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PERFORMANCE EVALUATION OF A SOLAR AIR-HEATING AND
NOCTURNAL COOLING SYSTEM IN CSU SOLAR HOUSE II

Final Report, June 1, 1977—September 30, 1978

MASTER

By
Susumu Karaki

April 1979

Work Performed Under Contract No. EY-76-S-02-2868

Solar Energy Applications Laboratory
Colorado State University
Fort Collins, Colorado

U.S. Department of Energy

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FINAL REPORT

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

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PREFACE

There are four experimental solar houses in the Solar Village at Colorado State University. The first building in the village, Solar House I, was constructed in 1973 with funds provided by the federal government, and the three other buildings were constructed in 1975 with funds provided by the Colorado State University Foundation. Three buildings in the complex, namely Solar Houses I, II and III, are similar in size and construction and are provided with experimental solar systems for purposes of research, development and demonstration. Because of the similarities of the buildings, comparisons of the performance of different solar systems can also be made. Solar Houses I and III are equipped with liquid-heating systems and Solar House II has an air-heating system. The fourth building is smaller in size and has an attached greenhouse and an air-heating solar system for collection and storage of heat.

The air-heating solar system in Solar House II was donated to the University by the Solaron Corporation of Denver, Colorado and installed with funds provided by the Sheet Metal and Air Conditioning Contractors National Association (SMACNA). With a grant from the National Training Fund (NTF) of the sheet metal industry, and augmented with funds from Colorado State University, a complement of instruments, including a data acquisition system and an on-line desk-top calculator were procured for the purpose of monitoring the performance of the solar system.

Monitoring the system performance began in 1 February, 1976 and continued through 12 May, 1978 through a contractual agreement with the U.S. Energy Research and Development Administration (ERDA) and subsequently with the U.S. Department of Energy (DOE). The performance of the air

heating system during the period 1 February through 16 May 1977 was reported previously in Report No. C00-2868-3 titled "Evaluation of a Residential Solar Air-Heating and Nocturnal Cooling System" and issued in December 1977. The current report contains the results of performance evaluations for the period 16 June 1977 through 12 May 1978.

Although there are sections of this report which are duplications of the earlier report they are included so that this report will be independent of the earlier one. The summary results of system performance during the period 1 February 1976 through 16 May 1977 are also included in this report.

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EXECUTIVE SUMMARY

BACKGROUND

The solar heating system in Solar House II consists of 67.1 m² of double-glazed air-heating collectors with flat-black absorbers, 10.3 m³ of pebble bed storage, air-to-water heat exchanger for preheating domestic water and one blower to circulate the air through the system. The nocturnal cooling system consists of an evaporative cooler and utilizes the pebble bed for cool storage. A schematic diagram of the system is shown in Figure ES-1.

Figure ES-1. Schematic Arrangement of the Solar System in CSU Solar House II.

The system was installed in 1975 and has been monitored since February 1976. From 1 February to 18 May 1976, which is approximately one-half of the heating season, the solar heating system supplied 71 percent

of the total load, or 33.5 GJ of heat for space and domestic water toward a total requirement of 47.2 GJ in the same period.

Some changes were made to the system controls before the 1976-77 heating season which resulted in an improvement in performance of about 10 percent. In quantitative terms, 48.3 GJ of solar heat was utilized toward a total load of 62.7 GJ, which resulted in a solar fraction of 0.77 for the period 4 November 1976 through 16 May 1977.

OBJECTIVES OF THE PROJECT

The objectives of the project are to (1) determine and evaluate seasonal performance of the solar heating and nocturnal cooling system (2) determine the impact of improvements in the system and (3) compare the thermal performance of air and liquid systems in Solar House II and Solar House I respectively.

THERMAL PERFORMANCE 1977-78

Cooling Season - 1977

The monthly average daily performance of the nocturnal cooling system in the summer of 1977 is shown in Figure ES-2. Total cooling supplied by the system was about 100 MJ/day, of which cool storage supplied about 80 percent. August was generally cool and there were many days when cooling was not required. Comparing the 1977 data with the previous year, there was 50 percent improvement in the capacity of the nocturnal cooling system, primarily as a result of changes in control strategy. Where previously in 1976, cold charging was controlled by temperature differences, in 1977 cold charging of storage was initiated with a clock timer.

Figure ES-2. Monthly Average Cooling Performance, Solar House II, 1977.

Heating Season - 1977-78

Monthly average daily collection of heat and contributions to monthly heating loads are shown in Figures ES-3 and ES-4. Over the season there was 217.5 GJ of total (measured) incident solar radiation on the collectors and 67.5 GJ converted to heat by the collectors. Of the total measured solar radiation, 181.2 GJ was incident on the collectors while the system was collecting solar heat (i.e., while the blower was operating). The seasonal collection efficiency of the system was therefore 37 percent, based on incident radiation while operating and 31 percent, based on total incident solar radiation, which compares with 30 and 26 percent respectively for the previous heating season. The improvement in performance was a direct result of increasing the blower speed and air circulation rate in the system. (While the same improvement in collection efficiency could have

resulted by increasing the air flow rate only in the collector loop, because the Solar House II system has a single blower, the air circulation rate through the house heating distribution system was also increased.) Air flow rate through the collectors was increased from 23 m³/min to 29 m³/min and the larger air flow rate resulted in increased collection efficiency.

Figure ES-3. Collection of Solar Heat During the 1977-78 Heating Season.

Figure ES-4. Solar and Auxiliary Contributions to Total Space and DHW Load, Solar House II, 1977-78 Heating Season.

Monthly mean daily solar and total heat loads, and percentage of solar contributions to the total load are shown in Figure ES-4. The total seasonal energy required was 82.8 GJ of which 63.6 GJ or 77 percent was supplied by the solar system.

Electrical Energy Used

An important factor in solar system operation is the amount of electrical energy required to collect and store solar heat, and the amount of electrical energy needed to circulate the heat from storage to the rooms. There was 3.31 GJ (919 kWh) of electrical energy required to collect and store 67.5 GJ of solar heat, for an overall "COP" of 20.4 ($67.5/3.31$). There was an additional 3.07 GJ (853.8 kWh) of electricity utilized to deliver 63.6 GJ of solar to the rooms. The heating "COP", excluding electricity required for collection, is therefore 20.7 ($63.6/3.07$). The "COP" for heating, including electricity to collect, store and deliver solar heat is 10.0 for the entire season ($63.6/6.38$).

Comparisons With Liquid Systems

Compared to a flat-plate liquid-heating system with similar collector characteristics on Solar House I, (i.e., non-selective absorber with two glass covers), the air-heating system provided about 20 percent more solar heat to the heating load. Compared to the evacuated tube liquid-heating collectors, made by the Corning Glass Company and tested on Solar House I, the evacuated tube collector system delivered about 20 percent more heat than the flat-plate air system. These results are reported in Ref. 6.

Comparisons with f-Chart

A comparison between predicted and measured monthly solar fractions, f , for space and water heating loads indicates that the f-chart predictions are less than measured values, particularly for the cold months of December, January and February. During March, April, and May, the f-chart predictions are close to measured solar fractions. In November of 1976 the f-chart prediction is within 6 percent of measured value but in 1977, the predicted fraction is 25 percent less than the measured solar fraction. The observed differences are that in November of 1976 the average daily solar radiation was 24 percent greater than in November of 1977, although solar radiation was low for November in both years. The variations between predicted monthly solar fractions and measured solar fractions are from -30 percent to +1 percent, and seasonal predictions are low by 10 to 13 percent. For the partial 1975-76 heating season the predicted solar fractions exceed the measured values but the system was not operating efficiently during that period.

CONCLUSIONS

The results of two and one-half years of data collection and system evaluation show that an air-heating system with pebble-bed storage can have a daily average efficiency of about 37 percent based on solar radiation while collecting. Thirty one percent of the total solar energy measured on the plane of the collector can be converted into usable heat.

A significant improvement in system performance resulted for the 1977-78 heating season compared to the previous year because of increased

air flow rate through the collectors. During the 1975-76 and 1976-77 heating seasons there was only $32 \text{ m}^3/\text{min}$ total air flow rate in the collector loop and of that amount $9 \text{ m}^3/\text{min}$ was attributable to leakage at the outlet end of the collector manifold. The air flow rate in the collector loop was increased to $40 \text{ m}^3/\text{min}$ for the 1977-78 season, with $11 \text{ m}^3/\text{min}$ due to leakage, but the air flow rate through the collector increased from 23 to $29 \text{ m}^3/\text{min}$. Although there was greater leakage into the collector loop, the air-flow rate through the collector increased by 26 percent, and this increase accounts for the improvement in system performance.

Overall, the air system collected about 20 percent more heat from the solar system than a comparable liquid system on Solar House I. This comparison is based on previous years of data because the flat-plate system on Solar House I, although operating, was not utilized for heating the house during the 1977-78 season. The Corning evacuated tube collector system was coupled to the house heating system in Solar House I. Compared to the Corning collector system the flat-plate air system delivered about 20 percent less heat than the high performance evacuated tube collectors.

Seasonal predictions of solar contributions from an air heating system to the total load, using the f-chart method underpredicts measured performance by 10 to 13 percent.

COLORADO STATE UNIVERSITY SOLAR HOUSE II SOLAR AIR HEATING AND NOCTURNAL COOLING SYSTEM

1 INTRODUCTION

1.1 OBJECTIVES OF THE PROJECT

The principal objectives of the project are to: (1) determine and evaluate the seasonal performance of a solar air-heating system for space and water heating and a nocturnal cooling system for space cooling; (2) determine the impact of improvements in the system; and, (3) compare the thermal performance of air and liquid systems.

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 of the region is semi-arid with continental winters and meager summer rainfall. Average annual precipitation is only 36.3 cm, consisting of 24.9 cm rainfall and 11.4 cm snowfall. Ambient temperatures are moderate during summer months, with highs generally below 40°C and low temperatures during the winter months are generally above -30°C. Average daily temperature in January is -1°C, and in July is 24°C. The normal total annual heating degree days (18.3°C base) is 3500°C-days.

The monthly average daily solar radiation on a horizontal surface in Boulder, Colorado (40°N latitude) is shown in Figure 1-1. Also shown on the figure is the monthly average daily radiation on a surface inclined southward at 45 degrees in Fort Collins.

Figure 1-1. Monthly Average Daily Solar Radiation on a Horizontal Surface in Boulder, on a 45° Slope in Fort Collins.

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

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

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

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

Figure 2-6. Cross Section of Solar House II.

set in wood frame with 80 percent glass area, and 30.5 m² of 4.5 cm solid-core exterior doors. The overall UA of the building is calculated to be 419 W/°C [36.20 MJ/(°C-day)].

2.2 THE SOLAR SYSTEM

2.2.1 Heating System

The heating system in Solar House II is an air-heating system with an auxiliary gas duct furnace as shown schematically in Figure 2-7. The solar system consists of air heating collectors, pebble-bed storage, ducts of various sizes, a blower with a constant speed motor, and automatic controls to collect, store and deliver solar heat to the building space. Whenever the solar-heated air is inadequate to heat the building, the auxiliary furnace provides the additional heat necessary to maintain comfort conditions.

Solar Collectors - The collectors on Solar House II were fabricated on the roof of the building (site-built) because at the time, prefabricated air-heating collectors were not commercially available. Generally, site-built collectors are labor intensive and skilled craftsmen are required to install a satisfactory and durable system. The cost of a site-built system therefore can be more expensive than the installed cost of a factory-built collector array made up of prefabricated modules. Photographs of collector installation and other components of the system were included in an earlier report of Solar House II (Ref. 1).

The area of the roof occupied by the collectors is 67.1 m² and the net absorber area is 64.1 m². As shown in the cross-sectional drawing of the collectors, Figure 2-8, the absorber surface of the collector is

Figure 2-7. Schematic Arrangement of the Solar System in CSU Solar House II.

Figure 2-8. Cross Section of Solar Air-Heating Collector on Solar House II.

the top of the air duct. The collectors were designed for a nominal air-flow rate of $40 \text{ m}^3/\text{min}$, but in this system the air flow rate through the collector was much less because of leakage at the manifolds.

The collectors are double glazed with double strength water-white glass and there is a layer of 10-cm thick fiberglass insulation beneath the absorber ducts.

The width of each collector unit is 61 cm and the length is 4.78 m. There are four 5-unit subarrays and one 3-unit collector subarray which makes up the total collector area of 67.1 m^2 .

Pebble-bed Storage - The pebble-bed storage is located in the basement of Solar House II. The container, as illustrated in Figure 2-9, 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.

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 lengthwise 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 lath is then placed over the bond beams which supports a 1.68-m depth of pebble bed

Figure 2-9. Pebble-Bed Storage Unit.

(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.

Furnace - The auxiliary furnace in Solar House II is a Lennox duct furnace, Model LD3-137 with a maximum rated heat output of 115.7 MJ/hr. The maximum air throughput is $56.7 \text{ m}^3/\text{min}$ and the minimum is $28.4 \text{ m}^3/\text{min}$. The burner jets and controls are set for natural gas.

Blowers - One blower in the system circulates air through the collectors and storage, or through the collectors and the house. The same blower also circulates air through storage and the house when useful heat cannot be delivered by the collectors. The blower is made by Lau, Model FGP-12-6A and is driven by a 746-watt Dayton electric motor. Motor and blower are belt connected with a variable diameter pulley on the motor shaft to enable adjustment of air flow rate through the system.

During the non-heating season a separate blower of the same manufacture and size as the main blower circulates air through the collectors and the air-to-water heat exchanger to heat domestic hot water. The main blower is used to cool the pebble-bed storage with an evaporative cooler during the night. It also circulates the room air through the cool pebble-bed during the day.

Ducts - Sheet metal ducts with 2.5-cm fiberglass lining and lapped joints are used for all ducts of the solar system. The supply and return ducts to the collector array are 71.1 x 35.6 cm; the duct connected to the furnace and the heat distribution system is 45.7 x 45.7 cm and other interconnecting ducts in the system are 55.8 x 40.6 cm.

The main heat distribution duct is mounted below the floor joists of the first floor level with 12.7-cm diameter feeder ducts to the floor heat registers. Heat distribution ducts are not insulated.

Dampers - There are nine motor-driven dampers and four manual (slide) dampers in the ducts of the system. Six motor-driven dampers are needed for operating the system in the heating mode. The other three are used when the system is in the cooling modes. Manual dampers are used to seal the summer bypass duct and the intake and exhaust ports of the cooling system during the winter.

The backdraft damper in the system is also motor driven. All the dampers are double bladed, with vinyl strips on the blades to effect a seal. Eight Barber Coleman hydraulic activators operating on 24 volts and 10 watts of power are used to open and close the dampers.

2.2.2 The Cooling System

The cooling system in Solar House II utilizes an evaporative cooler to cool the night air 10 to 12°C below the dry bulb temperature. Night-time wet bulb temperature of 10°C is common in Fort Collins in the summertime when the night-time dry bulb temperature may be near 20°C.

The evaporative cooler has a motor-driven slinger and rubberized fiber screen on which the water droplets are caught. As air is drawn through the wet screen evaporation takes place and the air is cooled. The cooled air is circulated through the pebble-bed storage, in a top-to-bottom direction, and the warm air from the bottom of storage is discharged outside the building.

During the day, the warm room air is circulated through the pebble-bed in a bottom to top direction and the air is cooled by contact with the cool pebbles. The cooled air is then recirculated to the rooms.

2.2.3 Domestic Hot Water System

Air-to-Water Heat Exchanger - The air-to-water heat exchanger for domestic hot water is placed in the return duct from the collectors and is located just below the first floor level. The copper tubes are in a serpentine arrangement with a large fin area for effective heat exchange from the heated air to the water. Water can be preheated only when the collector is operating.

Preheat Tank - The hot water preheat tank is a 300-liter standard electric water heater made by A. O. Smith Company. The electric heating element is not connected and the drain spigot is replaced with a pipe connection to the circulation pump.

Auxiliary Water Heater - A gas-fired auxiliary domestic hot water (DHW) heater of 150-liter capacity is connected in series with the preheat tank. The cold water supply is to the preheat tank and water must flow first through the preheat tank before entering the regular DHW

tank. Hot or warm water from the preheat tank is therefore delivered to the auxiliary unit and if the water is sufficiently hot, no auxiliary water heating is necessary. If, however, the temperature of the water from the preheat tank is less than the preset temperature of the DHW tank, the auxiliary heater provides the necessary balance of heat.

Preheater Circulation Pump - The pump which circulates water from the preheat exchanger is a March Model 809-03, 25-Watt pump. Because the circulation system is under mains pressure, the power required is only that which is needed to overcome friction losses in the pipeline with a flow rate of 3 liters per minute.

3 MODES OF SYSTEM OPERATION

The heating system in Solar House II was designed to provide the comfort level desired in the building from the solar system combined with the auxiliary heater. The cooling system consists of an evaporative cooler that cools the rock-bed storage at night and the rock bed is used as a heat sink during the day. There are five basic operating modes for heating and three basic modes for cooling with a number of submodes for both heating and cooling. The different modes of system operation are described in this section.

3.1 SPACE HEATING

3.1.1 Mode 1. Heating from Collector

Heating of space directly with solar heat from the collector is accomplished as shown in Figure 3-1. Solar heat is collected whenever there is sufficient solar radiation to generate useful heat in the collector. As heat is transmitted out of the building, the first-stage contact (T_{R1}) of the two-stage thermostat is made and dampers MD2A and MD2C open, and MD2B closes. Provided the temperature at the outlet from the collector is sufficiently high, dampers MD3A and MD3C open, MD3B closes, and blower B1 circulates the air from the rooms through the collectors. During a normal winter day, air is heated from about 20°C to 60°C. The heated air is blown through the duct furnace and delivered to the rooms.

3.1.2 Mode 2. Heating from Collector and Auxiliary Furnace

When the heat loss from the building is at a rate greater than can be supplied from the solar system alone, the space air temperature drops

Figure 3-1. Heating from Collector. (If auxiliary heating is required, the furnace automatically fires.)

and the second-stage thermostat contact (T_{R2}) is made. The auxiliary furnace turns on and boosts the temperature of the air delivered from the collectors. The heat delivery rate from the collectors and auxiliary heater is now greater than the heat loss rate from the building and the room air warms sufficiently to regain the set temperature at the thermostat. The air circulation path is the same as in Mode 1.

3.1.3 Mode 3. Storing Heat

When the heating need in the house has been satisfied and useful solar energy is collectible, MD2A and MD2C close, and MD2B opens and solar-heated air circulates through the pebble-bed storage as shown in Figure 3-2. The hot air is forced through storage from the top towards the bottom and as heat is transferred to the pebbles, the air emerges from storage at a temperature equal to the temperature of the pebbles at the bottom of the pebble bed. Normally, in the winter, the temperature of the pebbles at the bottom of storage will always remain at room temperature because the storage is sized to store all of the heat collectable during a winter day without propagating the thermocline to the bottom of storage. During early fall and spring seasons, the storage may become "full" because more heat is collected during the day than can be used at night. In that event the temperature of the pebbles at the bottom of storage rises and the air exiting from storage is also warm. The warm air returning to the collector increases the average temperature of the absorber in the collector, causing increased heat loss from the collector and reduction of collector efficiency.

Figure 3-2. Storing Heat.

3.1.4 Mode 4. Heating from Storage

The pebble-bed storage is the heat source when solar energy is not available from the collectors. In this mode, the air flows through storage from the bottom toward the top, and the room air is heated by contact with the hot pebbles as shown in Figure 3-3. Motorized dampers MD2B, MD3A and MD3C close; MD2A, MD2C and MD3B open. The air is circulated by the blower through the duct furnace and distributed into the rooms.

With normal solar energy collection during the day, the system is sized so that the pebble-bed storage will provide all the space heating needs during the night. When solar collection periods are interrupted by cloudiness during the day, or unusually cold air temperatures prevail during the night, the heat in storage may not be sufficient to last through the night.

3.1.5 Mode 5. Heating from Storage and Auxiliary Furnace

When the heat loss from the building is unusually large because of cold outdoor air temperature, or if there is insufficient heat in storage, T_{R2} contact of the thermostat is made and the auxiliary furnace is fired to provide supplemental heat to the air emerging from storage. The air circulation path is the same as shown in Figure 3-3.

The air system of Solar House II is designed to recover all the solar heat from storage because the room air is always circulated through the rock bed, even when auxiliary heating is necessary. By always circulating air through storage, even when there is no useful

Figure 3-3. Heating from Storage.

heat remaining, there is a small penalty for increased blower power which is necessary to overcome the pressure drop across storage. With the prevailing air flow rates in the system, the pressure drop across the pebble bed is only 3.8 mm, water gage, so the additional power required is about 20 watts, and the extra electric energy used may amount to about 50 to 60 MJ per year.

3.2 SPACE COOLING

3.2.1 Mode 1. Nocturnal Cooling of the Pebble-bed Storage

Evaporative cooling of dry air is accomplished relatively simply by an air washer. Using a slinger, water from a sump is splashed into the airstream. Eliminators, which are filters made of rubberized fiber material minimize the carry-over of water droplets with the airstream. Water is evaporated, heat is removed from the airstream, and the cool night air is used to chill the pebble bed. The cooling cycle is shown schematically in Figure 3-4. The cooled air circulates through the pebble bed from top to bottom and warm air from the bottom of storage is discharged outdoors.

3.2.2 Mode 2. Cooling from Storage

During the day when the temperature in the building rises above the preset temperature of the thermostat, air is circulated by blower B1 from the room through the pebble bed as shown schematically in Figure 3-5. Warm air from the room enters the pebble bed from the bottom and gradually cools as it comes into contact with the cool rocks in storage. Stratification is maintained as the thermocline moves upward through the pebble bed and as long as the pebbles near the top of storage remain cool, cool air is circulated to the rooms.

Figure 3-4. Nocturnal Cooling of the Pebble-Bed Storage.

Figure 3-5. Cooling from Storage.

The cooling capacity of the nocturnal cooling system is limited by the quantity of cool air circulated at night, the capacity of the evaporative cooler and the volume of the pebble-bed storage. Because the blower and pebble bed are economically sized for the solar heating system, the capacity of the cooling system is limited in the Solar House II system. Furthermore, this arrangement for evaporative cooling is effective only in arid or semi-arid regions of the country.

3.2.3 Mode 3. Direct Evaporative Cooling

On occasions, cooling may be effected by directly cooling the outdoor air and circulating the cooled moist air through the rooms. The air from the rooms is discharged directly outdoors as shown in Figure 3-6. Because of the limited air flow rate of blower B1, this mode of cooling has limited capability.

3.3 DOMESTIC WATER HEATING

3.3.1 Mode 1. Winter Operation

Domestic water preheating is accomplished by the air-to-water heat exchanger in the return duct from the collector, and is operative only when solar heat is being collected. In the winter operation, as shown on Figure 3-7, domestic water can be preheated only when direct space heating is not required, that is, only when heat is being stored. When the temperature of the air leaving the heat exchanger is less than 1.7°C warmer than the bottom of the pebble-bed storage, water circulation is stopped. Otherwise, air which is cooler than room temperature will be stored at the top of the pebble bed. Water circulation also stops when the preheat tank temperature reaches 60°C.

Figure 3-6. Direct Evaporative Cooling.

Figure 3-7. Domestic Water Preheating, Winter Operation.

3.3.2 Mode 2. Summer Operation

During summer, heat from the entire collector array is available for domestic water heating. As shown in Figure 3-8, the manual winter/summer damper is open, MD3A and MD3C are closed and blower B2 circulates warm air through the collector. In this case, domestic water can be preheated whenever the collector air temperature is greater than the temperature of the water at the bottom of the preheater tank. The water circulation pump will stop when the preheat tank temperature is 60°C.

Figure 3-8. Domestic Water Heating, Summer Operation.

4 SYSTEM CONTROLS

4.1 CONTROL FUNCTIONS

The solid state controller for the heating and cooling system in Solar House II requires input signals from six sensors and the room thermostat to regulate all the mechanical devices (dampers and blowers) 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) regulate the furnace 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 evaporative cooler. 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, one in the DHW preheater tank, and one sensor outdoors. 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 thermistor temperature sensors are 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 the array. One sensor is for solar

space heating and the other is for DHW preheating. 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.

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

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.

For both winter and summer operation the domestic hot water preheater circulation system is on a separate control circuit which is activated by the main controller with an enable/disable output signal. An aquastat limits the preheat tank temperature by overriding the power to the

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

circulation pump. Sensor T_{PH} , located inside the preheat tank, about 5 cm above the bottom of the tank, is connected to the DHW preheat controller. A comparator in the DHW controller compares T_{PH} with T_{CO} to regulate the circulation pump when useful energy can be gained from the solar-heated air.

4.3 CONTROL LOGIC AND TRUTH TABLE

A schematic wiring diagram of the controller is shown in Figure 4-3. The control functions are programmed in the Programmable Read Only Memory (PROM), which receives 8 input signals (addresses) and delivers 8 output signals to operate the mechanical equipment. Signals from the sensors are filtered and amplified and connected to one or more comparator network. The comparator networks determine the temperature differences between sensors and between sensors and fixed temperatures. Depending upon the set of "truths" which occurs at a given time, the pre-programmed logic in the PROM determines which mechanical devices (dampers and blowers) should be "on" or "off". The addresses of the PROM are monitored by light emitting diode (LED) displays on the control panel so that a visual verification can be made of comparator truths and operating modes. The specific comparisons made in the comparator circuits of the controller are shown in the schematic diagram.

4.3.1 Space and Water Heating

The controller as designed, requires a manual decision for operating the system in a heating or cooling mode. There is a manual winter or summer (W/S) switch which addresses A4 of the PROM (see Figure 4-3). Space can be heated in the summer mode (with the switch in the "S"

Figure 4-3. Schematic Wiring Diagram of Controller.

position) using the auxiliary heater, but there can be no cooling during the heating season (when the switch is in the "W" position).

The address for the first stage contact of the thermostat, T_{R1} , is located at A0. When the room air temperature drops below a preset temperature at the thermostat, a circuit is completed and a modulated signal is received by the PROM 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. Sensor T_{C0} is compared to a set temperature (potentiometer P13), and the temperature difference signal is sensed at address A3. Depending upon the level of the signal, that is, whether T_{C0} is much greater than T_{P13} , much less than T_{P13} , or within a hysteresis band about T_{P13} , (which is determined by an adjustable potentiometer P3), the input state is interpreted as "true" or "false" respectively by the PROM. When all the input states to the PROM meet the pre-programmed conditions, the circuit to the starter relay of B1 is completed, dampers MD2ABC and MD3ABC are properly activated and heat is delivered from the collectors to the rooms. The set of "truth" conditions for input and output states of the PROM to heat the rooms from the collectors is indicated on the top line of the truth table, Table 4-1.

