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# THE PERFORMANCE OF EVACUATED TUBULAR SOLAR COLLECTORS IN A RESIDENTIAL HEATING AND COOLING SYSTEM

Technical Report

Final Report for the Period October 1, 1978—September 30, 1979


By
W. S. Duff
G. O. G. Löf


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Colorado State University
Solar Energy Applications Laboratory
Fort Collins, Colorado


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Solar Energy

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TECHNICAL REPORT

FINAL REPORT FOR THE PERIOD
1 OCTOBER 1978 TO 30 SEPTEMBER 1979

W.S. DUFF
G.O.G. LÖF

MARCH 1981

SOLAR ENERGY APPLICATIONS LABORATORY
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO 80523

PREPARED FOR THE
U.S. DEPARTMENT OF ENERGY
CONSERVATION AND SOLAR APPLICATIONS
UNDER CONTRACT EY-76-S-02-2577

TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# 1. EXECUTIVE SUMMARY

## 1.1 ABSTRACT

Operation of CSU Solar House I during the heating season of 1978-1979 and during the 1979 cooling season was based on the use of systems comprising an experimental evacuated tubular solar collector supplied by the Philips Research Laboratories, a non-freezing aqueous collection medium, heat exchange to an insulated conventional vertical cylindrical storage tank and to a built-up rectangular insulated storage tank supplied by the Bally Case and Cooler Company, heating of circulating air by solar heated water and by electric auxiliary in an off-peak heat storage unit supplied by the TPI Corporation, space cooling by lithium bromide absorption chiller supplied by Arkla Industries, and service water heating by solar exchange and electric auxiliary. Automatic system control and automatic data acquisition and computation are provided. This system is compared with others evaluated in CSU Solar Houses I, II and III, and with computer predictions based on mathematical models.

Of the 69,513 MJ total energy requirement for space heating and hot water during a record cold winter, solar provided 32,281 MJ equivalent to 48 percent. Thirty percent of the incident solar energy was collected and 29 percent was delivered and used for heating and hot water. Of 33,320 MJ required for cooling and hot water during the summer, 79 percent of 26,202 MJ were supplied by solar. Thirty-five percent of the incident solar energy was collected and 26 percent was used for hot water and cooling in the summer.

Although not as efficient as the Corning evacuated tube collector previously used, the Philips experimental collector provided solar heating and cooling with minimum operation problems. Improved performance, particularly for cooling, resulted from the use of a very well-insulated heat storage tank. Day time (on-peak) electric auxiliary heating was completely avoided by use of off-peak electric heat storage. A well-designed and operated solar heating and cooling system provided 56 percent of the total energy requirement for heating, cooling, and hot water.

## 1.2 PREFACE AND ACKNOWLEDGEMENTS

This report is one of a series covering research and development on solar heating and cooling systems in CSU Solar House I. In a continuous program since September, 1973, solar heating and cooling components have been assembled into a series of integrated systems and their performance has been systematically measured and compared. Various types of solar collectors, heat storage containers, cooling units, controllers, and auxiliary heaters have been assembled into about six different systems and several modifications of those systems.

Reports of design and performance of previously developed systems have been submitted to sponsoring government agencies as listed below:

1. "Solar Heated and Cooled Building", G.O.G. Löf and D.S. Ward. Progress report COO-2577-1, for the period 1 September 1973 to 31 January 1974, submitted to the National Science Foundation/RANN, March 1974.

2. "Design and Construction of a Residential Solar Heating and Cooling System", G.O.G. Löf, D.S. Ward, J.C. Ward and C.C. Smith. Progress report COO-2577-4, for the period 1 January 1974 to 31 July 1974, submitted to the National Science Foundation/RANN, August 1974.

3. "Performance of a Residential Solar Heating and Cooling System", D.S. Ward, G.O.G. Löf and C.C. Smith. Progress report COO-2577-9, for the period 1 July 1974 to 1 February 1975, submitted to the Energy Research and Development Administration, June 1975.

4. "System Modifications and Refinements for a Residential Solar Heating and Cooling System", D.S. Ward, G.O.G. Löf and C.C. Smith. Interim report COO-2577-11, for the period 1 October 1975 to 1 July 1976, submitted to the Energy Research and Development Administration, September 1976.

5. "Design, Construction and Testing of a Residential Solar Heating and Cooling System", D.S. Ward and G.O.G. Löf. Progress report COO-2577-10, for the period 1 September 1974 to 31 August 1975, submitted to the Committee on the Challenges of Modern Society (CCMS), Energy Research and Development Administration, July 1976.

6. "Evaluation of the Corning and Philips Evacuated Tubular Collectors in a Residential Solar Heating and Cooling System", W.S. Duff. Final report COO-4012-1, for the period 1 May 1976 to 1 December 1976, submitted to the Energy Research and Development Administration, March 1977.

7. "Solar Evacuated Tube Collector-Absorption Chiller Systems Simulation", J.A. Leflar and W.S. Duff. Report COO-2577-13, Submitted to the Department of Energy, December 1977.

8. "Evaluation of High Performance Evacuated Tubular Collectors in a Residential Heating and Cooling System: Colorado State University Solar House I", T.M. Conway, W.S. Duff, R.B. Pratt, G.O.G. Löf, and D.B. Meredith. Progress report COO-2577-14, for the period 1 October 1976 to 30 September 1977, submitted to the Committee on the Challenges of Modern Society (CCMS), Department of Energy, July 1978.

9. "Comparative Performance of Two Types of Evacuated Tubular Solar Collectors in a Residential Heating and Cooling System", G.O.G. Löf and W.S. Duff. Progress report COO-2577-19, for the period 1 October 1977 to 30 September 1978, submitted to the Department of Energy, September 1979.

The authors of this report acknowledge with appreciation the support of the U.S. Department of Energy, Office of Solar Applications. Also recognized is the Chicago Operations Office of DOE, through which the contract is administered, and Lyle Groome, Charles Bishop, and their associates at the Solar Energy Research Institute in Golden, Colorado, the technical monitors of the project.

In indispensible supporting roles have been Dick Hill who has provided instrumentation and equipment design and operational supervision and Kathi McKenna who has provided secretarial and office support to the project.

This report is based on the effective contributions of numerous members of the project staff and of others in the CSU Solar Energy Applications Laboratory and other organizations. The authors wish to acknowledge with great appreciation the contributions which all the participants have made. Special recognition is accorded to Thomas Conway, co-leader of the project until his departure in January 1979 and Dr. John Appleyard of the University of Western Australia for his help in project coordination through February 1979. Members of the staff who have been directly responsible for system operation, data analysis, and computation of results, and on whom this work has heavily depended, include R. Millard, T.N. Bechtel, C.E. Hancock, P.C. Jacobs, E.B. Kepner, R.G. Pratt, and N.A. Weaver.

This project has been part of a bilateral cooperative project with the Solarhaus Freiburg in West Germany. Component suppliers have also been included in this arrangement. Substantial contributions to the planning and review of the project have been made by members of the cooperative project team. Dr. Konrad Schreitmüller and Mr. Klaus Vanoli of the DFVLR (Germany), Dr. Horst Hörster of the Philips Research Laboratory in Aachen, and Dr. Phillip Anderson of the Arkla Corporation have provided exceptionally valuable guidance and assistance. Other inputs to the success of the project were made by Drs. R. Bruno, R. Kersten and Mr. H. Körver of the Philips Research Laboratory and Dr. F. Masson and R. Ullrich of the North American Philips Company; Mr. Richard Merrick of Arkla Corporation; N.A. Buckley of Bally; and Dr. F. Morse and Dr. M. Davis of the U.S. Department of Energy.

## 1.3 SUMMARY

### 1.3.1 Objectives

The principal objectives in the current investigation are the development and evaluation of a solar system for heating, cooling, and hot water supply in which the principal components are a newly developed type of evacuated tube collector, a well-insulated sectional heat storage tank, a lithium bromide absorption chiller specifically designed for solar operation, and an off-peak electric heat storage unit for auxiliary heat supply. Related objectives are the evaluation of the mechanical performance and maintenance requirements of such a system, its efficiency and energy delivery capacity, and the validity of computer models for predicting performance of similar systems.

### 1.3.2 Environment and Climate

The project is located in a favorable climate for solar energy utilization. High levels of solar radiation in winter and summer, low cloudiness, and large space heating requirements of 3075 degree C (5535 degree F) days per year favor solar heating application. Although residential cooling demand is normally low, use of the building as offices and laboratories imposes cooling loads commensurate with residential requirements in most of the United States other than in excessively hot and humid zones. Average monthly solar and temperature conditions in the region range from 13 to 18 $MJ/m^2$-day and -4 to 24°C respectively.

### 1.3.3 The Building

Shown in Figure 1.1, Solar House I has two floors, totaling 249 square meters area not including separately heated garage area or entry vestibule. It is a well-built, modern frame structure with a design heating load of 16.1 kW at -23°C (55,000 Btu/hr at -10°F) at a reference temperature of 18.3°C (65°F).

The measured heating load has been lower than planned because of some energy conservation features added during construction of the house and because of greater than normal internal heat generation by high electric use for lighting and equipment as well as by greater personal occupancy than planned. Higher cooling loads have resulted from the latter factors.

Although the house is well constructed, with a comparatively low heat loss for a structure of its size, insulation usage is not exceptional.

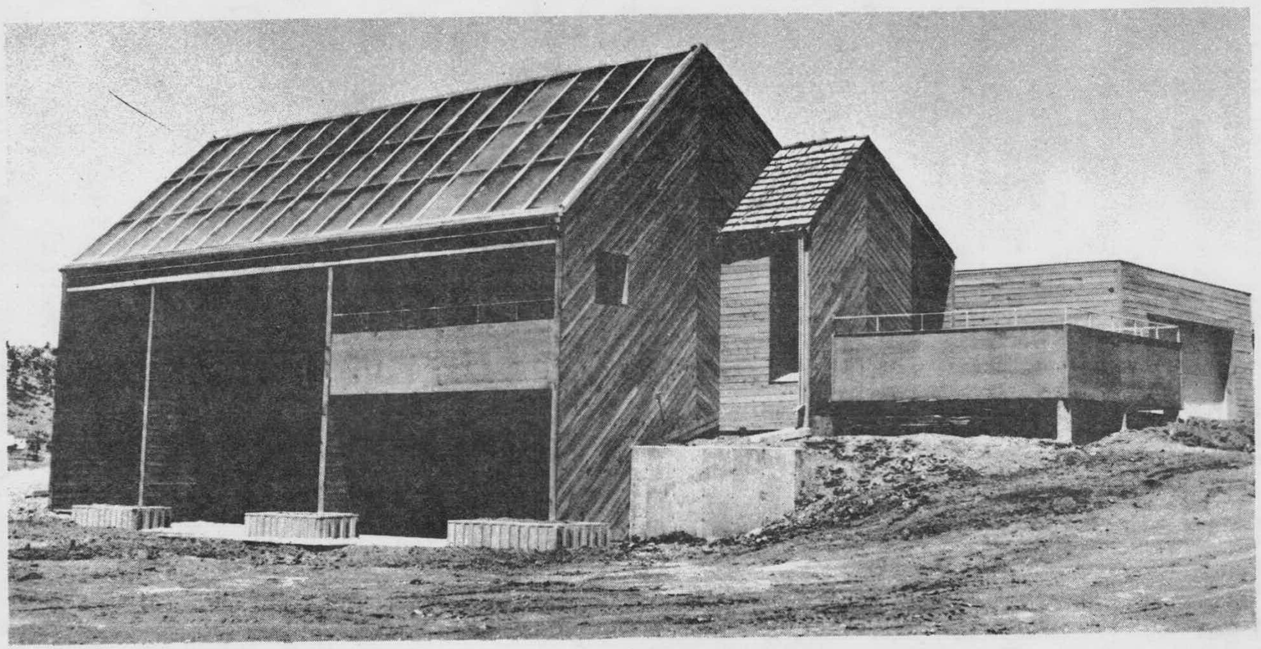


Figure 1-1.  CSU Solar House I

The walls are insulated with 7.6 cm of fiberglass, equivalent to R-1.94 $m^2$-°C/W (R-11 hr-$ft^2$-°F/Btu), and the ceiling insulation is equal to R-3.35 $m^2$-°C/W (R-19 hr-$ft^2$-°F/Btu). A sheltered entry with vestibule airlock (two doors) and triple glazing are, however, unusual energy conserving features.

1.3.4 Solar Energy System

The solar energy systems for space heating, cooling, and hot water supply are illustrated in Figures 1-2H and 1-2C. The experimental Philips evacuated tube collector was mounted on a platform adajcent to the house and tilted at an angle of 45° directly toward the south. The flat plate collector on the roof of the house was used for other purposes during the period covered by this report. The Philips collector, with an aperture area of 44.7 $m^2$, comprised an array of evacuated glass tubes resting against corrugated aluminum extrusions through which an antifreeze solution was circulated. A selective absorbing surface is deposited on the inside of the glass tube on the lower third of the circumference. Rain and dust protection was provided by flat glass covers. Antifreeze solution (ethylene glycol in water) was circulated through the collector at a rate of approximately 1.14 liters/second (18 gallons/minute) and through a tube-and-shell heat exchanger to which water from storage was pumped at a rate of .44 liters/second (7 gallons/minute). Heat storage was provided in a rectangular insulated tank of 4160 liters (1100 gallons) capacity, built up of interlocking insulated panels lined with a one-piece, shaped vinyl sheet. All piping enters and leaves the tank through openings in the insulated cover.

Heated water was pumped from storage for service water heating and space heating as indicated in Fig. 1-2H. A liquid-to-liquid heat exchanger for service hot water and a liquid-to-air coil for space heating are provided. As shown in Figs. 1-2H and 1-2C, service water was circulated through a heat exchanger by pumping from a 302 liter (80 gallon) preheat tank. Auxiliary hot water heat is furnished in a conventional electric water heater of 151 liters (40 gallons) capacity by an electric resistance coil. Auxiliary space heating is supplied in an off-peak electric heating unit in which ceramic blocks, heated at night by off-peak electric resistance, supply heat to the air stream when needed.

