	13.6	98.1	2.42	41.7	2.0	14.7	2.84	194.5	207.7	0.5	5.5	19.2	17.6	13.7
6	237.5	1.77	245.4	13.5	96.6	2.54	23.2	1.2	8.8	2.65	201.3	192.4	0.4	7.9	-0.5	17.7	13.9
7	256.9	1.82	243.4	13.6	97.0	2.51	35.8	1.9	14.2	2.52	197.8	198.9	0.5	6.8	8.5	17.5	14.2
8	138.2	1.18	241.2	13.5	97.4	2.48	0.0	0.0	0.0	0.00	196.3	113.5	1.3	7.4	-74.1	15.1	5.9
9	147.3	1.27	214.5	13.7	96.3	2.23	0.0	0.0	0.0	0.00	160.4	118.4	2.1	9.8	30.0	12.5	5.7
Total	1716.3		1847.3	107.9	760.8		111.4	5.7	42.1		1464.4	1398.7	12.9	67.8	15.0		89.1
Mean	190.7	1.71	205.3	12.0	84.5	2.43	12.4	0.6	4.7	2.65	162.7	155.4	1.4	7.5		14.6	9.9

*1435 skipped. Total solar corrected.

Table B8. Environmental Conditions, Collector Performance and Electrical Energy Requirements for the Month of September 1979

Day	ENVIRONMENTAL CONDITIONS		ELECTRICAL ENERGY REQUIREMENTS			ENVIRONMENTAL CONDITIONS WHILE COLLECTOR OPERATING						EAST ARRAY		WEST ARRAY		DOMESTIC HOT WATER					
	Ambient Temp °C	Indoor Temp °C	Total House Load MJ	Base House Load MJ	Instrumentation MJ	Total Incident Solar MJ	Incident Solar MJ	Horizontal Wind Speed (m/sec)	Wind Speed on Collector (m/sec)	Ambient Temp °C	Collector Inlet Temp °C	Energy Collected MJ	Efficiency	Energy Collected	Efficiency	Solar Heat to DHW MJ	Collector Blower Electricity MJ	Auxiliary Energy to DHW MJ	Hot Water Pump Electricity MJ	Fraction DHW	COP Heat Hot Water
1	20.0	23.9	205.3	77.0	34.0	1524.5	1375.3	3.60	2.38	23.7	27.2	328.0	47.7	325.8	47.4	88.0	10.3	5.7	5.6	0.94	5.54
2	21.1	23.6	157.6	65.3	33.8	1133.6	940.3	2.51	1.72	24.7	26.5	228.7	48.6	227.8	48.4	71.7	8.2	6.1	4.5	0.92	5.67
3	23.2	24.4	236.9	161.5	33.7	1536.8	1405.7	2.94	2.13	28.0	30.0	338.5	48.2	338.4	48.2	99.2	9.9	9.9	5.8	0.91	6.35
4	23.0	25.0	348.0	194.4	33.8	1424.4	1273.9	2.95	2.13	27.3	29.7	305.3	47.9	305.2	47.9	95.3	9.0	6.5	5.2	0.94	6.73
5	23.8	25.1	345.6	178.2	33.8	1489.5	1289.2	4.12	2.49	28.7	30.8	312.0	48.4	310.6	48.2	97.9	9.2	6.2	5.3	0.94	6.73
6	20.1	25.2	363.4	204.3	33.8	1320.5	1181.9	3.27	2.32	22.3	27.6	282.9	47.9	281.7	47.7	81.0	9.6	7.1	5.5	0.92	5.38
7	21.8	25.0	346.4	178.6	33.8	1471.9	1344.3	3.93	2.58	26.0	28.7	315.7	47.0	314.3	46.8	90.7	9.7	8.9	5.5	0.91	5.95
8	23.5	24.8	224.8	86.3	33.7	1219.0	1036.3	2.98	2.09	27.4	29.1	250.0	48.2	249.0	48.1	78.0	8.1	6.1	4.5	0.93	6.21
9	24.8	25.3	221.3	81.6	33.6	1263.4	1158.9	3.51	2.34	29.3	30.8	276.8	47.8	275.6	47.6	84.9	9.7	7.8	5.4	0.92	5.62
Total			2449.3	1227.2	304.1	12383.6	11005.8					2638.0		2628.3		786.8	83.5	54.3	47.4		
Mean	22.4	24.7	272.1	136.4	33.6	1376.0	1222.9	3.33	2.26	26.4	29.0	293.1	47.9	292.0	47.8	87.4	9.3	7.1	5.3	0.92	6.01

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