If the heat delivery rate from the collectors is insufficient to raise the temperature of room air to the preset temperature at the thermostat, the room air temperature will drop, T_{R2} contact is completed, the conditions on line 2 of the truth table are met, and output devices designated by "1" are activated. The status of a comparator can only be

Table 4-1. Truth Table for Modes of Operation

		INPUT CONDITIONS								PROGRAMMED OUTPUT							
PROM Terminal Designations:		A ₇	A ₆	A ₅	A ₄	A ₃	A ₂	A ₁	A ₀	D ₈	D ₇	D ₆	D ₅	D ₄	D ₃	D ₂	D ₁
WINTER MODES																	
Heat From Collector		X	X	X	1	0	0	0	1	1	0	0	0	0	1	1	0
Heat From Collector + Auxiliary		X	X	X	1	0	1	0	X	1	0	0	1	0	1	1	0
Cool Auxiliary Heat Exchanger (AHX)		X	X	X	1	0	1	1	1	1	1	0	0	0	1	1	0
after Heat From Collector + Aux		X	X	X	1	0	1	1	1	1	1	0	0	0	1	1	0
Heat From Storage (HFS)		X	0	X	1	1	X	0	1	1	0	0	0	0	1	0	0
Cool AHX after HFS + Aux		X	X	X	1	1	1	0	0	1	0	0	1	0	1	0	0
HFS + Aux...storage cold		X	1	X	1	1	0	0	1	1	0	0	1	0	1	0	0
HFS + Aux...high demand		X	X	X	1	1	X	1	1	1	0	0	0	0	0	1	0
Collector to Storage Only		1	X	1	1	0	0	X	0	1	0	0	0	0	0	1	0
Collector to Storage with		1	X	1	1	0	1	1	0	1	1	0	0	0	0	1	0
Hot Water Pump Enabled		0	X	1	1	0	0	X	0	1	1	0	0	0	0	1	0
Do Nothing-Winter		0	X	1	1	0	1	1	0	1	1	0	0	0	0	1	0
		X	X	0	1	X	0	X	0	0	0	0	0	0	0	0	0
Sensor Signal Description																	
SUMMER MODES		T _{SB} > T _{ST}	T _{ST}	T _{ST} < T ₀	T _{CO} > T _{SB}	T _{SB} > T ₀	W/S	T _{CO}	CTM	Aux Off	T _{R2}	T _{R1}	B1	HWPB enable	EVC	Aux	MD 1 AB
																	MD 2 ABC
																	MD 3 ABC
																	MD 1C
Cool From Outside		X	X	1	0	0	X	0	1	0	1	1	1	0	0	1	1
Cool From Evaporative Cooler		X	0	0	0	0	X	0	1	0	1	1	0	0	0	1	1
Cool From Storage		X	1	0	0	0	X	0	1	0	1	1	0	0	0	1	1
Cold Charge...T _{ST} > T ₀		0	0	1	0	1	0	0	0	0	1	1	1	0	1	0	0
Cold Charge...T _{SB} > T _{ST}		1	X	X	0	1	0	0	0	0	1	1	0	1	1	0	1
Summer Heating...T _{R1}		X	X	X	0	X	0	0	1	1	1	1	0	1	1	1	0
Summer Heating...T _{R2}		X	X	X	0	X	X	1	1	1	1	1	0	1	1	1	0
Cool AHX after Heating		X	X	X	0	X	1	0	X	1	1	0	0	0	0	0	0
Do Nothing-Summer...T ₀ contradiction		X	X	X	0	X	1	0	0	0	0	0	0	0	0	0	0
Do Nothing-Summer...No Cold Charge		0	1	X	0	1	0	0	0	0	0	0	0	0	0	0	0
		X	X	X	0	0	0	0	0	0	0	0	0	0	0	0	0

Winter: HWP = T_{CO} > T_{PH} HWPB enable

External ΔT controller completes HWPB control loops

Summer: HWPB2 = T_{CO} > T_{PH} HWPB enable

true (designated by 1) or false (designated by 0) but there are certain comparisons which are not germane to deciding the mode status in the control logic programmed in the PROM. Comparisons which are immaterial to a decision are marked "X", indicating "don't care".

The third line of the truth table is to allow the housing in the gas-fired auxiliary heater to be cooled to the room air after the gas valve has been shut off. A timer subassembly which provides input to address A2 of the PROM enables blower B1 to continue for 4 minutes after the gas burner is turned off.

Collection of solar heat to storage is initiated when T_{CO} is greater than T_{SB} by a preset amount of 11°C , and the system will continue to collect heat once started, until $T_{CO} - T_{SB}$ is equal to 1°C . A hysteresis of 10°C prevents cycling of blower B1 startup and shut down. In addition to meeting the requirement of T_{CO} greater than T_{SB} , T_{CO} must also be greater than the preset temperature. The requirements of input states can be seen in the truth table. During this mode, domestic water heating (HWPH) is enabled if T_{SB} is less than T_{ST} , but if T_{SB} is greater than T_{ST} , heat is not extracted for domestic water heating because the air temperature after the heat exchanger will drop further, and where the top of storage is already cold, the air entering storage may drop below room air temperature which is undesirable for storage.

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_{CO} must be less than the preset temperature) and T_{R1} and/or T_{R2} circuits must be completed. If T_{ST} is below 20°C the logic is set up so that the auxiliary heater turns on even before T_{R2} contact is made. 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 auxiliary furnace. When there is a large heat loss rate from the building, T_{R2} is activated and the auxiliary furnace will turn on, regardless of the temperature at T_{ST} .

4.3.2 Space Cooling

Several alternative possibilities in the control logic to cold charge storage were examined. During part of the 1978 summer season, a comparator for T_{SB} and outside temperature T_0 was used. Although the outside wet-bulb temperature compared to T_{SB} was desired, a suitable sensor could not be found. A temperature difference to estimate the wet-bulb depression from the dry-bulb temperature was estimated for "typical" summer night conditions in Fort Collins, however this comparator was found to be inadequate. Often, the cold charge started too soon in the evening, sometimes too late which inadequately charged the pebble bed, and occasionally no cold charge was initiated. After a period of time the comparator was replaced by a clock timer and was set to start at 2300 hrs, provided other conditions indicated in the truth table were also satisfied. A difficulty occurred when T_{ST} was warmer than T_{SB} and also greater than T_0 . To overcome the "inverted" storage condition, dual criteria for starting cold charge was included in the control logic. Cold charge terminates when either the clock time exceeds the preset "off" time, or if T_{SB} is less than T_0 by a preset amount. The latter criterion is used because cold charge should terminate when the evaporative cooler cannot adequately cool the air because of the high dry-bulb temperature.

Room air is circulated through storage to cool the rooms when the thermostat calls for cooling (T_{R2} for summer setting of the thermostat) and the temperature T_{ST} is less than the outside temperature by 7°C . If the outside temperature is less than the top of storage, either direct evaporative cooling is effected, or the temperature outside is so cool that the rooms can be cooled by ventilation. In both summer and winter modes the controller logic must include a state when the system is "doing nothing".

4.3.3 Domestic Water Preheating

For lack of adequate addresses in the PROM, the preheater circulation pump was controlled by a comparator external to the main controller. When water heating was "enabled" by the controller and T_{CO} was greater than the temperature at the bottom of the preheater tank, T_{PH} , the circulation pump was started. An aquastat was used to limit the temperature in the preheater tank to 60°C in the winter and 70°C in the summer.

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 east edge of the roof in the plane of the collectors, which is tilted at 45 degrees with respect to horizontal. Both instantaneous and integrated values 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 are provided in the data logging unit to an accuracy of $\pm 0.11^{\circ}\text{C}$ (Ref. 2). Temperature differences are measured with multiple-junction thermopiles and electrical output is converted to temperature differences using standard procedures (Ref. 3, 4, 5). 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 junctions 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 I	Leeds and Northrup, Omega, ThermoElectric; 72 and 26 gage	67	-184 to +390°C -40 to +150°C	±.4°C	Consider: Temperature gradient, 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 I	Leeds and Northrup, Omega 26 gage	7	-184 to +370°F +100°C diff.	±(1%+.05°C)	
Outside ambient temperature and humidity	Aspirator	Modified Cambridge Systems, Inc., Model #1105 - contains I.T.C. and I.R.H. sensor	1			
Air flow measurement (velocity pressure)	Total/static pressure tap array	Air Monitor Corp., duct air monitor device	7	+1 to +20 m/sec +1 to +3 m/sec	±(1.0%R +.02 N/m²), after calibration	More uniform pressure tap geometry and placement w.r.t. air streamliner, more taps and better pneumatic averaging should give more uniform pitot coefficients between units. Suitability of materials for high temperature should be checked.
Pneumatic multiplexer	Ganged wafer valves, actuator and electrical driver	Fluid Wafer Switch SCANCO Actuator: LEDEX S2 Controller: CLR10/S2-56	2 1	10000 N/m² max operating pressure	N/A	Dessiccant needed to prevent condensation of water vapor inside tubing, wafer valve, and differential pressure transducer.
Differential pressure	Variable capacitance diaphragm type	Datametrics (Gould) Transducer: 5700-IT-2C1-V1 Signal Conditioner: 1173-A1A-10A1-D1 Thermal Base: Model 525	1 1 1	±133 N/m² 0 to +4N/m²	±(.2%R +.02%F) (5)	RC=5 seconds filter inserted to mask turbulence induced fluctuations. Controlled temperature transducer environment essential to maintaining quoted error limits.
Mode/air-flow multiplexer encoder/controller		Locally made by SEAL	1	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	±(1.5%R +.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 (6)	Current coil and hall effect transducer	F.W. Bell, Inc., PX-2202B	6	±1KW or ±2KW 0 to 800 W	±(.25%R +.25%F)	Models offered by Ohio Semitronics are available with offset, scale factor adjustments and in a greater range of capacities.
Water flow	Turbine meter	Cox 21-1/2-15 Cox ANB-4 with graphite bearings	1 1	0.1 to 1.0 l/sec 0.1 to 0.3 l/sec 0.15 to .15 l/sec 0.03 to .06 l/sec	±.5%F ±.5%R	Sensitive to damage or error from excessive flow; passage of entrained air or dirt.
Auxiliary fuel consumption (piped natural gas)	Conventional positive displacement meter with optical pickup	Sprague Optical pickup by SIAL	2	0 to 1.4 l/sec 0 to +1.2 l/sec	±(1%R +.2%F) (estimated)	Instrumented demonstration project should employ electric auxiliary sources to ensure an accurate primary or redundant measure of the delivered auxiliary energy.
Integrators		AGM Electronics EA-4011-5	7	Unipolar input/output range specified per individual module	±(.25%R +.25%F)	Pick range carefully. Large accumulated errors due to offset avoided by setting offsets slightly negative and rejecting negative values during data processing.
Pulse counters		AGM Electronics EA-4050-2	4			
Barometric pressure	Variable capacitance diaphragm; vacuum reference	Rosemont 1332A	1	0 to 15 psia .73 to .83 atm	±0.2%R	
Relative humidity	Brady Array (AC excited solid state sensor)	Thunder Scientific PC-200	3		±.5%F	Individual calibrations required.
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 ±1.0 VDC; -40 to 150°C	±(.03%R +.005% F +1.5uv) Thermocouple conversion ±0.3°C	Integration of computer and D/A functions should be considered now that such equipment is increasingly available. Provision for digital inputs would be helpful.

NOTES:

- (1) R = of Reading; F = of Full Scale
- (2) All thermocouples and thermopiles are fabricated from premium grade wire. All except sheathed junctions are twisted, and electric arc welded; junctions are directly exposed to the surrounding air.
- (3) The two thermopile circuits (one grounded and one ungrounded) are used to measure absolute temperature in four locations. This simultaneous use of thermocouple junctions for absolute and differential temperature measurements is possible because the A/D unit (Doric) has a very high input impedance, and because its input terminals are isolated from one another and from ground.
- (4) Each thermopile circuit is fabricated from a single spool of wire.
- (5) ±1.0% of reading is typical accuracy achieved in this application because the readings are a small fraction of the full scale range of the instrument.
- (6) A pair of these transducers, each excited by a 20:1 current transformer, serve to measure the larger power intensities drawn into the house through two legs of a 3-phase trunk line serving the solar village.

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

The locations of the thermocouples and thermopiles are shown in Figures 5-3, 5-4 and 5-5. The circled numbers on the figures indicate the locations and the numbers are the data acquisition channels. 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 by a Rosemont Series 1332 pressure transducer, 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 Electric 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 seven flow monitors are multiplexed to the single differential pressure transducer through a Scanivalve. One set of ports on the Scanivalve is short circuited so that a zero differential

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

Figure 5-4. Sensor Location Numbered According to DAU Channel (Table 5-2).

Figure 5-5. Sensor Location Numbered According to DAU Channel (Table 5-2).

Table 5-2. Instruments in Solar House II (Assigned numbers refer to channels on the data logger)

46 H.W. delivery temp.	73 Air temp. after H.W. heat exchanger
47 outdoor air temp. (dry-bulb)	74 Temp. difference across H.W. heat exchanger
48 temp. in room 102	75 Air temp. to evaporative cooler
49 temp. in room 106	76 Air temp. after evaporative cooler
50 temp. in room 104	77 Temp. difference across evaporative cooler
51 temp. in room 105	78 Water temp. at top of preheat tank
52 temp. in room N2 (near thermostat)	79 Water temp. at bottom of preheat tank
53 temp. difference across auxiliary heater	80 Total solar flux (45 tilt)
54 room air supply temp.	81 Total solar insolation (45 tilt)
55 room air return temp.	82 Mode indicator
56 temp. difference, room return to Blower B1	83 Pressure difference at air monitor (one of seven)
57 Storage temp. (top of bed)	84 Dynamic pressure at air monitor
58 Storage temp. (0.5 ft)	85 Quantity of hot water supplied
59 Storage temp. (1.5 ft)	86 Quantity of hot water recirculated
60 Storage temp. (2.5 ft)	87 Relative humidity outdoor
61 Storage temp. (3.5 ft)	88 Relative humidity at main blower
62 Storage temp. (4.5 ft)	89 Relative humidity at thermostat
63 Storage temp. (5.5 ft at support mesh)	90 Barometric pressure at site
64 Air temp., top port of storage	91 Blank
65 Air temp., bottom port of storage	92 Auxiliary heater gas consumption
66 Temp. difference across storage	93 H.W. Heater gas consumption
67 Air temp. at inlet to Main Blower (B1)	94 Electrical power used in the building
68 Temp. difference, top of storage to B1	95 Electrical power used for instrumentation and data logger
69 Air temp. at collector outlet	96 Electrical energy for main Blower
70 Air temp. at collector inlet	97 Electric energy for Blower B2 and H.W. pump
71 Temp. difference across collector	98 Electrical energy for evaporative cooler
72 Air temp. before H.W. heat exchanger	99 Electrical energy for controller, and motorized dampers

pressure reading is obtained for the Barocel, sequentially in the rotation of the Scanivalve.

In addition to barometric pressures, gage pressures and pressure differences along the flow circuit were measured with a sloping water manometer. The locations in the circuit where pressure measurements were recorded are shown on Figure 5-6.

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 two 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 seven air flow monitoring stations in the system. Also, there are hot wire traverse stations at three locations where integrated velocity traverses were made to compare with flow rates measured by the air flow monitors. The air monitoring stations are shown on Figure 5-7 and the hot wire monitoring stations are shown on Figure 5-8. All air monitors were calibrated with an ASME standard nozzle in a wind tunnel with the entrance to the air monitor configured 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 turbine flow

STATIC PRESSURE TAPS ARE
INDICATED BY LETTERS A-H

MD - MOTORIZED DAMPER

Figure 5-6. Static Pressure Tap Locations.

Figure 5-7. Air Flow Monitor Stations.

Figure 5-8. Hot-Wire Anemometer Traverse Stations.

meters. Pulse-count-to-voltage converters were used in the output circuitry. Considerable difficulties were encountered in maintaining the turbine flow meters. They are sensitive to damage from particles in the flow and require frequent calibration. The turbine meters were replaced with a Rotameter and readings were made manually.

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 Gas Consumption Meter

Gas consumption by the auxiliary furnace and auxiliary hot water heater are measured by separate meters. Standard gas meters were adapted for electronic sensing by using photo choppers on the most sensitive meter dial. Meters were also read manually every day for cross-checking purposes. The photo-electric sensors consist of two light emitting diodes (LED), a small wheel with small slots at 22.5 degrees around the circumference that constitutes a light chopper, two photo Darlington's and RS flip-flop. The photo-chopper is shown schematically in Figure 5-9.

A pair of LED/Darlington slot readers are positioned 33.75 degrees apart so that only one beam is sensed at any time. As the wheel turns, each slot is registered on the Darlington driven flip-flop. The flip-

Figure 5-9. Gas Meter Photo-Chopper.

flop is set and then reset as the two beams are alternately interrupted by the opaque sections between the slots.

5.2.8 Electric Power Meters

Seven watt transducers of different ratings were used to record the electric power requirements of different components in the solar system and the building. 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.

House power is measured with two 20-kW power transducers (one for each two incoming legs of three-phase power). 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.

5.2.9 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 form 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.

5.2.10 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 5 basic heating modes, and 3 cooling modes of the system, but there are a number of alternative system states for some modes. For both heating and cooling modes, there are a total of 24 system states or submodes. Each submode refers to a unique position or condition of blowers, dampers, preheat circulation pump and evaporative cooler. 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.

5.2.11 Air Monitor Controller

With one differential pressure transducer to measure the air velocities at seven air flow monitoring stations, an air monitor controller was needed to switch the Scanivalve through appropriate air monitors for each system submode. For a short duty cycle all of the appropriate monitors may not be sampled and monitors that are scanned provide point differential pressure readings. Pneumatic filters, electronic filters and integrators were considered to enable measurement of average velocities. Pneumatic 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 24 submodes is identified and for every submode the applicable air monitors are identified in a pre-programmed logic. At the end of a 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.

5.2.12 Integrators

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

Series 4000 Resettable Integrators. Signals for the pyranometer, gas consumption meters, watt meters and water flow meters are integrated. The gas meters 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 10-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 source tape (i.e., the 7-track tape recorded by the Kennedy tape deck) is removed weekly, generally on Monday morning, and is immediately processed to diagnose all problems of instrumentation and recording. Immediately thereafter, the source tape is copied onto a "master" tape and a back-up copy of the master tape is also produced. After making copies of the source data, the master tape is processed and all voltage quantities are converted to physical units. Some elementary calculations are also made and the converted and calculated quantities are written onto a binary tape. Further processing of scan-wise data can then be made from the binary tape. The use of the binary tape in computer processing improves the time factor by about 4 when compared to the processing time using the master tape. Both the binary and master tapes are kept as permanent records, while the source tape is recycled. The data handling and processing procedure is depicted in the diagram of Figure 6-1.

Figure 6-1. General Procedure for Data Handling and Processing.

A flow chart for on-line data processing is shown on Figure 6-2. With the desk-top computer, "real-time" quantities are stored or calculated and summed into accumulating hourly quantities. Minute-by-minute mode histories are stored as are the air flow rates from the air monitors. Heat flow and solar flux quantities are accumulated into hourly registers. At the end of the day (2400 hours) the mode and air-flow rate histories, and the hourly quantities are written onto a cassette tape, and at a convenient time, the cassette tape data are processed in appropriate form and printed on hard copy.

6.2 DIRECT CONVERSION

Data that are directly convertible to physical quantities are solar flux, submode numbers, air monitor number, atmospheric pressure, pressure differences, gas consumption and electric energy used. The physical quantity is determined by a direct multiplication of the instrument output in volts (or millivolts) and the calibration constant of the instrument. Temperatures are recorded directly in degrees Celsius by the DAU. Temperature differences, volumetric and mass air flow rates, heat flow rates and accumulated heat quantities must be calculated.

6.3 OTHER CONVERSIONS

6.3.1 Differential Temperature Determination

Thermopile outputs (Δe) in microvolts are converted to temperature differences (ΔT) by polynomial representations of the relationships between emf and temperature. Because of the nonlinear relationship between emf and temperature, temperature differences are

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

dependent upon the absolute temperature of the air as well as the emf output from the thermopile. In the Solar House II system a thermocouple is placed at each end of a thermopile. With air temperature, T_1 , known and Δe obtained from the thermopile, the calculation for ΔT proceeds as follows:

1. Determine e_1 corresponding to T_1 from $e_1 = e(T_1)$, where $e(T_1)$ is a polynomial function.
2. Determine $e_2 = e_1 + \Delta e$.
3. Determine T_2 corresponding to e_2 from $T_2 = T(e_2)$, where $T(e_2)$ is a polynomial inverse function of $e(T_1)$.
4. Determine $\Delta T = T_2 - T_1$.

The coefficients for the polynomial functions $e(T_1)$ and $T(e_2)$ are listed in Table 6-1. The coefficients for $e(T)$ were obtained from the NBS monograph (Ref. 5) and the coefficients for $T(e)$ were determined by curve fitting. Fewer terms in the polynomials may be used consistent with accuracy desired. The error in determining ΔT will be approximately equal to the error in measuring Δe , but is relatively insensitive to the absolute error in determining T_1 .

6.3.2 Air Flow Rate Determination

Volume flow rate of air through an air monitor is obtained by the sequence of steps described below:

1. Determine Δp from the Barocel output by

$$\Delta p = k_B (E_1 - E_z) \quad (6-1)$$

where k_B is the calibration constant of the pressure transducer, E_1 is the output voltage proportional to Δp and E_z is the output voltage for zero pressure difference.

Table 6-1. Thermocouple Linearization Polynomials

$e = \sum_{i=1}^n a_i T^i$				$T = \sum_{i=1}^n b_i e^i$			
$i \quad a_i: \text{ Value, Exp.}$				$b_i: \text{ Value, Exp.}$			
n=14 -270 to 0°C	1	3874	-2	n=8 -50 to 0°C	2581	-5	
	2	4412	-5		-7579	-10	
	3	1141	-7		6395	-17	
	4	1997	-8		-2072	-16	
	5	9045	-10		-2000	-19	
	6	2277	-11		-9882	-23	
	7	3625	-13		-2459	-26	
	8	3865	-15		-2520	-30	
	9	2830	-17				
	10	1428	-19				
	11	4883	-22				
	12	1080	-24				
	13	1395	-27				
	14	7980	-31				
n=8 0 to 400°C	1	3874	-2	n=8 0 to 100°C	2581	-5	
	2	3319	-5		-5706	-10	
	3	2071	-7		-6731	-14	
	4	-2195	-9		3492	-17	
	5	1103	-11		-7494	-21	
	6	-3093	-14		9898	-25	
	7	4565	-17		-7774	-29	
	8	-2762	-20		2793	-33	

2. Determine the instantaneous average air velocity at the air monitor by

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

where k_v is the velocity coefficient for the air monitor determined by calibration, ρ is the "instantaneous" air density determined from $p = \rho RT$, in which p is the barometric pressure, R is the gas constant for air and T is absolute air temperature.

3. Determine the local volumetric flow rate from $\dot{V} = AV$, where A is the cross-sectional area of the flow monitor.
4. Convert the local volumetric air flow rate to a reference (blower exit) air flow rate by

$$\dot{V}_r = \dot{V}_l \left(\frac{p_l T_r}{p_r T_l} \right) \quad (6-3)$$

where subscripts r and l refer to reference and local conditions respectively. When the reference is chosen to be the blower outlet condition, $p_l/p_r \approx 1$, within measurement accuracy which reduces the above equation to

$$\dot{V}_r = \dot{V}_l (T_r/T_l). \quad (6-4)$$

The correction to blower conditions is made instead of "standard" air conditions because with a constant rotational rate of the blower, the volumetric air flow rate delivered by the blower is constant for a fixed pressure drop across the blower. For a given mode of operation the pressure drop across the blower is nearly constant, and volumetric air flow rates delivered are nearly constant so that local air flow rates measured at each monitor can be corrected to air conditions at the blower exit.

5. Determine long-term averages of air flow rates for each air monitor in each mode.

6.4 HEAT FLOW RATE CALCULATIONS

6.4.1 Definition of Terms

The heat quantities that are calculated from direct measurements are:

1. Total solar insolation	(ST)
2. Solar insolation while collecting	(SOP)
3. Infiltration into the collector loop	(QFI)
4. Heat delivered from the collectors	(QCS)
5. Overheating of the rooms	(QOH)
6. Solar heat to DHW preheat	(QXA)
7. Solar heat to load from the collector	(QCL)
8. Solar heat to storage	(QSI)
9. Solar heat from storage to load	(QSO)
10. Auxiliary heat to DHW	(QWA)
11. Auxiliary heat to space heater	(QAH)
12. Total space heating	(QHR)
13. Heat removed from the building	(QCR)
14. Heat removed from storage by EVC	(QES)
15. Space heat removed by EVC	(QEL)
16. Space heat removed by ventilation	(QDC)
17. Heat removed by the EVC	(QEV)

Heat losses from storage are calculated indirectly from measured temperatures, estimated values of UA, and daily heat balances in storage.

6.4.2 Solar Insolation

Total solar radiation (ST) on the plane of the collector during a time interval, Δt , is calculated from

$$ST = A_c K_p K_e \int_0^{\Delta t} (mv) dt \quad , \quad (6-5)$$

where

ST is the incident radiation in a scan time interval,

Δt (10 min), MJ

$\int_0^{\Delta t} (mv) dt$ is the integrated pyranometer output in millivolt-minutes

K_e is the integrator constant in mv/(mv-min)

K_p is the pyranometer calibration constant ($\text{MJ} \cdot \text{m}^{-2} \cdot \text{min}^{-1} / \text{mv}$)

dt is integration time

A_c is collector area, m^2 .

The calculation of incident solar radiation while operating, SOP, is performed as in Eq. 6-5, except that the equation is valid only when the collector is operating.

6.4.3 Heat from the Collector

Heat delivered from the collector in a time interval Δt is calculated from

$$QCS = \sum \{ \dot{m}_o c_p (\Delta T) + \dot{m}_l c_p (T_{in} - T_{amb}) \} \Delta t \quad , \quad (6-6)$$

where

QCS is the useful heat delivered from the collector, MJ

$\dot{m}_o$ is the mass flow rate of air out of the collector, $\text{kg}/(10 \text{ min})$

$\dot{m}_l$ is the mass flow rate of air leakage into the collector, kg/(10 min)
 c_p is the specific heat of air, MJ/(kg·°C)
 ΔT is the air temperature difference into and out from the collector, °C
 T_{in} is the air temperature into the collector, °C
 T_{amb} is the ambient air temperature, °C
 Δt is the time increment, 10 min.

The last term in the bracket is the heat contribution, QFI, due to air leakage into the collector, and $\dot{m}_l$ is the measured difference between the outflow and inflow rates to the collector array. The ambient temperature is determined at the weather station near Solar House II. Heat loss from the distribution manifolds is excluded from the quantity QCS because the points of temperature and air flow measurements into and out of the collector are before and after the distribution manifolds respectively.

6.4.4 Heat from Collector to Load

Heat delivered to the load directly from the collector, QCL, is equal to the heat delivered from the collector during the times when the rooms require heating. The summation in Eq. 6-6 takes place during the appropriate mode. The ducts below the points of air flow and temperature measurement to and from the collector are within the heated envelope, therefore the measured heat flow rate is ultimately delivered to the load.

6.4.5 Heat from Collector to Storage

Heat delivered to storage was calculated from

$$QSI = \sum \dot{m} c_p (T_{in} - T_{out}) \Delta t \quad (6-7)$$

where

- QSI is heat inflow to storage, MJ
 $\dot{m}$ is the mass flow rate measured in the duct connected to the bottom port, kg/(10 min)
 c_p is the specific heat of air, MJ/(kg·°C)
 T_{in} is the air temperature into storage, °C
 T_{out} is the air temperature out of storage, °C
 Δt is the scan time interval, 10 minutes.

6.4.6 Heat from Storage to Load

Heat delivered from storage to space heating load,

$$QSO = \sum \dot{m} c_p (T_{out} - T_{in}) \Delta t \quad , \quad (6-8)$$

where

- QSO is the heat supplied from storage, MJ
 $\dot{m}$ is the mass flow rate measured at the bottom port, kg/(10 min)
 T_{out} is the temperature of the air at the top port of storage, °C
 T_{in} is the temperature of the air at the bottom port of storage, °C
 ΔT is the scan time interval, 10 minutes.

6.4.7 Auxiliary Heating

Heat delivered by the auxiliary space heater is determined by

$$Q_{AH} = H\eta \int_0^{\Delta t} \dot{V} dt \quad (6-9)$$

where

Q_{AH} is the total heat supplied by the auxiliary heater, MJ

H is the heat content of natural gas at the furnace or heater, MJ/m³

$\int_0^{\Delta t} \dot{V} dt$ is the integrated volume of gas used by the auxiliary furnace, m³

η is the burner efficiency, 0.60

The auxiliary heat for DHW, Q_{WA} , was also calculated from Equation (6-9).