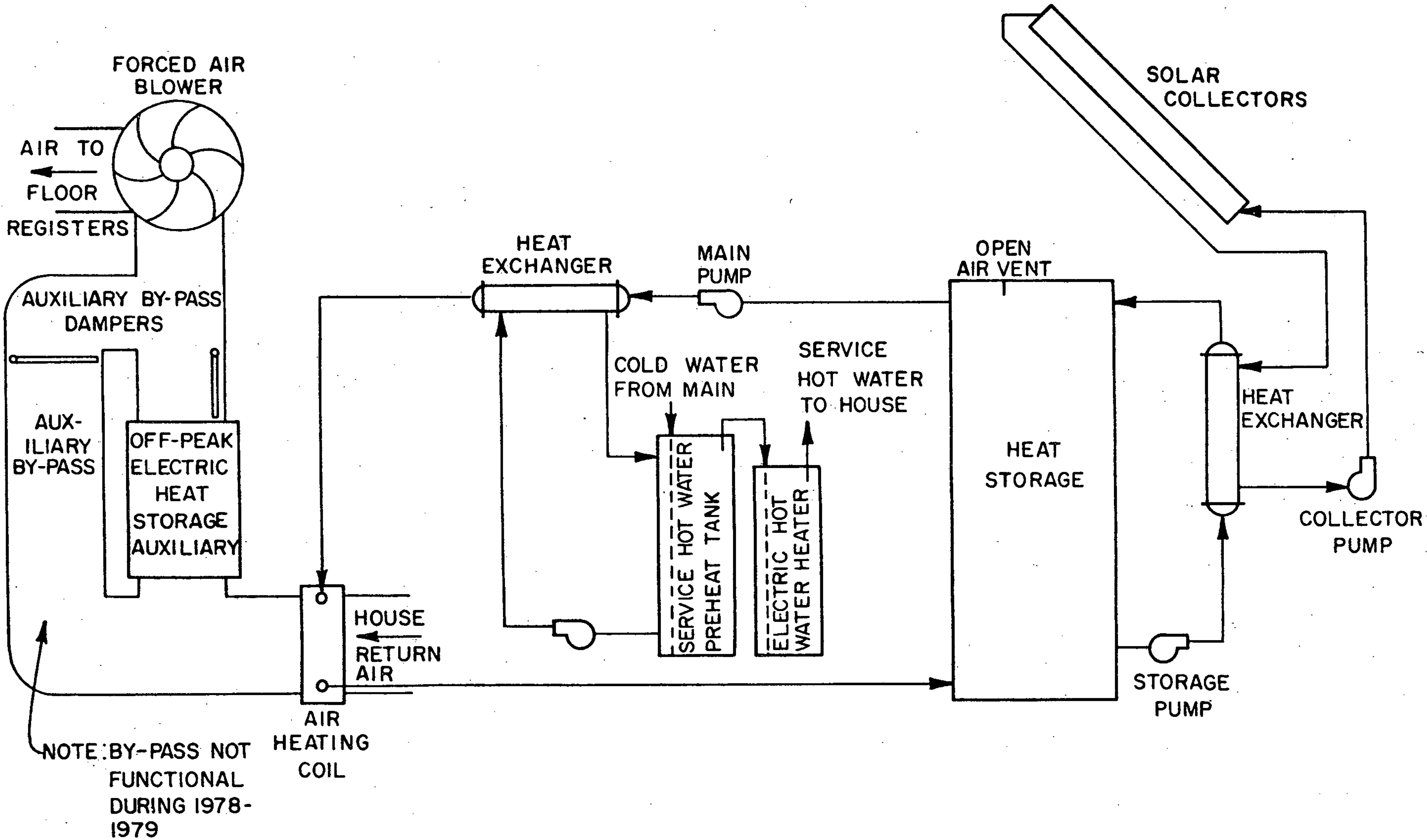



Figure 1-2H. Solar House I System Schematic, Winter 1978-1979

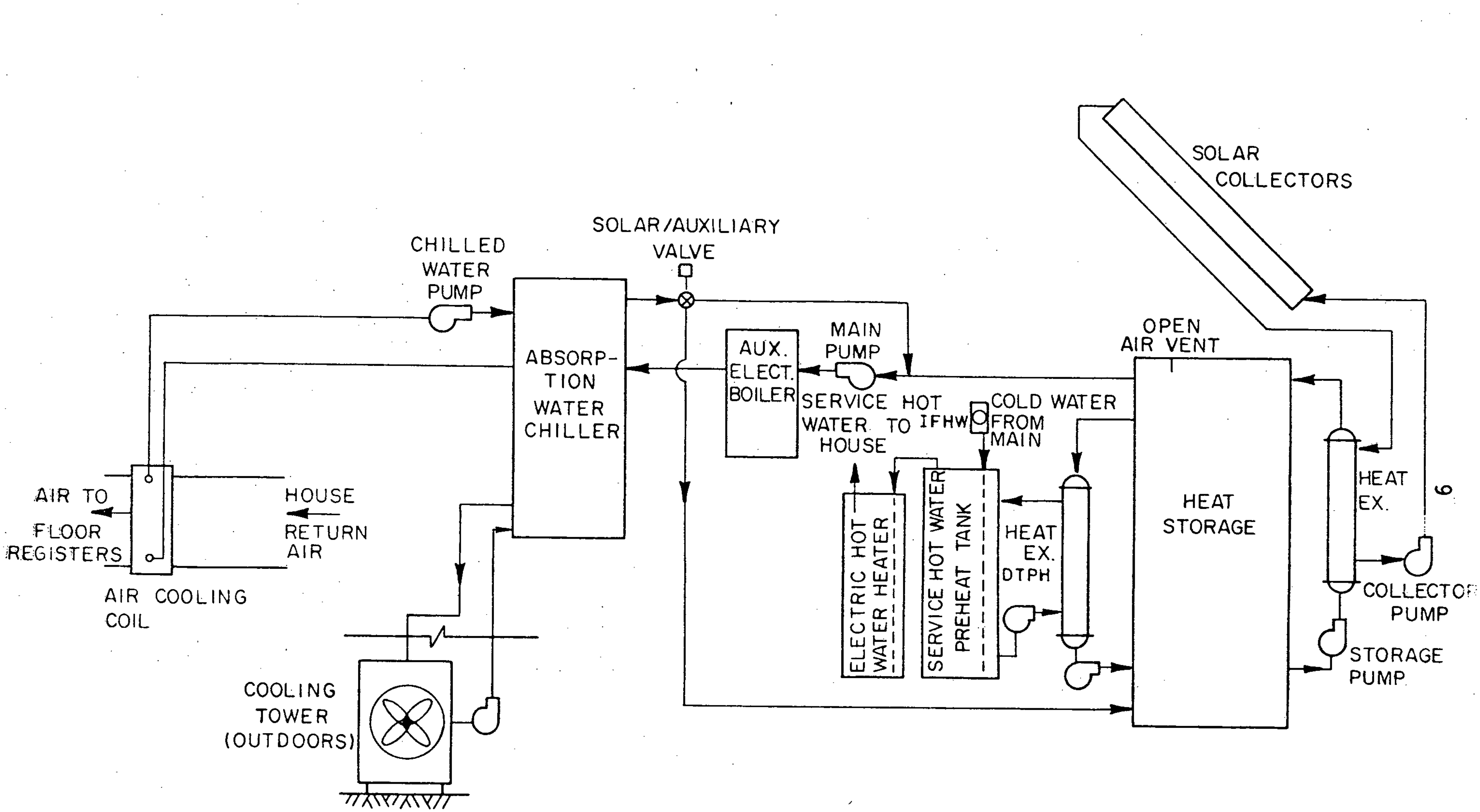



Figure 1-2C. Solar House I System Schematic, Summer 1979

Cooling was furnished by a 3-ton ARKLA lithium bromide absorption chiller, driven by hot water from main storage as shown in Figure 1-2C. Chilled water is pumped through a coil in the air stream passing to the rooms and is returned to the chiller. Heat was discarded from the system in a cooling tower mounted outside the building. Auxiliary cooling, when required, was supplied by circulating hot water from an electric boiler through the generator of the chiller.

1.3.5 Operating Modes

During the heating season, the three primary operating modes are (1) solar heat collection and delivery to storage, (2) use of hot water from storage to heat air circulating to the rooms, and (3) use of solar storage to supply heat to service hot water. Mode (3) is used only in conjunction with Mode (2).

In addition to the solar modes, there are three types of operations involving auxiliary space heating and one involving auxiliary service water heating. For space heating, an off-peak electric auxiliary unit (a) is charged at night (off-peak) by supply of electricity to heating elements in brickwork, (b) is used during the day (peak periods) to supply auxiliary heat from hot brickwork to air from the solar coil when solar heat is not sufficient to meet demand, and (c) is used to supply auxiliary electric heat directly to the air stream during nighttime (off-peak) periods. The direct heating elements may also be used in the day time if there has been a failure to adequately charge the electric heat storage unit the previous night (this mode was never necessary in the operation of House I).

For service water heating, solar heated water flows to a conventional electric water heater whenever a hot water tap is opened. If the temperature in the auxiliary electric water heater falls below a preset level, electric heat is automatically supplied until the desired temperature is obtained.

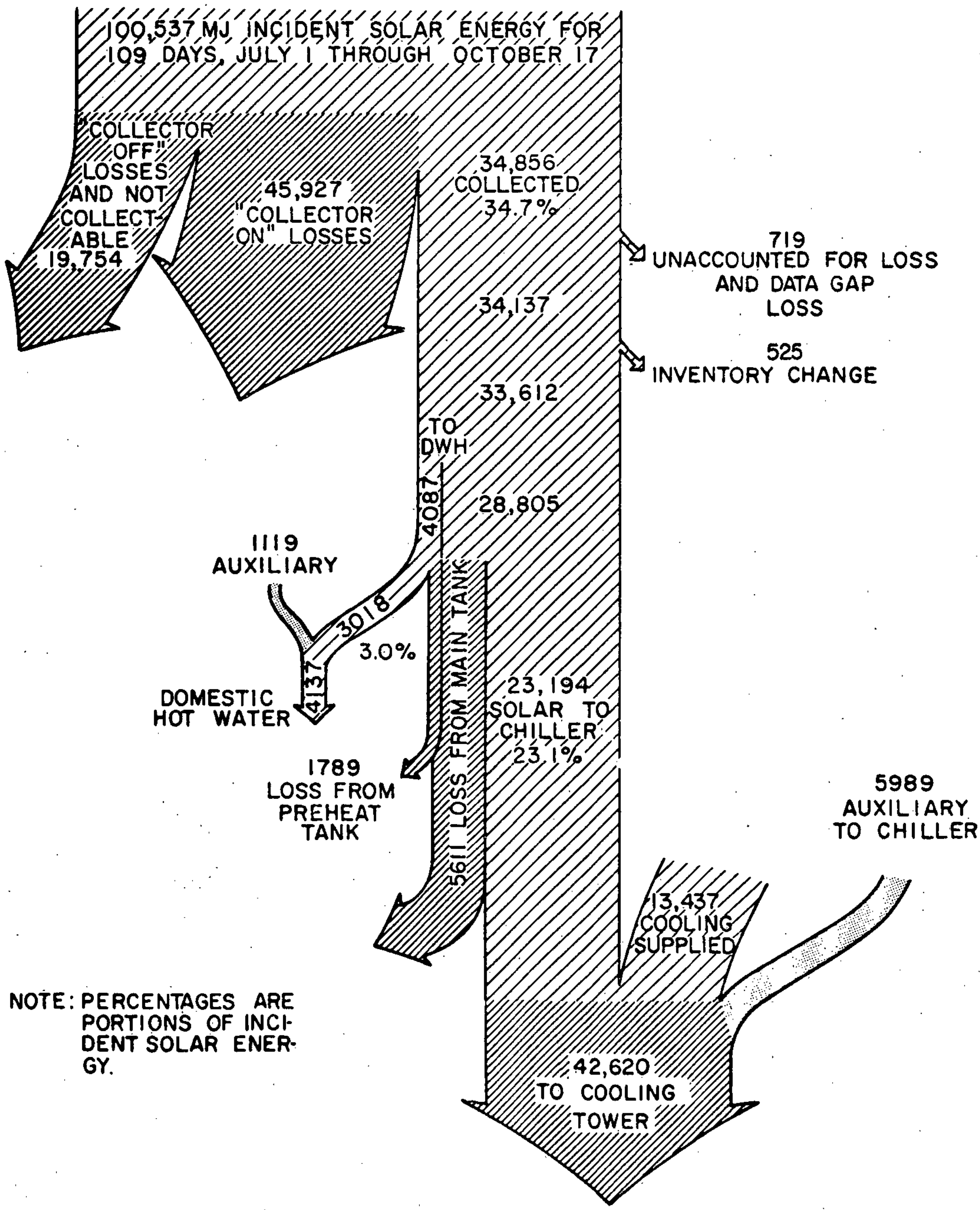
During the summer, the three primary solar operations are (1) delivery of solar heated water from collector to storage, (2) use of stored heated water to supply energy to the chiller from which refrigerated water is pumped to a coil in which circulating air is cooled and dehumidified, and (3) use of solar heated water in an exchanger for service hot water supply. Two additional modes involving auxiliary electric energy are (4) when the solar storage tank is cooler than a preset temperature (typically 70°C), this source is replaced by hot water circulated through an electrically heated boiler, and (5) auxiliary heat for service hot water is supplied as described above.

### 1.3.6 Evaluation Program

The evaluation program comprises (1) measurement of approximately 100 variables (temperature, flow, radiation, electric energy use) every ten minutes throughout the entire year, (2) calculation of hourly, daily, monthly, and annual performance factors such as energy supply, energy delivery, collection efficiency, auxiliary energy use, energy supply to the several uses, (3) assessment of operational problems and maintenance requirements, reliability, and practicality of systems for general public use, (4) comparison of system performance with theoretical predictions and evaluation and validation of models on which predictions are based, (5) comparision of system performance with those previously evaluated in the CSU program.

### 1.3.7 Major Results and Conclusions

The major results of the one-year study involving the systems previously described are shown in Figures 1-3H and 1-3C. These results show that substantial portions of the heating, cooling, and hot water requirements were met by the solar systems involving the Philips MKIV evacuated tube collector and Arkla water chiller. Off-peak electric heat storage, sectional rectangular solar storage tank, baffles for achieving stratified temperatures in storage, and other accessories proved satisfactory. System efficiencies, although not as high as those achieved with the Corning evacuated tube collector and associated system, are higher than those previously obtained with site-built flat-plate collectors. Were it not for an evacuated tubular collector retaining snow cover several days longer than does a flat plate collector, system efficiencies for the Philips MKIV collector would have been higher than the selective, single-glazed state-of-the-art flat plate collectors on Solar Houses II and III.




NOTE: PERCENTAGES ARE PORTIONS OF INCIDENT SOLAR ENERGY.

Figure 1-3H. 1978-79 Heating Season Energy Flows for Solar House I

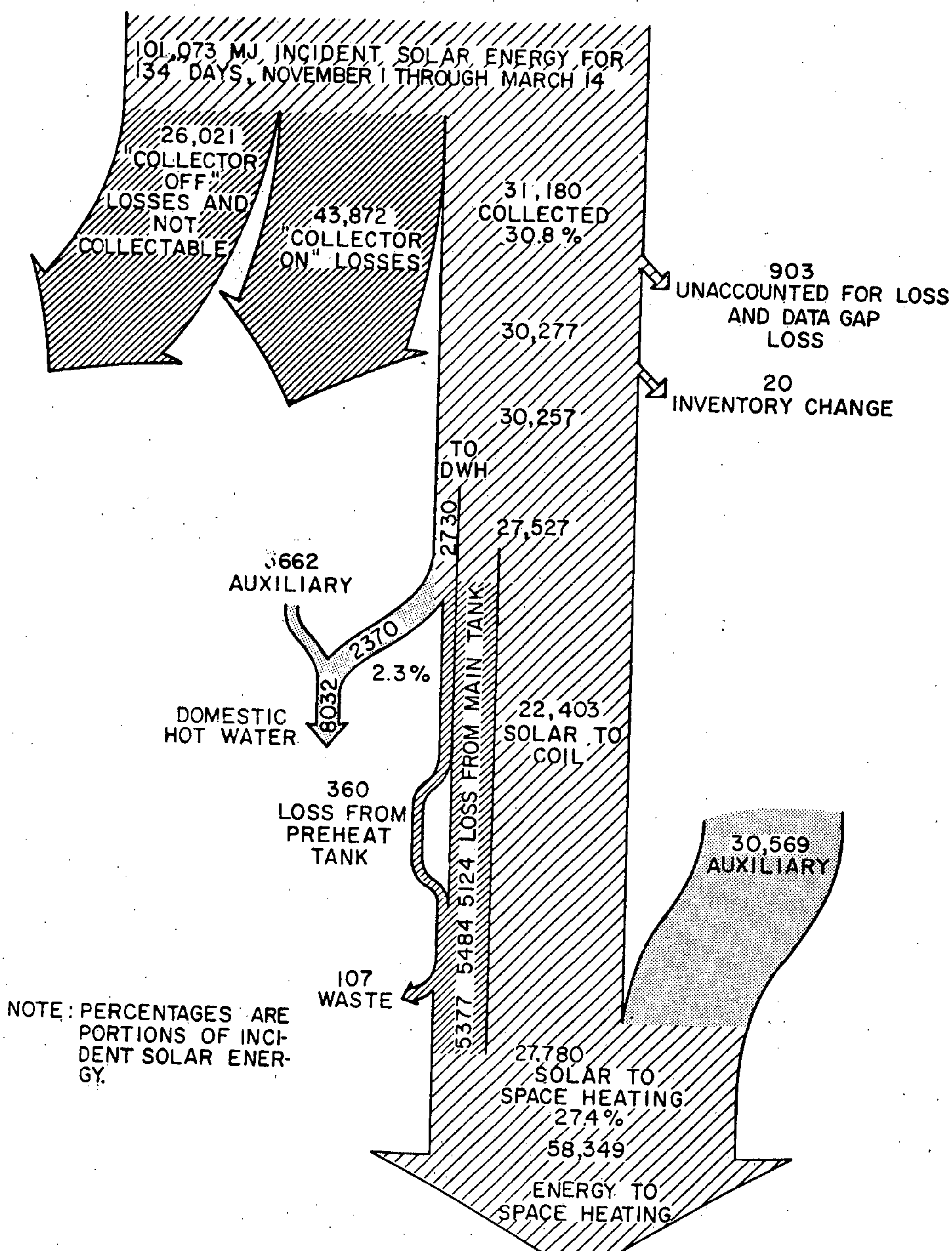



Figure 1-3C. 1979 Cooling Season Energy Flows for Solar House I

## 1.4 INTRODUCTION AND BACKGROUND

The objectives of the program in CSU Solar House I are the development and evaluation of systems for solar heating and cooling of buildings. The portion of the program covered in this report involves evaluation of systems which included an experimental evacuated tubular collector supplied by Philips, Aachen, West Germany Research Laboratory, a sectional heat storage tank supplied by the Bally Case and Cooler Company, a chiller supplied by Arkla Industries, an off-peak electric heat storage unit supplied by the TPI Corporation, and other heating, cooling, and hot water equipment. Determination of system effectiveness as measured by efficiency, portion of heat requirements met by solar, maintenance and repair and reliability assessment, and system performance comparisons with other systems and with theory are also involved.