6.4.8 Heat to DHW Preheater

Heat delivered from the collectors to the preheat water tank is calculated from

$$Q_{XA} = \sum \dot{m}_o c_p (\Delta T) \Delta t, \quad (6-10)$$

where

Q_{XA} is the heat transferred to the DHW preheat circulation loop, MJ

$\dot{m}_o$ is the mass flow rate out of the collector, kg/(10 min)

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

ΔT is the temperature difference measured across the air-to-water heat exchanger, °C

Δt is the scan interval, 10 minutes

6.4.9 Overheating

The quantity QOH is:

$$QOH = QCS - QXA - QSI \quad (6-11)$$

6.4.10 Total Space Heating

Total space heating is determined from:

$$\begin{aligned} QHR = & QSO + QCL + QOH + \text{heat losses from storage} \\ & + \text{heat losses from DHW tanks} \end{aligned} \quad (6-12)$$

6.4.11 Heat Removal Rates

Heat removed by the evaporative cooler is determined by:

$$QEV = \sum \dot{m} c_p (\Delta T) \Delta t \quad (6-13)$$

where

- $\dot{m}$ is the mass flow rate through the EVC, kg/(10min)
- c_p is the specific heat of air, MJ/(kg·°C)
- ΔT is the temperature difference across the EVC, °C
- Δt is the scan interval, 10 minutes

Heat removed from the building space by storage is:

$$QCR = QSO - QSI \quad (6-14)$$

Heat removed from storage and from load directly by the evaporative cooler is determined from Eq. (6-13) and heat removed by ventilation is determined

from the mass flow rate into the room, specific heat of air and the temperature difference in the room supply and room return air ducts.

6.5 INFORMATION PRODUCED

The processed data are produced on hard copies both from the CSU computer center and from the desk-top computer. The daily records are from midnight to midnight, although during the heating season, it is convenient to define a day from 8:00 am to 8:00 am and during a cooling season from 10:00 pm to 10:00 pm. The following data and computed quantities are produced:

1. MODE HISTORY - A list of modes, changes in modes and their corresponding times.
2. FLOW HISTOGRAM - A tabular record of the air-flow monitor identified by an index, average air flow rate, standard deviation of samples considered, number of total samples for each monitor, the sample intervals and the numbers of samples in each interval.
3. DAILY ENERGY SUMMARIES - An hourly tabulation of heat flow quantities for various components of the system, average temperatures, electric energy used, auxiliary energy supplied and total daily quantities.
4. COLLECTOR OPERATION SUMMARY - An hourly tabulation of total solar insolation, solar insolation while collecting, inlet air temperatures, average temperature rise and collector efficiency parameters.
5. STORAGE TEMPERATURE PROFILE - A table of temperature levels through storage at the end of each hour of the day.

6.6 SPECIAL PROBLEMS IN DATA PROCESSING

Data processing techniques are a function of the type of computer used, programming style and availability of computer funds. Time (speed) and memory constraints of the desk-top computer restricted the processing technique of the on-line system, while cost of computing restricted the technique in processing the 7-track tape.

In processing both the logged data tape and real-time data, so-called index threads were extensively used to simplify and condense the calculations. Otherwise data handling would be, at best, cumbersome. Overlays were necessary to minimize coding and use of special-purpose variables in memory.

Time and memory constraints were not the only problems confronted in data processing. Peculiar to continuous, real-time analyses of non-repeatable data, there is necessity to contend with many special cases, peculiarities in logging, and anomolous data. Peculiarities like non-standard scan intervals, missed scans, illegal modes and illegal values must be properly identified and processed in such a way as to maintain the integrity of the calculated quantities and to maintain continuous processing. At the same time, diagnostic flags must be raised so that at later perusal, the system state and calculated quantities can be thoroughly scrutinized.

7 THERMAL PERFORMANCE

7.1 ENERGY FLOW DIAGRAM

The overall energy flow diagram for analyzing system performance in Solar House II is shown in Figure 7-1. Definitions and methods of computing the heat quantities are explained in Section 6.4. To aid the computer processing of the data, a truth table for heat flow rates and heat quantities was established as shown in Table 7-1.

7.2 AIR FLOW RATES

Air flow rates measured at a particular air monitor station will vary with each mode because the pressure drop in the flow circuit will be different. To aid the computer calculations of heat flow rates, identifying indices were established for each monitor in each mode. Table 7-2 lists the identifying indices for the pertinent air monitors and modes. The flow rates for each index identifier is listed in Table 7-3.

7.3 DAILY SYSTEM PERFORMANCE

7.3.1 Space Cooling 1977

The computed daily quantities for space cooling, solar and auxiliary water heating, and electricity used for operating the solar system, cooling system and electricity used in the house are tabulated in Tables 7-4 through 7-7 for the period 16 June 1977 through 30 September 1977. A cooling day is defined to be 2300 hours to 2300 hours, because cold charge of storage generally begins at about 11:00 p.m. Graphical representations of the daily performance of the nocturnal cooling system for the same period are shown in Figure 7-2 through 7-5 in which the cooling provided by outdoor air circulation, from storage, and by direct evaporative cooling are identified separately.

Figure 7-1. Energy Flow Diagram for Solar House II System.

Table 7-1. Truth Table for Calculated Heat Flow Rates and Heat Quantities

	Sub-Mode	Description	To Storage QSI	From Storage QSO	Collector to Preheater & Storage QCS	Collector to Load QCL	DHW Preheater (air side) QXA	DHW Preheater (water side) QXW	Aux. Space Heating QAH	Total Space Heating QHR	Total Space Cooling QCR	EVC to Storage Cooling QES	EVC to Space Cooling QEL	Excess to Space Heating QOH	Infiltrator Load QFI
Heating	1	Space Heating from Collector and Auxiliary	0	0	0	1	0	0	1	1	0	0	0	1	1
	2	Space Heating from Collector Only	0	0	0	1	0	0	0	1	0	0	0	1	1
	3	Space Heating and Cooling Auxiliary Furnace	0	0	0	1	1	1	0	1	0	0	0	1	1
	4	Space Heating from Storage	0	1	0	0	0	0	0	1	0	0	0	0	0
	5	Space Heating from Storage and Auxiliary	0	1	0	0	0	0	1	1	0	0	0	0	0
	6	Heat Flow to Storage (DHW)	1	0	1	0	1	1	0	0	0	0	0	1	1
	7	Heat Flow to Storage no (DHW)	1	0	1	0	0	0	0	0	0	0	0	1	1
Cooling	8	Ventilating or Cooling Auxiliary Furnace - no Collector Circulation	0	0	0	0	0	0	0	1	1	0	0	0	0
	9	Ventilating or Cooling Auxiliary Furnace, Cooling Collector	0	0	0	0	0	0	0	1	1	0	0	1	1
	10	Ventilating or Cooling Auxiliary Furnace, DHW Preheating	0	0	1	0	1	1	0	1	1	0	0	1	1
	11	Direct EVC to Space, no Collector Circulation	0	0	0	0	0	0	0	0	1	0	1	0	0
	12	Direct EVC to Space Cooling Collector	0	0	0	0	0	0	0	0	1	0	1	1	1
	13	Direct EVC to Space Heating Hot Water	0	0	1	0	1	1	0	0	1	0	1	1	1
	14	Space Cooling from Storage, and Cooling the Collector	0	1	0	0	0	0	0	0	1	0	0	1	1
	15	Cooling From Storage, Heating Hot Water	0	1	1	0	1	1	0	0	1	0	0	1	1
	16	To Storage (cold charge), no Collector Circulation	1	0	0	0	0	0	0	0	0	1	0	0	0
	17	To Storage, Cooling Collector	1	0	0	0	0	0	0	0	0	1	0	1	1
	18	To Storage, Heating Hot Water	1	0	1	0	1	1	0	0	0	1	0	1	1
	19	Summer Space Heating, no Collector Circulation	0	0	0	0	0	0	1	1	0	0	0	0	0
	20	Summer Space Heating, Cooling Collector	0	0	0	0	0	0	1	1	0	0	0	1	1
	21	Summer Space Heating, Hot Water	0	0	1	0	1	1	1	1	0	0	0	1	1
	22	Do Nothing	0	0	0	0	0	0	0	0	0	0	0	0	0
	23	Cooling Collector	0	0	0	0	0	0	0	0	0	0	0	1	1
	24	Space Heating Hot Water	0	0	1	0	1	1	0	0	0	0	0	1	1

Table 7-2. Table of Indices for Applicable Air Monitors for Each Submode
(See Figure 5-7 for air monitor locations and Table 7-2 for air flow rates)

Mode of Operation	Sampling Station							
	Collector Supply CS	Collector Return CR	Flow up Through Storage SU	Flow down Through Storage SD	Top Duct to Storage ST	Room Supply RS	Evap. Cooler Duct EV	Short Circuit Zero Mode SC
1	2	3	0	0	0	4	0	1
2	2	3	0	0	0	4	0	1
3	2	3	0	0	0	4	0	1
4	0	0	5	0	6	7	0	1
5	0	0	5	0	6	7	0	1
6	8	9	0	10	0	0	0	1
7	8	9	0	10	0	0	0	1
4	0	0	5	0	6	7	9	1
8	0	0	0	0	0	11	12	1
9	21	22	0	0	0	11	12	1
10	21	22	0	0	0	11	12	1
11	0	0	0	0	0	13	14	1
12	21	22	0	0	0	13	14	1
13	21	22	0	0	0	13	14	1
14	21	22	15	0	16	17	0	1
15	21	22	15	0	16	17	0	1
16	0	0	0	18	0	0	19	1
17	21	22	0	18	0	0	19	1
18	21	22	0	18	0	0	19	1
19	0	0	0	0	0	11	12	1
20	21	22	0	0	0	11	12	1
21	21	22	0	0	0	11	12	1
22	20	20	20	20	20	20	20	1
23	21	22	0	0	0	0	0	1
24	21	22	0	0	0	0	0	1

Table 7-3. Average Volumetric Flow Rates and Standard Deviation (m^3/min)

Index Identifier	16 June 1978 - 30 September 1977		8 October 1977 - 6 November 1977		7 November 1977 - 9 December 1977		10 December 1977 - 22 December 1977		23 December 1977 - 22 January 1978		23 January 1978 - 19 April 1978		20 April 1978 - 15 May 1978	
	Flow Rate	Standard Deviation	Flow Rate	Standard Deviation	Flow Rate	Standard Deviation	Flow Rate	Standard Deviation	Flow Rate	Standard Deviation	Flow Rate	Standard Deviation	Flow Rate	Standard Deviation
1			0.00		0.00		0.00		0.00		0.00		0.00	
2			22.80		22.80	1.00	22.86	2.00	21.73	0.26	22.86	0.36	22.14	
3			40.24		40.24		40.24	0.33	42.06	0.15	42.03	0.60	42.03	0.60
4			42.92		43.90		44.93	0.30	42.92	0.07	41.94	0.97	41.94	0.97
5	32.32	0.62	36.22	0.76	36.22	0.74	24.42	0.71	31.97	0.40	32.54	0.59	29.90	0.75
6	35.90	1.67	37.54	0.20	43.39	0.37	30.00	0.27	38.13	0.48	38.43	0.37	39.18	0.78
7	44.04	0.50	44.90	1.04	44.90	1.00	43.94	0.40	45.86	0.59	44.63	0.40	45.84	0.66
8			29.00	0.82	29.00	0.84	27.95	0.63	27.38	0.20	28.72	0.38	28.45	0.50
9			42.20		39.98	0.70	39.98	0.69	41.39	0.49	40.96	0.65	40.51	0.60
10			32.00		31.47	1.04	31.47	0.88	30.82	0.22	32.90	0.38	33.10	0.48
11	46.31	0.77												
12	34.17	0.91												
13	46.03	0.68												
14	34.22	1.06												
15	32.66	0.43												
16	41.38	0.14												
17	43.95	0.39												
18	30.42	0.81												
19	34.50	1.03												
20	0.00													
21	30.87	0.37												
22	35.11	0.29												

Table 7-4. System Performance for the Month of June 1977 (MJ/Day)

Day	SPACE COOLING				DOMESTIC HOT WATER			COLLECTOR PERFORMANCE				STORAGE		ELECTRIC ENERGY		
	From Outdoors	From Storage	From EVC	TOTAL	Solar	Auxiliary	TOTAL	Total Solar	While Operating	Heat Delivered	Average Efficiency	Cold Charge	Discharge	For Solar	For Cooling	For House
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12																
13																
14																
15	Begin Cooling Season Data															
16	0.0	101.6	0.0	101.6	45.5	0.0	45.5	1400	667	149.9	0.22	86.1	101.6+	3.3	36.0+	107.3+
17	0.0	17.7	0.0	17.7	45.5+	0.0	45.5+	586+	508+	106.0+	0.21+	127.6	17.7	4.3	23.8	83.0
18	1.7	22.8	16.2	40.7	37.1	0.0	37.1	557	371	79.2	0.21	110.6	22.8	4.2	33.3	88.2
19	0.0	58.1	9.6	67.7	47.1	0.0	47.1	763	516	113.9	0.22	66.9	58.1	4.5	28.1	70.1
20	0.0	43.3	0.0	43.3	19.9	0.0	19.9	852	633	70.2	0.11	50.2	43.3	3.9	22.9	62.5
21	4.4	116.7	19.7	140.8	76.6	3.8	80.4	1349	919	217.1	0.24	75.7	116.7	8.9	51.3	125.2
22	2.1	120.7	12.8	135.6	63.6	0.0	63.6	1312	595	127.7	0.21	136.3	120.7	7.0	46.6	110.5
23	17.2	106.3	12.4	135.9	65.1	3.8	68.9	1233	816	170.8	0.21	129.4	106.3	8.8	46.2	128.1
24	0.0	124.3	4.7	129.0	75.7	0.0	75.7	1613	745	170.3	0.23	143.0	124.3	7.9	42.9	105.0
25	0.0	119.5	0.0	119.5	63.8	4.0	67.8	1463	639	135.4	0.21	131.1	119.5	5.8	29.4	76.1
26	0.0	132.0	0.0	132.0	68.8	0.0	68.8	1191	679	134.0	0.20	88.1	132.0	5.5	21.1	62.3
27	2.8	72.8	24.7	100.3	59.3	4.2	63.5	1511	550	102.7	0.19	23.1	72.8	----	----	----
28	0.6	44.6	75.6	120.8	63.9	0.0	63.9	1603	657	154.3	0.24	165.2	44.6	----	----	----
29	0.0	100.0	14.3	114.3	43.4	6.3	49.7	687	440	70.9	0.16	123.3	100.0	----	----	----
30	76.3	0.0	16.3	92.6	32.6+	5.2	37.8	710+	444*	88.9+	0.20*	0.0	0.0	----	----	----
31																
Total	105.1	1180.4	206.3	1491.8	807.9	27.3	835.2	16824	9179	1841.3	----	1456.6	1180.4	64.1	381.6	1018.3
Mean	7.0	78.7	13.7	99.4	53.9	1.8	55.7	1122	612	122.8	0.20	97.1	78.7	5.8	34.7	92.6

* Calculated Values

+ Missing Scans

Table 7-5. System Performance for the Month of July 1977 (MJ/Day)

Day	SPACE COOLING				DOMESTIC HOT WATER			COLLECTOR PERFORMANCE				STORAGE		ELECTRIC ENERGY		
	From Outdoors	From Storage	From EVC	TOTAL	Solar	Auxiliary	TOTAL	Total Solar	While Operating	Heat Delivered	Average Efficiency	Cold Charge	Discharge	For Solar	For Cooling	For House
1	0.0	138.0	0.0	138.0	88.1	0.0	88.1	1580	773	194.5	0.25	163.5	138.0	9.2	46.1	134.4
2	7.4	111.7	0.0	119.1	65.9	0.0	65.9	1468	540	115.8	0.21	30.6	111.7	9.5	54.7	129.2
3	24.2	0.0	61.6	85.8	65.5	0.0	65.5	1274	671	143.0	0.21	0.0	0.0	11.7	62.1	124.6
4	28.4	1.0	94.1	123.5	50.1	0.0	50.1	1020	392	95.1	0.24	0.0	1.0	5.1	55.2	106.8
5	6.8	79.1	23.5	100.4	48.5	4.4	52.9	926	333	78.4	0.24	124.0	70.1	4.2	59.3	183.2
6	0.0	112.5	0.0	112.5	0.0	8.4	8.4	1304	0	0.0	----	73.6	112.5	0.8	50.9	171.7
7	9.7	102.9	53.0	165.6	0.0	28.7	28.7	1108	0	0.0	----	106.3	102.9	0.8	70.5	199.2
8	10.6	85.2	3.4	99.2	0.0	32.4	32.4	1018	0	0.0	----	112.4	85.2	0.8	69.3	191.0
9	2.6	106.7	1.8	111.1	14.9	32.5	47.4	1002	60*	14.3	0.24	99.0	106.7	4.6	55.7	144.8
10	5.6	152.6	17.6	175.8	70.1	14.3	84.4	1526	612	122.5	0.20	118.8	152.6	17.0	71.9	170.5
11	0.0	112.2	25.6	137.8	80.9	9.9	90.8	1484	740	162.4	0.22	160.5	112.2	10.7	65.8	234.1
12	0.0	140.7	28.7	169.4	58.2	9.3	67.5	1476	700	158.5	0.23	121.2	140.7	4.7	66.5	160.5
13	4.9	127.6	42.4	174.9	40.0	17.0	57.0	704	658	106.6	0.16	114.7	127.6	29.8	68.8	211.0
14	2.6	3.2	60.4	66.2	72.9	35.2	108.1	1276	602	119.6	0.20	0.0	3.2	30.0	22.6	176.5
15	0.0	109.7	0.0	109.7	69.3	22.5	91.9	1158	516	117.8	0.23	153.9	109.7	8.1	73.4	148.8
16	0.0	49.9	0.0	49.9	79.1	12.1	91.2	1002	568	115.4	0.20	106.4	49.9	9.8	37.6	89.4
17	0.0	133.9	0.0	133.9	78.8	6.1	84.9	944	542	115.0	0.21	23.4	133.9	10.0	45.3	118.7
18	0.0	104.8	0.0	104.8	57.1	7.2	64.3	1220	349	73.9	0.21	109.9	104.8	8.4	40.9	147.5
19	7.1	50.3	0.0	57.4	0.0	26.2	26.2	904	0	0.0	----	87.4	50.3	0.9	71.0	219.6
20	0.0	33.9	1.1	35.0	0.0	29.9	29.9	775	0	0.0	----	81.7	33.9	1.1	48.0	136.1
21	0.0	0.0	0.0	0.0	22.0	20.6	42.7	193	118	38.1	0.32	35.5	0.0	7.9	24.3	154.0
22	-0.2	79.2	1.6	80.6	60.3	4.5	64.8	856	560	151.9	0.27	0.0	79.2	11.8	31.5	127.1
23	0.0	48.9	0.0	48.9	39.8	4.3	44.1	1409	387	80.3	0.21	0.0	48.9	6.7	26.0	123.9
24	0.0	27.6	0.0	27.6	54.8	8.9	63.7	912	572	150.6	0.26	111.7	27.6	9.4	58.1	126.3
25	0.0	0.0	0.0	0.0	3.2	14.3	17.5	172	32	7.7	0.24	32.3	0.0	2.0	8.1	122.3
26	0.0	0.0	0.0	0.0	106.3	4.4	110.7	1358	890	233.4	0.26	0.0	0.0	10.9	1.5	136.9
27	-0.1	17.5	0.0	17.4	74.6	0.0	74.6	1508	653	171.2	0.26	0.3	17.5	10.1	17.1	172.4
28	-0.3	0.0	0.0	-0.3	55.4	0.0	55.4	1474	424	113.3	0.27	66.9	0.0	5.4	33.8	149.4
29	0.3	124.1	0.0	124.4	79.0	0.0	79.0	1410	641	153.6	0.24	29.8	124.1	8.5	61.0	186.1
30	0.0	112.1	0.0	112.1	21.1	4.5	25.6	1483	367	77.3	0.21	89.3	112.1	5.4	54.4	122.7
31	0.0	90.0	0.0	90.0	28.1	9.0	37.1	1683	406	90.4	0.22	129.5	90.0	4.7	63.7	119.1
Total	109.6	2246.3	414.8	2770.7	1484.2	366.6	1850.8	35627	13146	3000.6	----	2282.6	2246.3	260.0	1515.1	4737.8
Mean	3.9*	80.2*	14.8*	98.9*	47.9	11.8	59.7	1149	424	96.8	0.23	73.6	72.5	8.4	48.9	152.8

* Calculated Values

+ Missing Scans

- Average of 28 Cooling Days

Table 7-6. System Performance for the Month of August 1977 (MJ/Day)

Day	SPACE COOLING				DOMESTIC HOT WATER			COLLECTOR PERFORMANCE				STORAGE		ELECTRIC ENERGY		
	From Outdoors	From Storage	From EVC	TOTAL	Solar	Auxiliary	TOTAL	Total Solar	While Operating	Heat Delivered	Average Efficiency	Cold Charge	Discharge	For Solar	For Cooling	For House
1	0.0	0.0	0.0	0.0	25.3	0.0	25.3	1640	388	83.7	0.22	115.2	0.0	3.9	38.8	116.9
2	0.0	131.7	0.0	131.7	30.1	4.5	34.6	1585	397	88.3	0.22	16.3	131.7	5.9	46.3	148.5
3	0.0	97.9	0.0	97.9	32.5	4.5	37.0	1170	410	90.2	0.22	83.5	97.9	6.5	44.8	152.6
4	20.9	38.6	27.6	87.1	33.4	4.5	37.9	869	434	104.5	0.24	129.8	38.6	6.7	72.3	219.0
5	19.1	0.0	0.0	19.1	5.5	8.7	14.2	512	85	14.8	0.17	59.7	0.0	2.9	41.4	151.6
6	0.0	7.7	0.0	7.7	57.9	9.2	67.1	1569	531	115.6	0.22	0.0	7.7	7.2	3.2	74.4
7	19.7	0.0	6.9	26.6	58.5	4.6	63.1	1323	516	123.9	0.24	17.9	0.0	8.3	23.1	123.1
8	1.8	2.6	45.4	49.8	66.5	0.0	66.5	825	582	142.2	0.24	14.5	2.6	8.4	39.0	137.3
9	0.0	64.9	0.0	64.9	62.2	0.2	62.4	1405	543	127.5	0.24	42.5	64.9	7.5	25.3	128.3
10	24.6	39.9	2.9	67.4	107.6	10.7	118.3	974	656	205.4	0.31	101.9	39.9	12.7	54.0	210.3
11	0.0	0.0	0.0	0.0	32.0	25.4	57.4	488	269	59.7	0.22	75.6	0.0	6.2	52.5	103.9
12	0.0	87.4	14.9	102.3	65.2	4.5	69.7	1482	587	138.1	0.24	0.0	87.4	8.0	32.0	111.0
13	0.0	0.0	0.0	0.0	66.5	4.4	70.9	1330	603	143.8	0.24	103.0	0.0	8.3	32.8	97.2
14	0.0	0.0	0.0	0.0	30.9	14.5	45.4	441	252	63.2	0.25	0.0	0.0	8.0	1.2	56.8
15	17.2	53.7	15.8	86.7	60.9	0.0	60.9	790	528	128.4	0.24	1.6	53.7	7.8	52.8	148.5
16	0.0	0.0	0.0	0.0	24.4	15.6	40.0	352	157	41.4	0.26	0.0	0.0	5.4	1.3	115.4
17	-0.3	0.0	0.0	-0.3	0.0	16.1	16.1	209	0	0.0	----	0.0	0.0	0.9	2.2	85.3
18	-1.7	0.0	0.0	-1.7	8.6	28.5	37.1	599	33	13.2	0.40	0.0	0.0	1.2	1.6	109.7
19	0.0	0.0	0.0	0.0	0.0	31.3	31.3	649	0	0.0	----	0.0	0.0	0.7	1.4	45.2
20	-1.1	54.1	0.0	54.0	68.8	8.0	76.8	1674	510	120.5	0.24	0.0	54.1	8.0	24.9	68.3
21	-1.1	0.0	0.0	-0.1	53.6	4.4	58.0	1211	471	114.8	0.24	92.3	0.0	6.1	38.1	103.5
22	0.0	89.8	11.9	101.7	60.6	4.1	64.7	1411	554	105.6	0.19	0.0	89.8	8.4	28.4	163.7
23	0.0	101.8	0.0	101.8	31.1	4.5	35.6	1267	416	86.9	0.21	116.9	101.8	6.0	74.3	213.8
24	0.0	112.1	0.0	112.1	67.0	0.0	67.0	1206	684	132.8	0.19	111.5	112.1	9.3	72.0	166.5
25	0.0	0.0	0.0	0.0	0.0+	4.3+	4.3+	85+	0	0.0	----	0.0	0.0	0.3+	0.3+	35.5+
26	0.0	0.0	0.0	0.0	0.0	8.8	8.8	1431	0	0.0	----	0.0	0.0	0.9	1.1	146.3
27	0.0	0.0	0.0	0.0	0.0	7.6	7.6	1123	0	0.0	----	0.0	0.0	0.9	1.1	94.0
28	0.0	0.0	0.0	0.0	0.0	8.3	8.3	1164	0	0.0	----	0.0	0.0	0.9	1.1	97.2
29	0.0	0.0	0.0	0.0	0.0	8.2	8.2	1579	0	0.0	----	0.0	0.0	0.9	1.1	166.5
30	0.0	86.1	22.2	108.3	78.0	9.0	87.0	1377	562	128.8	0.73	0.0	86.1	6.1	24.2	207.0
31	0.0	0.0	0.0	0.0	23.1	4.4	27.5	1300	464	95.8	0.21	130.2	0.0	6.0	36.0	176.8
Total	101.1	968.3	147.6	1217.0	1150.2	258.8	1409.0	33040	10632	2469.1	----	1212.4	968.3	170.3	868.6	3974.1
Mean	6.3+	60.5+	9.2+	76.0+	37.1	8.4	45.5	1066	343	79.6	0.23	39.1	31.2	5.5	28.0	128.2

* Calculated Values

+ Missing Scans

+ Average of 16 Cooling Days

Table 7-7. System Performance for the Month of September 1977 (MJ/Day)

Day	SPACE COOLING				DOMESTIC HOT WATER			COLLECTOR PERFORMANCE				STORAGE		ELECTRIC ENERGY		
	From Outdoors	From Storage	From EVC	TOTAL	Solar	Auxiliary	TOTAL	Total, Solar	While Operating	Heat Delivered	Average Efficiency	Cold Charge	Discharge	For Solar	For Cooling	For House
1	0.0	66.4	2.9	69.3	41.5	0.0	41.5	1379	568	136.0	0.24	57.9	66.4	2.5	50.3	195.1
2	2.1	117.1	0.0	119.2	44.6	4.5	49.1	1590	391	101.7	0.26	40.2	117.1	0.3	53.9	214.4
3	7.9	76.7	5.2	89.8	55.0	4.5	59.5	746	471	115.9	0.25	78.0	76.7	0.3	60.4	160.0
4	0.0	93.2	0.0	93.2	39.7	4.5	44.2	1578	351	76.3	0.22	107.1	93.2	0.3	59.6	156.3
5	0.0	86.1	0.0	86.1	45.1	4.5	49.6	1626	392	98.2	0.25	103.0	86.1	0.3	51.6	197.3
6	0.0	158.9	29.7	188.6	48.2	4.4	52.6	1603	380	91.5	0.24	88.6	158.9	0.3	76.6	245.6
7	3.0	132.7	28.0	163.7	60.0	4.5	64.5	1454	487	124.8	0.26	145.4	132.7	0.3	79.6	253.3
8	4.7	141.2	1.1	147.0	58.5	4.4	62.9	1438	550	102.6	0.19	139.9	141.2	0.3	66.9	243.9
9	0.0	0.0	0.0	0.0	47.6	4.4	52.0	1480	458	110.3	0.24	206.7	0.0	0.3	48.3	187.0
10	0.0	81.9	0.0	81.9	44.9	4.4	49.3	1299	303	71.6	0.24	24.6	81.9	3.1	50.1	174.4
11	0.2	0.0	0.0	0.8	11.4	5.0	16.4	293	63	19.8	0.32	47.1	0.0	3.0	25.5	122.0
12	0.0	29.8	6.9	36.7	21.4	15.8	37.2	826	128	37.5	0.29	0.0	29.8	3.7	16.0	139.6
13	1.1	82.0	0.0	83.1	88.6	9.4	98.0	1708	529	171.5	0.32	73.7	82.0	7.0	47.5	163.6
14	0.3	125.4	0.0	125.7	47.2	9.2	56.4	1682	422	103.9	0.25	96.6	125.4	5.3	55.1	180.3
15	0.0	95.5	0.0	95.5	49.4	4.3	53.7	1278	396	102.2	0.26	121.1	95.5	4.9	63.3	183.1
16	0.0	81.1	0.0	81.1	61.1	8.7	69.8	1136	652	161.7	0.25	101.7	81.1	10.1	55.8	160.2
17	0.0	118.1	0.0	118.1	39.1	4.7	43.8	1509	446	100.3	0.22	96.0	118.1	6.6	59.1	138.0
18	0.0	0.0	11.0	11.0	45.7	5.5	51.2	1669	478	114.5	0.24	140.6	0.0	6.9	52.3	132.6
19	3.6	75.7	8.3	91.6	59.2	7.3	66.5	853	631	166.0	0.26	0.0	79.7	11.9	20.4	167.3
20	0.0	152.3	7.6	159.9	56.9	4.4	61.3	1419	359	128.7	0.23	87.5	152.3	7.7	68.9	214.2
21	0.0	27.4+	12.4+	39.8+	0.0+	0.0+	0.0+	841+	0	0.0	----	0.0+	27.4+	0.4+	9.3+	80.9+
22	0.0	89.6	0.0	89.6	62.8	4.7	67.5	1551	592	142.4	0.24	84.6	89.6	9.7	60.6	173.9
23	0.0	0.0	0.0	0.0	78.4	4.8	83.2	1689	840	185.6	0.22	99.7	0.0	10.5	47.3	154.5
24	0.0	21.5	7.6	29.1	3.5	5.6	9.1	1172	136	9.9	0.07	0.0	21.5	2.1	7.2	72.5
25	-0.9	21.7	0.0	20.8	52.2	3.6	61.8	1664	451	106.7	0.24	55.4	21.7	5.3	43.6	114.1
26	8.1	89.6	6.8	104.5	77.7	6.4	84.1	1178	648	163.8	0.25	6.5	89.6	9.0	22.8	145.3
27	4.5	150.3	18.2	173.0	59.8	4.7	64.5	1321	514	130.8	0.25	114.7	150.3	4.2	71.6	229.6
28	4.6	140.1	37.3	182.0	40.3	4.7	45.0	1197	434	102.4	0.24	136.3	140.1	2.4	79.4	223.4
29	7.7	128.0	31.6	167.3	61.3	4.4	65.7	1080	570	138.9	0.24	129.0	128.0	0.4	85.1	240.6
30	1.2	18.4	5.8	25.4	29.0	17.0	46.0	584	218	53.9	0.25	144.2	18.4	0.3	55.4	165.6
31	End Cooling Season Data															
Total	48.7	2404.7	220.4	2673.8	1430.1	175.3	1606.4	38843	13058	3169.4	----	2526.1	2404.7	119.4	1543.5	5228.6
Mean	1.7+	85.9+	7.9+	95.5+	47.6	5.9	53.5	1295	435	105.6	0.24	84.2	80.2	4.0	51.4	174.3

* Calculated Values

+ Missing Scans

- Average of 28 Cooling Days

Figure 7-2. Nocturnal Cooling System Performance, Solar House II.