The philosophy in this and other solar projects at Colorado State University is based on the clear indication that the greatest need for technical input in solar heating and cooling of buildings is in the integration of the many components into effective and reliable systems. Assessment of performance and operating problems are primary requirements for evolving the best system designs.

The program is organized under the directorship of the Solar Energy Applications Laboratory with two solar specialists supervising the work, a skilled technician in daily charge of equipment and instrumentation, and several engineering graduate students carrying out data procurement and analysis. Report preparation is primarily the responsibility of the senior staff, and decisions on system design, operation, and modification are made in general consultation by the whole staff.

The steps in carrying out the work of the project, usually taken annually, are (1) analysis and decisions as to components and system integration involving new equipment and changes in existing equipment, (2) modification and/or installation of solar and auxiliary equipment and monitoring facilities, (3) initial testing of new system design and correction of faults, (4) automatic operation of heating, cooling, and hot water systems with continuous data logging, (5) simultaneously with step 4, continuous review of operations and data, logging of faults, and solution of problems, (6) computation and analysis of results, comparisons with those of earlier and contemporary systems, and preparation of full reports.

Conventional heating systems in the region are usually supplied with natural gas in warm air or hydronic systems. Service hot water is usually heated by natural gas, although some electric heaters are used. There is very little residential cooling (air conditioning), but in a few houses, vapor compression systems are used. In other parts of the country, fuel oil is also used, to the extent of 10-20% of national space heating requirements. Natural gas comprises 50-60%, and electricity the balance.

In climates similar to that in central Colorado, typical residences of 150-200 square meter floor area require about 100 gigajoules (about 100 million Btu) per year for space heating and hot water. Of the total energy consumption, approximately 15 GJ are typically required for service hot water supply and the balance for space heating. The three solar heated houses in the CSU Solar Village have averaged about 80 GJ per year since their construction. The buildings are somewhat larger than average, but construction is better than usually encountered.

In regions where residential cooling is common, 3- to 5-ton units may operate for periods of 200-2000 hours per year, depending on the climate. Annual cooling delivery may range from six GJ in mild climates to 100 GJ in very hot and humid regions. The amount of energy required for cooling depends on the COP of the equipment, but assuming a vapor compression type with an average COP of 2, electric energy consumption would be roughly half of those cooling delivery quantities.

The cost of conventional energy supplied by natural gas ranges from about $2 per GJ to $10 per GJ, throughout the U.S., assuming approximately 50% combustion efficiency. At the CSU Solar Village, the cost is approximately $4/GJ. Rapid price increases are occurring. Electricity prices range from one cent per kWh to more than ten cents per kwH ($3/GJ to $30 per GJ). At the CSU Solar Village, the cost of electricity is approximately 4 cents per kWh, equivalent to $11 per GJ. Fuel oil for residential heating, used mainly in the northeast and north central parts of the U.S., costs approximately $15/GJ at 50% combustion efficiency.

# 2. ENVIRONMENT AND LOCATION

## 2.1 LOCATION

The CSU Solar Village is located in the Foothills Research Campus, 6.4 km west of Fort Collins, 96.6 km north of Denver, Colorado. The latitude 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, and the air is generally clear of local pollution. Immediately to the west, the Rocky Mountains rise to the Continental Divide, about 50 km distant. Eastward from the site of the Solar Village the terrain is generally flat. There are no obstructions to direct sunlight on the site except for shading by the mountains for the last 15 to 30 minutes before sunset.

## 2.2 CLIMATE

The climate of the region is semi-arid with continental winters and meager summer rainfall. Average annual precipitation is 36.3 cm, consisting of 24.9 cm rainfall and 11.4 cm water from snowfall. Ambient temperatures are moderate during summer months, with mean July highs about 32°C and mean low temperatures during the coldest winter months about -10°C. Average daily temperature in January is -1°C and in July, 24°C. The normal total annual heating degree days (18.3°C base) is 3075 °C-days. Monthly average daily radiation on a surface inclined southward at 45 degrees in Fort Collins and monthly average ambient temperatures are shown in Figure 2-1.

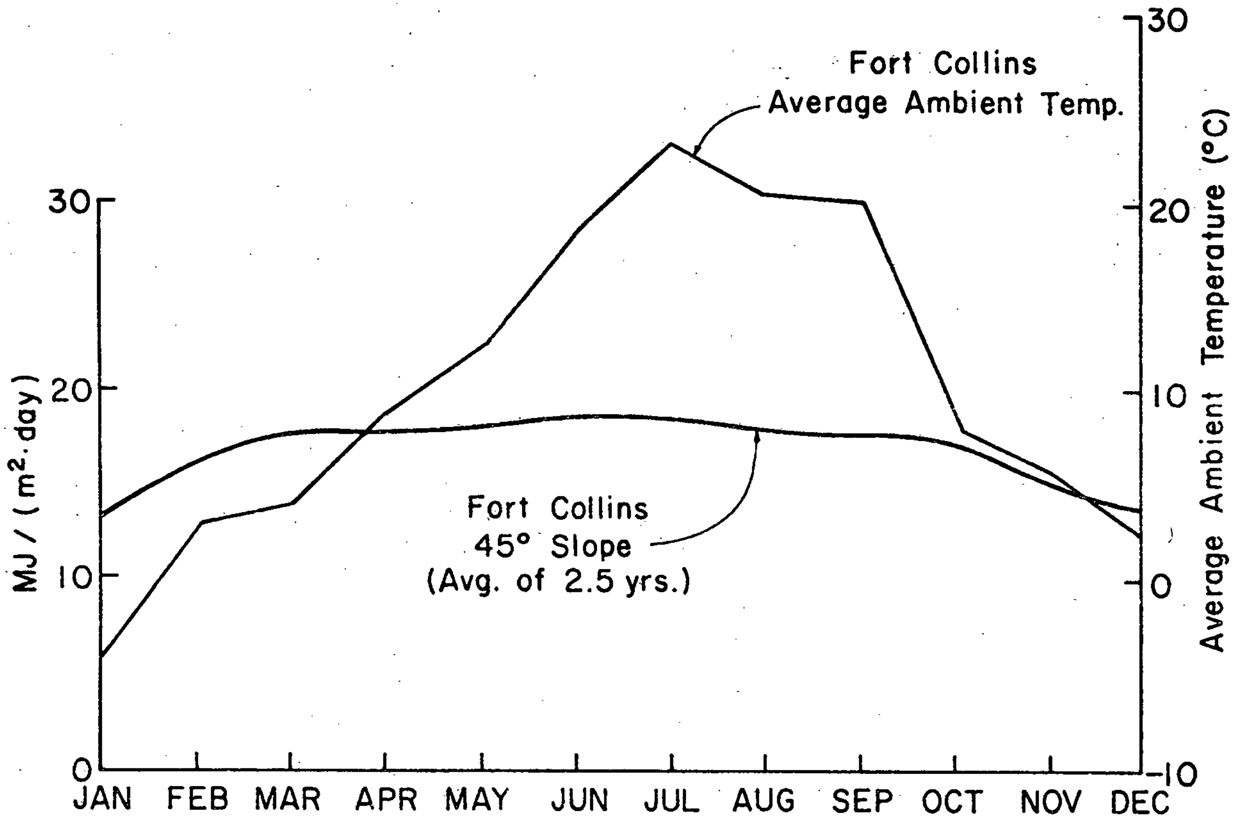



Figure 2-1. Monthly Average Daily Ambient Temperatures and Daily Solar Radiation on a 45° South-Facing Surface in Fort Collins

# 3. DESCRIPTION OF BUILDING AND SYSTEM

## 3.1 THE BUILDING

### 3.1.1 Description

Solar House I is a residential-type 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 utilized for offices. The first floor is the "living" area, with 126 square meters floor space, exclusive of the unheated vestibule and separately heated garage area. The full basement, with 123 square meters floor area has additional offices as well as space for the solar equipment. A photograph of the building is shown in Figure 1-1.

### 3.1.2 Plans and Cross-Section

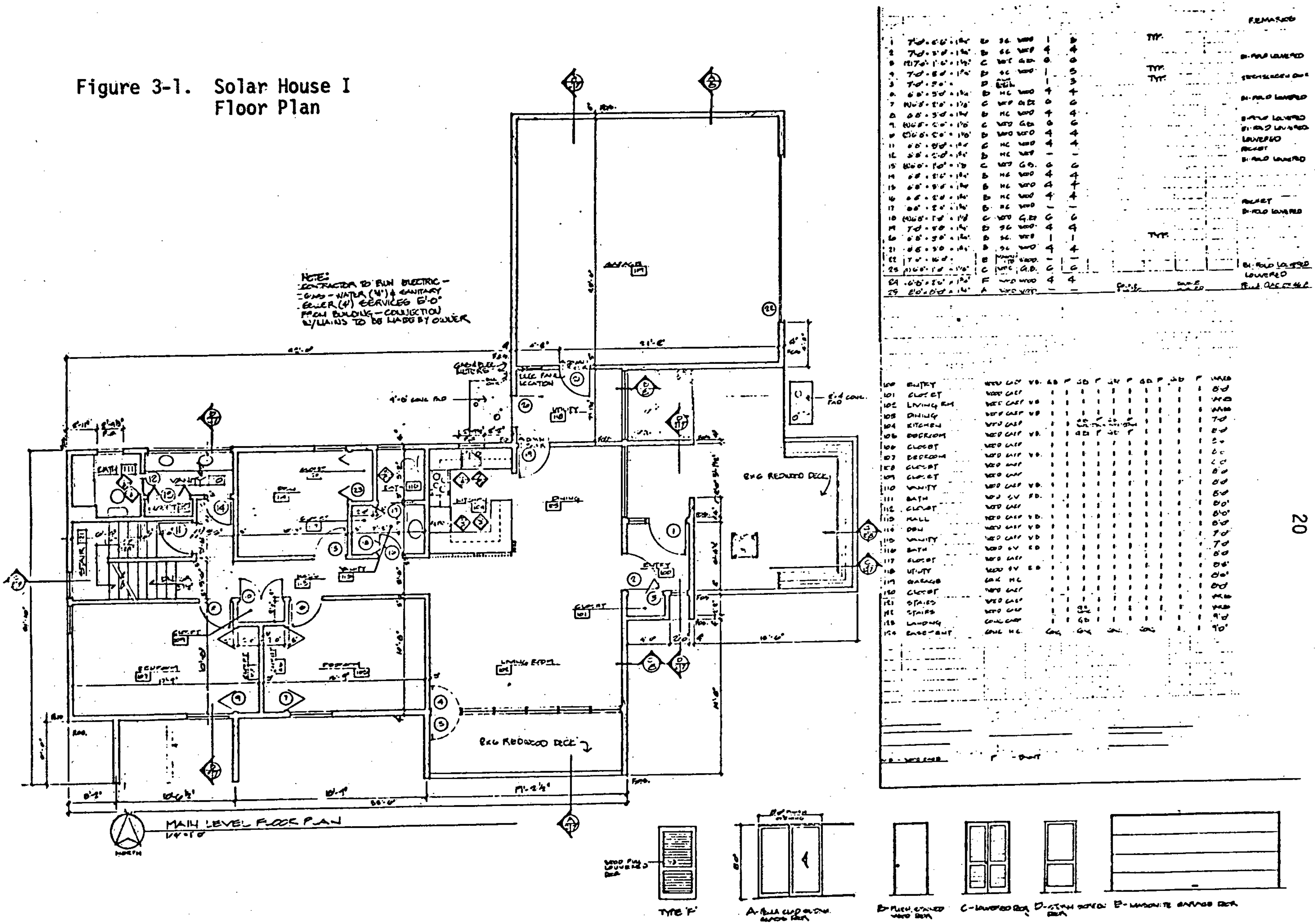
The south side of the basement is entirely above grade while the north wall is all below grade. A floor plan and sections of the building structure are shown in Figures 3-1 and 3-2. The garage has been converted to offices that are heated and cooled by a separate electric supply not associated with the solar system.

Solar collectors are mounted on the south side of the 45 degree roof. The roof is partially supported by four walls which extend outward 1.83 m from the south wall of the building (see Figure 1-1). A 1.83 m overhang shades the south-facing windows on the first floor in the summer and admits sunlight during the winter. Shading of the south-facing windows in the early morning and late afternoon is provided by vertical support walls (fins) extending from the south wall.

### 3.1.3 Heating and Cooling Loads

Frame walls are constructed of 5 by 10 cm studs on 40.6 cm centers. Exterior sheathing is 1.27 cm thick beneath 1.1 cm lapped cedar siding. The interior wall is 1.6 cm gypsum board, behind which is 7.6 cm fiberglass batt insulation with R = 1.94 °C-$m^2$/W (11 hr-$ft^2$-°F/Btu). The ceiling consists of joists, 5 by 15 cm on 51 cm centers, with 1.6 cm gypsum board overlaid with 14 cm fiberglass blanket insulation with R = 3.35 °C-$m^2$/W (19 hr-$ft^2$-°F/Btu).

Figure 3-1. Solar House I
Floor Plan



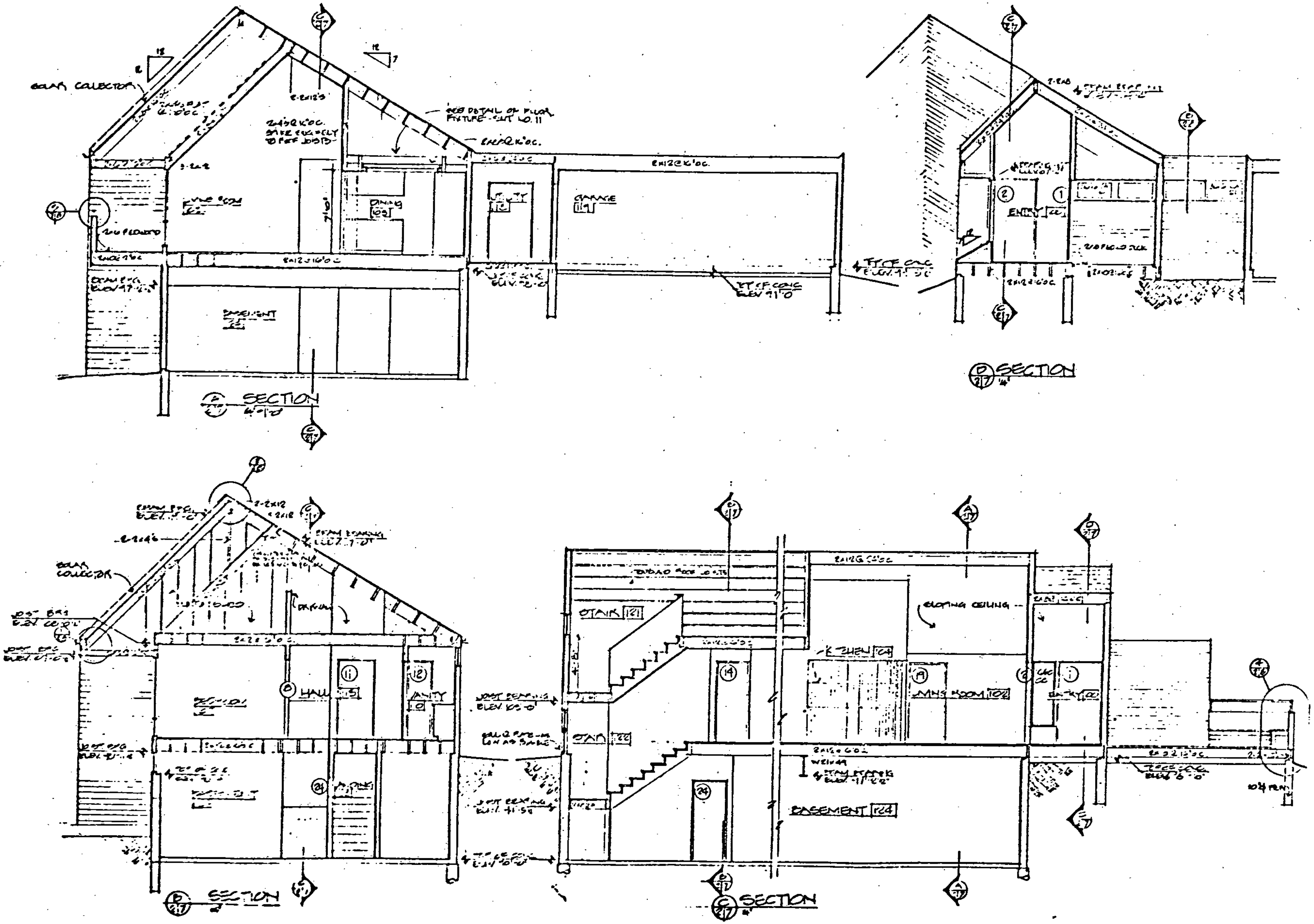



Figure 3-2. Solar House I - Sectional Views

The exposed wall area of the building totals 110 square meters and the underground concrete wall area is 73 square meters. There are 20.35 square meters of triple-glazed windows set in wood and a 5.76 square meter double glazed sliding glass door in an aluminum frame. The design heating load was computed to be 16.1 kW at -23°C (55,000 Btu/hr at -10°F), corresponding to 33.65 MJ/°C-day (17,600 Btu/°F-day) based on a reference temperature of 48.3°C (65°F). The calculated overall UA of the building is thus 390 W/°C (1.4 MJ/hr-°C; 740 Btu/hr-°F). The design cooling load is approximately 10.5 kW (3-tons or 36,000 Btu/hr).