Figure 7-3. Nocturnal Cooling System Performance, Solar House II.

Figure 7-4. Nocturnal Cooling System Performance, Solar House II.

Figure 7-5. Nocturnal Cooling System Performance, Solar House II.

Maximum and minimum average room, average storage, and ambient temperatures are also shown on the graphical presentations.

The monthly average daily cooling provided by the nocturnal system in 1977 is shown graphically in Figure 7-6, and for comparison, the average monthly cooling performance for 1976 is shown in Figure 7-7. It is evident from the figures that cooling performance was greatly improved in 1977 over 1976. Cooling from storage supplied 80 percent of the cooling that was provided in June, July and August, and 90 percent in September, 1977.

Some features of the cooling performance in Solar House II are worth noting. The overall cooling provided by the system was 8153.3 MJ which utilized 4447.6 MJ of electrical energy to cold charge storage and cool the rooms from storage. The ratio of the two quantities can be interpreted as a COP for cooling, and the ratio is equal to 1.83. While the capital cost of the nocturnal cooling system, coupled to an air-heating solar system, is small, the electrical energy required to operate the cooling system is large.

The cooling rate provided from storage averaged about 15 MJ/hour (over 5 hours of the day) during June, July and August. The average in September was 17 MJ/hour because the average night-time temperatures were lower and therefore storage temperatures were lower. The maximum cooling rate during the season was experienced on 6 September, when 189 MJ of heat was removed during a 7-hour period. The average cooling period during the day in 1977 was 5 hours, which is an increase of nearly two hours over the 1976 season, but still inadequate to maintain comfort conditions in the rooms throughout the day. The occupants of the building typically would shut the system down in the early afternoon, open windows and doors and seek relief from the heat build-up in the rooms.

Figure 7-6. Monthly Average Cooling Performance, Solar House II, 1977.

Figure 7-7. Cooling Performance, Solar House II, 1976.

Room temperature ranges and maximum room temperatures are shown on Figures 7-2 through 7-5. Room temperatures above 25°C occurred frequently throughout the hotter summer months. The maximum room temperatures were not significantly lower than the daily maximum ambient temperatures.

7.3.2 Space and Water Heating 1976-77

The performance results of the 1976-77 heating season was reported previously [Ref. 1]. Subsequent to the distribution of the report, an error was discovered in the computer program that was used to analyze the data. The energy flow diagram of Figure 7-1 indicates the energy quantities that were measured and calculated, and the daily quantities in the system performance summaries are explained in Table 7-8. Corrected values of daily system performance for each month are tabulated in Tables 7-9 through 7-15 from 4 November 1976 through 16 May 1977.

The quantity of solar heat delivered for each month by the system reduced by 4.5 to 8 percent from that previously reported and the total seasonal heating load for space and DHW reduced by about 8 percent. The largest corrections were for daily solar contributions to domestic water heating and auxiliary space heating. Monthly average daily heat collection is summarized on Figure 7-8. Of the total seasonal (4 November 1976 through 16 May 1977) solar radiation of 193.77 GJ measured by the pyranometer on the total collector surface of 67.1 m², 87 percent or 168.89 GJ was incident on the collector while the blower was operating. Thirty percent of the 168.89 GJ of solar radiation, or 50.00 GJ of solar heat was collected by the solar system. The seasonal collection efficiency based on total solar radiation measured was 26 percent.

Table 7-8. Daily Quantities Listed in the Performance Summary Tables (Refer to Figure 7-1 for the Energy Flow Diagram)

Subsystem	Column	Heat Quantity
Total energy for space and water heating	1	QOH+QHR+Storage heat loss to building space
	2	Total heat in DHW delivered to building
	3	Total space and domestic water heating
Solar energy utilized	4	QSO+QCL+Storage heat loss to building space
	5	QXA
	6	Total solar to building
Auxiliary energy needed	7	QAH
	8	QWA
	9	QAH+QWA
Solar Fractions	10	Column 4 $\div$ Column 1
	11	Column 5 $\div$ Column 2
	12	Column 6 $\div$ Column 3
Collector Performance	13	ST
	14	SOP
	15	QCS
	16	Column 15 $\div$ Column 14
Storage heat flows	17	QSI
	18	QSO
	19	Heat loss from storage to ground
	20	Daily change in storage
Electric power required	21	Electric power to collect solar energy
	22	Electric power to deliver both solar and auxiliary heat to building
	23	Total power utilized in the building

Table 7-9. System Performance for the Month of November 1976 (MJ/Day)

DAY	SPACE AND DOMESTIC HOT WATER HEATING												COLLECTOR PERFORMANCE				STORAGE				ELECTRIC ENERGY		
	ENERGY REQUIRED			SOLAR ENERGY USED			AUX. ENERGY USED			SOLAR FRACTION			TOTAL INCIDENT SOLAR	SOLAR WHILE COLLECTING	HEAT FROM COLLECTOR	AVE. EFF.	HEAT IN	HEAT OUT	HEAT LOSS	CHANGE IN STORAGE	SOLAR	CIRCULATION	HOUSE
1																							
2																							
3	Begin Heating Season Data 1976-77																						
4	171.0	36.0	207.0	171.0	24.9	195.9	0.0	11.1	11.1	1.00	0.69	0.95	1303	1150	194.0	0.17	112.1	105.0	7.8	-9.7	18.3		
5	172.3	32.9	205.2	172.3	24.6	196.9	0.0	8.3	8.3	1.00	0.75	0.96	1447	1360	227.1	0.17	137.2	97.5	8.0	22.2	26.2		
6	208.8	10.7	219.5	208.8	8.0	216.8	0.0	2.7	2.7	1.00	0.75	0.99	742	542	65.5	0.12	30.5	173.3	7.5	-158.8	14.0		
7	220.7	16.8	237.5	220.7	15.8	237.5	0.0	0.0	0.0	1.00	1.00	1.00	1430	1313	276.5	0.21	181.5	133.8	7.5	31.5	24.8		
8	124.2	29.0	153.1	124.1	20.7	144.8	0.0	8.3	8.3	1.00	0.71	0.95	1293	1201	232.3	0.19	137.9	40.9	8.0	79.5	22.8		
9	153.2	29.8	183.0	153.2	27.1	180.3	0.0	2.7	2.7	1.00	0.91	0.99	1332	1222	194.1	0.16	100.8	77.2	8.3	5.5	22.4		
10	201.5	18.6	220.1	201.5	1.9	203.4	0.0	16.7	16.7	1.00	0.10	0.92	478	187	16.9	0.09	8.3	186.3	7.5	-194.0	6.2		
11	398.0	7.4	405.4	290.0	0.0	290.0	108.0	7.4	115.4	0.73	0.00	0.72	51	0	0.0	----	0.0	286.3	4.1	-294.1	2.6		
12	284.5	7.4	291.9	6.7	0.0	6.7	277.8	7.4	285.2	0.02	0.00	0.02	88	0	0.0	----	0.0	6.2	2.0	-8.7	1.9		
13	317.7	7.4	325.1	6.9	0.0	6.9	310.8	7.4	318.2	0.02	0.00	0.02	256	0	0.0	----	0.0	6.4	2.0	-8.9	1.9		
14	278.4	36.2	314.6	164.6	25.1	189.7	113.8	11.1	124.9	0.59	0.69	0.60	820	658	205.0	0.31	133.7	117.4	2.5	12.8	20.5		
15	141.2	41.0	182.2	141.2	41.0	182.2	0.0	0.0	0.0	1.00	1.00	1.00	1363	1369	455.4	0.33	311.7	34.0*	4.5	268.7	31.1*		
16	334.9	5.6	340.5	334.9	0.0	334.9	0.0	5.6	5.6	1.00	0.00	0.98	1251*	1178*	414.2	0.35	191.0	105.2	6.0	73.3	29.4*		
17	179.5	46.3	225.8	179.5	43.6	223.1	0.0	2.7	2.7	1.00	0.94	0.99	1405	1345	393.6	0.29	228.0	49.2	7.2	163.3	31.4	NO DATA	NO DATA
18	129.9	13.2	143.1	129.9	2.1	132.0	0.0	11.1	11.1	1.00	0.16	0.92	438	262	60.3	0.23	33.3	97.0	7.0	-78.7	9.4		
19	229.7	59.1	288.8	229.7	48.0	277.7	0.0	11.1	11.1	1.00	0.81	0.96	1264	1143	326.0	0.29	182.6	125.6	7.5	40.8	26.7		
20	506.0	4.8	510.8	506.0	4.8	510.8	0.0	0.0	0.0	1.00	1.00	1.00	985	888	205.8	0.23	125.3	423.3	6.5	-311.5	26.8		
21	542.9	24.1	567.0	542.9	21.4	564.3	0.0	2.7	2.7	1.00	0.89	1.00	1381	1289	414.6	0.32	287.8	431.0	6.0	-155.7	31.1		
22	228.3	11.1	239.4	145.7	0.0	145.7	82.6	11.1	93.7	0.64	0.00	0.61	252	40	10.9	0.27	7.5	140.3*	3.0	-137.8	3.6		
23	215.0	40.0	255.0	215.0	7.4	222.4	0.0	32.6	32.6	1.00	0.19	0.87	951	806	268.9	0.33	195.3	146.3	3.5	43.0	25.6		
24	208.5	65.3	273.8	208.5	32.7	241.2	0.0	32.6	32.6	1.00	0.50	0.88	1228	1172	430.3	0.37	311.0	116.9	5.0	184.1	29.6		
25	349.5	92.6	442.1	349.5	42.6	392.1	0.0	50.0	50.0	1.00	0.46	0.89	1209	1124	318.1	0.28	197.2	264.7	6.0	-80.0	27.1		
26	415.9	48.6	464.5	132.0	4.1	136.1	283.9	44.5	328.4	0.32	0.08	0.29	464	244	53.4	0.22	22.2	103.9	2.5	-85.2	10.4		
27	498.9	52.4	551.3	235.5	24.6	260.1	263.4	27.8	291.2	0.47	0.47	0.47	1096	923	265.3	0.29	175.6	162.4	7.0	-1.8	23.7		
28	314.5	52.6	367.1	97.0	8.1	105.1	217.5	44.5	262.0	0.31	0.15	0.29	817	570	119.0	0.21	53.0	38.6	2.0	11.9	21.9		
29	256.6	39.5	296.1	67.1	6.2	73.3	189.5	33.3	222.8	0.26	0.16	0.25	566	299	71.2	0.24	40.8	42.4	2.0	-4.1	11.8		
30	225.8	65.2	291.0	90.7	9.6	100.3	135.1	55.6	190.7	0.40	0.15	0.34	547	338	99.8	0.30	64.4	63.1	2.0	-2.5	12.6		
31																							
Total	7307.3	893.6	8200.9	5324.9	445.3	5770.2	1982.4	448.3	2430.7	-----	-----	-----	24457	20623	5318.2	-----	3268.7	3579.2	142.9	-594.9	513.8		
Mean	270.6	33.1	303.7	197.2	16.5	213.7	73.4	16.6	90.0	0.73	0.50	0.70	906	764	197.0	0.26	121.1	132.4	5.3	-22.0	19.0		

*Calculated Values

Table 7-10. System Performance for the Month of December 1976 (MJ/Day)

DAY	SPACE AND DOMESTIC HOT WATER HEATING												COLLECTOR PERFORMANCE				STORAGE				ELECTRIC ENERGY		
	ENERGY REQUIRED			SOLAR ENERGY USED			AUX. ENERGY USED			SOLAR FRACTION			TOTAL INCIDENT SOLAR	SOLAR WHILE COLLECTING	HEAT FROM COLLECTOR	AVE. EFF.	HEAT IN	HEAT OUT	HEAT LOSS	CHANGE IN STORAGE	CIRCULATION		
	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL									SOLAR	HOUSE	
1	229.3	21.4	250.7	189.3	21.4	210.7	40.0	0.0	40.0	0.83	1.00	0.84	924	757	235.0	0.31	171.4	142.1	4.6	19.7	23.7		200.0
2	210.3	65.3	275.6	210.3	41.1	251.4	0.0	24.2	24.2	1.00	0.63	0.91	1127	982	374.8	0.38	288.4	156.0	7.3	116.1	26.3		200.4
3	276.0	54.8	330.8	276.0	25.1	301.1	0.0	29.7	29.7	1.00	0.46	0.91	937	823	252.2	0.31	192.0	231.4	7.4	-56.3	21.9		21.0
4	448.1	64.7	512.8	295.6	0.0	295.6	152.5	64.7	217.2	0.66	0.00	0.58	810	683	234.0	0.34	179.1	236.2	4.1	-65.7	21.6		201.6
5	505.4	24.2	529.6	236.0	0.0	236.0	269.4	24.2	293.6	0.47	0.00	0.45	935	779	241.7	0.31	149.4	136.7	3.7	2.0	20.6		197.5
6	266.3	39.2	305.5	266.3	25.8	292.1	0.0	13.4	13.4	1.00	0.66	0.96	1299	1205	374.4	0.31	290.4	201.6	6.0	76.3	29.8		266.7
7	195.6	77.7	273.3	195.6	69.6	265.2	0.0	8.1	8.1	1.00	0.90	0.97	1060	935	308.2	0.33	197.0	146.0	6.4	36.6	23.9		230.3
8	196.7	0.0	196.7	196.7	0.0	196.7	0.0	0.0	0.0	1.00	0.00	1.00	1050*	916*	285.9*	0.31	182.8*	84.1	7.4	81.8	25.0*		274.6
9	344.8	5.1	349.9	334.6	-8.3	326.3	10.2	13.4	23.6	0.97	----	0.93	1107*	983*	306.7*	0.31	206.1*	216.2	7.4	-27.0	20.0*		242.4
10	395.4	57.2	452.6	354.7	57.2	411.9	40.7	0.0	40.7	0.90	1.00	0.91	1279	1151	353.6	0.31	226.9	275.7	6.8	-65.1	27.0		209.0
11	229.7	59.2	288.9	229.7	59.2	288.9	0.0	0.0	0.0	1.00	1.00	1.00	1232	1138	409.3	0.36	287.5	160.7	6.0	114.4	27.0		193.8
12	333.3	56.0	389.3	333.3	56.0	389.3	0.0	0.0	0.0	1.00	1.00	1.00	1319	1240	373.2	0.30	225.5	233.6	6.4	-22.5	29.9		181.5
13	230.9	79.9	310.8	230.9	79.9	310.8	0.0	0.0	0.0	1.00	1.00	1.00	1352	1282	460.4	0.36	313.8	154.7	7.4	142.2	29.7		249.9
14	196.7	56.7	253.4	196.7	54.0	250.7	0.0	2.7	2.7	1.00	0.95	0.99	750	636	174.6	0.27	87.0	153.1	8.3	-84.4	16.6		216.4
15	130.7	73.0	203.7	130.7	70.3	201.0	0.0	2.7	2.7	1.00	0.96	0.99	1106*	937*	283.0	0.30	288.5	192.9	11.0	71.0	20.0*		229.5*
16	NO DATA																						
17	NO DATA																						
18	NO DATA																						
19	NO DATA																						
20	300.1	56.9	357.0	289.9	56.9	346.8	10.2	0.0	10.2	0.95	1.00	0.96	1301	1186	368.1	0.31	243.3	209.0	9.7	11.6	28.4		305.5
21	202.6	83.7	286.3	202.6	83.7	286.3	0.0	0.0	0.0	1.00	1.00	1.00	1305	1139	378.2	0.33	229.2	125.3	10.1	81.8	30.2		323.8
22	558.7	0.0	558.7	558.7	0.0	558.7	0.0	0.0	0.0	1.00	0.00	1.00	1292*	1196	364.6	0.30	205.0	385.6	9.2	-203.3	20.0*		225.0*
23	522.9	38.8	561.7	223.0	33.4	256.4	299.9	5.4	305.3	0.43	0.86	0.46	593	363	127.9	0.35	74.2	197.7	4.9	-133.4	11.0		173.6
24	399.2	20.8	420.0	99.3	15.4	114.7	299.9	5.4	305.3	0.25	0.74	0.27	368	248	67.3	0.27	32.3	77.7	2.8	-50.2	10.2		148.9
25	405.2	56.3	461.5	224.8	45.5	270.3	180.4	10.8	191.2	0.55	0.81	0.59	908	775	245.0	0.32	146.5	169.1	3.2	-28.5	26.4		183.6
26	207.3	51.1	258.4	207.3	51.1	258.4	0.0	0.0	0.0	1.00	1.00	1.00	970	845	295.1	0.35	207.1	63.9	5.5	31.2	24.2		208.3
27	260.5	64.9	325.4	260.5	62.2	322.7	0.0	2.7	2.7	1.00	0.96	0.95	1167	1113	313.7	0.28	194.6	195.6	6.9	-15.9	31.4		227.4
28	273.5	80.4	353.9	273.5	69.6	343.1	0.0	10.8	10.8	1.00	0.87	0.97	1320	1260	412.6	0.33	279.4	201.9	6.6	62.9	31.3		246.1
29	521.8	82.4	604.2	333.8	69.6	403.4	183.0	13.4	196.4	0.66	0.84	0.67	1207	1136	352.3	0.31	222.1	267.8	7.8	-63.3	31.5		225.6
30	676.0	16.2	692.2	23.0	0.0	23.0	653.0	16.2	669.2	0.03	0.00	0.03	240	0	0.0	----	0.0	20.5	2.8	-25.8	3.1		231.4
31	403.0	41.3	444.3	34.5	19.7	54.2	358.5	21.6	580.1	0.09	0.09	0.09	530	185	48.1	0.26	15.2	19.3	2.3	-8.4	8.1		203.2
Total	8920.0	1327.2	10247.2	6412.3	1057.8	7470.1	2507.7	269.4	2777.1	----	----	----	27488	23893	7639.9	----	5135.0	4754.4	172.0	-2.2	618.8		5817.0
Mean	330.4	49.2	379.6	237.5	39.2	276.7	92.9	10.0	102.9	0.72	0.80	0.73	1318	885	283.0	0.32	190.2	176.1	6.4	-0.1	22.9		215.4

*Calculated Values

Table 7-11. System Performance for the Month of January 1977 (MJ/Day)

DAY	SPACE AND DOMESTIC HOT WATER HEATING												COLLECTOR PERFORMANCE				STORAGE				ELECTRIC ENERGY		
	ENERGY REQUIRED			SOLAR ENERGY USED			AUX. ENERGY USED			SOLAR FRACTION			TOTAL INCIDENT SOLAR	SOLAR WHILE COLLECTING	HEAT FROM COLLECTOR	AVE. EFF.	HEAT IN	HEAT OUT	HEAT LOSS	CHANGE IN STORAGE	SOLAR	CIRCULATION	HOUSE
	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL											
1	650.2	70.8	721.0	252.3	70.8	323.1	397.9	0.0	397.9	0.39	1.00	0.45	1055	972	336.3	0.35	167.1	165.9	4.4	8.8	23.9	17.5	250.0*
2	365.8	61.9	428.7	346.8	61.9	408.7	20.0	0.0	20.0	0.95	1.00	0.95	1293	1175	430.6	0.37	254.8	215.6	7.7	14.4	27.7	18.8	250.1
3	254.3	68.1	322.4	138.2	59.9	198.1	116.1	8.2	124.3	0.54	0.88	0.61	636	528	187.3	0.35	99.7	102.8	1.8	-15.6	17.0	16.1	342.2
4	486.5	36.5	523.0	7.1*	0.0	7.1	479.4*	36.5	515.9	0.01	0.00	0.01	166+	0	0.0	----	0.0	6.0*	2.3*	-9.4*	1.2	32.3*	331.7*
5	400.3	53.2	453.5	132.4	39.6	172.0	267.9	13.6	281.5	0.35	0.74	0.38	702	546	167.1	0.31	34.3	85.3	3.6	-8.5	18.0	22.3	302.4
6	304.3*	58.3	362.6*	126.4*	54.0	180.4*	177.9	4.3	182.2	0.42	0.93	0.50	782+	567	191.4	0.32	94.2	87.0	3.3*	-2.3*	16.3	17.0	282.8*
7	423.9	69.0	492.9	353.9	63.7	417.6	70.0	5.3	75.3	0.83	0.92	0.85	1221	1135	419.0	0.37	278.4	257.6	8.7	-7.3	26.0	22.0	258.4
8	453.3	31.2	484.5	10.2	0.0	10.2	443.1	31.2	474.3	0.02	0.00	0.02	399	0	0.0	----	0.0	8.7	2.2	-12.4	1.2	33.7	275.5
9	570.5	73.3	643.8	308.2	61.0	369.2	262.3	12.3	274.6	0.54	0.83	0.57	1434	1195	370.5	0.31	207.1	194.6	4.4	-3.1	25.0	30.2	266.4
10	368.0	55.6	423.6	220.9	44.3	265.2	147.1	11.3	158.4	0.60	0.80	0.63	987	795	261.0	0.33	140.9	135.6	4.5	-8.7	23.8	24.6	309.9
11	396.2	86.2	482.4	374.0	74.0	448.0	22.2	12.2	34.4	0.94	0.86	0.93	1376	1279	476.9	0.37	297.6	248.4	8.4	20.5	29.4	20.9	295.6
12	247.3	35.4	282.7	4.7	0.0	4.7	242.6	35.4	278.0	0.02	0.00	0.02	279	0	0.0	----	0.0	2.9	2.5	-7.2	1.2	19.6	284.5
13	383.6	87.4	465.0	283.4	31.4	364.8	100.2	0.0	100.2	0.74	1.00	0.78	1219	1098	381.2	0.35	233.6	201.7	6.5	9.9	24.4	22.0	241.2
14	336.9	64.7	401.6	243.8	50.1	303.9	93.1	4.6	97.7	0.72	0.93	0.76	1020	895	307.6	0.34	184.0	167.4	6.1	-2.4	26.0	23.8	287.3
15	432.8	27.8	460.6	5.0	2.0	7.0	427.8	25.8	453.6	0.01	0.07	0.02	372	59	8.2	0.14	1.4	-1.7	2.1	-0.9	3.4	30.1	259.5
16	384.9	75.1	460.0	200.0	70.4	270.4	184.9	4.7	189.6	0.52	0.94	0.59	996	846	284.1	0.34	147.1	124.3	4.2	9.5	21.5	13.1	248.4
17	310.4	66.7	377.1	244.1	62.1	306.2	66.3	4.6	70.9	0.79	0.93	0.81	1019	927	316.9	0.34	197.9	173.4	6.1	4.6	24.2	22.1	253.8
18	262.0	40.3	302.3	14.8	18.3	33.1	247.2	22.0	269.2	0.06	0.45	0.11	409	111	33.1	0.30	8.5	6.7	2.5	-2.5	6.4	18.6	224.2
19	430.1	78.9	509.0	350.8	78.9	429.7	79.3	0.0	79.3	0.82	1.00	0.84	1314	1245	432.1	0.35	275.2	255.8	7.0	-4.6	29.5	24.7	302.4
20	340.2	80.0	420.2	334.8	80.0	414.8	5.4	0.0	5.4	0.98	1.00	0.99	1361	1297	480.2	0.37	316.5	229.1	9.5	55.9	29.4	16.3	240.8
21	172.8	47.2	220.0	172.8*	47.2	220.0	0.0	0.0	0.0	1.00	1.00	1.00	900	801	283.4	0.35	168.5	93.4*	5.1*	58.3*	17.1	7.9*	157.1*
22	247.0	17.2	264.2	10.8*	-0.6*	10.2	236.2	17.6	254.0	0.04	-0.03	0.04	105+	12+	10.7*	0.85*	9.6*	7.4*	2.1*	-1.6*	3.2*	15.3*	227.7*
23	464.8	64.8	529.6	344.8	64.8	409.6	120.0	0.0	120.0	0.74	1.00	0.77	1198	1129	401.9	0.36	258.0	249.8	6.8	-14.5	29.4	25.2	256.4
24	419.5	58.0	477.5	361.8	58.0	419.8	57.7	0.0	57.7	0.86	1.00	0.88	1384	1272	419.8	0.31	263.3	245.8	7.3	-7.3	30.2	24.2	321.2
25	346.5	75.6	422.1	333.7	75.6	409.3	12.8	0.0	12.8	0.96	1.00	0.97	1497	1424	471.6	0.31	311.9	225.5	5.8	56.5	31.2	15.3	294.6
26	290.4	67.0	357.4	229.1	60.3	289.4	61.3	6.7	68.0	0.79	0.90	0.81	840	668	231.5	0.35	137.3	182.2	7.4	-65.3	17.9	23.1	323.4
27	372.7	80.9	453.6	372.7	80.9	453.6	0.0	0.0	0.0	1.00	1.00	1.00	1500	1431	470.6	0.33	310.7	271.5	9.8	7.2	29.7	20.6	315.2
28	441.4	71.6	513.0	358.1	71.6	429.7	53.3	0.0	53.3	0.81	1.00	0.84	1378	1285	402.5	0.31	246.1	255.8	7.8	-35.0	31.4	14.2	333.7
29	434.5	66.6	501.1	346.0	66.6	412.6	38.5	0.0	38.5	0.80	1.00	0.82	1336	1183	400.0	0.31	234.6	230.3	7.5	-20.1	25.1	24.4	270.3
30	380.5	71.7	452.2	371.1	71.7	442.8	9.4	0.0	9.4	0.98	1.00	0.98	1466	1336	455.4	0.34	274.3	242.7	8.3	4.3	29.5	19.1	293.4
31	358.5	71.5	430.0	358.5*	71.5	430.0	0.0*	0.0	0.0	1.00	1.00	1.00	1450	1374	462.2	0.34	302.6	255.4	6.7*	25.5*	32.0*	2.3*	224.6
Total	11731.1	1906.5	13637.6	7211.2	1650.0	8861.2	4519.9	256.5	4776.4	----	----	----	31098	26585	9086.3	----	5525.7	4924.9	178.4	46.7	654.2	637.3	8524.7
Mean	378.4	61.5	439.9	232.6	53.2	285.8	145.8	8.3	154.1	0.61	0.87	0.65	1003	858	293.1	0.34	178.3	158.9	5.8	1.5	21.1	20.6	275.0