The actual heating load is less than 80 percent of the anticipated value because of departures from the design on which the load was based. The principal differences are due to the use of triple glazed windows rather than double, reduced infiltration by use of a vestibule entry, and higher interior heat generation resulting from lighting, electric equipment, and occupants. Internal heat generation and heat lost from storage into the house also increase the cooling load significantly.

Although used as offices and laboratories rather than as a dwelling, the building is continuously heated and cooled by use of a room thermostat at a constant setting of 21°C (70°F) in winter and 24°C (74°F) in summer. Hot water use is simulated by automatic dumping of regulated volumes at preset intervals. This quantity, about 300 liters per day, is typical for a family of four persons.

## 3.2 THE SOLAR ENERGY AND HVAC SYSTEMS

### 3.2.1 General Characteristics of Present Systems

There are two solar energy systems in CSU Solar House I. Heat may be supplied from a flat-plate liquid collector on the roof or from an evacuated tube liquid collector on an adjacent platform. Two storage tanks and two tube-and-shell heat exchangers are available for storing heat from both collectors. Heated water may be supplied from either tank to the heating, cooling, and service hot water equipment in the house, while heat is rejected from the other tank to the atmosphere.

In the period 1 October 1978 to 30 September 1979, only the evacuated tube collector was used to supply the heating and cooling requirements of the building. The heating and cooling systems are shown in Figures 1-2H and 1-2C. The principal components are an experimental evacuated tube collector, a heat storage tank, an off-peak electric auxiliary heater, a lithium bromide absorption chiller, a heat exchanger and tank for solar water heating, and heat exchangers for collector-to-storage transfer and for storage-to-warm air transfer.

Solar collection was accomplished by operation of the collector pump and storage pump, transferring heat in an exchanger from a 50 percent glycol solution to water in storage. For solar space heating, hot water was pumped from storage to a heating coil through which house air was circulated, water being returned to the tank. Auxiliary space heating was supplied by an off-peak electric heat storage unit through which air passed before distribution to the rooms. Service hot water was heated in a tube-and-shell exchanger through which hot water from main storage was pumped. Auxiliary heat for hot water was supplied in a conventional electric water heater.

### 3.2.2 System Modifications

As described in previous reports, the solar heating and cooling systems in Solar House I have undergone numerous changes since initial start-up in July 1974. Until December 1976, the system comprised a site-built, flat-plate collector of 71.3 square meters on the roof of the house, a heat storage tank of 4500 liters, a liquid-to-liquid heat exchanger for transfer of heat from a glycol solution circulated through the collector, air heating coil, Arkla model 501 WF lithium bromide absorption air conditioner, a liquid-to-liquid heat exchanger and solar hot water preheat tank, and gas-fired auxiliary hot water boiler and auxiliary hot water tank.

Between December 1976 and July 1978, a second heat collection and storage system was used in CSU Solar House I. The new equipment comprised an evacuated tube collector supplied by the Corning Glass Works, with an aperture area of 50 square meters, mounted on a 45 degree sloping platform immediately south of the house. An additional heat exchanger was used for transferring heat from circulating glycol solution to water stored in a second 4500 liter insulated storage tank. The systems were designed so that either collector and storage assembly could be used to supply heating, cooling, and hot water to the building, while heat from the other system was rejected to the atmosphere by means of a fan coil unit through which outdoor air was circulated.

After 18 months of testing and evaluation, the Corning collector was shipped to the joint FRG project in Germany (July 1978), and a second evacuated tubular collector, supplied by the Philips Company, was installed in its place. Minor changes in system design were also made, including system switching valves and the domestic hot water heat exchanger location.

Another important system change was made in September 1976, when the original absorption air conditioner was replaced by an Arkla model WF-36 lithium bromide absorption water chiller designed specifically for solar operation. House air was cooled and dehumidified by circulation through a finned coil in which chilled water from the Arkla unit was circulated. During the period of system operation with evacuated tube collectors, the flat-plate site-built collector was operated in the heat rejection mode or it was used in a separate experiment involving a direct contact liquid-to-liquid heat exchange system.

A complete description of the heating and cooling systems involving first the Corning evacuated tube collector and later, the Philips Mark IV evacuated tube collector, and other system components, is presented in the report COO-2577-19, "Comparative Performance of Two Types of Evacuated Tubular Solar Collectors in a Residential Heating and Cooling System", covering the period October 1977 through September 1978.

Three additional major changes have been made in other system components during the current period between October 1978 and September 1979. In November 1978, an auxiliary heat supply system comprising an off-peak electric heat storage unit was installed and operated throughout the winter of 1978-79. In January 1979, the original site-built flat-plate collectors on the roof of the house were replaced with an array of Miromit factory collectors with galvanized steel tubes and absorber plates, and selective black nickel coatings. These collectors were put to immediate use with the direct contact liquid-liquid heat exchanger/ storage system in a separate research project. In May 1979, the original galvanized steel heat storage tank, with badly deteriorated insulation, was replaced with a modular, sectional, rectangular tank with vinyl liner, supplied by the Bally Case and Cooler Company, and operated with vertical baffles which provided stratified temperatures in the storage tank.

Details of these last three changes are presented elsewhere in this report.

### 3.2.3 Solar Heating System with Evacuated Tube Collector

During the 1978-1979 heating season, the system employed in Solar House I was as shown in Figure 1-2H. The Philips evacuated tubular collectors provided heat to storage by means of a tube-and-shell heat exchanger and two centrifugal pumps. Hot water was stored in a poorly insulated cylindrical tank, and when space heating was required the water was pumped through a small service water heat exchanger to the main air heating coil through which house air was simultaneously circulated by a centrifugal blower. When water heating was also required, the domestic water circulating pump operated. Auxiliary heat was supplied to service hot water in a thermostatted electric water heater, while auxiliary space heating was provided in an electric off-peak heat storage unit.

Specifications on each of the components of this system are shown in Tables 3-1 and 3-2H. More detailed descriptions of the collector and the off-peak auxiliary heating unit are shown in sections below.

### 3.2.4 Solar Cooling System

Figure 1-2C shows the configuration of the energy supply system for space cooling and for water heating during the summer of 1979. In May, the heat storage tank was replaced with a new sectional, well-insulated tank supplied by the Bally Case and Cooler Company, which provides 4200 liters of storage in a vinyl-lined cube-shaped container. Tight-fitting sections are joined together by latching devices, to form the bottom, side, and top surfaces. All fluid streams enter and leave the tank through openings in the top.

The system for heat transfer to storage is the same as that used the previous winter, but the service hot water supply equipment was modified so that water was drawn from main storage for service water heating through a heat exchanger exclusively for that purpose. An electric booster heater is used as during the previous winter.

When cooling was required, hot water was circulated from the upper portion of the stratified storage tank to the Arkla absorption chiller (described below), provided that the storage temperature was above 70°C. If the water temperature was lower than 70°C, the solar/auxiliary valve was

Table 3-1. Heat Exchanger Specifications

| Location | Manufacturer | Model | UA Factor w/°C | Quantity |
|---|---|---|---|---|
| Collector (winter only) | Young Radiator Company | F303 DY one pass | 6625 | Two in series |
| Hot Water | Young Radiator Company | F303 HY one pass | 530 | one |

Table 3-2H. Pump Specifications
Winter, 1978-79

| Location | Manufacturer/Model | Power (watts) | Flow Rate (liters/sec) |
|---|---|---|---|
| Collector | Gorman-Rupp 120 Series Model #12895-2 | 250 | 1.1 |
| Storage | Bell & Gossett 1/6 hp Series 100 | 125 | 1.6 |
| Load | Gorman-Rupp 120 Series Model #12895-7 | 250 | .65 |
| Hot Water | Teel 1/20 hp Model #1P761 | 38 | .25 |
| Fan | Dayton 1/2 hp 115/230V Model 5K451 | 375 | 800 cfm |

repositioned, the electric hot water boiler was actuated, and hot water was circulated to the absorption chiller from this auxiliary unit. Whether with solar heated water or auxiliary, the absorption chiller provided chilled water to the air cooling coil located in the main house air duct system, thereby cooling and dehumidifying air sent to the rooms of the building by means of the main circulating blower. Heat was discharged to the atmosphere through the cooling tower located at the rear of the building.

Specifications for the summer season equipment are given in Tables 3-1 and 3-2C.

Table 3-2C. Pump Specifications, Summer 1979

| Location | Manufacturer/Model | Power (watts) | Flow Rate (liters/second) |
|---|---|---|---|
| Collector | Gorman-Rupp 120 Series Model 12895-2 | 250 | 1.1 |
| Storage | Gorman-Rupp 2800 Series Model #11896-000 | 95 | .45 |
| Load | Gorman-Rupp 120 Series Model 12895-7 | 250 | .65 |
| Hot Water Storage | Gorman-Rupp 2800 Series Model 11896-00 | 38 | .4 |
| Hot Water Preheat | Teel 1/20 hp Model #1P761 | 38 | .25 |
| Cooling Tower | Teel 3/4 hp Model #6K581 | 560 | .75 |
| Chilled Water | Teel 1/3 hp Model #6K578 | 250 | .45 |
| Fan | Dayton 1/2 hp 115/230V Model 5K451 | 375 | 800 cfm |

## 3.3 THE COMPONENTS

### 3.3.1 Philips Evacuated Tube Collector

The Philips collector, shown in Figures 3-3, 3-4, and 3-5, is essentially a heat exchanger plate covered by evacuated tubes with internal solar absorbing coatings. A unique feature of this collector is a selective surface (cobalt sulfide) on a thin silver mirror, deposited on the inside of the lower half of the tube. The tubes are spring clamped to the aluminum channel, and heat is transferred to the fluid by conduction through the glass wall into the aluminum heat exchanger. Each 4.75 m by 1.9 m module contains 108 tubes. Four tubes, approximately one meter long, are laid end to end in each of the 27 aluminum channels. Silicone hoses are spring clamped to the aluminum fluid tubes and to the headers. Each module has a net absorbing area (projected on the collector plane) of 6.77 square meters, a glazed area of 7.45 square meters, and a cover area of 9.03 square meters. Thus the gross surface area occupied by the three arrays of two modules each on the test bed was 54.2 square meters, exclusive of space between modules for access and piping. The glazed (aperture) area of the collector was 44.7 square meters.

### 3.3.2 Heat Storage Tank

The 4160 liter Bally heat storage tank is shown in Figure 3-6. Designed on the principle of a walk-in refrigerator, the wall, floor, and top sections are composed of two sheets of galvanized steel between which 10.2 cm of urethane foam insulation is integrally bonded. With tongue-and-groove edges, the tank sections are locked together by means of specially designed latches to form a rigid rectangular enclosure. Prior to placement of the cover sections, a shaped vinyl liner of .5 mm thickness was secured to the upper edge of the tank, extending to the floor and completely covering the interior surface. All inlet and outlet piping is brought through holes in the top of the tank, thereby avoiding penetrations of the liner and possible leakage.

Operation of the solar system during the winter of 1978-79 involved use of the old 4160 liter steel storage tank, poorly insulated, with vertical baffles to enhance temperature stratification. In May 1979, the rectangular Bally tank was installed with two vertical baffles

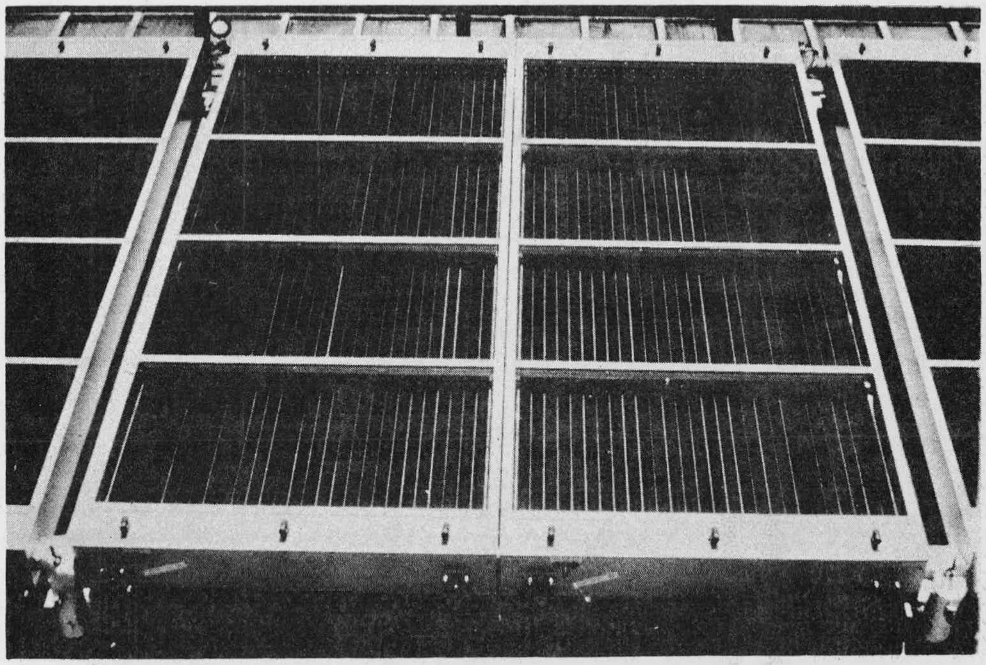


Figure 3-3. Philips Evacuated Tubular Collector Installed on CSU Solar House I Test Bed

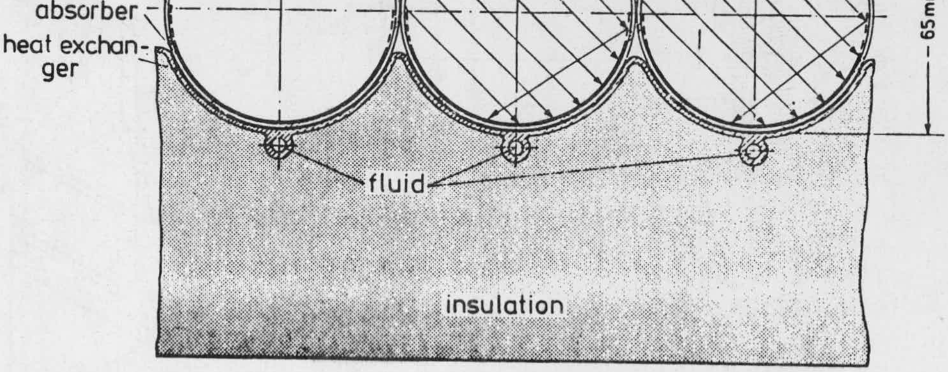



Figure 3-4. Cross-Section Schematic of the Philips Evacuated Tubular Collector

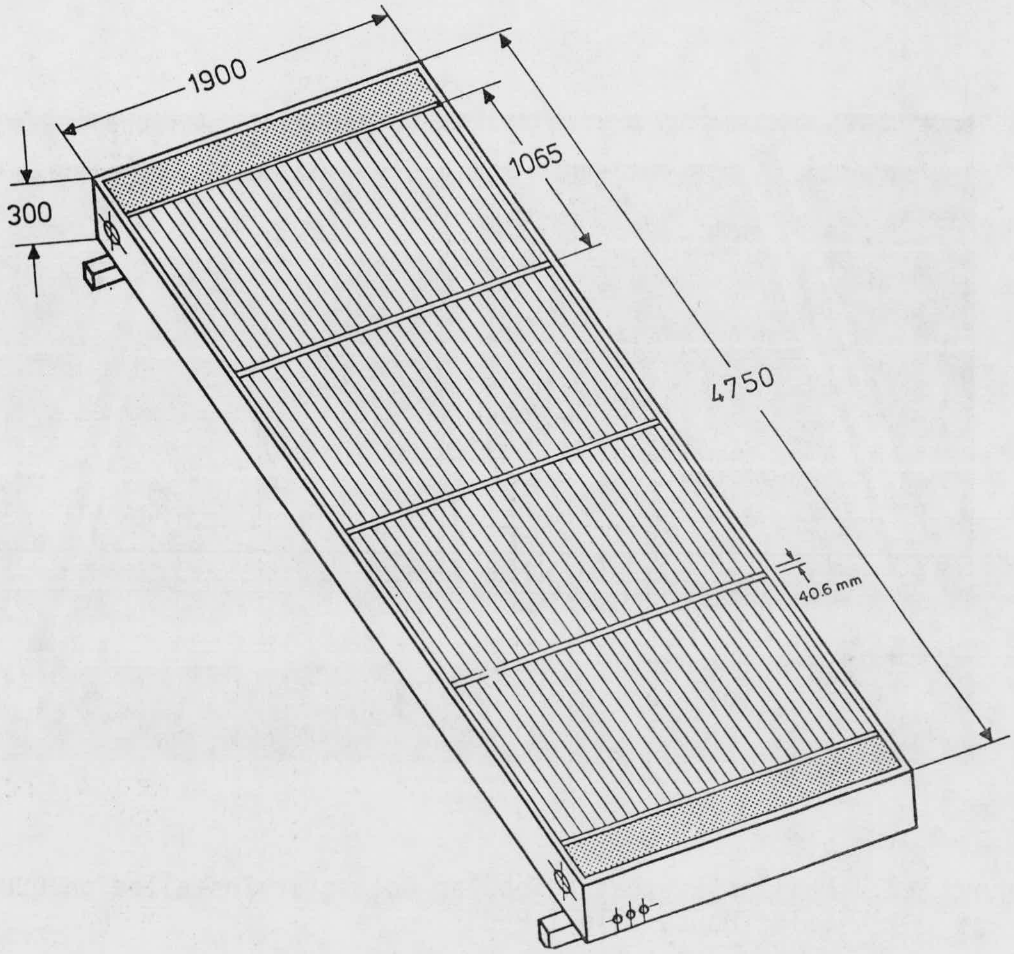



Figure 3-5. Philips Mark IV Evacuated Tubular Collector

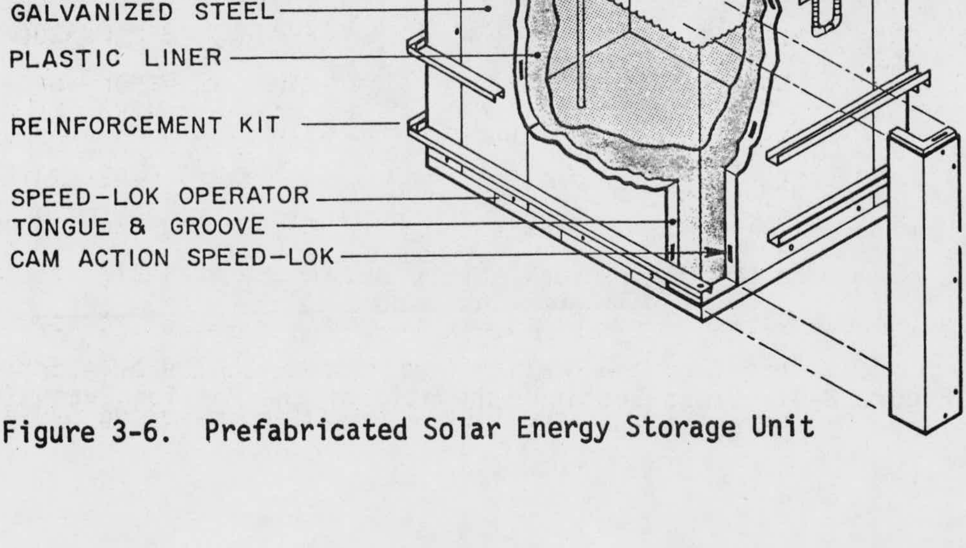



Figure 3-6. Prefabricated Solar Energy Storage Unit

surrounding the return piping from collector and from the load. Figure 3-7 shows the configuration of the piping and temperature stratification facilities in the Bally tank.

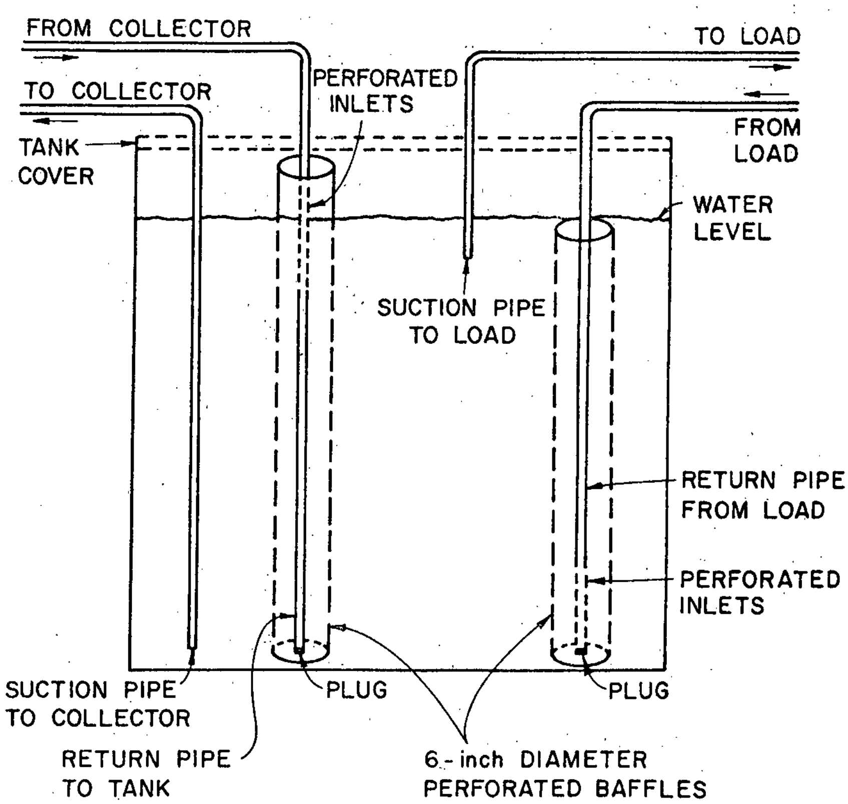



Figure 3-7. Stratified Storage Design

Urethane foam insulation in the storage tank walls has a theoretical R factor of 6 $m^2$-°C/W (34 $ft^2$-hr-°F/Btu). Because of heat conduction through the numerous connecting pipes and some vapor loss, the effective R is only about half this value, measured at 2.4 $m^2$-°C/W (14 $ft^2$-hr-°F/Btu). This factor results in a tank heat loss rate of 0.022 MJ/hr-°C. Thirteen pipe connections through the top of the tank, about double the number in a normal installation, contribute to a significant portion of the tank loss. As pointed out elsewhere, however, these "losses" are contributions to the heating requirements of the building whenever heat is required, and are true losses only in mild spring and fall weather and, of course, in the summer.

3.3.3. Service Hot Water Heat Exchanger

As shown in Figure 1-2H, the service hot water heat exchanger was located in the main load loop during the winter of 1978-79. In this position, either hot water or space heating or both could be supplied as required. When space heating was needed, the main load pump was operated, and water from storage was circulated through both the service hot water exchanger and the main air heating coil. When hot water was also required, the small circulating pump in the service hot water loop was also actuated. By this design, only one pump is was needed in the solar load loop. A disadvantage, compared with the system in which the hot water exchanger is in a completely separate loop heated from main storage, is the use of a much larger pump when only hot water is required. As actually operated, however, solar heated water was pumped from main storage only when space heating was required, so service water was not solar heated except when stored solar heat was being supplied to the building. This design and method of control resulted in low supply of solar hot water.

The hot water system was changed in the spring of 1979, as shown in Figure 1-2C, to provide a completely separate circulation loop from storage through the exchanger, back to storage. Operation of the hot water system, with its two small pumps, is therefore independent of the space cooling system.

Although both service hot water system designs operated satisfactorily, the advantages of the separate loop with its two small pumps, with respect to quantity of solar heated water and control simplicity, outweigh the elimination of one pump in the series design used in the winter of 1978-79.

3.3.4 Off-Peak Electric Heat Storage Unit for Auxiliary Heating

In November 1978, the commercial electric off-peak heating unit shown in Figure 3-8, manufactured by the TPI Corporation, was installed in CSU Solar House I. In its simplest form, the device is an assembly of refractory bricks contained in a heavily insulated metal cabinet. Electric heating elements supply heat to the bricks during the night (off-peak). When auxiliary heat is needed, the dampers inside the storage unit open slightly so that some of the air being circulated

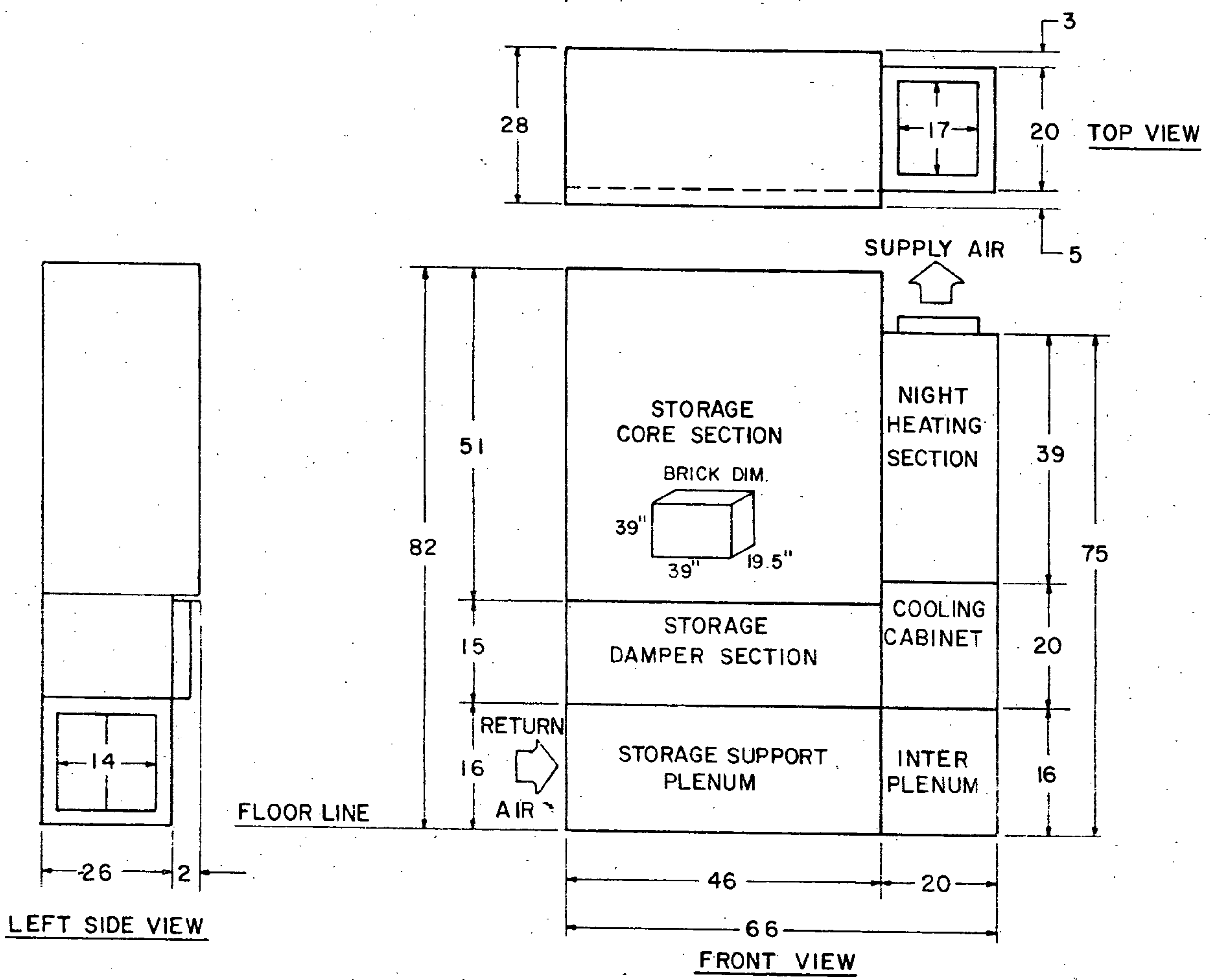



Figure 3-8. Off Peak Heat Storage Unit

from the solar coil passes through the heated core. After mixing with the balance of the air stream, the heated air flows to the rooms through the conventional duct system. Heat input to the core occurs only during off-peak periods. Within some utility networks, this off-peak period has been defined as being 10:00 pm to 6:00 am. The storage capacity of the unit is sized to be capable of supplying all required space heating needs during even the coldest 16 hour on-peak period (6:00 am to 10:00 pm). During the night off-peak cycle, space heating is supplied to the air stream by direct resistance heating.

The advantages to the electric utility of this type of auxiliary supply are: (1) delaying the need for construction of additional electric generation equipment, (2) providing greater utilization of existing transmission and distribution facilities, (3) improving system load factor, and (4) improving system operating efficiency. The advantage to the user is lower electricity costs by utilizing off-peak rates.

Central to the concept of an off-peak furnace is the storage unit, which comprises three basic sections; (1) the storage core, (2) the air flow dampers, and (3) the structural support plenum. The storage core section contains refractory blocks, insulation, heating elements, wiring, and three thermal control devices. The overall size of the core section is 51 inches high, 46 inches wide, and 28 inches from front to back.

The core comprises twelve layers of blocks, and each layer contains twelve blocks. As the blocks are assembled into rows, airway passages are formed between the blocks as a result of wide vertical channels molded into the sides of the blocks. After leaving the core, the heated air is tempered with by-pass air to obtain the desired outlet temperature.

Three types of insulation surround the core; vermiculite next to the blocks, compressed powder slabs encased in woven glass cloth, and dense long fiber mineral wool adjacent to the sheet metal cabinet. Eleven electric resistance nichrome wire coils are sandwiched between the twelve layers of blocks.

Thermally responsive devices to monitor, control, and safeguard the electric thermal storage process comprise a thermocouple, a hydraulic bulb limit, and thermal fuse links. The charge control type K thermocouple is the normal means of controlling the storage core temperature. It provides the input necessary for the charge controller to determine the amount of charge in the core at any time during the off-peak period. The maximum normal core temperature is 750°C (1382°F).

The storage damper section, shown in detail in Figure 3-9, is located directly below the core section and on top of the support plenum. It is 15 inches high, 46 inches wide, and 28 inches from front to back. This unit contains the air mixing dampers and the electrical control panels for the storage unit. The upper set of mixing dampers (Figure 3-9) controls the amount of air passing through the core, and the lower set controls the volume of by-pass air. When the bottom (internal by-pass) dampers are fully open, the upper (face) dampers are closed. Each set of dampers is linked directly to the damper actuator motor which is a modulating type controlled by the proportional mixed air thermostat that is in the main supply duct.

The night heating section is located downstream from the heat storage core. The lower half of this section normally contains the fan for the entire system, but in this solar installation, the main blower is separately mounted as shown in Figure 1-2H. The upper half contains the control panel and the open coil resistance type heating elements used for night time heating of the house and for stand-by, on-peak heating. Also shown in Figure 1-2H is an internal auxiliary by-pass. The by-pass was installed late in the heating season and was not used during this reporting period.