*Calculated Values

-Missing Scans

Table 7-12. System Performance for the Month of February 1977 (MJ/Day)

DAY	SPACE AND DOMESTIC HOT WATER HEATING												COLLECTOR PERFORMANCE				STORAGE				ELECTRIC ENERGY		
	ENERGY REQUIRED			SOLAR ENERGY USED			AUX. ENERGY USED			SOLAR FRACTION			TOTAL INCIDENT SOLAR	SOLAR WHILE COLLECTING	HEAT FROM COLLECTOR	AVE. EFF.	HEAT IN	HEAT OUT	HEAT LOSS	CHANGE IN STORAGE	ELECTRIC ENERGY		
	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL									SOLAR	CIRCULATION	HOUSE
1	271.7	30.9	302.6	94.2	12.9	107.1	177.5	18.0	195.5	0.35	0.42	0.35	452	173	48.0	0.28	23.9	78.2	4.6	-63.7	8.6	29.2	338.0
2	290.0	62.7	352.7	225.3	62.7	288.0	64.7	0.0	64.7	0.78	1.00	0.82	959	960	297.6	0.35	177.8	156.3	6.0	3.6	25.0	18.5	303.1
3	307.9	79.6	387.5	298.5	75.5	374.0	9.4	4.1	13.5	0.97	0.95	0.97	1429	1305	461.3	0.35	302.5	193.0	10.1	77.2	28.3	11.7	312.1
4	326.9	85.4	412.3	326.9	85.4	412.3	0.0	0.0	0.0	1.00	1.00	1.00	1515	1429	471.0	0.33	288.8	202.6	13.8	44.9	26.5	15.6	289.5
5	352.8	28.5	381.3	211.7	11.8	223.5	141.1	16.7	157.8	0.60	0.41	0.59	501	245	63.9	0.26	36.8	186.2	7.2	-166.9	13.0	33.6	240.9
6	347.3	78.3	425.6	299.7	78.3	378.0	47.6	0.0	47.6	0.86	1.00	0.89	1312	1178	406.1	0.34	260.2	211.9	7.8	20.3	25.8	21.2	260.0
7	274.4	79.8	354.2	274.4	79.8	354.2	0.0	0.0	0.0	1.00	1.00	1.00	1539	1444	498.9	0.35	328.9	166.4	10.4	134.3	31.9	11.3	291.3
8	277.3	89.6	366.9	277.3	89.6	366.9	0.0	0.0	0.0	1.00	1.00	1.00	1559	1476	480.9	0.33	292.0	145.7	14.4	99.6	31.7	7.7	287.2
9	292.2	94.4	386.6	292.2	94.4	386.6	0.0	0.0	0.0	1.00	1.00	1.00	1579	1497	443.9	0.30	242.8	153.9	18.1	39.2	31.4	7.5	295.3
10	281.7	95.2	376.9	281.7	95.2	376.9	0.0	0.0	0.0	1.00	1.00	1.00	1539	1431	401.5	0.28	198.3	141.8	19.5	5.1	30.5	7.3	288.3
11	304.5	53.6	358.1	304.5	53.6	358.1	0.0	0.0	0.0	1.00	1.00	1.00	955	776	172.1	0.22	66.4	229.7	15.6	-201.6	22.9	18.5	289.6
12	230.6	54.7	285.3	230.6	54.7	285.3	0.0	0.0	0.0	1.00	1.00	1.00	749	547	194.0	0.35	106.2	183.1	8.9	-100.2	14.5	26.2	257.1
13	234.4	33.9	268.3	216.9	33.9	250.8	17.5	0.0	17.5	0.93	1.00	0.93	512	408	128.1	0.31	76.0	187.6	7.2	-129.9	13.0	17.1	246.5
14	284.0	56.9	340.9	148.3	41.5	189.8	135.7	15.4	151.1	0.52	0.73	0.56	505	335	125.5	0.37	65.6	122.3	5.0	-69.3	12.2	25.9	339.7
15	181.6	46.0	227.6	32.9	22.3	55.2	148.7	23.7	172.4	0.18	0.48	0.24	272	162	59.6	0.37	24.7	17.7	2.8	1.6	7.6	12.0	325.5
16	182.3	83.2	265.5	168.5	79.3	247.8	13.8	3.9	17.7	0.92	0.95	0.93	1136	1088	400.0	0.37	253.7	82.8	8.5	143.7	28.2	7.4	327.7
17	213.6	67.9	281.5	213.6	63.6	277.2	0.0	4.3	4.3	1.00	0.94	0.98	873	795	277.0	0.35	160.0	141.8	10.6	-10.8	21.0	9.8	286.5
18	263.3	76.1	339.4	263.3	76.1	339.4	0.0	0.0	0.0	1.00	1.00	1.00	1237	1194	376.1	0.31	206.9	145.7	13.8	22.9	33.8	9.7	259.1
19	277.2	70.6	347.8	277.2	70.6	347.8	0.0	0.0	0.0	1.00	1.00	1.00	1191	1141	398.2	0.35	234.3	156.1	15.2	35.2	29.4	9.9	261.6
20	186.9	91.4	278.3	186.9	91.4	278.3	0.0	0.0	0.0	1.00	1.00	1.00	1446	1386	448.8	0.32	254.4	51.8	18.1	152.4	31.7	2.9	247.4
21	202.8	66.5	269.3	202.8	66.5	269.3	0.0	0.0	0.0	1.00	1.00	1.00	742	666	178.7	0.27	63.9	128.5	18.5	-109.1	19.1	7.9	234.3
22	397.6	68.8	466.4	397.6	60.8	458.4	0.0	8.0	8.0	1.00	0.88	0.98	818	784	203.9	0.26	92.3	324.2	14.9	269.4	22.1	30.0	305.6
23	396.2	85.1	481.3	396.2	81.3	477.5	0.0	3.8	3.8	1.00	0.96	0.99	1500	1394	476.5	0.34	279.1	258.9	9.4	-10.4	31.3	22.6	311.9
24	358.6	58.2	416.8	220.0	46.1	266.1	138.6	12.1	150.7	0.61	0.79	0.64	816	685	248.2	0.36	146.3	153.2	5.5	-23.4	24.5	27.6	277.0
25	307.0	40.9	347.9	92.0	17.0	109.0	215.0	23.9	238.9	0.30	0.42	0.31	487	340	117.7	0.35	69.2	54.5	3.7	5.0	17.0	17.4	258.2
26	320.2	31.0	351.2	6.3	3.7	10.0	313.9	27.3	341.2	0.02	0.12	0.03	318	19	4.3	0.23	0.7	4.1	2.3	-8.0	1.4	23.0	215.8
27	418.5	71.6	490.1	215.3	67.5	282.8	203.2	4.1	207.3	0.51	0.94	0.58	951	817	295.2	0.36	156.7	128.2	4.4	8.0	23.9	21.2	221.6
28	325.3	67.0	392.3	325.3	63.7	389.0	0.0	3.3	3.3	1.00	0.95	0.99	1364	1312	498.9	0.38	336.2	202.4	10.4	99.5	32.8	11.2	310.0
29																							
30																							
31																							
Total	8106.8	1847.8	9954.6	6480.1	1679.2	8159.3	1626.7	168.6	1795.3	----	----	----	28257	24889	5175.9	----	4739.2	4208.6	286.8	-270.2	639.1	463.9	7889.8
Mean	261.8	59.6	321.4	212.6	54.0	266.6	52.5	5.4	57.9	0.80	0.91	0.82	1009	789	167.3	0.33	169.3	150.3	10.2	-9.6	22.8	16.6	281.8

Table 7-13. System Performance for the Month of March 1977 (MJ/Day)

DAY	SPACE AND DOMESTIC HOT WATER HEATING									COLLECTOR PERFORMANCE				STORAGE				ELECTRIC ENERGY					
	ENERGY REQUIRED			SOLAR ENERGY USED			AUX. ENERGY USED			SOLAR FRACTION			TOTAL INCIDENT SOLAR	SOLAR WHILE COLLECTING	HEAT FROM COLLECTOR	AVE. EFF.	HEAT IN	HEAT OUT	HEAT LOSS	CHANGE IN STORAGE	SOLAR	CIRCULATION	
	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL										TION	HOUSE
1	394.6	73.2*	467.8*	394.6*	73.2*	467.8*	0.0	0.0	0.0	1.00	1.00	1.00	1309*	1193*	462.2*	0.39	272.4*	253.5*	12.5	-18.1	24.5*	11.0*	252.5
2	399.7*	14.5*	414.2*	110.2*	0.0*	110.2*	289.5*	14.5	304.0	0.28	0.00	0.27	97	0	0.0	----	0.0	103.7*	5.7*	-115.9*	1.4	23.0*	271.2
3	433.7*	58.3*	492.0*	348.9*	21.8*	370.7*	84.8*	36.5	121.3	0.80	0.37	0.75	1064*	1000*	367.0*	0.37	278.9*	262.6*	9.1*	-12.8*	24.5*	20.0*	290.5
4	489.0	40.4	529.4	459.0	8.7	467.7	30.0	31.7	61.7	0.94	0.22	0.88	1511	1442	503.6	0.35	360.3	300.0	9.4	26.5	32.6	28.5	338.7
5	390.1	36.6	426.7	322.7	5.8	328.5	67.4	30.8	98.2	0.83	0.16	0.77	975	853	314.7	0.37	232.4	229.7	6.9	-20.7	28.6	31.1	317.0
6	313.2	41.9	355.1	313.2	18.4	331.6	0.0	23.5	23.5	1.00	0.44	0.93	1566	1488	554.4	0.37	414.1	161.7	11.8	211.0	34.0	11.1	280.2
7	218.3	77.3	295.6	218.3	73.1	291.4	0.0	4.2	4.2	1.00	0.95	0.99	1039	968	289.9	0.30	137.3	116.6	13.9	-15.4	36.0	8.9	293.6
8	246.1	95.0	341.1	246.1	84.0	330.1	0.0	11.0	11.0	1.00	0.88	0.97	1310	1273	418.2	0.33	258.4	142.2	15.4	72.7	33.5	8.1	304.9
9	91.4*	43.0	134.4*	91.4*	43.0	134.4*	0.0	0.0	0.0	1.00	1.00	1.00	967	853	192.3	0.23	73.4	0.0*	10.3*	47.6*	31.9	0.0*	197.2*
10	334.9*	5.9	340.8*	135.4*	0.0	135.4	199.5*	5.9*	205.4	0.40	0.00	0.40	0*	0*	0.0	----	0.0	128.8*	5.2*	-140.6*	1.4*	32.9*	251.2*
11	402.4	0.0	402.4	-0.2	0.0	-0.2	402.6	0.0	402.6	0.00	----	0.00	230	12	0.0	----	0.0	-1.7	2.5	-2.3	1.4	30.6	297.9
12	298.1	106.3	404.9	298.1	106.8	404.9	0.0	0.0	0.0	1.00	1.00	1.00	1629	1550	589.1	0.38	386.1	174.3	11.3	172.9	34.8	10.0	258.6
13	247.6	72.1	319.7	247.6	72.1	319.7	0.0	0.0	0.0	1.00	1.00	1.00	1629	1553	525.4	0.34	326.7	86.8	17.4	188.3	34.4	5.1	294.5
14	294.7	56.0	350.7	294.7	56.0	350.7	0.0	0.0	0.0	1.00	1.00	1.00	889	808	222.9	0.28	100.9	200.7	18.1	-145.9	20.3	12.8	376.8
15	281.6	64.4	346.0	281.6	64.4	346.0	0.0	0.0	0.0	1.00	1.00	1.00	1004	822	249.1	0.30	143.7	215.3	15.1	-112.0	23.5	20.7	342.5
16	229.5	80.1	309.6	229.5	80.1	309.6	0.0	0.0	0.0	1.00	1.00	1.00	1446	1364	494.6	0.36	315.1	98.7	16.0	169.0	35.6	6.2	355.6
17	269.1	14.7	283.8	269.1	14.7	283.8	0.0	0.0	0.0	1.00	1.00	1.00	527	295	62.3	0.21	24.2	228.1	12.9	-234.4	18.1	20.9	360.0
18	344.5	31.3	375.8	173.0	31.3	204.3	171.5	0.0	171.5	0.50	1.00	0.54	647	468	139.2	0.30	73.7	128.8	6.3	-71.4	18.6	33.3	334.3
19	354.7	72.6	427.3	336.1	72.6	408.7	18.6	0.0	18.6	0.95	1.00	0.96	1445	1300	427.6	0.33	264.3	226.7	7.6	11.3	31.4	20.9	342.2
20	456.7	62.7	519.4	360.3	62.7	423.0	96.4	0.0	96.4	0.79	1.00	0.81	1254	1168	412.9	0.35	244.3	237.2	7.1	-17.2	26.8	24.5	277.5
21	318.3	82.1	400.4	318.3	76.2	394.5	0.0	5.9	5.9	1.00	0.93	0.99	1497	1401	500.7	0.36	317.0	188.3	9.6	96.6	31.4	16.5	353.2
22	148.4	91.9	240.3	148.4	91.9	240.3	0.0	0.0	0.0	1.00	1.00	1.00	1616	1545	559.5	0.36	361.2	9.9	15.6	303.6	34.1	5.5	300.3
23	104.8	73.3	258.1	184.8	72.1	256.9	0.0	1.2	1.2	1.00	0.98	1.00	1389	1323	382.1	0.29	160.8	0.0	22.4	102.8	33.6	0.0	333.5
24	144.6	84.5	229.1	144.6	84.5	229.1	0.0	0.0	0.0	1.00	1.00	1.00	1334	1267	243.9	0.19	47.2	0.0	23.1	-8.3	34.4	0.0	335.5
25	154.3	71.3	225.6	154.3	71.3	225.6	0.0	0.0	0.0	1.00	1.00	1.00	1386	1255	284.0	0.23	93.3	0.0	23.9	34.5	33.0	0.0	306.4
26	125.9	59.1	185.0	125.9	59.1	185.0	0.0	0.0	0.0	1.00	1.00	1.00	1130	1008	170.9	0.17	17.7	0.0	22.6	-36.7	33.7	0.0	287.7
27	155.4	80.2	235.6	155.4	80.2	235.6	0.0	0.0	0.0	1.00	1.00	1.00	1471	1408	308.6	0.22	108.9	0.0	23.4	49.6	34.9	0.0	309.6
28	519.4	38.5	557.9	505.3	28.0	533.3	14.1	10.5	24.6	0.97	0.73	0.96	1250	1067	128.6	0.12	-0.8	376.5	19.1	-423.8	30.2	23.9	339.0
29	331.1	31.5	362.6	83.9	6.0	89.9	247.2	25.5	272.7	0.25	0.19	0.25	583	246	50.5	0.20	2.7	36.8	4.6	-44.0	25.4	18.9	380.4
30	362.7	92.0	454.7	362.7	92.0	454.7	0.0	0.0	0.0	1.00	1.00	1.00	1570	1490	528.3	0.35	343.2	244.8	9.9	63.7	36.0	13.3	367.7
31	285.2	57.1	342.3	285.2	57.1	342.3	0.0	0.0	0.0	1.00	1.00	1.00	1191	1102	395.6	0.36	244.6	168.4	11.5	41.5	30.1	10.7	365.8
Total	9220.0	1808.3	11028.3	7598.4	1607.1	9205.5	1621.6	201.2	1822.8	----	----	----	34955	31524	3778.1	----	3602.3	4316.4	400.2	172.4	550.1	448.4	9716.0
Mean	297.4	58.3	355.7	245.1	51.9	297.0	52.3	6.5	58.8	0.82	0.89	0.83	1128	1017	315.4	0.31	180.7	139.3	12.9	5.6	17.5	14.5	313.4

*Calculated Values

+Missing Scans

Table 7-14. System Performance for the Month of April 1977 (MJ/Day)

DAY	SPACE AND DOMESTIC HOT WATER HEATING												COLLECTOR PERFORMANCE				STORAGE				ELECTRIC ENERGY		
	ENERGY REQUIRED			SOLAR ENERGY USED			AUX. ENERGY USED			SOLAR FRACTION			TOTAL INCIDENT SOLAR	SOLAR WHILE COLLECTING	HEAT FROM COLLECTOR	AVE. EFF.	HEAT IN	HEAT OUT	HEAT LOSS	CHANGE IN STORAGE	SOLAR	CIRCULATION	HOUSE
	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL											
1	259.2	35.0	294.2	244.9	22.7	267.6	14.3	12.3	26.6	0.94	0.65	0.91	555	384	131.8	0.34	60.2	200.9	9.5	-145.3	24.4	21.0	377.6
2	255.6	28.8	284.4	2.9	0.0	2.9	252.7	28.8	281.5	0.01	0.00	0.01	286	0	0.0	----	0.0	0.7	2.9	-5.8	14.4	13.8	310.6
3	433.5	93.0	526.5	420.0	93.0	513.0	13.5	0.0	13.5	0.97	1.00	0.97	1793	1622	537.3	0.33	342.2	294.7	9.3	15.0	33.1	18.6	296.4
4	249.8	21.5	271.3	213.8	21.3	235.1	36.0	0.2	36.2	0.86	0.99	0.87	836	686	226.1	0.33	143.7	142.0	5.8	-14.8	34.3	14.3	379.3
5	179.8	81.2	261.0	179.8	81.2	261.0	0.0	0.0	0.0	1.00	1.00	1.00	1634	1558	553.6	0.36	374.5	54.0	12.3	280.3	36.0	4.5	382.2
6	201.0	76.0	277.0	201.0	76.0	277.0	0.0	0.0	0.0	1.00	1.00	1.00	1601	1520	477.1	0.31	256.0	21.8	19.9	180.2	39.2	1.0	353.1
7	181.8	76.9	258.7	181.8	76.9	258.7	0.0	0.0	0.0	1.00	1.00	1.00	1464	1384	369.3	0.27	146.9	0.0	24.3	86.3	36.5	0.0	336.2
8	187.1	48.4	235.5	187.1	48.4	235.5	0.0	0.0	0.0	1.00	1.00	1.00	1385	1288	289.1	0.22	91.2	0.0	25.8	27.8	37.2	0.0	267.6
9	190.2	40.5	230.7	190.2	40.5	230.7	0.0	0.0	0.0	1.00	1.00	1.00	1614	1507	346.0	0.23	156.3	0.0	27.9	87.4	31.9	0.0	192.9
10	125.7	28.7	154.4	125.7	28.7	154.4	0.0	0.0	0.0	1.00	1.00	1.00	889	836	100.9	0.12	-21.9	0.0	26.3	-79.8	29.7	0.0	199.7
11	33.3	34.0	67.3	33.3	0.0	33.3	0.0	34.0	34.0	1.00	0.00	0.49	36	0	0.0	----	0.0	0.0	23.7	-57.0	5.5	0.0	285.6
12	75.5	41.9	117.4	75.5	23.4	98.9	0.0	18.5	18.5	1.00	0.56	0.84	676	501	72.0	0.14	4.3	0.0	21.9	-48.8	23.4	0.0	265.8
13	232.2	50.0	282.2	218.7	33.0	251.7	13.5	17.0	30.5	0.94	0.66	0.89	460	205	32.1	0.16	-5.2	191.0	16.8	-236.4	15.6	16.2	276.1
14	187.7	72.5	260.2	187.7	72.5	260.2	0.0	0.0	0.0	1.00	1.00	1.00	1222	1133	375.0	0.33	229.9	35.6	16.6	98.2	36.3	6.1	233.1
15	264.2	21.3	285.5	264.2	0.0	264.2	0.0	21.3	21.3	1.00	0.00	0.93	81	0	0.0	----	0.0	248.2	12.0	-276.2	6.2	25.4	219.6
16	148.5	81.2	229.7	148.5	72.3	220.8	0.0	8.9	8.9	1.00	0.89	0.96	1081	1001	403.4	0.40	248.5	45.5	10.1	172.5	33.9	5.4	205.0
17	120.7	81.6	202.3	120.7	81.6	202.3	0.0	0.0	0.0	1.00	1.00	1.00	1240	1170	416.4	0.36	242.3	0.0	16.1	198.0	31.4	0.6	213.9
18	190.9	23.3	214.2	190.9	0.0	190.9	0.0	23.3	23.3	1.00	0.00	0.89	49	0	0.0	----	0.0	171.6	14.0	-204.9	3.6	13.0	235.3
19	193.7	34.7	228.4	136.7	10.8	147.5	57.0*	23.9*	80.9	0.71	0.31	0.65	148	51	18.8	0.37	6.1	118.8*	8.5	-137.2*	3.6*	16.0*	266.9*
20	178.8	56.9	235.7	178.8	51.9	230.7	0.0	5.0	5.0	1.00	0.91	0.98	1082	970	347.5	0.36	246.4	115.6	7.6	109.2	33.9*	16.0*	231.6
21	174.9	70.2	245.1	174.9	70.2	245.1	0.0	0.0	0.0	1.00	1.00	1.00	1501	1424	446.1	0.31	309.1	92.6	11.5	189.5	35.0*	10.0*	228.7
22	149.1	66.8	215.9	149.1	66.8	215.9	0.0	0.0	0.0	1.00	1.00	1.00	1417	1362	410.8	0.30	263.6	34.7	17.5	177.4	31.4*	5.4*	226.0
23	131.8	58.7	190.5	131.8	58.7	190.5	0.0	0.0	0.0	1.00	1.00	1.00	1293	1233	283.6	0.23	135.1	0.0	19.5	73.6	31.9*	0.6*	225.6
24																							
25	178.8	51.8	230.6	178.8	51.8	230.6	0.0	0.0	0.0	1.00	1.00	1.00	1403	1258	268.0	0.21	75.2	0.0	26.8	10.6	27.7	0.0	210.4
26	174.7	70.5	245.2	174.7	70.5	245.2	0.0	0.0	0.0	1.00	1.00	1.00	1436	1339	269.0	0.20	59.6	0.0	26.7	-2.9	30.6	0.0	199.1
27	53.5	13.0	66.5	53.5	0.0	53.5	0.0	13.0	13.0	1.00	1.00	1.00	354	98	0.0	----	-23.3	0.0	23.3	-76.8	4.2	0.6	176.3
28	79.0	26.0	105.0	79.0	6.3	85.3	0.0	19.7	19.7	1.00	0.24	0.81	540	400	66.5	0.17	12.9	0.0	23.0	-41.8	9.3	0.0	192.5
29	77.0	33.4	110.4	77.0	13.6	90.6	0.0	19.8	19.8	1.00	0.41	0.82	511	360	43.9	0.12	-8.7	11.1	20.3	-67.0	14.8	0.5	186.7
30	129.2	90.5	219.7	129.2	90.5	219.7	0.0	0.0	0.0	1.00	1.00	1.00	1400	1314	328.7	0.25	140.7	0.0	21.2	87.8	32.7	0.0	174.3
31																							
Total	5037.2	1508.3	6545.5	4650.2	1262.6	5912.8	387.0	245.7	632.7	-----	-----	-----	27987	24604	6813.0	-----	3505.7	1328.8	501.1	399.1	727.7	189.0	7348.1
Mean	173.7	52.0	225.7	160.4	43.5	203.9	13.3	8.5	21.8	0.92	0.84	0.90	965	848	234.9	0.28	120.9	63.1	17.3	13.8	25.1	6.5	253.4

*Calculated Values

Table 7-15. System Performance for the Month of May 1977 (MJ/Day)

DAY	SPACE AND DOMESTIC HOT WATER HEATING												COLLECTOR PERFORMANCE				STORAGE				ELECTRIC ENERGY		
	ENERGY REQUIRED			SOLAR ENERGY USED			AUX. ENERGY USED			SOLAR FRACTION			TOTAL INCIDENT SOLAR	SOLAR WHILE COLLECTING	HEAT FROM COLLECTOR	AVE. EFF.	HEAT IN	HEAT OUT	HEAT LOSS	CHANGE IN STORAGE	SOLAR	CIRCULATION	HOUSE
SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL												
1	169.9	19.4	189.3	169.9	10.1	180.0	0.0	9.3	9.3	1.00	0.52	0.95	398	299	36.4	0.12	-11.6	107.3	18.7	-162.3	14.4	7.9	166.7
2	36.2	44.5	80.7	36.2	44.5	80.7	0.0	0.0	0.0	1.00	1.00	1.00	477	360	103.6	0.29	44.0	0.0	15.2	7.7	10.9	0.0	123.3
3	106.4	65.8	172.2	106.4	65.8	172.2	0.0	0.0	0.0	1.00	1.00	1.00	1116	910	186.7	0.21	42.6	0.0	20.7	-6.2	24.2	0.0	206.9
4	250.4+	70.5+	320.9+	209.3+	70.5+	279.8+	41.1+	0.0	41.1	0.84	1.00	0.87	1558+	1527+	299.0+	0.20+	103.3+	51.5+	21.3+	-2.1	33.0+	0.2+	217.3+
5	135.2	77.9	213.1	135.2	77.9	213.1	0.0	0.0	0.0	1.00	1.00	1.00	1598	1478	302.9	0.20	122.2	0.0	21.3	68.5	28.4	0.0	243.4
6	180.8	63.6	244.4	180.8	63.6	244.4	0.0	0.0	0.0	1.00	1.00	1.00	1616	1455	348.3	0.24	139.0	0.0	23.9	80.0	30.0	0.0	187.3
7	107.7	29.2	136.9	107.7	25.1	132.8	0.0	4.1	4.1	1.00	0.86	0.97	1013	825	101.5	0.12	-2.8	0.0	23.1	-54.4	24.0	0.0	187.2
8	154.5	65.4	219.9	154.5	65.4	219.9	0.0	0.0	0.0	1.00	1.00	1.00	1566	1436	324.5	0.23	140.0	0.0	24.6	80.0	29.9	0.0	194.3
9	143.3+	33.4+	176.7+	143.3+	33.4+	176.7	0.0	0.0	0.0	1.00	1.00	1.00	1142+	1013+	215.7+	0.21+	72.4+	0.0	24.4+	14.6+	19.9+	0.0	194.5+
10	139.4	35.1	175.5	139.4	36.1	175.5	0.0	0.0	0.0	1.00	1.00	1.00	1241	1009	179.1	0.18	39.8	0.0	26.5	-22.9	17.4	0.0	210.3
11	150.2	67.6	217.8	150.2	67.6	217.8	0.0	0.0	0.0	1.00	1.00	1.00	1630	1388	205.9	0.15	21.3	0.0	24.9	-36.8	29.7	0.0	257.9
12	126.6	61.2	187.8	126.6	61.2	187.8	0.0	0.0	0.0	1.00	1.00	1.00	1275	1125	179.2	0.16	20.3	0.0	22.9	-31.5	34.2	0.0	215.1
13	131.0	60.0	191.0	131.0	60.0	191.0	0.0	0.0	0.0	1.00	1.00	1.00	1283	1132	228.0	0.20	67.1	0.0	22.5	14.5	33.7	0.0	224.6
14	92.4	28.9	121.3	92.4	24.7	117.1	0.0	4.2	4.2	1.00	0.85	0.97	925	689	105.6	0.15	18.3	0.0	21.3	-32.8	22.5	0.0	185.9
15	169.2	55.2	224.4	159.9	55.2	215.1	0.0	0.0	9.3	0.95	1.00	0.96	1452	1260	218.8	0.17	54.4	23.6	18.9	-15.2	31.5	1.4	176.4
16	116.9	65.0	181.9	116.9	65.0*	181.9	0.0	0.0	0.0	1.00	1.00	1.00	1235	867	157.7	0.18	38.0*	35.2*	18.9	-43.1	30.4*	1.4*	313.5
17	END HEATING SEASON 1976-77																						
18																							
19																							
20																							
21																							
22																							
23																							
24																							
25																							
26																							
27																							
28																							
29																							
30																							
31																							
Total	2210.1	843.7	3053.8	2159.7	826.1	2985.8	50.4	17.6	68.0	-----	-----	-----	19525	16773	3132.9	0.19	508.3	217.6	349.1	-142.0	414.1	10.9	3334.6
Mean	138.1	52.7	190.8	135.0	51.6	186.6	3.1	1.1	4.3	0.98	0.98	0.98	1220	1048	199.6	0.19	30.8	13.6	21.8	-8.9	25.9	0.7	206.5

+Missing Scans

Figure 7-8. Collection of Solar Heat During the 1976-77 Heating Season.