The rate of air flow through the storage core varies with the charge level, that is, with the storage temperature. At lower charge levels, air flow rate through the core is higher, flow through the internal by-pass is lower, and the total flow through the entire unit is lower. The maximum air rate is obtained when the bottom damper is fully open and the face damper is closed. This maximum amount of air is available whenever the system is not extracting heat from the core and is therefore also the air volume available for air conditioning. The minimum total flow of air exists when the bottom damper is closed and the face damper is fully open. This condition exists at the end of the

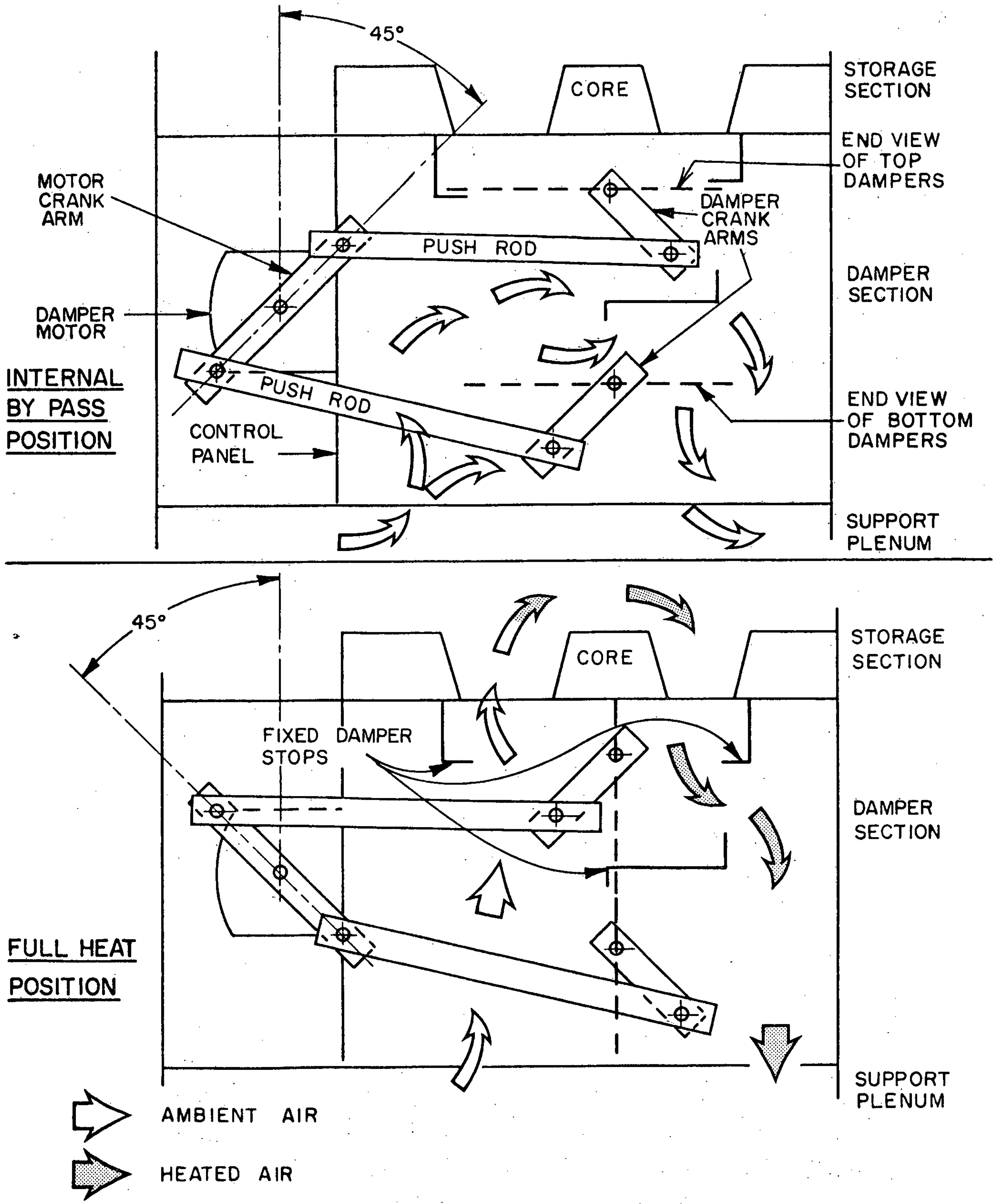



Figure 3-9. Internal Modulating Dampers - Off-Peak Heat Storage Unit

discharge period when all of the air is passing through the core and the temperature of the air leaving the core is at or below the set point of the mixed air duct thermostat.

Specifications and conditions of operation of the electric off-peak heating unit are presented in Table 3-3.

During the off-peak period, the night heating section supplies auxiliary heat, if needed, to air being circulated from the solar heating coil. During this period, the heat storage unit is also being charged by electric supply to a temperature automatically determined by reference to water temperature in the solar storage tank. The charge input is electronically calculated from the "desired charge level" less the amount of solar heat in storage and less the amount of charge remaining in the core from the previous off-peak period.

During the on-peak period, stored heat is extracted from the core by actuating the main blower and the internal dampers as called for by the second stage contact in the room thermostat. The face and by-pass dampers in the off-peak unit, controlled by the mixed air thermostat, supply a suitable portion of the circulated air through the hot core, to provide the desired supply air temperature to the house.

### 3.3.5 Chiller Characteristics

An Arkla Model WF-36 lithium bromide absorption water chiller, designed specifically for solar hot water operation, was installed in September 1976, along with an additional duct coil for cooling as shown in Figure 1-2C. The chiller has a nominal rating of 10.5 kW cooling output (3 refrigeration tons) at a chilled water outlet temperature of 7.2°C when supplied with 14.7 kW from hot water at 91°C and cooling water at 29°C. The resulting coefficient of performance (COP) is 0.72. Full cooling output is obtained within 20 minutes after start-up (compared with two to three hours for the 501 WF model). Solution concentration was reduced from the standard 52 percent to approximately 50 percent to take advantage of lower condenser water temperatures (24°C) available in the dry Colorado climate. Minimum useful hot water generator temperature has been thereby reduced to 68°C from the normal design minimum of 77°C for operation with 30°C condenser water. The performance characteristics of the Solar House I Arkla chiller are shown in Figure 3-10.

Table 3-3. Specifications for TPI Off-Peak Electric Auxiliary Heating Unit

## Electrical Specifications for Off-Peak Unit

| | |
|---|---|
| Storage capacity | 200 kWh |
| Charging load | 28.9 kW |
| Voltage | 240 volts |
| Amperage | 121 amps |
| Number of elements | 11 |
| Wattage per element | 2625 watts |
| Amperage per element | 11 amps |
| Number of supply circuits | 3 |
| Number of elements per circuit | |
| Top supply circuit | 4 |
| Middle supply circuit | 4 |
| Bottom supply circuit | 3 |
| Minimum wire sizes, supply circuits | 6 AWG CU<br>4 AWG AL |
| Fuse sizes, Top supply circuit | 60 amps |
| Middle supply circuit | 60 amps |
| Bottom supply circuit | 45 amps |
| Control voltage | 24 volts |
| Damper motor voltage | 24 volts |
| Charge controller, supply voltage | 24 volts |

## Night Heater Section

| | |
|---|---|
| Elements | |
| Total wattage | 15 kW |
| Voltage | 240 volts |
| Total amperage | 62.5 amps |
| Number of elements | 3 |
| Wattage per element | 5 kW |
| Amperage per element | 20.8 amps |
| Minimum wire sizes, supply circuit | 3 AWG CU |
| Fuse sizes, Two elements | 60 amps |
| One element | 30 amps |
| Fan motor, PSC type, 1/3 hp | |
| Voltage | 240 volts |
| Amperage, high speed | 3.1 amps |
| RPM, high speed | 1050 rpm |
| Minimum wire size | 14 GA CU |
| Fuse sizes | 10 amps |

continue on next page

Control circuit

| | |
|---|---|
| Maximum VA available for entire system | 75 VA |
| Voltage | 24 volts |

Maximum Air Flow

| Estimated Static Pressure | High Speed | Medium Speed |
|---|---|---|
| 0.2 in. | 1180 CFM | 1130 CFM |
| 0.5 in. | 1040 CFM | 990 CFM |

Minimum Air Flow

| Estimated Static Pressure | High Speed | Medium Speed |
|---|---|---|
| 0.2 in. | 890 CFM | 880 CFM |
| 0.5 in. | 730 CFM | 720 CFM |

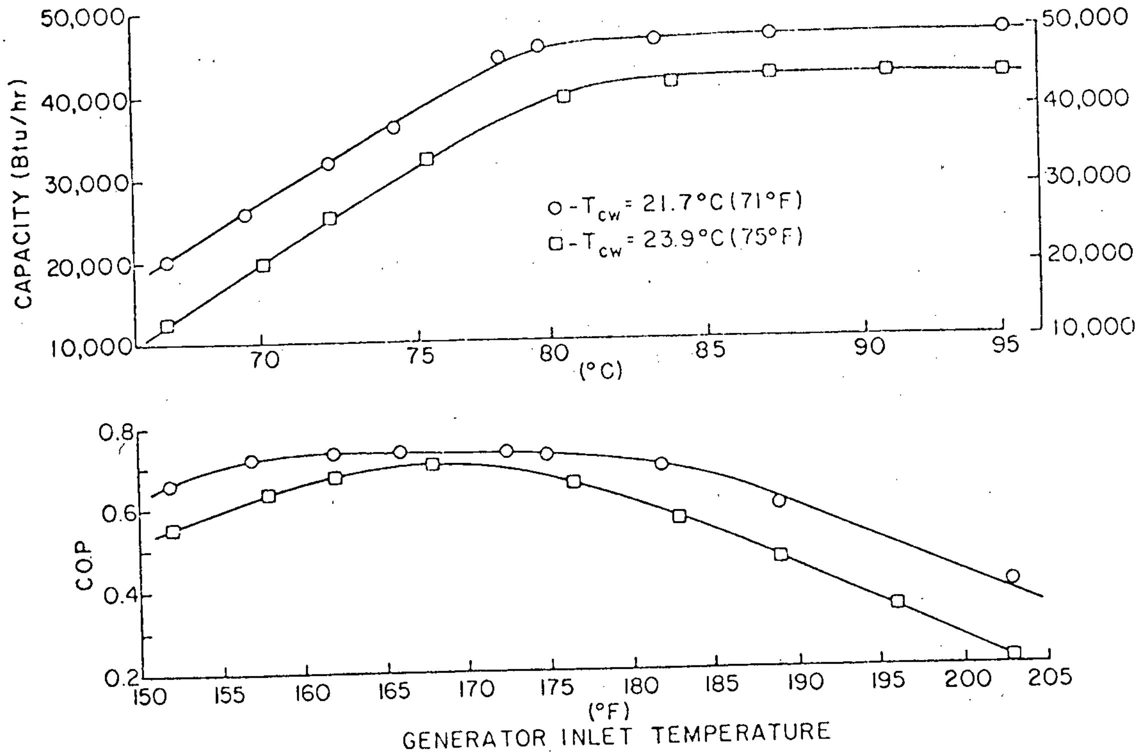



Figure 3-10. Modified Charge Arkla WF-36 Chiller Performance Characteristics

Normal hot water supply temperature to the chiller was 75 to 80°C, from solar storage or from the electrically heated boiler. Heat was rejected from the unit through a cooling tower, model number MO-697-12, located adjacent to the house. Chilled water at a temperature of approximately 7°C was circulated from the unit through the duct coil from which it returned to the chiller at a temperature of about 12°C.

When first installed, the cooling system included two cold water storage tanks each of 2270 liter capacity. "Cool" water from one tank at about 12°C was pumped through the evaporator coil of the chiller, and delivered to the "cold" tank at about 7°C. Water was then pumped from this storage tank through the air cooling coil and returned to the warmer "cool" tank at about 12°C. This arrangement provided cool storage and reduced somewhat the on/off cycling of the chiller. It was found, however, that the benefits of cool storage were not sufficient to justify its operation and cost, performance not being significantly affected by the cycling operation. The cold storage system was therefore not used in 1977 and was removed in the summer of 1978.

# 4. SYSTEM OPERATION

## 4.1 OPERATING MODES

There are two primary applications of collected solar energy in Solar House I: space heating and service hot water supply and space cooling and service hot water supply. Space heating or cooling includes options; (1) solar use for temperature control in the living space and (2) auxiliary use for the same purposes. Finally, service hot water is provided by heat exchange with solar storage, when possible, and supplemented by electric auxiliary heat in a "booster" solar water heater, as required. Figures 4-1H and 4-1C show the various winter and summer modes of operation of the systems.

### 4.1.1 Solar Collection and Storage

Whenever the absorber plate of the Philips Mark IV evacuated tube collector exceeded the temperature near the bottom of the storage tank by more than 10°C the collector and storage pumps were actuated, glycol solution was circulated through the collector and heat exchanger, and water from the bottom of the storage tank was circulated through the exchanger in a counterflow direction, back to the top of the storage tank. Heat was thus delivered to storage whenever conditions permitted. When the temperature at the exit of the collector fell to a level within 2° of the temperature at the bottom of the storage tank, the pumps were shut off.

The respective flow rates were 66 liters per minute in the collector loop and 26 liters per minute in the storage loop.

### 4.1.2 Solar Space Heating

When the room thermostat signaled a demand for heat in the living space, and if the temperature at the top of the storage tank exceeded 25°C, the main load pump was actuated and water from storage was circulated through the service water heat exchanger and through the air heating coil, back to the bottom of the storage tank. Simultaneously, the blower in the air duct was actuated, thereby drawing air through the coil and the off-peak unit and delivering it via ductwork to the rooms.

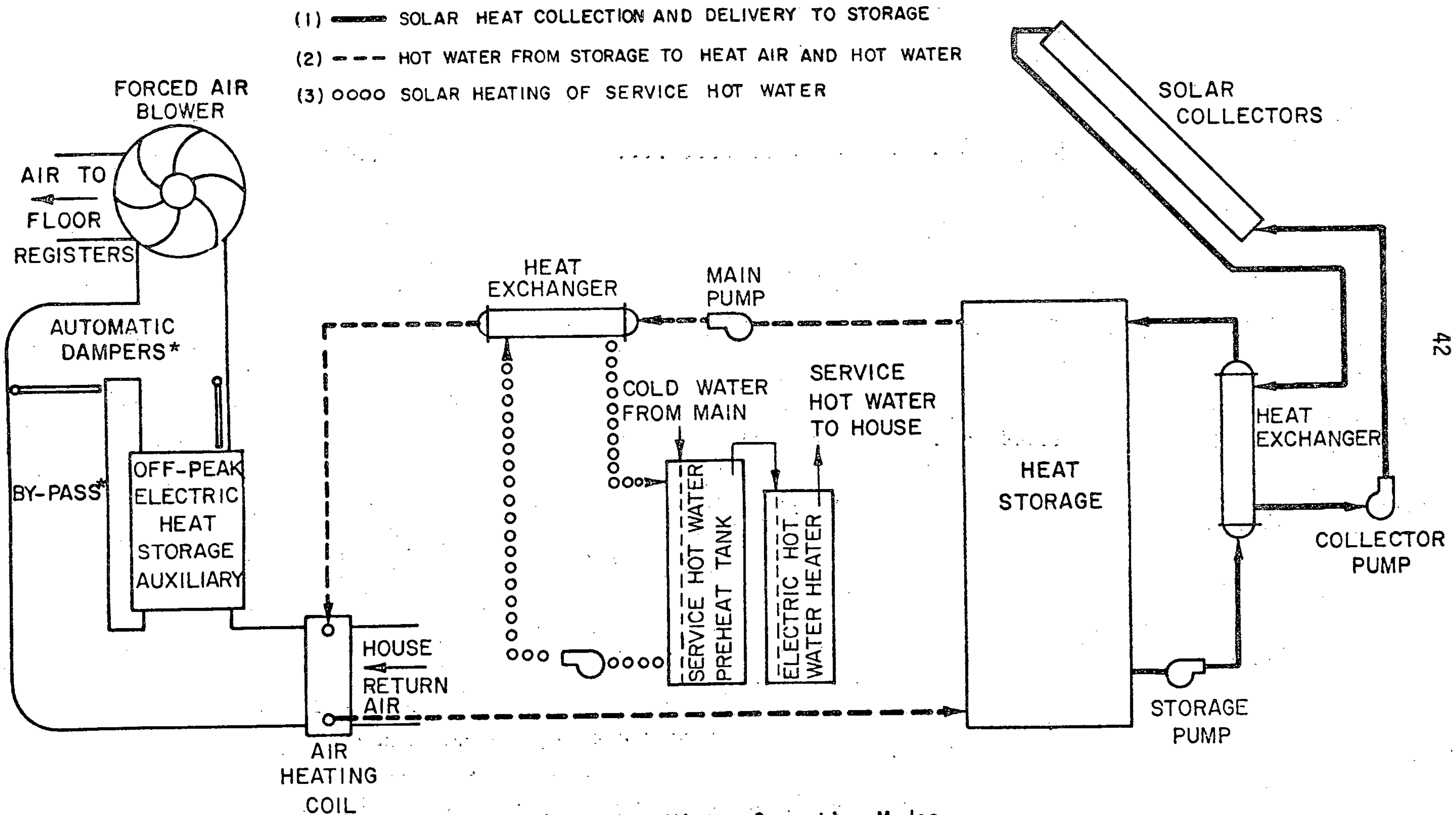



Figure 4-1H. Winter Operating Modes

*By-pass installed after winter of 1978-1979

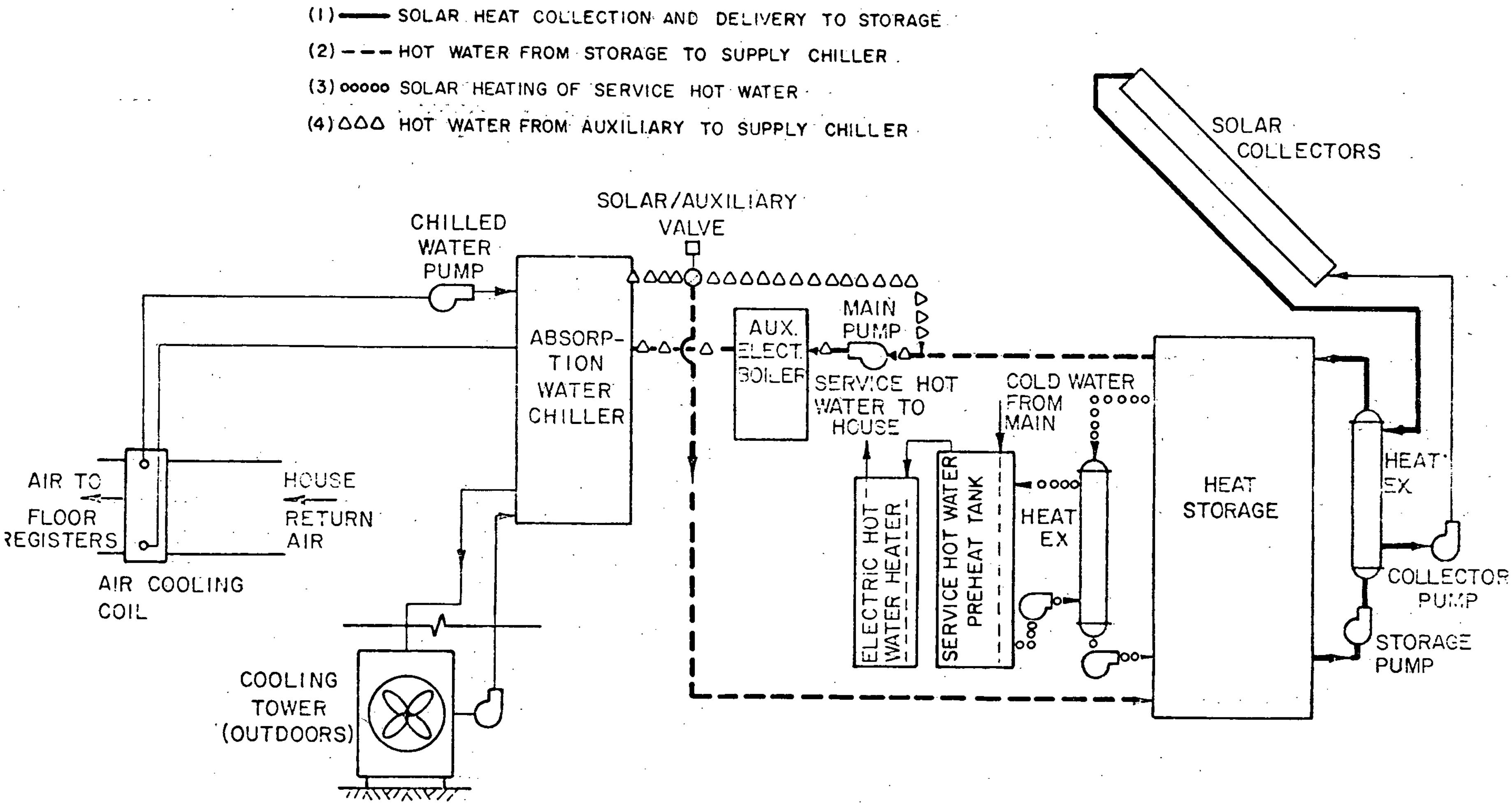



Figure 4-1C. Summer Operating Modes

When the room temperature increases above the "deadband" of the thermostat, the main circulating pump and the air blower cease operation. The heat utilization side of the system is then idle until the next call for heat. If, however, room temperature does not rise, but rather continues to decrease, a second contact in the room thermostat closes at a temperature about 1°C lower than the initial set temperature. The internal by-pass dampers are positioned so that enough air passes through the core to bring the air leaving the off-peak unit to a temperature of 60°C. During the period between 6:00 am and 10:00 pm (high utility system demand), modulating dampers in the off-peak furnace direct a portion of the air through the hot brickwork to a section in which this hot air is mixed with the balance of the air, then to the blower and the rooms. When needed at night, auxiliary electric heat is supplied directly to the air by electric resistors in the night section of the off-peak furnace. Under all conditions, the air stream passing to the rooms is at a temperature sufficient for subsequent return of the temperature in the living space to the desired level. At that point, solar and auxiliary heat supply are terminated and the system is again idle. On days that are substantially colder than average, and at times when stored solar heat is insufficient, auxiliary heat which has previously been supplied to the electric storage unit is thus used. There are no electric heat demands during day-time utility system peaks.

#### 4.1.3 Charging of Off-Peak Heat Storage Unit

Electric heat is supplied to the off-peak heat storage unit between 10:00 pm and 6:00 am during each night when sensors indicate insufficient solar heat in storage for supplying all space heating requirements the following day (until 10:00 pm), assuming no solar energy is received during that period and that coldest design temperature prevails. In that case, the controller actuates switches which deliver electric energy to the elements in the off-peak heat storage unit for a sufficient number of hours to provide stored heat which, when added to the solar heat in storage, will assure full heating the following day. If controls and monitors indicate adequate solar heat is in storage, no electricity is used to recharge the off-peak heat storage electric furnace. During the winter of 1978-79, the amount of electric energy added to off-peak heat storage was changed each month to recognize the difference in heating requirements during the milder months and during more severe weather. Less stored heat was required in April than in December, so the recharging of the off-peak unit reflected those differences in requirements.

An electric duct heater is also provided in the off-peak unit to provide day-time electric resistance heating if needed. At no time, however, during the winter of 1978-79 was day-time electric heating required, there always being sufficient solar heat and off-peak stored electric heat to meet the demand.

4.1.4 Service Water Heating, Winter 1978-79

When space heating was required and when the water at the top of the main solar storage tank reached a temperature 10°C higher than the temperature in the bottom of the service hot water tank, the main circulating pump started, and the small service hot water pump was actuated to transfer heat into the service hot water supply in the heat exchanger provided for that purpose. When the temperature in the service hot water preheat tank rose to within 2° of the temperature in the main solar heat storage tank, the small pump was shut off. This system design involved use of only one pump for circulating storage water, but service water could be heated only when space heating was also required. If both were required, potable water was circulated through one heat exchanger and air from the living space was circulated through the other.

4.1.5 Solar Cooling

When the system had previously been in the solar mode, the auxiliary valve was in a position such that water was drawn from solar storage through the pump and returned from the absorption chiller to the bottom of the storage tank. When room temperature rose above the wall thermostat set point, the main circulating pump was actuated, the chilled water pump and the cooling tower pump started, and the main system blower for air circulation through the cooling coil and the house was turned on. If the temperature at the top of the storage tank was greater than 70°C, the valve position remained unchanged, and the chiller generator was supplied with hot water from solar storage. However, if the temperature at the top of the solar storage tank was below 70°C, the auxiliary valve moved to the auxiliary position, and the chiller generator was supplied with water from the thermostatted hot water boiler to which electricity was simultaneously supplied.

When the system had previously been in the auxiliary mode and cooling was called for, it was supplied from auxiliary unless and until the storage tank top temperature rose above 75°C. When the storage top temperature rose above 75°C, the auxiliary valve position changed and the generator was supplied from solar storage.

The 75°C and 70°C set points were changed slightly several times during the cooling season in order to increase cooling performance. In another effort to increase cooling output and COP, an automatic tempering valve for blending outlet flow from the generator with inlet flow to the generator was installed in the latter part of the cooling season. Overfiring of the generator was thus prevented and maximum COP was obtained at storage temperatures even higher than 80°C (see Figure 3-9). Stratification is also enhanced by the resulting lower flow rates in and out of storage.

Operation of the chiller, either from main solar storage or from the auxiliary boiler, continued until the temperature in the living space fell below the thermostat setting, whereupon the heat supply to the chiller was terminated. However, the other chiller operations, (chilled water pump, cooling tower pump, and house air circulation fan) continued for several minutes in order that cooling capability stored in the chiller resulting from the elevated generator temperature and the low evaporator temperature could be fully utilized. After this delay, these elements were also shut off automatically.

Various controls in the absorption chiller itself regulate the temperature of cooling water supplied to the condenser, the temperature of the hot water supply to the generator, and the operation of the small solution pump which circulates the absorbent liquid.

4.1.6 Service Hot Water Heating in Summer

A "conventional" position of the service hot water heat exchanger, which provides direct exchange from main storage to service hot water via two small pumps and a heat exchanger, is shown in Figure 4-1C. When the temperature in main storage exceeds the temperature in the bottom of the service hot water preheat tank by 10°, the two pumps are actuated and heat is transferred to the service hot water. When this temperature difference falls below 2°, the pumps are shut off. If the temperature in the preheat tank exceeds 60°C no further energy is supplied from the main tank. As water is drawn from the service hot water system, cold water enters the preheat tank and warm water flows from the preheat tank to the auxiliary electric hot water heater. If the temperature in the electric water heater falls below the thermostat setting in that tank, electricity is automatically supplied and the temperature of the water is raised to the thermostat setting.

## 4.2 CONTROLS

Table 4-1H and 4-1C show, for winter and summer seasons, the various modes of operation, the conditions applicable to each mode, and the position or operation of the various elements which control air and liquid flow. In reality, the question of whether cooling or heating was required is answered by the same instrument, the house thermostat, with different contacts and settings applicable to each function.

It is seen that space heating and water heating, and the storing of solar and auxiliary heat, involved nine operating modes, the last two of which are the absence of heat supply or demand. Seven temperature sensor conditions and one time-of-day condition, under the category, "Conditions," controlled the ten operating components in the "Motors and Switches" category to provide each type of system operation. Some of the sensors, such as the two-stage house thermostat, detected a difference between an actual temperature and a preset value, whereas others were used in circuits which detected differences between varying temperatures at two locations in the system. The table shows that each operating mode was implemented by a sensor condition being met (Y = yes) and other sensor conditions either not being met (N = no) or not being relevant (X).

Motors and switches which drove pumps, fans, damper and valve motors, and electric heating elements were actuated by relays receiving signals from the sensors. Operation is indicated by Y (yes), and the idle condition is N (no). The symbols O and C indicate whether dampers and valves are open or closed, respectively. The X symbol indicates that in the applicable operating mode, the sensor condition and the motor-switch function are not relevant, and could be either Y or N, O or C. The X symbol also applies to conditions and functions in an operating mode that may be occurring simultaneously with another

# Table 4-1H. Truth Table for Winter Modes of Operation

| OPERATION | CONDITIONS: TFC > (STB + 9°)* | (OPCM + fSTM) < monthly setting | THD < Setting #1 | THD < Setting #2 | Time after 10 pm, before 6 am | STT > (TPB + 10°C) and TPT < 60°C TPT < 60°C | STT > (TPB + 10°C) and TPT > 60°C | TSHW < setting | MOTORS AND SWITCHES: Collector pump | Storage pump | Main pump (loads) | D.H.W. Pump | House Blower | By-Pass Damper | Off-Peak Furnace Damper | Power Switch for Electric Storage | Power Switch for Night Auxiliary Heat | Power Switch for DHW Auxiliary |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Winter Modes** | | | | | | | | | | | | | | | | | | |
| • Collecting Solar Heat | Y | X | X | X | X | X | X | X | Y | Y | X | X | X | X | X | X | X | X |
| • Charging off-peak electic | X | Y | X | N | Y | X | X | X | X | X | X | X | X | X | X | Y | X | X |
| • Space heating from solar** | X | X | Y | N | X | X | X | X | X | X | Y | X | Y | O | C | X | N | X |
| • Space heating from solar plus auxiliary at night (10 pm to 6 am) | X | X | Y | Y | Y | X | X | X | X | X | Y | X | Y | C | O | N | Y | X |
| • Space heating from solar plus auxiliary during day (6am to 10pm) | X | X | Y | Y | N | X | X | X | X | X | Y | X | Y | C | O | N | N | X |
| • Service hot water heating-solar** | X | X | X | X | X | Y | N | X | X | X | Y | Y | X | X | X | X | X | X |
| • Service hot water heating-auxiliary | X | X | X | X | X | X | X | Y | X | X | X | X | X | X | X | X | X | Y |
| • No energy supply or demand | N | N | N | N | X | N | X | N | N | N | N | N | N | X | X | N | N | N |
| • Solar service hot water overheated | X | X | X | X | X | X | Y | X | X | X | X | N | X | X | X | X | X | X |

Notes:

Temperature difference necessary to start collecting. Collection continues until temperature difference falls below 2°C
**Solar supply to space heating and hot water is always from solar storage

f = multiplying factor
TFC = temperature from collector
STB = temperature at bottom of storage
OPCM = off-peak core temperature
STM = mean temperature in storage
THD = temperature of house air
STT = temperature at top of storage

Y = Yes
N = No
O = Open
C = Closed
X = does not matter

# Table 4-1C. Truth Table for Summer Modes of Operation

| OPERATION | CONDITIONS: TFC > (STB+9°)* | THD > Setting and STT > 70°C | THD > Setting and STT > 74°C | THD > Setting and STT < 70°C | STT > (TPB+10°C) and TPT < 60°C | STT > (TPB+10°C) and TPT > 60°C | TSHW < Setting | MOTORS AND SWITCHES: Collector Pump | Storage Pump | Main Load Pump | Tempering Valve | Chilled Water Pump | Cooling Tower Pump | Cooling Tower Fan | Solar/Auxiliary Valve | House Blower | 2 Service Hot Water Pumps | Power switch for electric boiler | Power switch for DHW aux. heater |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Summer Modes | | | | | | | | | | | | | | | | | | | |
| • Collecting Solar Heat | Y | X | X | X | X | X | X | Y | Y | X | X | X | X | X | X | X | X | X | X |
| • Space Cooling from Solar** | X | Y | N | N | X | X | X | X | X | Y | C | Y | Y | Y | S | Y | X | N | X |
| • Space Cooling from Solar | X | Y | Y | N | X | X | X | X | X | Y | O | Y | Y | Y | S | Y | X | N | X |
| • Space Cooling from Auxiliary | X | N | N | Y | X | X | X | X | X | Y | O | Y | Y | Y | A | Y | X | Y | X |
| • Service water** heating-solar | X | X | X | X | Y | N | X | X | X | X | X | X | X | X | X | X | Y | X | X |
| • Service service water tank overheated | X | X | X | X | N | Y | X | X | X | X | X | X | X | X | X | X | N | X | X |
| • Service water heating-auxiliary | X | X | X | X | X | X | Y | X | X | X | X | X | X | X | X | X | X | X | Y |
| • No solar heat collection or demand | N | N | N | N | N | N | N | N | N | N | X | N | N | N | X | N | N | N | N |

Notes:

*Temperature difference necessary to start collecting. Collection continues until temperature difference falls below 2°C.
**Solar supply to space cooling and hot water is always from solar storage

TFC = temperature from collector
STB = temperature at bottom of storage
THD = temperature of house air
STT = temperature at top of storage
TPB = temperature at bottom of service water preheat tank
TPT = temperature at top of service water preheat tank
TSHW = temperature of service hot water in auxiliary heater

Y = Yes
N = No
O = Open
C = Closed
X = does not matter
S = value in solar position
A = value in auxiliary heating position

mode, such as solar heat collection and space heating from solar with or without auxiliary. Charging off-peak electric storage simultaneously with service water heating represents another example. The truth table can be read, in such situations, by combining the two modes, replacing X symbols in each with the condition N, Y, O, or C shown in the other simultaneous mode.

Table 4-1C applicable to the cooling season is equivalent to Table 4-1H but with seven modes (plus a minor subdivision of one), seven sensor conditions, and 12 motor-switch functions.

# 5. THERMAL PERFORMANCE EVALUATION

An easily understood report should have a structure that allows the reader to grasp salient points without having to repeatedly refer to other parts of the text. In dealing with a complex topic requiring definition of numerous quantities, the nomenclature must be meaningful and consistent. Otherwise, the reader will be faced with the task of memorizing a large number of definitions before he can begin to read and understand the report. This section contains a thermal performance evaluation structure based on recommendations in the IEA Reporting Format report [11]. The nomenclature is based on that given in the IEA document with a few additions, changes, and standardizations which were needed to make definitions more self evident and consistent. The standard nomenclature designators are shown in Tables 5-1 through 5-4.

The structure and nomenclature were established to best meet several objectives. The first is to be able to make a direct and easily understood thermal performance comparison with conventional space heating, space cooling, and service hot water heating systems. A second is to make results understandable by both the technical and semitechnical reader. The third is to associate appropriate measures of thermal performance with distinguishable subsystems so that performance changes, operating malfunctions, and measurement errors can be readily traced to their source.