The monthly average daily loads for space and water heating, and the solar heat supplied to the load are shown by the bar graph of Figure 7-9. For the measurement period, the total load for space and water heating was 62.67 GJ, and 77 percent or 48.36 GJ of the total was supplied by the solar system. The difference between 50.00 GJ collected and 48.36 GJ used, or 1.64 GJ, was lost from the system in the attic of the building and from storage to the ground.

7.3.3 Space and Water Heating 1977-78

The computed daily quantities of heat provided for space and water heating during the period 8 October 1977 through 14 May 1978 are tabulated in Tables 7-16 through 7-23. The tabulated quantities are explained in Table 7-8 and are the same quantities tabulated for the 1976-77 heating season.

The daily heat quantities (and heat equivalents) in the tables are balanced for each solar day, where a solar day is defined from 0800 hours (mountain standard time) to 0800 hours (which is the same for the 1976-77 season). This definition of a day is convenient because at 0800 hours storage is generally depleted, particularly during the winter periods, and collection, on a sunny day, begins shortly thereafter. Daily energy balance for storage is calculated from measured total heat flows into and out of storage, and calculated transmission losses to the ground and to the heated space. The daily quantities of solar and auxiliary energies used for space and water heating are plotted on Figures 7-10 through 7-17 along with the total solar flux and average daily room and ambient temperatures. The set temperature of the thermostat was 22°C.

Figure 7-9. . Solar and Auxiliary Contributions to Total Space and DHW Load, 1976-77 Heating Season

Table 7-16. System Performance for the Month of October 1977 (MJ/Day)

DAY	SPACE AND DOMESTIC HOT WATER HEATING									COLLECTOR PERFORMANCE				STORAGE				ELECTRIC ENERGY					
	ENERGY REQUIRED SPACE DHW TOTAL			SOLAR ENERGY USED SPACE DHW TOTAL			AUX. ENERGY USED SPACE DHW TOTAL			SOLAR FRACTION SPACE DHW TOTAL			TOTAL INCIDENT SOLAR	SOLAR WHILE COLLECTING	HEAT FROM COLLECTOR	AVE. EFF.	HEAT IN	HEAT OUT	HEAT LOSS	CHANGE IN STORAGE	SOLAR	CIRCULATION	HOUSE
1																							
2																							
3																							
4																							
5																							
6																							
7	Beginning of Data																						
8	353.7	123.9	477.6	353.7*	123.9*	477.6	0.0	0.0	0.0	1.00	1.00	1.00	1783*	1563*	918.5*	0.59	467.3*	7.9	3.2*	437.7	27.0*	1.2*	87.5*
9	178.2	59.4	237.6	178.2*	54.3*	232.5	0.0	5.1	5.1	1.00	0.91	0.98	555*	489*	261.7*	0.53	157.8*	91.6	9.1	20.1	11.0*	7.6	73.1*
10	222.5	24.5	247.0	165.7*	1.9*	167.6	56.8	22.6	79.4	0.74	0.08	0.68	239*	22*	10.1*	0.46	3.3*	151.5	6.5	-164.0	0.5*	20.0	112.9*
11	456.8	88.9	545.7	450.7	80.0	530.7	6.1	8.9	15.0	0.99	0.90	0.97	1791	1636	666.7	0.41	336.0	172.8	11.7	124.3	29.3	9.3	146.2
12	307.2	91.3	398.5	307.2	82.4	389.6	0.0	8.9	8.9	1.00	0.90	0.98	1757	1636	594.8	0.36	256.1	17.5	18.4	186.8	29.2	1.4	136.2
13	321.6	98.4	420.0	321.6	98.4	420.0	0.0	0.0	0.0	1.00	1.00	1.00	1700	1471	552.6	0.38	169.5	0.0	23.7	108.9	26.0	0.0	124.2
14	345.3	77.6	422.9	343.7	77.6	421.3	1.6	0.0	1.6	1.00	1.00	1.00	1514	1339	484.2	0.36	106.9	4.6	26.4	36.5	24.3	6.5	97.0
15	313.8	66.9	380.7	313.8	59.5	373.3	0.0	7.4	7.4	1.00	0.89	0.98	1415	1254	364.9	0.29	28.5	0.6	25.4	-33.8	23.8	2.3	73.2
16	336.0	59.7	395.7	336.0	54.8	390.8	0.0	4.9	4.9	1.00	0.92	0.99	1664	1507	499.6	0.33	148.9	0.0	26.7	82.1	25.8	0.0	110.2
17	304.9	74.5	379.4	304.9	68.9	373.8	0.0	5.6	5.6	1.00	0.92	0.99	1504	1273	383.4	0.30	47.3	0.0	27.0	-17.4	21.7	0.0	116.2
18	316.5	73.1	389.6	316.5	68.1	384.6	0.0	5.0	5.0	1.00	0.93	0.99	1610	1400	435.5	0.31	89.9	0.0	27.1	23.8	23.4	0.0	142.1
19	292.5	64.3	356.8	292.5*	54.2	346.7	0.0	10.1	10.1	1.00	0.84	0.97	1494	1265	411.2	0.33	99.4	0.0	24.6*	39.9*	20.7	0.0*	167.5*
20	28.0	20.7	48.7	28.0*	0.0	28.0	0.0	20.7	20.7	1.00	0.00	0.57	514*	0	0.0	----	0.0	0.0	21.4*	-49.4*	1.8	0.0*	167.6*
21	245.3	60.6	305.9	245.3	60.6	305.9	0.0	0.0	0.0	1.00	1.00	1.00	923	747	257.5	0.34	54.3	71.4	21.8	-70.2	14.6	3.1	157.9
22	251.2	76.0	327.2	251.2*	69.3*	320.5	0.0	6.7	6.7	1.00	0.91	0.98	1084*	938*	306.5	0.33	71.0*	56.3	191.1*	-33.1	16.7*	3.2	148.7
23	142.7	68.7	211.4	142.7*	67.7*	210.4	0.0	1.0	1.0	1.00	0.99	1.00	1143*	948*	283.3*	0.33	93.5*	0.0	13.6*	39.3	13.9*	0.0	152.0
24	93.3	51.9	145.2	93.3*	51.9*	145.2	0.0	0.0	0.0	1.00	1.00	1.00	699*	390*	130.3*	0.33	11.2*	0.0	19.9*	-34.8*	7.4*	0.0	233.8*
25	180.0	43.0	223.0	180.0*	43.0*	223.0	0.0	0.0	0.0	1.00	1.00	1.00	1018*	935*	329.4*	0.35	132.6*	0.0	17.0*	89.4*	11.9*	0.0	161.3*
26	336.1	64.9	401.0	336.1	64.9	401.0	0.0	0.0	0.0	1.00	1.00	1.00	1626	1357	496.4	0.37	148.2	13.5	27.1	68.3	22.8	0.0	234.6
27	423.3	90.8	514.1	423.3	90.8	514.1	0.0	0.0	0.0	1.00	1.00	1.00	1555	1346	473.8	0.35	63.7	71.5	23.6	-63.9	22.0	0.0	249.2
28	286.6	75.3	361.9	286.6	75.3	361.9	0.0	0.0	0.0	1.00	1.00	1.00	1488	1283	434.3	0.34	101.6	0.0	21.3	50.1	18.3	0.0	170.3
29	304.2	27.3	331.5	304.2	14.8	319.0	0.0	12.5	12.5	1.00	0.54	0.96	1000	683	204.1	0.30	46.2	134.2	19.2	-134.1	7.4	7.5	124.8
30	193.9	94.1	288.0	193.9	94.1	288.0	0.0	0.0	0.0	1.00	1.00	1.00	1433	1217	404.0	0.33	145.0	0.0	18.3	97.7	19.4	0.0	162.7
31	237.8	18.5	256.3	237.8*	0.0	237.8	0.0	18.5	18.5	1.00	0.00	0.93	706	232	73.9	0.32	20.9	157.8*	18.9	-182.8	5.5	8.7*	183.7*
Total	6471.4	1594.3	8065.7	6406.9	1456.4	7863.3	64.5	137.9	202.4	----	----	----	30215	24831	8976.7	----	2779.1	951.2	471.0	642.4	424.4	70.8	3532.9
Mean	269.7	66.4	336.1	267.0	60.7	327.6	2.7	5.7	8.4	0.99	0.91	0.97	1259	1035	374.0	0.36	115.8	39.6	19.6	26.8	17.7	3.0	147.2

* Calculated Values

+ Missing Scans

Table 7-17. System Performance for the Month of November 1977 (MJ/Day)

DAY	SPACE AND DOMESTIC HOT WATER HEATING												COLLECTOR PERFORMANCE				STORAGE				ELECTRIC ENERGY		
	ENERGY REQUIRED			SOLAR ENERGY USED			AUX. ENERGY USED			SOLAR FRACTION			TOTAL INCIDENT SOLAR	SOLAR WHILE COLLECTING	HEAT FROM COLLECTOR	AVE. EFF.	HEAT IN	HEAT OUT	HEAT LOSS	CHANGE IN STORAGE	SOLAR	CIRCULATION	HOUSE
	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL											
1	381.3*	50.2*	431.5	381.3*	49.5	430.8	0.0	0.7	0.7	1.00	0.99	1.00	1053*	858*	302.5*	0.35*	114.6	216.2	17.1	-145.4	14.1	10.2	201.3
2	172.6	85.2	257.8	172.6	78.9	251.5	0.0	6.3	6.3	1.00	0.93	0.98	1140	908	355.9	0.39	159.5	27.3	17.4	87.0	17.5	1.7	199.1
3	366.1	84.2	450.3	366.1	79.9	446.0	0.0	4.3	4.3	1.00	0.95	0.99	1515	1291	453.1	0.35	133.1	95.3	19.7	-12.6	22.3	5.4	224.1
4	199.0	59.6	258.6	199.0	59.6	258.6	0.0	0.0	0.0	1.00	1.00	1.00	795	611	255.6	0.42	76.0	53.2	18.1	-21.1	16.4	2.6	206.1
5	197.4	71.3	268.7	197.4	71.3	268.7	0.0	0.0	0.0	1.00	1.00	1.00	1039	987	375.0	0.38	146.6	8.8	20.2	86.1	19.5	0.6	145.0
6	167.2	17.0	184.2	167.2	2.9	170.1	0.0	14.1	14.1	1.00	0.17	0.92	343	52	26.5	0.51	6.1	124.9	17.8	-161.4	4.2	7.2	185.7
7	Integrator Problems																						
8	Integrator Problems																						
9	160.0	14.5	174.5	-13.4	0.0	-13.4	173.4	14.5*	187.9*	-0.08	0.00	-0.08	634	0	0.0	----	0.0	-17.7	5.4	8.0	0.0	25.0*	358.2*
10	390.7	108.3	499.0	390.7	93.8	484.5	0.0	14.5*	14.5*	1.00	0.87	0.97	1095	945	547.4	0.58	258.6	174.8	9.9	53.0	28.3	10.6	232.0
11	405.9*	85.3*	491.2*	405.9*	80.6	486.5*	0.0	4.7*	4.7*	1.00	0.94	0.99	1404*	1234*	543.3	0.45*	256.8	180.0*	9.8*	47.0	30.0*	10.8*	225.0*
12	No Data																						
13	Part Day																						
14	209.7	98.4	308.1	209.7	90.5	300.2	0.0	7.9	7.9	1.00	0.92	0.97	1133	1038	401.7	0.39	137.3	9.2	17.6	83.9	18.6	1.4	241.9
15	228.2	81.5	309.7	228.2	65.7	293.9	0.0	15.8	15.8	1.00	0.81	0.95	743	643	226.5	0.35	37.0	81.9	16.5	-83.9	14.2	5.3	240.0
16	311.3*	59.4	370.7*	260.4*	8.8	269.2*	50.9	50.6	101.5	0.84*	0.15	0.73*	221	91	35.0	0.38	9.9	229.7*	10.6*	-244.8*	2.9	26.2*	219.9*
17	291.2	71.5	362.7	129.6	25.0	154.6	161.6	46.5	208.1	0.45	0.35	0.43	554	431	171.7	0.40	54.2	31.6	4.0	13.1	168.0	108.0	242.0
18	347.7	81.9	429.6	265.7	48.4	314.1	82.0	33.5	115.5	0.76	0.59	0.73	792	715	304.6	0.43	125.3	124.3	5.9	-15.4	20.0	14.4	259.4
19	485.8	60.6	546.4	198.1	23.6	221.7	287.7	37.0	324.7	0.41	0.39	0.41	464	380	192.7	0.51	62.8	844.0	4.7	-33.7	14.0	17.3	156.9
20	730.6	79.9	810.5	515.3	53.8	569.1	215.3	26.1	241.4	0.71	0.67	0.70	1551	1419	548.2	0.39	185.9	195.3	5.2	-26.1	23.2	25.2	184.0
21	558.1	93.3	651.4	506.1	62.0	568.1	52.0	31.3	83.3	0.91	0.66	0.87	1257	1176	574.8	0.49	240.1	217.7	6.8	-0.1	22.9	26.3	243.5
22	221.2	54.2	275.4	43.5	13.6	57.1	177.7	40.6	218.3	0.20	0.25	0.21	280	171	65.6	0.38	24.4	14.0	2.2	6.3	7.0	15.3	208.0
23	367.7	88.9	456.6	343.9	62.6	406.5	23.8	26.3	50.1	0.94	0.70	0.89	1037	948	459.1	0.48	228.1	159.7	7.3	45.3	19.8	14.0	222.7
24	286.7	67.0	353.7	169.6	32.0	201.6	117.1	35.0	152.1	0.59	0.48	0.57	506	391	167.9	0.43	44.2	73.8	3.2	-36.9	14.5	26.0	135.2
25	318.4	74.7	393.1	262.1	44.7	306.8	56.3	30.0	86.3	0.82	0.60	0.78	814	765	308.4	0.40	115.8	106.4	4.0	-2.4	25.4	24.6	236.0*
26	Part Day																						
27	Part Day																						
28	436.9	52.4	489.3	123.5	15.7	139.2	313.4	36.7	350.1	0.28	0.30	0.28	385	276	139.2	0.50	54.4	51.9	2.5	-2.5	10.9	14.0	----
29	415.6*	36.7	452.3*	101.4*	7.7	109.1*	314.2	29.0	343.2	0.24*	0.21	0.24*	223	191	86.0*	0.45*	28.4	49.5	2.5	-25.6	10.4*	23.5*	----
30	435.7*	70.5	506.2*	213.9*	40.8*	254.7*	221.8	29.7	251.5	0.49*	0.58	0.50*	648*	572*	275.4*	0.45*	84.9	77.2	2.5	3.2	21.8*	19.4*	----
31																							
Total	8085.0	1646.5	9731.5	5837.8	1111.4	6949.2	2247.2	535.1	2782.3	----	----	----	19,686	16093	6798.1	----	2584.0	2369.4	230.9	-382.0	394.7	350.1	4566.0
Mean	336.9	68.6	405.5	243.2	46.3	289.5	93.6	22.3	115.9	0.72	0.68	0.71	820	671	283.3	0.42	107.7	96.7	9.6	-15.9	16.4	14.6	210.4

*Calculated Values

+Missing Scans

Table 7-18. System Performance for the Month of December 1977 (MJ/Day)

DAY	SPACE AND DOMESTIC HOT WATER HEATING												COLLECTOR PERFORMANCE				STOPPAGE				ELECTRIC ENERGY		
	ENERGY REQUIRED			SOLAR ENERGY USED			AUX. ENERGY USED			SOLAR FRACTION			TOTAL INCIDENT SOLAR	SOLAR WHILE COLLECTING	HEAT FROM COLLECTOR	AVE. EFF.	HEAT IN	HEAT OUT	HEAT LOSS	CHANGE IN STORAGE	SOLAR	CIRCULATION	HOUSE
	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL											
1	458.5	73.2	531.7	261.0	38.1	299.1	197.5	35.1	232.6	0.57	0.52	0.56	667	637	300.8*	0.47	131.3*	123.9*	3.8	-2.1*	17.2	15.2	----
2	259.8	82.1	341.9	255.4	46.6	302.0	4.4	35.5	39.9	0.98	0.57	0.89	800	750	314.4*	0.42	161.1*	142.7*	5.2	7.2*	16.9	7.7	----
3	347.3	32.8	380.1	333.7	5.9	340.6	13.6	25.9	39.5	0.96	0.21	0.90	858	857	374.6*	0.44	202.9	161.9*	6.8	27.2	19.7	8.2	----
4	367.6	40.3	407.9	365.5	17.1	382.6	2.1	23.2	25.3	0.99	0.42	0.94	895	873	367.9*	0.42	150.1	156.8*	7.4	-22.1*	19.8	3.7	----
5	465.7	51.1	516.8	15.2	-4.9	10.3	450.5	56.0	506.5	0.03	-0.10	0.02	126	107	7.1*	0.37	0.5	-6.6	1.8	-5.0	1.2	23.1	----
6	120.6*	63.4	184.0	15.7	-1.0	14.7	104.9	64.4	169.3	0.13	-0.02	0.08	201	46	0.6	0.31	-7.0	-6.9	0.9	-15.0	3.7	6.4	----
7	360.6	98.1	458.7	245.8	68.7	314.5	114.8	29.4	144.2	0.68	0.70	0.69	374	804	352.0	0.44	175.0	126.4	5.5	32.0	18.2	23.2	----
8	529.2	61.3	590.5	120.7	20.2	140.9	408.5	41.1	449.6	0.23	0.33	0.24	647	407	139.2	0.34	34.4	34.1	2.2	-3.9	10.7	29.2	129.0
9	574.1	77.3	651.4	244.3*	40.9*	285.2	329.8	36.4	366.2	0.43	0.53	0.44	807*	629*	273.1*	0.43	76.2*	84.3	3.0*	-15.1*	13.2	30.5	158.5
10	347.8	96.1	443.9	331.5	76.9	408.4	16.3	19.2	35.5	0.95	0.80	0.92	1196	1130	500.8	0.44	237.6	129.1	8.0	84.4	24.2	18.2	110.9
11	296.7	83.8	380.5	296.7	69.2	365.9	0.0	14.6	14.6	1.00	0.83	0.96	1244	1195	535.9	0.45	284.3	91.8	11.7	158.3	23.0	7.3	136.0
12	155.0	66.5	221.5	155.0	25.4	180.4	0.0	41.1	41.1	1.00	0.38	0.81	376	188	73.6	0.39	29.0	124.8	9.2	-116.0	6.5	20.8	215.7
13	272.2	118.3	390.5	227.0	74.7	301.7	45.2	43.6	88.8	0.83	0.63	0.77	828	742	337.1	0.45	141.2	97.0	5.2	30.2	17.8	27.3	198.6
14	156.9	19.8	176.7	143.5	15.3	158.8	13.4	4.5	17.9	0.91	0.77	0.90	593	547	237.5	0.43	139.4	50.8	6.0	72.7	17.1	11.2	179.7
15	184.9	106.9	291.8	65.5	28.2	93.7	119.4	78.7	198.1	0.35	0.26	0.32	265	179	76.8	0.43	27.5	41.2	3.7	-20.6	7.6	23.6	167.3
16	431.2	66.1	499.3	132.1	35.4	167.5	299.1	32.7	331.8	0.31	0.52	0.34	718	530	190.2	0.36	63.6	37.8	3.0	19.7	14.3	26.1	149.3
17	471.8	69.9	541.7	407.0	45.8	452.8	64.6	24.1	88.9	0.86	0.66	0.84	1199	1114	457.7	0.41	230.9	210.0	7.6	-2.7	23.8	39.1	126.6
18	333.6	67.8	401.4	333.6	48.0	381.6	0.0	19.8	19.8	1.00	0.71	0.95	943	341	394.5	0.47	182.1	157.3*	5.6*	7.3*	18.8	21.0	116.3*
19	435.5	63.2	498.7	279.8	44.2	324.0	155.7	19.0	174.7	0.64	0.70	0.65	1076	1064	415.0	0.39	193.5	91.9	3.9	67.1	24.1	27.1	180.5
20	376.6	36.0	412.6	328.8	24.6	353.4	47.8	11.4	59.2	0.87	0.68	0.86	1097	1001	381.1	0.38	196.7	154.8	6.8	20.9	17.6	31.0	194.9
21	311.3	75.3	386.6	309.6	56.1	365.7	1.7	19.2	20.9	0.99	0.75	0.95	1171	1094	450.5	0.41	235.6	133.9	8.4	76.4	21.2	11.8	213.8
22	423.2	82.3	505.5	423.2	63.4	486.6	0.0	18.9	18.9	1.00	0.77	0.96	1328	1209	460.9	0.38	207.1	213.8	10.2	-35.9	21.1	18.8	186.5
23	386.6	87.6	474.2	386.6	74.8	461.4	0.0	12.8	12.8	1.00	0.85	0.97	1195	1128	475.7	0.42	235.4	199.7	11.1	3.2	20.6	16.1	156.4
24	629.9	75.8	705.7	548.4	59.2	607.6	81.5	16.6	98.1	0.87	0.78	0.86	1389	1313	532.0	0.41	217.4	274.7	9.0	-84.6	24.5	34.6	142.2
25	607.7	72.5	679.2	511.6	53.5	565.1	95.1	19.0	114.1	0.84	0.74	0.83	1431	1283	545.6	0.43	221.3	226.2	6.6	-26.1	21.4	33.0	131.8
26	573.1	79.0	652.1	474.1	59.4	533.5	99.0	19.6	118.6	0.83	0.75	0.82	1358	1283	525.1	0.41	237.6	229.6	7.2	-15.6	22.6	32.0	148.4
27	460.4	41.2	501.6	234.1	5.6	239.7	206.3	35.6	241.9	0.55	0.14	0.52	680	573	249.2	0.43	112.0	114.5	4.3	-14.8	13.1	30.1	130.9
28	468.4	46.6	515.0	453.1	0.0	453.1	15.3	46.6	61.9	0.97	0.00	0.88	1417	1342	572.4	0.43	297.3	154.9	10.7	108.6	22.9	12.9	150.3
29	340.9	73.3	414.2	255.1	38.9	294.0	85.6	34.4	120.2	0.75	0.53	0.71	468	340	152.7	0.45	48.6	178.7	7.4	-146.7	11.1	36.6	160.6
30	369.4	64.4	433.8	105.0	32.6	137.6	264.4	31.6	296.2	0.28	0.51	0.32	434	314	143.7	0.46	47.7	38.3	2.7	3.4	10.2	24.1	106.2
31	677.7	64.3	742.0	223.1	37.7	260.8	454.6	26.6	481.2	0.33	0.59	0.35	919	659	244.7	0.37	71.8	83.6	2.7	-18.8	13.2	34.4	100.6
Total	12193.2	2138.3	14331.5	8501.7	1201.5	9703.2	3691.5	936.8	4628.3	-----	-----	-----	27202	24179	10082.4	-----	4582.1	3851.6	187.6	191.6	527.3	684.3	3693.5
Mean	393.3	69.0	462.3	274.2	38.8	313.0	119.1	30.2	149.3	0.70	0.56	0.68	878	780	325.2	0.42	147.8	124.2	6.0	6.2	17.0	22.1	153.9

* Calculated Values

+ Missing Scans

† Furnace Not Operating

Table 7-19. System Performance for the Month of January 1978 (MJ/Day)

DAY	SPACE AND DOMESTIC HOT WATER HEATING									COLLECTOR PERFORMANCE				STORAGE				ELECTRIC ENERGY					
	ENERGY REQUIRED			SOLAR ENERGY USED			AUX. ENERGY USED			SOLAR FRACTION			TOTAL INCIDENT SOLAR	SOLAR WHILE COLLECTING	HEAT FROM COLLECTOR	AVE. EFF.	HEAT IN	HEAT OUT	HEAT LOSS	CHANGE IN STORAGE	SOLAR	CIRCULATION	HOUSE
	SPACE	DHW	TOT.L	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL											
1	727.9	72.3	800.2	477.6	54.6	532.2	250.3	17.7	268.0	0.66	0.76	0.67	1332	1211	512.8	0.42	167.3	176.6	4.8	-24.2	20.0	34.8	100.5
2	513.5	82.6	596.1	501.5	70.7	572.2	12.0	11.9	23.9	0.98	0.86	0.96	1473	1272	501.6	0.43	269.9	231.3	8.9	10.5	22.8	20.1	174.2
3	271.3	51.7	323.0	93.5	26.2	119.7	177.8	25.5	203.3	0.34	0.51	0.37	369	249	94.2	0.38	30.8	52.9	3.1	-28.5	5.6	30.2	160.5
4	264.6	60.9	325.5	94.9	30.2	125.1	169.7	30.7	200.4	0.36	0.50	0.38	408	280	125.6	0.45	44.0	39.9	2.9	-2.4	9.8	16.4	161.8
5	253.0	73.4	326.4	238.4	54.4	292.8	14.6	19.0	33.6	0.94	0.74	0.90	765	665	295.7	0.43	133.3	120.9	5.1	-2.2	14.2	20.4	160.3
6	275.5	62.0	338.4	171.6	39.9	211.5	103.9	23.0	126.9	0.62	0.63	0.63	587	520	210.8	0.41	95.0	89.0	4.1	-4.8	12.6	23.3	151.4
7	459.4	81.7	541.1	402.1	68.9	471.0	57.3	12.8	70.1	0.88	0.84	0.87	1100	1006	454.2	0.45	202.7	204.5	7.0	-23.8	23.0	28.2	152.5
8	458.6	46.0	504.6	66.9	16.2	83.1	391.7	29.8	421.5	0.15	0.35	0.16	372	187	75.3	0.40	14.0	-0.7	2.4	-10.2	7.9	25.0	127.2
9	402.4	65.7	468.1	81.5	29.2	110.7	320.9	36.5	357.4	0.20	0.44	0.24	440	270	119.9	0.45	31.0	19.8	2.5	6.7	8.7	22.2	229.5
10	431.5	92.4	523.9	141.0	37.1	178.1	290.5	55.3	345.8	0.33	0.40	0.34	552	390	181.0	0.46	50.5	44.4	2.8	0.1	8.8	28.6	195.8
11	357.8	86.8	444.6	275.7	54.3	330.0	82.1	32.5	114.6	0.77	0.63	0.74	843	756	336.7	0.45	133.0	118.0	4.7	2.0	16.5	24.9	214.9
12	359.1	104.6	463.7	328.7	83.8	412.5	30.4	20.8	51.2	0.92	0.80	0.89	1087	1007	423.4	0.42	195.0	171.0	6.6	4.3	16.5	23.0	214.6
13	539.7	92.2	631.9	525.0	80.6	605.6	14.7	11.6	26.3	0.97	0.87	0.96	1457	1365	600.6	0.44	276.3	260.9	9.5	-14.5	22.9	22.9	188.4
14	390.1	52.6	442.7	243.3	33.8	277.1	146.8	18.8	165.6	0.62	0.64	0.63	597	499	229.9	0.46	85.2	125.7	4.0	-51.2	15.3	36.9	150.1
15	372.9	43.3	416.2	-16.9	0.0	-16.9	389.8	43.3	433.1	-0.05	0.00	-0.04	134	0	0.0	----	0.0	-17.0	2.0	14.9	0.2	27.8	110.3
16	516.5	115.7	632.2	296.3	72.4	368.7	220.2	43.3	263.5	0.57	0.63	0.58	1388	998	365.6	0.37	103.7	101.0	3.6	-6.7	15.5	29.0	232.0
17	321.4	59.8	381.2	245.9	41.3	287.2	75.5	18.5	94.0	0.77	0.69	0.75	778	622	291.0	0.47	112.5	101.0	4.6	-0.5	17.2	20.6	186.3
18	456.4	101.2	557.6	224.8	62.9	287.7	231.6	38.3	269.9	0.49	0.62	0.52	882	683	292.1	0.43	37.9	76.2	3.3	1.1	14.4	25.1	182.9
19	425.6	47.4	473.0	23.8	9.1	32.9	401.8	38.3	440.1	0.06	0.19	0.07	388	96	45.8	0.48	2.9	-10.5	1.9	11.0	4.5	23.4	164.2
20	432.6	88.8	521.4	96.4	27.6	124.0	336.2	61.2	397.4	0.22	0.31	0.24	461	267	132.0	0.49	15.0	5.4	2.3	5.7	10.9	22.3	170.7
21	536.6	86.6	623.2	526.4	77.6	604.0	10.2	9.0	19.2	0.98	0.90	0.97	1533	1434	629.0	0.44	291.8*	263.4*	5.5	19.5	22.9*	22.9*	190.3*
22	528.0	78.5	606.5	528.0	74.4	602.4	0.0	4.1	4.1	1.00	0.95	0.99	1546	1405	654.9	0.47	273.2	195.2	10.3	42.2	22.4	18.4	163.4
23	222.9	36.0	258.9	20.5*	0.0	20.5	202.4	36.0*	238.4	0.09	0.00	0.08	227	0	0.0	----	0.0	16.9*	3.9*	-24.4	0.2	18.0	163.5
24	404.2	127.5	531.7	404.2	105.8	510.0	0.0	21.7	21.7	1.00	0.83	0.96	1217	1129	590.5	0.52	271.1	174.9*	5.7*	74.8	18.7	14.7	159.7
25	680.7	62.6	743.3	308.5	33.6	342.1	372.2	29.0	401.2	0.45	0.54	0.46	966	818	274.6	0.34	76.8	136.9	4.7	-72.2	18.0	38.3	232.0
26	466.3	58.5	524.8	313.1	0.0*	313.1	153.2	58.5	211.7	0.67	0.00	0.60	808	707	316.2	0.45	137.7	124.0	4.3	0.6	15.7	27.0	260.1
27	497.0	14.5	511.5	485.0*	0.0	485.0	12.0	14.5*	26.5	0.98	0.00	0.95	1255	1114	504.9	0.45	295.6	256.7*	7.5*	12.4*	15.0*	23.0*	222.5*
28	562.1	590.9	582.0	582.0	0.0	582.0	0.1	9.8	8.9	1.00	0.00	0.98	1479	1343	551.4	0.43	310.4	267.8	10.2	-10.9	21.0	28.6	177.7
29	511.6	11.1	522.7	230.1	0.0	230.1	281.5	11.1	292.6	0.45	0.00	0.44	654	455	215.0	0.47	113.1	120.4	4.2	-19.3	11.6	36.1	202.4
30	313.5	17.3	330.8	52.4	0.0	52.4	261.1	17.3	278.4	0.17	0.00	0.16	363	175	63.4	0.36	25.9	12.8	2.5	5.5	5.6	17.8	225.6
31	346.3	15.5	361.8	-13.7	0.0	-13.7	360.0	15.5	375.5	-0.04	0.00	-0.04	180	0	0.0	----	0.0	-14.0	2.1	11.6	0.2	23.1	213.3
Total	13319.0	1998.9	15317.9	7948.5	1184.6	9133.1	5370.5	314.3	6184.8	----	----	----	25247	21043	9210.2	----	3645.6	3491.3	147.0	-69.9	418.6	722.9	5626.3
Mean	429.6	64.5	494.1	256.4	38.2	294.6	173.2	26.3	199.5	0.60	0.59	0.60	814	678	297.1	0.44	114.0	112.6	4.7	-2.2	13.5	24.8	181.3

* Calculated Values

+ Missing Scans

- Heat Exchanger Froze

Table 7-20. System Performance for the Month of February 1978 (MJ/Day)

DAY	SPACE AND DOMESTIC HOT WATER HEATING												COLLECTOR PERFORMANCE				STORAGE				ELECTRIC ENERGY		
	ENERGY REQUIRED			SOLAR ENERGY USED			AUX. ENERGY USED			SOLAR FRACTION			TOTAL INCIDENT SOLAR	SOLAR WHILE COLLECTING	HEAT FROM COLLECTOR	AVE. EFF.	HEAT IN	HEAT OUT	HEAT LOSS	CHANGE IN STORAGE	SOLAR	CIRCULATION	HOUSE
	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL											
1	43.8	9.5	53.3	26.1+	0.0	26.1+	15.7	9.5	25.2	0.64	0.00	0.53	361	77	37.2	0.48	7.3	-2.3+	2.4+	6.7+	5.8	22.0	211.7
2	445.5	10.4	455.9	445.5	0.0	445.5	0.0	10.4	10.4	1.00	0.00	0.98	1455	1341	492.5	0.37	258.0	208.5	3.4	43.6	22.5	15.4	161.0
3	357.7	5.3	363.6	357.7	0.0	357.7	0.0	5.9	5.9	1.00	0.00	0.98	923	765	323.3	0.42	154.1	182.0	8.0	-42.4	18.0	16.4	243.9
4	429.2	10.3	439.5	429.2	0.0	429.2	0.0	10.3	10.3	1.00	0.00	0.98	1573	1473	534.8	0.36	298.6	183.0	12.2	93.4	22.0	17.1	93.9
5	488.0	11.4	499.4	271.3	0.0	271.3	216.7	11.4	228.1	0.56	0.00	0.54	534	340	151.7	0.45	58.7	168.6	6.9	-126.5	12.0	35.8	156.9
6	244.9+	11.1+	256.0	-9.3+	0.0	-9.3+	254.2+	11.1+	265.3+	-0.04	0.00	-0.04	159+	0	0.0	----	0.0	-9.9+	2.1+	7.2+	0.2	16.1+	189.6+
7	283.2	12.4	295.6	-7.3	0.0	-7.3	290.5	12.4	302.9	-0.03	0.00	-0.02	130	0	0.0	----	0.0	-7.7	2.1	5.2	0.2	16.3	231.6
8	326.3	12.2	338.5	-9.1	0.0	-9.1	335.4	12.2	347.6	-0.03	0.00	-0.03	32	0	0.0	----	0.0	-9.6	2.2	6.9	0.2	21.0	200.7
9	280.0	20.6	300.6	0.7	0.0	0.7	279.3	20.6	299.9	0.00	0.00	0.00	214	19	9.3	0.49	2.5	-6.5	2.3	6.3	1.5	19.8	233.0
10	281.8	6.5	288.3	275.3+	0.0	275.3+	6.5	6.5	13.0	0.98	0.00	0.95	613+	550+	242.4+	0.44	130.0+	152.8	6.0+	-38.9+	14.2+	23.5+	220.0+
11	373.2	9.4	382.6	-4.3	0.0	-4.3	377.5	9.4	386.9	-0.01	0.00	-0.01	64	0	0.0	----	0.0	-5.7	2.5	1.8	0.2	29.4	133.1
12	493.5	8.8	502.3	185.0	0.0	185.0	308.5	8.8	317.3	0.37	0.00	0.37	607	424	193.1	0.46	86.5	73.1	3.2	4.9	13.3	31.5	131.6
13	519.5	10.7	530.2	394.4	0.0	394.4	125.1	10.7	135.8	0.76	0.00	0.74	1023	876	397.1	0.45	186.5	171.9	5.8	-3.1	20.3	30.3	279.9
14	454.6	8.0	462.6	371.9	0.0	371.9	82.7	8.0	90.7	0.82	0.00	0.80	865	771	370.5	0.48	200.4	188.7	6.0	-7.4	15.6	29.9	259.7
15	451.5	4.1	455.6	427.0	0.0	427.0	24.5	4.1	28.6	0.95	0.00	0.94	1054	952	433.9	0.46	242.4	218.7	7.8	-0.9	17.3	27.0	264.2
16	420.0	12.8	432.8	64.3	0.0	64.3	355.7	12.8	368.5	0.15	0.00	0.15	467	174	76.0	0.44	23.9	10.1	3.0	8.7	7.3	22.6	236.0
17	608.4	8.1	616.5	592.0+	0.0	592.0+	16.4	8.1	24.5	0.97	0.00	0.96	1783+	1647+	649.4+	0.39	346.1+	263.9	10.5	46.9	23.6+	28.3	216.6+
18	597.9	4.5	602.4	565.4	0.0	565.4	32.5	4.5	37.0	0.95	0.00	0.94	1467	1321	557.0	0.42	279.7	267.2	9.2	-17.6	21.7	28.7	206.3
19	573.3	12.9	586.2	489.7	0.0	489.7	83.6	12.9	96.5	0.85	0.00	0.84	1335	1255	488.9	0.39	252.6	235.1	8.3	-9.1	24.6	36.6	232.1
20	548.5	15.1	563.6	525.4	0.0	525.4	23.1	15.1	38.2	0.96	0.00	0.93	1794	1652	636.3	0.39	356.1	218.4	12.0	98.9	24.6	14.2	242.7
21	378.9	4.0	382.9	378.9	0.0	378.9	0.0	4.0	4.0	1.00	0.00	0.99	1728	1649	618.1	0.37	335.4	60.4	18.8	220.4	24.0	4.7	245.6
22	481.6	4.4	486.0	481.6	0.0	481.6	0.0	4.4	4.4	1.00	0.00	0.99	1686	1568	485.8	0.31	198.3	157.8	22.8	-18.6	22.3	8.0	211.7
23	331.0	3.8	334.8	331.0+	0.0	331.0+	0.0	3.8	3.8	1.00	0.00	0.99	1713+	1578+	543.4	0.34	264.2	11.0	25.0+	187.4	21.9	0.5	253.2+
24	271.1	7.5	278.6	271.1	0.0	271.1	0.0	7.5	7.5	1.00	0.00	0.97	642	234	58.8	0.25	21.0	201.5	22.9	-235.2	4.1	10.6	178.6
25	382.2	7.6	389.8	256.5	0.0	256.5	125.7	7.6	133.3	0.67	0.00	0.66	45	0	0.0	----	0.0	240.7	11.8	-268.3	0.2	36.2	173.8
26	375.3	9.4	384.7	340.5	0.0	340.5	34.8	9.4	44.2	0.91	0.00	0.89	921	824	343.9	0.42	206.3	187.8	7.3	-3.9	18.0	24.3	165.8
27	231.3	9.3	240.6	21.8	0.0	21.8	209.5	9.3	218.8	0.09	0.00	0.09	178+	26	12.7	0.48	4.8	12.1+	3.0+	-12.1+	1.9	19.8	197.0+
28	408.1	8.1	416.2	100.5+	0.0	100.5	307.6	8.1	315.7	0.25	0.00	0.24	473+	237	95.4	0.40	41.0	42.9+	3.0+	-8.1+	4.2	24.4+	167.5+
29																							
30																							
31																							
Total	11080.3	258.8	11339.1	2574.8	0.0	2574.8	3505.5	258.8	3764.3	-----	-----	-----	23839	19753	7751.5	-----	3954.4	3414.5	230.5	-53.8	361.7	610.5	5737.7
Mean	395.8	9.2	405.0	270.5	0.0	270.5	125.2	9.2	134.4	0.68	0.00	0.67	851	705	276.8	0.39	141.2	122.0	8.2	-1.9	12.9	21.8	204.9

+Missing Scans

Table 7-21. System Performance for the Month of March 1978 (MJ/Day)

DAY	SPACE AND DOMESTIC HOT WATER HEATING												COLLECTOR PERFORMANCE				STORAGE				ELECTRIC ENERGY		
	ENERGY REQUIRED			SOLAR ENERGY USED			AUX. ENERGY USED			SOLAR FRACTION			TOTAL INCIDENT SOLAR	SOLAR WHILE COLLECTING	HEAT FROM COLLECTOR	AVE. EFF.	HEAT IN	HEAT OUT	HEAT LOSS	CHANGE IN STORAGE			
	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL									SOLAR	CIRCULATION	HOUSE
1	306.3	11.2	317.5	26.4	0.0	26.4	277.9	11.3	289.2	0.09	0.00	0.09	286	73	31.0	0.42	5.2	1.5	2.5	0.1	4.0	19.8	168.8
2	544.0	13.6	557.6	214.1	0.0	234.1	309.9	13.6	323.5	0.43	0.00	0.42	913	714	241.4	0.34	111.8	97.8	3.7	3.6	12.5	34.0	226.0
3	547.4	14.2	561.6	165.2	0.0	165.2	382.2	14.2	396.4	0.30	0.00	0.29	972	552	172.7	0.31	61.8	50.9	2.8	4.7	11.9	31.7	184.2
4	560.0	8.3	568.3	548.8	0.0	548.8	11.2	8.3	19.5	0.98	0.00	0.97	1773	1642	692.7	0.42	365.0	194.0	11.6	132.3	25.3	13.7	122.7
5	354.1	9.6	363.7	354.1	0.0	354.1	0.0	9.6	9.6	1.00	0.00	0.97	1087	943	392.2	0.42	210.7	145.8	15.0	23.1	18.5	11.3	105.1
6	295.2	9.6	304.8	295.2	0.0	295.2	0.0	9.6	9.6	1.00	0.00	0.97	808	674	258.6	0.36	132.0	146.7	14.1	-50.7	16.5	11.2	182.0
7	421.9	11.9	433.8	421.9	0.0	421.9	0.0	11.9	11.9	1.00	0.00	0.97	1799	1688	602.2	0.36	324.1	109.6	18.2	162.1	24.9	7.1	191.9
8	403.6	4.6	408.2	403.6	0.0	403.6	0.0	4.6	4.6	1.00	0.00	0.99	1635	1514	492.2	0.33	206.5	83.2	21.4	67.2	22.9	5.8	215.8
9	204.5	10.4	214.9	204.5*	0.0	204.5*	0.0	10.4	10.4	1.00	0.00	0.95	936*	570*	180.9*	0.32	94.5*	88.7	20.4*	-44.0*	9.1*	5.3	192.7*
10	330.3	4.0	334.3	330.3	0.0	330.3	0.0	4.0	4.0	1.00	0.00	0.99	610	475	159.7	0.34	82.7	227.2	17.5	-188.1	8.4	17.2	153.2
11	468.5	4.6	473.1	468.5	0.0	468.5	0.0	4.6	4.6	1.00	0.00	0.99	1821	1649	594.9	0.36	335.8	173.4	18.2	108.2	23.6	9.3	91.3
12	364.3	8.3	372.6	364.3	0.0	364.3	0.0	8.3	8.3	1.00	0.00	0.98	851	682	275.8	0.38	125.0	205.3	16.4	-122.9	14.5	13.6	73.9
13	415.5	7.8	423.3	415.5	0.0	415.5	0.0	7.8	7.8	1.00	0.00	0.98	1466	1325	466.7	0.35	244.0	163.1	16.5	34.7	22.4	11.2	144.1
14	538.0	3.3	541.3	538.0	0.0	538.0	0.0	3.3	3.3	1.00	0.00	0.99	1672	1521	512.0	0.34	255.8	250.2	17.5	-43.5	23.2	12.5	154.1
15	515.2	6.8	522.0	515.2	0.0	515.2	0.0	6.8	6.8	1.00	0.00	0.99	1393	1173	419.2	0.36	221.5	289.0	15.7	111.7	17.9	19.2	163.5
16	414.9	8.9	423.8	414.9	0.0	414.9	0.0	8.9	8.9	1.00	0.00	0.98	1292	1130	411.7	0.36	193.7	175.5	11.7	-14.9	25.6	16.1	148.9
17	343.1	5.9	349.0	343.1	0.0	343.1	0.0	5.9	5.9	1.00	0.00	0.98	1809*	1729*	669.5	0.39	407.7	45.3*	18.9	307.5	23.5	11.2	193.5
18	292.5	3.2	295.7	292.5	0.0	292.5	0.0	3.2	3.2	1.00	0.00	0.99	1198*	1146*	328.6*	0.29*	112.1	35.8	21.5	14.6	18.0	1.6	87.4
19	257.8	4.3	262.1	257.8	0.0	257.8	0.0	4.3	4.3	1.00	0.00	0.98	1220	1065	346.4	0.33	157.8	31.2	24.5	64.1	15.4	0.9	66.6
20	340.2	9.6	349.3	340.2	0.0	340.2	0.0	9.6	9.6	1.00	0.00	0.97	1751	1539	446.6	0.29	157.4	10.6	26.7	79.7	20.0	0.9	114.7
21	336.3	6.0	342.3	336.3	0.0	336.3	0.0	6.0	6.0	1.00	0.00	0.98	1780	1536	459.1	0.30	166.9	0.0	29.5	93.3	19.8	0.0	150.1
22	294.3	6.2	300.5	294.3	0.0	294.3	0.0	6.2	6.2	1.00	0.00	0.98	1012	559	160.2	0.29	25.3	121.3	27.7	-161.8	9.0	5.7	161.7
23	352.7	7.8	360.5	352.7	0.0	352.7	0.0	7.8	7.8	1.00	0.00	0.98	132	0	0.0	----	0.0	325.2	20.1	-372.8	0.2	18.1	153.8
24	261.3	4.4	265.7	261.3	0.0	261.3	0.0	4.4	4.4	1.00	0.00	0.98	571	440	196.4	0.45	113.5	161.9	10.3	-75.2	9.9	25.6	172.1
25	427.3	3.4	430.7	427.3	0.0	427.3	0.0	3.4	3.4	1.00	0.00	0.99	1737	1459	611.7	0.42	347.5	135.1	12.6	171.8	24.9	9.8	86.5
26	353.6	8.5	362.1	353.6	0.0	353.6	0.0	8.5	8.5	1.00	0.00	0.98	1561	1421	514.6	0.36	266.8	70.9	19.8	141.4	23.3	3.9	102.3
27	331.5	5.0	336.5	331.5	0.0	331.5	0.0	5.0	5.0	1.00	0.00	0.99	1625	1492	481.7	0.32	208.1	20.2	24.1	126.1	22.4	0.9	149.0
28	365.6	0.0	365.6	365.6	0.0	365.6	0.0	0.0	0.0	1.00	0.00	0.99	1781	1618	532.7	0.33	208.9	0.0	28.7	136.4	20.8	0.0	167.6
29	344.6	7.7	352.3	344.6	0.0	344.6	0.0	7.7	7.7	1.00	0.00	0.98	1776	1499	416.7	0.28	116.3	0.0	31.3	40.8	18.7	0.0	150.0
30	283.0	4.1	287.1	283.0	0.0	283.0	0.0	4.1	4.1	1.00	0.00	0.99	1503	1217	347.8	0.29	109.9	0.0	32.3	32.5	16.3	0.0	135.6
31	195.3	4.0	199.3	195.3	0.0	195.3	0.0	4.0	4.0	1.00	0.00	0.98	1236	817	218.8	0.27	65.6	0.0	31.5	-8.0	11.8	0.0	103.0
Total	11462.8	217.3	11680.1	10481.6	0.0	10481.6	981.2	217.3	1198.5	-----	-----	-----	39909	33872	11614.9	-----	5432.9	3359.4	582.7	550.6	535.2	317.6	4512.2
Mean	369.8	7.0	376.8	338.1	0.0	338.1	31.6	7.0	38.6	0.91	0.00	0.90	1287	1093	374.7	0.34	175.2	108.4	18.6	17.8	17.3	10.3	145.6

* Calculated Values

** Missing Scans

Table 7-22. System Performance for the Month of April 1978 (MJ/Day)

DAY	SPACE AND DOMESTIC HOT WATER HEATING												COLLECTOR PERFORMANCE				STORAGE				ELECTRIC ENERGY		
	ENERGY REQUIRED			SOLAR ENERGY USED			AUX. ENERGY USED			SOLAR FRACTION			TOTAL INCIDENT SOLAR	SOLAR WHILE COLLECTING	HEAT FROM COLLECTOR	AVE. EFF.	HEAT IN	HEAT OUT	HEAT LOSS	CHANGE IN STORAGE	SOLAR	CIRCULATION	HOUSE
1	317.1	3.9	321.0	317.1	0.0	317.1	0.0	3.9	3.9	1.00	0.00	0.99	64	0	0.0	----	0.0	282.5	25.0	-342.1	0.2	12.2	60.7
2	284.0	4.5	288.5	284.0	0.0	284.0	0.0	4.5	4.5	1.00	0.00	0.98	1154	992	346.4	0.35	181.0	84.1	21.5	40.9	19.0	4.8	70.6
3	287.3	9.1	296.4	287.3	0.0	287.3	0.0	9.1	9.1	1.00	0.00	0.97	1332	1154	358.0	0.31	170.1	63.1	22.9	47.8	16.6	3.0	105.2
4	326.5	4.5	331.0	326.5	0.0	326.5	0.0	4.5	4.5	1.00	0.00	0.99	1612	1408	476.4	0.34	199.6	11.1	24.7	125.2	19.4	1.2	130.8
5	384.8	4.4	389.2	384.8	0.0	384.8	0.0	4.4	4.4	1.00	0.00	0.99	1600	1392	457.2*	0.33	189.0*	76.6	25.1	47.3	19.0	3.2	110.0
6	291.6	3.9	295.5	291.6	0.0	291.6	0.0	3.9	3.9	1.00	0.00	0.99	1581	1322	412.7	0.31	172.1	7.8	28.6	92.5	17.5	0.5	112.8
7	308.9	4.5	313.4	308.9	0.0	308.9	0.0	4.5	4.5	1.00	0.00	0.99	1670	1423	422.1	0.30	156.2	0.0	29.6	83.6	19.7	0.0	122.4
8	301.2	0.0	301.2	301.2	0.0	301.2	0.0	0.0	0.0	1.00	0.00	1.00	1522	1190	345.1	0.29	87.1	0.0	31.4	12.5	17.2	0.0	67.1
9	304.9	9.4	314.3	304.9	0.0	304.9	0.0	9.4	9.4	1.00	0.00	0.97	99	0	0.0	----	0.0	269.7	25.0	-329.9	0.2	12.0	77.0
10	286.9	11.6	298.5	286.9	0.0	286.9	0.0	11.6	11.6	1.00	0.00	0.96	643	394	146.4	0.37	68.8	185.1	16.5	-157.0	10.4	15.1	153.5
11	273.0	8.0	281.0	273.0	0.0	273.0	0.0	8.0	8.0	1.00	0.00	0.97	1646	1511	522.5	0.35	309.1	24.7	19.0	230.5	24.0	1.7	145.4
12	339.4	9.2	348.6	339.4	0.0	339.4	0.0	9.2	9.2	1.00	0.00	0.97	1850	1642	491.2	0.30	188.8	0.0	23.7	128.1	22.1	0.0	223.3
13	143.1	11.4	154.5	143.1	0.0	143.1	0.0	11.4	11.4	1.00	0.00	0.93	913	481	138.7	0.29	34.8	6.5	24.3	-28.7	7.5	1.0	237.6
14	103.1	3.5	106.6	103.1	0.0	103.1	0.0	3.5	3.5	1.00	0.00	0.97	710	218	63.2	0.29	23.2	32.9	22.2	-62.1	4.0	2.1	181.4
15	212.3	4.5	216.8	212.3	0.0	212.3	0.0	4.5	4.5	1.00	0.00	0.98	325	115	28.6	0.25	19.5*	168.7*	15.2*	-198.9*	6.5	7.0	167.0*
16	272.4	10.0	282.4	272.4	0.0	272.4	0.0	10.0	10.0	1.00	0.00	0.96	443	286	116.2	0.41	63.7	205.3	13.5	-169.7	9.9	15.3	179.3
17	528.6	12.5	541.1	528.6	0.0	528.6	0.0	12.5	12.5	1.00	0.00	0.98	1785	1643	562.3	0.34	322.7	269.4*	13.5	20.2	24.4	14.0*	189.1*
18	341.8	8.3	350.1	341.8*	0.0	341.8*	0.0	8.3	8.3	1.00	0.00	0.98	1585*	1403*	478.7*	0.34	268.5*	102.5	15.8*	121.1	19.6	7.2	161.1
19	425.5	9.8	435.3	425.5	0.0	425.5	0.0	9.8	9.8	1.00	0.00	0.98	1696	1589	548.3	0.35	267.2	107.4	21.9	100.9	22.0	5.8	158.3
20	390.5	13.9	404.4	390.5	0.0	390.5	0.0	13.9	13.9	1.00	0.00	0.97	1606	1460	481.4	0.33	200.0	70.7	24.3	66.6	20.6	4.1	151.0
21	375.2	3.9	379.1	375.2	0.0	375.2	0.0	3.9	3.9	1.00	0.00	0.99	1480	1236	402.3	0.33	178.2	109.9	26.5	0.6	17.1	4.7	123.4
22	425.0	8.8	433.8	425.0	0.0	425.0	0.0	8.8	8.8	1.00	0.00	0.98	1679	1384	374.3	0.27	151.5	164.6	23.5	-74.2	18.6	8.2	84.9
23	397.4	6.1	403.5	397.4	0.0	397.4	0.0	6.1	6.1	1.00	0.00	0.98	1773	1611	437.7	0.27	198.8	120.9	22.5	17.4	22.2	7.1	91.0
24	302.1	6.7	308.8	302.1	0.0	302.1	0.0	6.7	6.7	1.00	0.00	0.98	1648	1515	393.9*	0.26	178.9	49.5*	23.5	68.8	20.0*	6.0*	100.0*
25	185.6*	12.4	198.0	185.6*	0.0	185.6*	0.0	12.4	12.4	1.00	0.00	0.94	1130*	799	265.7	0.33	104.5	0.0	17.1*	63.0*	12.9	0.0	142.8*
26	181.0	11.1	192.1	181.0	0.0	181.0	0.0	11.1	11.1	1.00	0.00	0.94	1462	1201	254.0	0.21	128.0	2.0	28.0	45.0	18.6*	0.0	100.0*
27	126.3	7.2	133.5	126.3	0.0	126.3	0.0	7.2	7.2	1.00	0.00	0.95	1090	754	203.6*	0.27	34.5	7.3	26.8	0.4	16.0*	1.5	120.0*
28	109.2	3.6	112.8	109.2	0.0	109.2	0.0	3.6	3.6	1.00	0.00	0.97	300	299	75.6	0.27	35.3	30.7	24.9	-55.5	4.8	1.5	99.8
29	216.3	4.4	220.7	216.3	0.0	216.3	0.0	4.4	4.4	1.00	0.00	0.98	1010	759	232.5	0.31	101.1	50.0	24.9	-5.7	13.2	4.9	125.0
30	181.1	7.1	188.2	181.1	0.0	181.1	0.0	7.1	7.1	1.00	0.00	0.96	698*	462	131.4	0.26	46.8	65.7	21.6	-71.5	10.1	3.4	97.9
31																							
Total	8622.5	218.2	8840.7	8622.5	0.0	8622.5	0.0	218.2	218.2	-----	-----	-----	36806	29633	9169.4	-----	4133.7	2566.7	623.1	-136.2	455.3	147.8	3896.4
Mean	278.1	7.0	294.7	278.1	0.0	278.1	0.0	7.0	7.0	1.00	0.00	0.92	1227	988	305.7	0.31	137.8	86.6	20.8	-4.6	15.2	4.9	130.0

* Calculated Values

- Missing Scans

Table 7-23. System Performance for the Month of May 1978 (MJ/Day)

DAY	SPACE AND DOMESTIC HOT WATER HEATING												COLLECTOR PERFORMANCE				STORAGE				ELECTRIC ENERGY		
	ENERGY REQUIRED			SOLAR ENERGY USED			AUX. ENERGY USED			SOLAR FRACTION			TOTAL INCIDENT SOLAR	SOLAR WHILE COLLECTING	HEAT FROM COLLECTOR	AVE. EFF.	HEAT IN	HEAT OUT	HEAT LOSS	CHANGE IN STORAGE	SOLAR	CIRCULATION	HOUSE
	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL	SPACE	DHW	TOTAL											
1	246.3	12.5	258.8	246.3	0.0	246.3	0.0	12.5	12.5	1.00	0.00	0.95	110	0	0.0	----	0.0	223.7	17.1	-263.4	0.2	21.0	179.5
2	184.9	11.5	196.4	82.0	0.0	82.0	102.9	11.5	114.4	0.44	0.00	0.42	320	62	24.3	0.39	9.1	60.3	5.8	-63.5	3.4	30.1	202.6
3	227.6	12.1	239.7	227.6	0.0	227.6	0.0	12.1	12.1	1.00	0.00	0.95	847	668	272.3	0.41	157.2	101.0	6.3	38.4	19.4	16.3	175.5
4	282.0	8.1	290.1	282.0	0.0	282.0	0.0	8.1	8.1	1.00	0.00	0.97	942	716	275.2	0.38	164.4	155.9	8.6	-15.4	18.0	22.7	152.6
5	34.7	4.5	39.2	20.9+	0.0	20.9+	13.8+	4.5+	18.3	0.60	0.00	0.53	73	0	0.0	----	0.0	19.5+	1.7+	-22.6+	0.2	12.2+	120.0*
6	No Data																						
7	287.5	9.3	296.8	287.5+	0.0	287.5+	0.0	9.3	9.3	1.00	0.00	0.97	1213+	1204+	447.6+	0.37	230.1+	51.3	10.7+	149.4+	21.5+	6.6	74.6+
8	386.6	9.4	396.0	386.6	0.0	386.6	0.0	9.4	9.4	1.00	0.00	0.98	1799	1656	571.0	0.34	254.6	37.2	18.8	165.6	24.7	2.5	185.2
9	411.2	10.9	422.1	411.2	0.0	411.2	0.0	10.9	10.9	1.00	0.00	0.97	1930	1758	591.6	0.34	238.4	18.5	25.0	155.4	23.0	0.9	162.5
10	311.8	7.7	319.5	311.8	0.0	311.8	0.0	7.7	7.7	1.00	0.00	0.98	1532	1245	381.5	0.31	120.2	10.5	27.9	41.8	17.7	0.4	118.8
11	155.5	6.6	162.1	155.5	0.0	155.5	0.0	6.6	6.6	1.00	0.00	0.96	741	159	47.3	0.30	13.4	88.5	24.9	-133.1	4.3	5.0	108.0
12	300.7	7.7	308.4	300.7	0.0	300.7	0.0	7.7	7.7	1.00	0.00	0.98	1736	1475	407.9	0.28	174.5	28.1	25.1	82.1	19.7	2.0	101.2
13	283.9	3.8	287.7	283.9	0.0	283.9	0.0	3.8	3.8	1.00	0.00	0.99	1616	1403	415.4	0.30	172.3	0.0	27.2	104.3	19.2	0.0	-48.6
14	306.1	6.9	313.0	306.1	0.0	306.1	0.0	6.9	6.9	1.00	0.00	0.98	1706	1470	416.5	0.28	151.8	0.0	29.8	80.6	20.5	0.0	49.9
15	End of Heating Season																						
16																							
17																							
18																							
19																							
20																							
21																							
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31																							
Total	3418.8	111.0	3529.0	3302.1	0.0	3302.1	116.7	111.0	227.7	----	----	----	14565	11316	3850.6	----	1636.0	794.5	228.9	319.6	191.5	119.7	1680.0
Mean	263.0	8.5	271.5	254.0	0.0	254.0	9.0	8.5	17.5	0.97	0.0	0.94	1120	909	296.2	0.33	123.7	61.1	17.6	24.6	14.8	9.2	129.2

* Calculated Values

+ Missing Scans

Figure 7-10. Daily Solar and Auxiliary Energies Supplied, October 1977.

Figure 7-11. Daily Solar and Auxiliary Energies Supplied, November 1977.

Figure 7-12. Daily Solar and Auxiliary Energies Supplied, December 1977.

Figure 7-13. Daily Solar and Auxiliary Energies Supplied, January 1978.

Figure 7-14. Daily Solar and Auxiliary Energies Supplied, February 1978.

Figure 7-15. Daily Solar and Auxiliary Energies Supplied, March 1978.

Figure 7-16. Daily Solar and Auxiliary Energies Supplied, April 1978.

Figure 7-17. Daily Solar and Auxiliary Energies Supplied, May 1978.

Monthly mean daily collection of solar heat and the percent of total incident solar energy collected is shown on Figure 7-18. Over the season there was 217.47 GJ of total incident solar energy measured, and 67.45 GJ was delivered from the collectors. Of the total collected, 63.63 GJ was supplied to space and domestic water heating and 3.82 GJ was lost from the system. Of the total solar insolation, 181.22 GJ was incident on the collectors while the blower was operating, resulting in a seasonal collection efficiency of 37 percent, which is an improvement from 30 percent for the 1976-77 season. The increased collection efficiency is a consequence of increased air flow rate through the collector, from $23 \text{ m}^3/\text{min}$ to $29 \text{ m}^3/\text{min}$.

The monthly average daily energy delivered to the load is shown in Figure 7-19. The total energy required for heating water and space from 8 October 1977 through 14 May 1978 (exclusive of 6 days in November, and 1 day in May) was 82.84 GJ, of which 63.63 GJ or 77 percent was supplied from solar energy. Of the total energy required, 8.18 GJ or 9.9 percent was for heating water. This small fraction resulted because there was no solar heating of water after January 25 when the heat exchanger froze. Dumping of 260 liters of hot water per day was terminated on 25 January for the balance of the heating season. Until 25 January 4.95 GJ of solar heat was contributed to water heating within a total of 7.25 GJ of energy used for water heating.

7.4 MONTHLY AND ANNUAL SUMMARIES

A summary of the thermal performance of the solar heating and nocturnal cooling system is provided in Table 7-24 in terms of monthly

Figure 7-18. Collection of Solar Heat During the 1977-78 Heating Season.

Figure 7-19. Solar and Auxiliary Contributions to Total Space and DHW Load, Solar House II, 1977-78 Heating Season.

Table 7-24. System Thermal Performance Summary (MJ/Day)

Month	No. of Days of Data	Total Incident Solar ST	Solar While Collecting SOP	Solar Heat Collecting QCS	Solar to Space Heat QOH+QCL+QSO+QHL	Auxiliary to Space Heat QAH	Solar to DHW QWA	Auxiliary to DHW QWA	Space Cooling QCR+QEL+QDC	Fraction Solar for Space Heating	Fraction Solar for DHW	Electrical Energy to Collect EOP	Electric for Circulation EDC	Total Electricity
June	15	1122	612	122.8	0.0	0.0	53.9	1.8	99.4	0.00	0.97	5.8+	34.7+	92.6+
July	31	1149	424	96.8	0.0	0.0	47.9	11.8	98.9	0.00	0.80	8.4	48.9	152.8
August	31	1066	343	79.6	0.0	0.0	37.1	8.4	76.0	0.00	0.82++	5.5	28.0	128.2
Sept.	30	1295	435	105.6	0.0	0.0	47.6	5.9	95.5	0.00	0.89	4.0	51.4	174.3
Oct.	24	1259	1035	374.0	267.0	2.7	60.7	5.7	0.0	0.99	0.91	17.7	3.0	147.2
Nov.	24	820	671	283.3	243.2	93.6	46.3	22.3	0.0	0.72	0.68	16.4	14.6	217.4
Dec.	31	878	780	325.2	274.2	119.1	38.8	30.2	0.0	0.70	0.56	17.0	22.1	153.9.
Jan.	31	814	679	297.1	256.4	173.2	38.2	26.3	0.0	0.60	0.59**	13.5	24.9	181.5
Feb.	28	851	705	276.8	270.5	125.2	0.0	9.2	0.0	0.68	0.00	12.9	21.8	204.9
Mar.	31	1287	1093	374.7	338.1	31.6	0.0	7.0	0.0	0.91	0.00	17.3	10.3	145.6
April	30	1227	988	305.7	287.4	0.0	0.0	7.3	0.0	1.00	0.00	15.2	4.9	130.0
May	13	1120	909	296.2	254.0	9.0	0.0	8.5	0.0	0.97	0.00	14.8	9.2	129.2
Annual*	319	1071	712	244.3	276.8	75.4	47.7	14.8	93.7+	0.79	0.76	11.6	23.4	156.5

* Averages are for appropriate days in each column

** Averaged with 25 days in January

+ Averaged with 7 days of cooling

++ Averaged with 26 days in August

÷ Averaged with 11 days in June

• Averaged with 24 days in December

and annual (1977-78) average daily energy quantities. Annual values are averaged over appropriate days of cooling or heating. Also listed in the table is the electrical energy utilized for lights and appliances in the building. Electricity used for circulating air through the pebble bed to either heat or cool the building is included in the "circulation" (EDC) column. The total electricity utilized excludes electricity for instruments and data logging equipment, which amounts to about 35 MJ/day.

7.5 COMPARISONS WITH PREVIOUS SEASONS

Comparisons of system performance during heating seasons are shown by the bar graphs in Figures 7-20 through 7-22. The monthly average daily heat collection is shown in Figure 7-20, collection efficiencies are shown in Figure 7-21 and solar fractions of total load are shown in Figure 7-22. Collection efficiency was improved during the 1977-78 season over the 1976-77 season, primarily as a consequence of increasing the air flow rate through the collectors. The electrical energy consumption to collector solar energy was reduced from an average of 23.4 MJ/day to 15.6 MJ/day, and combined with increased collection efficiency, the overall reduction in electrical energy consumption was significant. During the 1976-77 season, 4.42 GJ of electrical energy was required to collect 50.00 GJ of solar heat or operating energy required was 8.8 percent of the total solar collected. During the 1977-78 heating season, 3.31 GJ of electrical energy was required to collect 67.45 GJ of solar heat and the electrical energy consumption was 4.9 percent of total solar collected. Motor size was changed in 1977 from a smaller (over-loaded) motor (560 W) to a larger (adequate) motor (750 W) operating at higher efficiency.

Figure 7-20. Average Daily Solar Radiation and Heat Collected, Solar House II, 1 February 1976 - 14 May 1978.

Figure 7-21. Monthly Average Daily Collection Efficiency Based on Solar Radiation While Operating, Solar House II.

Figure 7-22. Solar Fraction of Total Load, Solar House II.

The seasonal collection efficiencies were 26 percent (based on total measured solar radiation) in 1975-76, 26 percent in 1976-77 and 31 percent in 1977-78. The corresponding efficiencies based on total solar insolation while the collector was operating, was 34 percent in 1975-76, 30 percent in 1976-77, and 37 percent in 1977-78. A reduction in collection efficiency is seen from 1975-76 to 1976-77 because the controller logic was changed to collect heat earlier in the morning and later in the afternoon. The solar fraction of the total load was 0.71 in the 1975-76 partial season, 0.77 in 1976-77 and 0.77 in 1977-78. The design target for the system was to achieve a seasonal solar fraction of 0.75.

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8 COLLECTORS

8.1 STEADY-STATE COLLECTOR EFFICIENCIES

A nominal flow rate for air-heating solar collectors in heating and cooling systems is about $10 \text{ l}/(\text{sec} \cdot \text{m}^2)$, or for the array size on Solar House II, the total air flow rate should be about $40.3 \text{ m}^3/\text{min}$. During the 1976-77 heating season the air flow rate was about $32 \text{ m}^3/\text{min}$. The blower speed was changed for the 1977-78 heating season so that the air flow rate through the blower was $40 \text{ m}^3/\text{min}$ in the heat collection mode. If there were no leaks in the circuit, this would also be the flow rate through the collectors. However, with the air leaks, the air flow rate through the absorber ducts in the collectors was $29 \text{ m}^3/\text{min}$, which is an increase of $6 \text{ m}^3/\text{min}$ over the previous season.

The steady-state efficiency lines for the air-heating collectors are shown in Figure 8-1. The dashed line is for the 1976-77 season, and was determined from mid-day efficiencies calculated on bright sunny days from October through May. Also shown on the figure is a solid line for the 1977-78 season calculated from the increase in air flow rates. The circled points are data obtained during the 1977-78 season. Both efficiency lines include the effects of air leakage into the collector circulation loop at the tcp manifold (outlet) of the collector array. The equations of the two lines are:

$$1. \quad \eta = 0.43 - 4.29 \left(\frac{T_i - T_a}{I_T} \right) \quad (1976-77) \quad (8-1)$$

$$2. \quad \eta = 0.52 - 5.36 \left(\frac{T_i - T_a}{I_T} \right) \quad (1977-78) \quad (8-2)$$

Figure 8-1. Steady-State Collection Efficiencies.

In the previous year's performance report [Ref. 1] it was stated that $F_{R\tau\alpha} = 0.57$, and $F_{R}U_L = 6.73 \text{ W/(m}^2\cdot\text{°C)}$. Equation (8-1) is now believed to be a better representation of steady-state collector efficiency for the 1976-77 heating season.

8.2 HEAT CAPACITANCE EFFECTS

The "instantaneous" efficiencies of the collector array (for successive 10-minute intervals) from start-up in the forenoon to shut-down in the afternoon are shown in Figures 8-2 through 8-5 for four selected days during the heating season. Also shown are the integrated (10-minute) solar flux, and instantaneous ambient and inlet air temperatures. It is distinctly noticeable in the figures that efficiencies in the forenoon are lower than efficiencies in the afternoon. Within each 10-minute interval, as the intensity of solar radiation increases or decreases, the efficiencies are below or above the "steady-state" efficiency line because of the heat capacity of the collector array. The effect of heat capacitance is exaggerated by the apparent heat gain from air infiltration, QFI. When the quantity QFI is subtracted from the total heat output from the collector and only the heat gain from the collectors, QC, is used to determine collection efficiency, η' , the variations of η' through the day are shown in Figures 8-6 through 8-9, which correspond to Figures 8-2 through 8-5.

The differences in forenoon and afternoon efficiencies from mid-day efficiencies are not as large as seen in Figure 8-2 through 8-5, however, the heat capacity effect in the collectors is still noticeable.

For short time increments, the collector efficiency can be corrected for by an additive term to the standard equation:

$$\eta = \eta_0 - C_1 \left(\frac{\Delta T}{I_T} \right) \pm \frac{\Delta Q}{I_T} \quad , \quad (8-3)$$

where

$$\eta_0 = F_R \overline{\tau \alpha}$$

$$C_1 = F_R U_L$$

$$\Delta Q = Mc\Delta T_1$$

M is the mass of the collector array subjected to heating

c is the specific heat of the mass

ΔT_1 is the temperature rise of the mass in time interval Δt .

In short-time simulations of solar systems, it is clearly important to include the heat capacity effects. Over long-time interval simulations, say hour-by-hour, the effect is not as important because the amount of heat stored or retrieved from the collectors is small compared to the total quantity of heat delivered from the collectors during one-hour time intervals.

Figure 8-2. Collection Efficiency, Including Leakage.

Figure 8-3. Collection Efficiency, Including Leakage.

Figure 8-4. Collection Efficiency, Including Leakage.

Figure 8-5. Collection Efficiency, Including Leakage.

Figure 8-6. Collection Efficiency, Excluding Leakage.

Figure 8-7. Collection Efficiency, Excluding Leakage.

Figure 8-8. Collection Efficiency, Excluding Leakage.

Figure 8-9. Collection Efficiency, Excluding Leakage.

9 COMPARISONS OF CALCULATED AND MEASURED VALUES

Predictions of monthly and seasonal fractions of the total load using the f-chart method, developed by the University of Wisconsin, are compared to measured solar fractions in Tables 9-1 through 9-3 for two and one-half seasons, from February 1976 to mid-May 1978. In Table 9-1, computed solar fractions for February through mid-May 1976 are generally greater than the solar fractions determined from experimental data. As was indicated in an earlier report [Ref. 1], the system was not operating in an optimal manner in 1975-76, largely because of control deficiencies.

In Tables 9-2 and 9-3, it will be noted that the calculated solar fractions consistently underpredict measured values. System performance was improved in 1976-77 by a significant margin over the previous year, and in 1977-78 there was even greater improvement in performance based upon measured solar radiation and building loads.

Comparisons of predicted and measured monthly and seasonal contributions of solar heat to the building load indicate that month-by-month predictions are lower than measured performance by as much as 30 percent. The monthly variations are systematic in that the f-chart calculations of solar heat contributions are low during the winter months. From March through May the calculated and measured values compare reasonably well. Bar graphs which show monthly comparisons of predicted and measured solar fractions for the 1976-77 and 1977-78 heating seasons are shown on Figures 9-1 and 9-2. On a seasonal basis the f-chart method for air systems underpredicts measured performance in Solar House II by 12 to 14 percent.

Table 9-1. Comparisons of Predicted and Measured Solar Fractions of Total Monthly Loads for the Partial 1975-76 Heating Season.

1975-76 Heating Season	Total Mo. Solar Radiation on 45° plane(S) MJ/(mo•m ²)	Total Heating Load (L) MJ/mo	f-Chart Coordinates		Calculated Monthly Solar Fraction(f')	Measured Monthly Solar Fraction (f)	Difference in Percent
			X**	Y††			
February	541.7	16202	4.22	.96	0.60	0.64	-6.3
March	685.2	17938	3.93	1.10	0.71	0.70	+1.4
April	530.0	8834	7.32	1.73	0.90	0.79	+13.9
May*	343.4	4228	8.87	2.34	1.00	0.86	+16.3
Season†	2100.3	47202			0.73	0.71	+2.8

* 18 days or 432 hours/month

† For months tabulated

** $X = A_c F_{R\overline{\alpha}} U_L K_1 K_2 \Delta T t / L$

†† $Y = A_c F_{R\overline{\alpha}} S / L$

$$A_c = 67.1 \text{ m}^2$$

$$F_{R\overline{\alpha}} = 0.43$$

$$F_{R\overline{\alpha}} U_L = 4.29 \text{ W/(m}^2 \cdot ^\circ\text{C)}$$

$$K_1 = 0.86 \text{ (Capacitance rate correction)}$$

$$K_2 = 1.12 \text{ (Storage mass correction)}$$

$$t = \text{hours/month}$$

Table 9-2. Comparisons of Predicted and Measured Solar Fractions of Total, Monthly and Season Loads for the 1976-77 Heating Season.

1976-77 Heating Season	Total Mo. Solar Radiation on 45° plane(S) MJ/(mo·m ²)	Total Heating Load (L) MJ/mo	f-Chart Coordinates		Calculated Monthly Solar Fraction(f')	Measured Monthly Solar Fraction (f)	Difference in Percent
			X**	Y++			
November*	364.5	8201	7.648	1.282	.66	.70	-5.7
December*	409.7	10247	6.184	1.154	.64	.73	-12.3
January	463.5	13638	5.771	0.981	.55	.65	-15.4
February	421.1	9955	6.871	1.220	.66	.82	-19.5
March	520.9	11028	6.396	1.363	.76	.83	-8.4
April+	417.1	6546	9.231	1.838	.87	.90	-3.3
May+	291.0	3054	10.916	2.749	.97	.98	-1.0
Season	2887.7	62669			.69	.77	-10.4

* 27 days or 648 hours/month

+ 29 days or 696 hours/month

++ 16 days or 384 hours/month

** $X = A_c F_{R,L} U_L K_1 K_2 \Delta T t / L$

++ $Y = A_c F_{R,L} \overline{\tau \alpha} S / L$

$$A_c = 67.1 \text{ m}^2$$

$$F_{R,L} \overline{\tau \alpha} = 0.43$$

$$F_{R,L} U_L = 4.29 \text{ W/(m}^2 \cdot ^\circ\text{C)}$$

$$K_1 = 0.86 \text{ (Capacitance rate correction)}$$

$$K_2 = 1.12 \text{ (Storage mass correction)}$$

$$t = \text{hours/month}$$

Table 9-3. Comparisons of Predicted and Measured Solar Fractions of Total, Monthly and Season Loads for the 1977-78 Heating Season.

1977-78 Heating Season	Total Mo. Solar Radiation on 45° plane(S) MJ/(mo·m ²)	Total Heating Load (L) MJ/mo	f-Chart Coordinates		Calculated Monthly Solar Fraction(f')	Measured Monthly Solar Fraction (f)	Difference in Percent
			X**	Y++			
October*	450.3	8066	7.928	1.948	.95	.97	-2.1
November*	293.4	9732	7.325	1.052	.53	.71	-25.4
December	405.4	14332	6.492	0.987	.52	.68	-23.5
January	376.3	15318	6.570	0.857	.42	.60	-30.0
February	355.3	11339	7.714	1.093	.54	.67	-19.4
March	594.8	11680	7.722	1.777	.90	.90	0.0
April	548.5	8841	9.353	2.165	.97	.98	-1.0
May+	217.1	3529	9.816	2.147	.95	.94	+1.1
Season	3241.1	82837			.67	.77	-13.0

* 24 days or t = 576 hours

+ 13 days or t = 312 hours

** $X = A_c F_{RUL} K_1 K_2 \Delta T t / L$

++ $Y = A_c F_{R\overline{\tau\alpha}} S / L$

$$A_c = 67.1 \text{ m}^2$$

$$F_{R\overline{\tau\alpha}} = 0.52$$

$$F_{RUL} = 5.36 \text{ W/(m}^2 \cdot ^\circ\text{C)}$$

$$K_1 = 0.88 \text{ (Capacitance rate correction)}$$

$$K_2 = 1.12 \text{ (Storage mass correction)}$$

$$t = \text{hours/month}$$

Figure 9-1. Comparisons of f-Chart Predicted and Measured Solar Fractions for CSU Solar House II, 1976-77.

Figure 9-2. Comparisons of f-Chart Predicted and Measured Solar Fractions for CSU Solar House II, 1977-78.

10 DISCUSSION AND RECOMMENDATIONS

The solar air-heating system in Solar House II is a relatively simple operating system. The principal difficulty experienced during the 1977-78 season was a faulty damper in the collector supply duct which did not close tight during one cold night and caused cold air to flow past the air-to-water heat exchanger. The water in the pipe of the heat exchanger froze and ruptured the pipe. It is recommended that the heat exchanger be located between the blower and storage so that there will be less possibility of freezing.

During the summer of 1977, the site-built collectors were allowed to stagnate for 30 days from May 17 through June 15. In two sections, the internal cover glass on the collectors (0.6 m x 1.2 m size) cracked during the test period. It is not clear whether the breakage occurred as a consequence of thermal stress alone, or in combination with settlement of the building. Later during the summer, one additional internal glass pane cracked. No additional breakage occurred since the summer of 1977. The difficulty with site-built collectors is to assemble the pieces with enough tolerance to allow for building movement.

There was more air leakage into the collector loop in the 1977-78 year compared to the previous year as a consequence of increased flow rate through the blower, which caused a greater pressure difference between the atmosphere and the top collector manifold. As the results indicate, however, the added leakage was not noticeably detrimental to system performance, and overall, there was a significant increase in collector efficiency.

As a consequence of operating experiences with the air-heating solar system it is recommended that:

1. Air-to-water heat exchangers in the air-heating solar systems be placed on the downstream side of the circulating blower so that the heat exchanger will not be subjected to air at freezing temperatures.
2. Collectors be installed carefully to minimize air leakage, whether the collectors are site-built or factory made.
3. Dampers be installed carefully to minimize leakage.
4. Air circulation rate through the collectors be about $10 \text{ l}/(\text{sec} \cdot \text{m}^2)$.

11 CONCLUSIONS

From an evaluation of the performance data of the CSU Solar House II air-heating and nocturnal cooling system, the following conclusions are made:

1. An air-heating solar system with flat-plate collectors with non-selective absorbers and pebble-bed storage can be designed to operate effectively with seasonal mean daily efficiencies of about 30 percent based on total solar radiation.
2. The total quantity of heat collected can be affected significantly, by as much as 10 percent, if proper attention is not given to sensor locations and temperature difference settings in the controller which start and stop heat collection.
3. Air systems should be designed with a small number of dampers to maximize system performance. Each damper is a source of leakage, which mixes cold air into a warm air stream thereby reducing the effectiveness of the circulating air to heat the building.
4. A nocturnal (evaporative) cooling system which utilizes the same blower air flow rate and rock bed volume as the solar heating system is too small for properly cooling many residential buildings. To be suitable for effective cooling, the nocturnal cooling system requires large air flow rate and rock volume (at least twice that in Solar House II).
5. The mean daily COP for solar heating of space with an air-heating solar system, i.e., solar heat supplied divided by electrical energy used for solar heat collection and

circulation of the air from the storage to the rooms, should be greater than 9 for well-designed air systems. The COP for solar heat collection and storage should be greater than 17.

6. The instantaneous efficiencies of air-heating collectors are less than the steady-state efficiency during periods of increasing solar insolation and greater than the steady-state efficiency during periods of decreasing solar insolation because of heat capacitance in the collector hardware.
7. On the basis of measured energy quantities in Solar House II, the f-chart prediction method for monthly contributions of solar heat from an air heating system tends to under-predict the measured performance, particularly during the cold months of December, January and February.

12 REFERENCES

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13 ACKNOWLEDGMENTS

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