The specifications of Table 5-1 allow immediate identification of the subsystem in which the measurement or energy flow is occuring. Quantities summarizing overall system performance are also readily identified. Specifications in Table 5-2 identify the form of the energy or what type of quantity is represented, such as a temperature or a performance indicator. Table 5-3 is particularly important in providing a designator which identifies the source of values used in the tables and figures in this report, that is, whether based on measured or estimated quantities. By reserving the designators in Table 5-4 for specific types of energies applicable to most or all subsystems, the total number of definitions that need to be associated with different designators may be reduced.

Table 5-1. Subsystem Designations

| Number Sequence | Subsystem/Data Group |
|---|---|
| 001-099 | Climatological |
| 100-199 | Collector subsystem |
| 200-299 | Storage subsystem |
| 300-399 | Domestic hot water subsystem |
| 400-499 | Space heating subsystem |
| 500-599 | Space cooling subsystem |
| 600-699 | Building and system summary |

Table 5-2. Quantity or Energy Form Designations

| Preceding Letter | Quantity or Energy Form |
|---|---|
| E | Electrical energy |
| F | Fossil or chemical energy |
| N | Performance indicator |
| Q | Thermal energy |
| S | Solar irradiant energy |
| T | Temperature |
| W | Flow |

Table 5-3. Method of Evaluation Designation

| Appended Letter | Method of Evaluation |
|---|---|
| M | Measured or calculated solely from measured quantities |
| E | Estimated or calculated solely from estimated quantities |
| C | Calculated from measured and estimated quantities |

Table 5-4. Reserved Designations Applicable to All Subsystems

| Number | Designation |
|---|---|
| -00 | Controlled energy from other subsystems |
| -01 | Auxiliary energy |
| -02 | Controlled energy to other subsystems (also cooling requirements satisfied) |
| -03 | Operating energy |
| -04 | Total heat loss |
| -05 | Energy stored |
| -06 | Total energy from other subsystems |
| -07 | Total energy to other subsystems |
| -50 | Usable heat loss |
| -52 | Unusable heat loss |

## 5.1 THERMAL PERFORMANCE FACTORS

To clearly indicate what measurements were made and what quantities are being reported, the following energy quantities, temperatures, and thermal performance indicators are defined. The thermal performance factors defined were calculated for hourly, daily, or monthly periods.

### 5.1.1 Energy Quantities

Figure 5-1H displays the energy quantities relevant to the 1978-1979 heating season. Figure 5-1C displays the 1979 cooling season quantities. Figures 5-2H through 5-5H provide a more detailed breakdown of the energy flows and quantities, illustrate calculations, and indicate which quantities were measured, estimated, and calculated. Figures 5-2C through 5-5C provide the same information for the cooling season. Energy quantities shown in the Notes pertaining to each subsystem (Figures 5-2 through 5-5) are identified in the accompanying flow diagram or in the total system diagrams, Figures 5-1H and 5-1C.

Table 5-5H lists the energy quantities that were used in evaluating thermal performance during the 1978-1979 heating season. Table 5-5C lists those quantities relevant to the 1979 cooling season. Both the current CSU acronyms and proposed IEA acronyms are indicated as are the periods for which computations have been performed.

Though many of the quantities in Figures 5-2H through 5-5H and 5-2C through 5-5C are not designated M, E or C, sufficient information is available for calculation of these quantities if desired. For example, the operating hours for the collector were recorded hourly and daily so that an accurate calculation of individual values (Figure 5-2H) of E120, E121, Q159, and Q163, based on known characteristics of the pumps and motors, could be made. Consequently, Q200 can be calculated. The figures do reflect precisely the values and calculations used in the evaluation of performance in Solar House I.

### 5.1.2 Thermal Performance Indicators

Table 5-6H provides definitions, descriptions, and formulas for the thermal performance indicators used in the evaluation of thermal performance during the heating season. Similar information is shown in Table 5-6C for the cooling season.

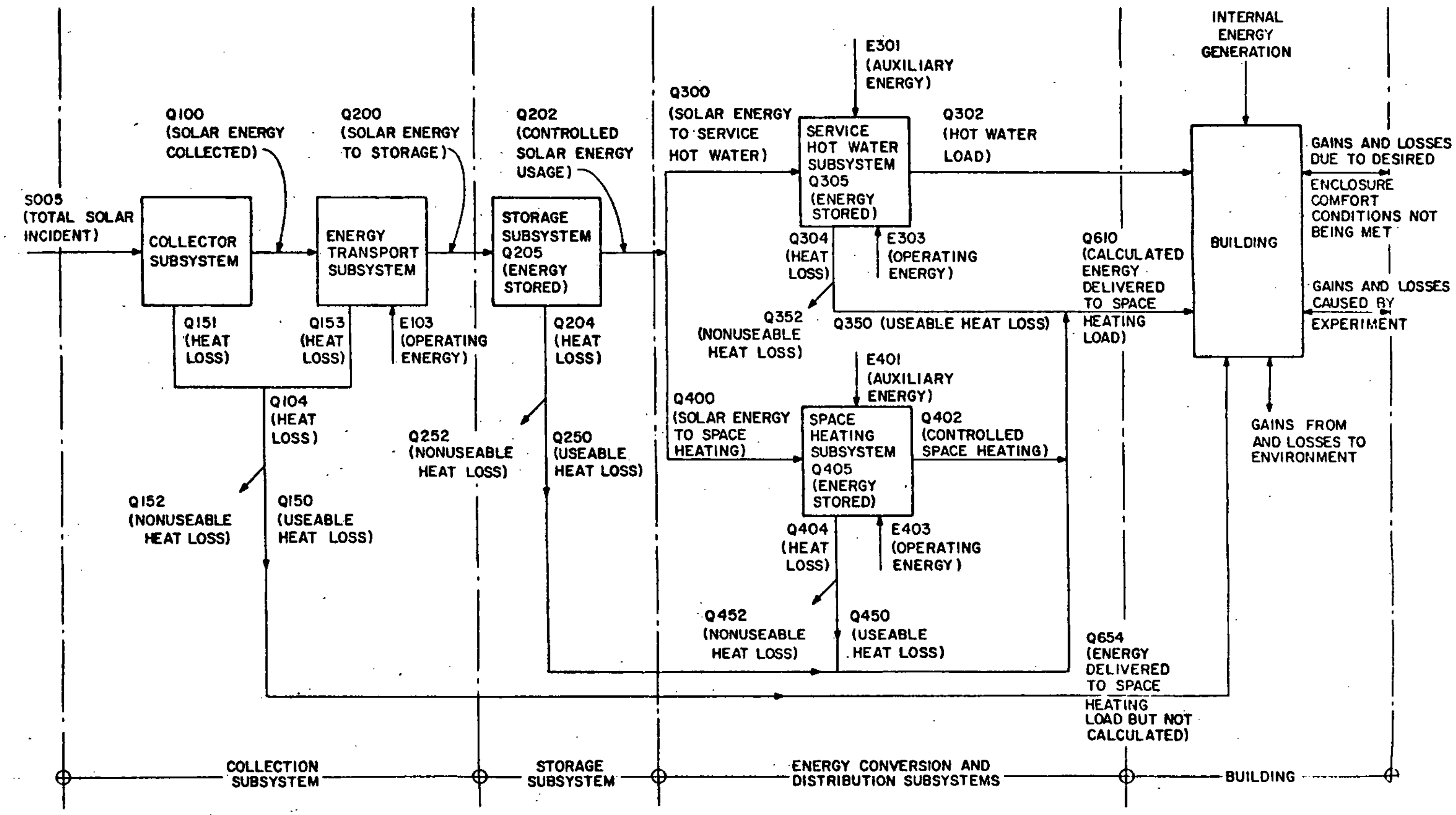



Figure 5-1H. Solar House I Energy Flows, Winter 1978-1979

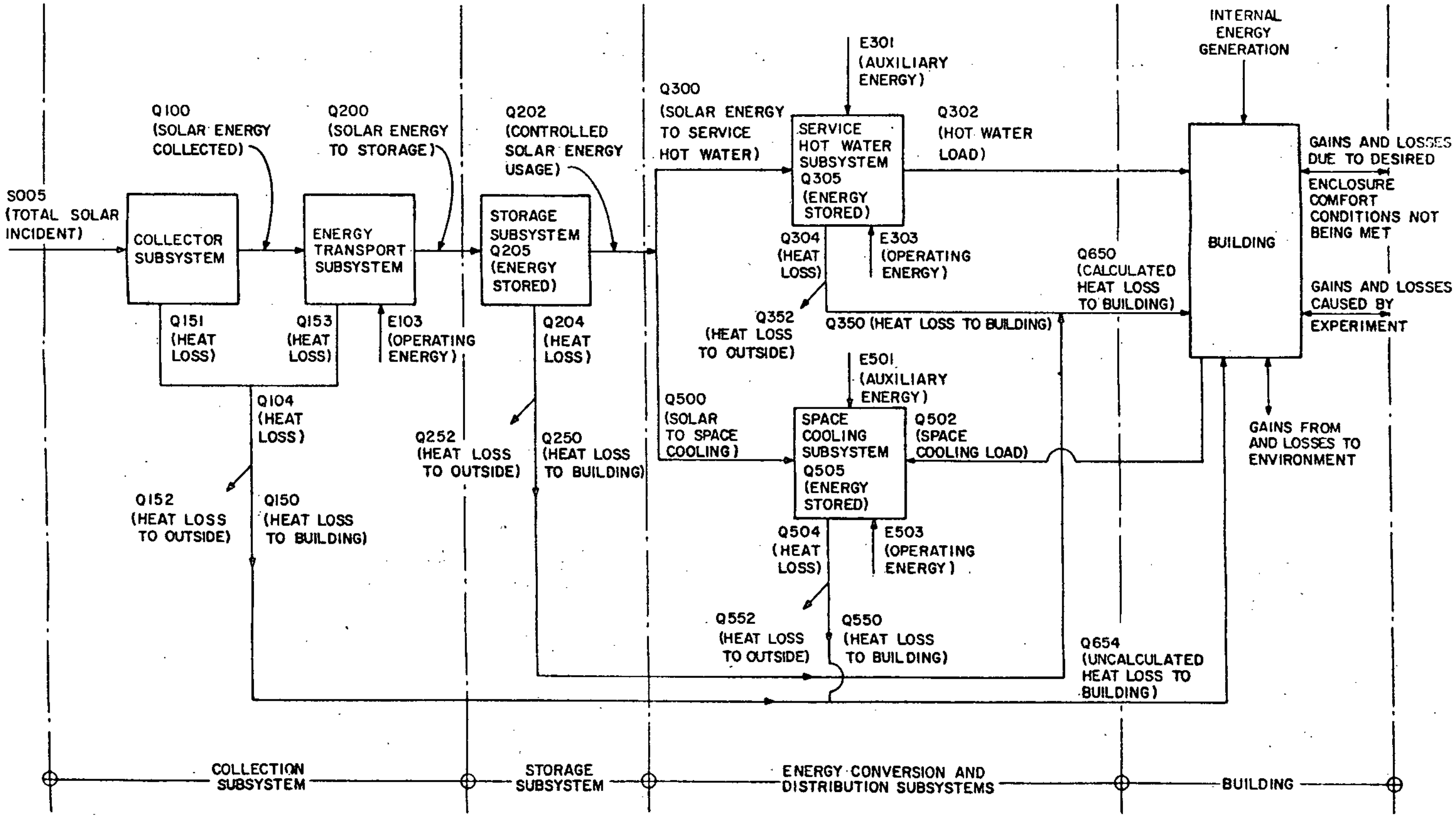
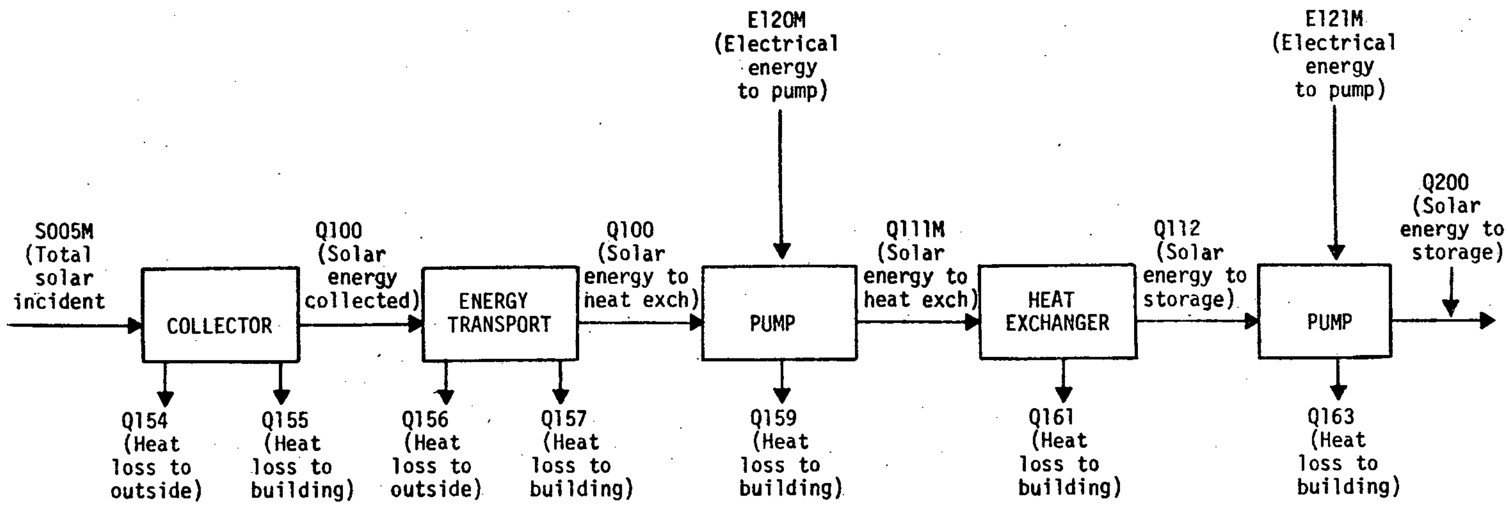


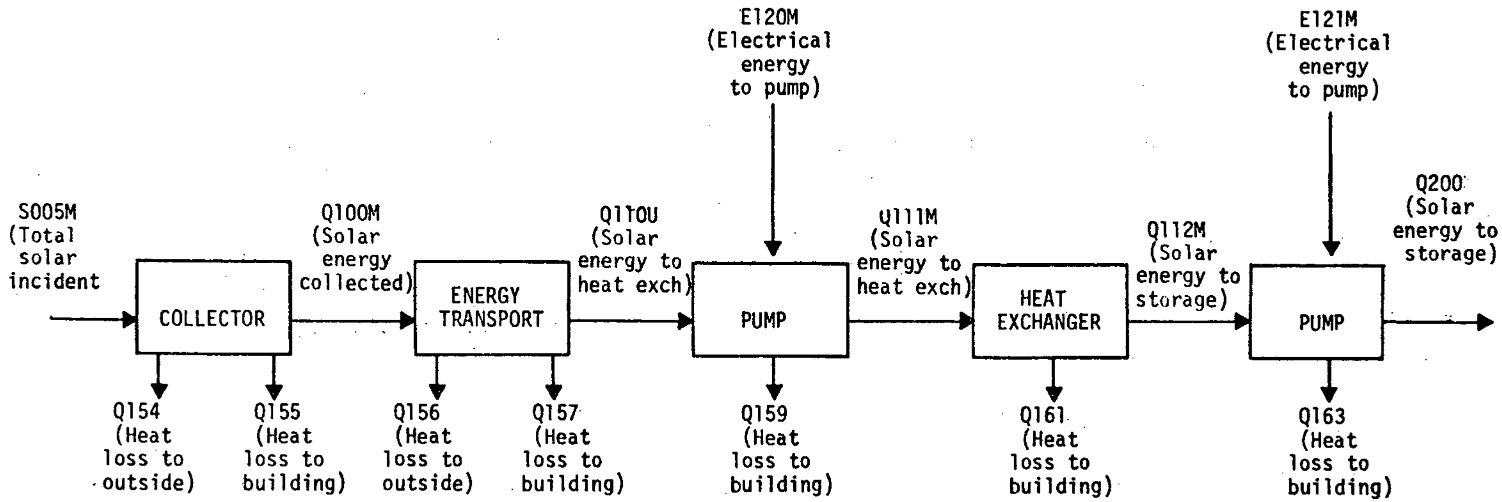

Figure 5-1C. Solar House I Energy Flows, Summer 1979




NOTES:

E120, E121, and E303 are measured collectively
E103 = E120 + E121
Q151 = Q154 + Q155
Q153 = Q156 + Q157 + Q159 + Q161 + Q163
Energy stored in the collection system, Q105, is generally lost overnight
Q150 = Q155 + Q157 + Q159 + Q161 + Q163
Q152 = Q154 + Q156
Q104 = Q150 + Q152
In the winter 1978-1979 performance calculations Q111 is used as "Solar energy delivered to main storage" in place of Q200

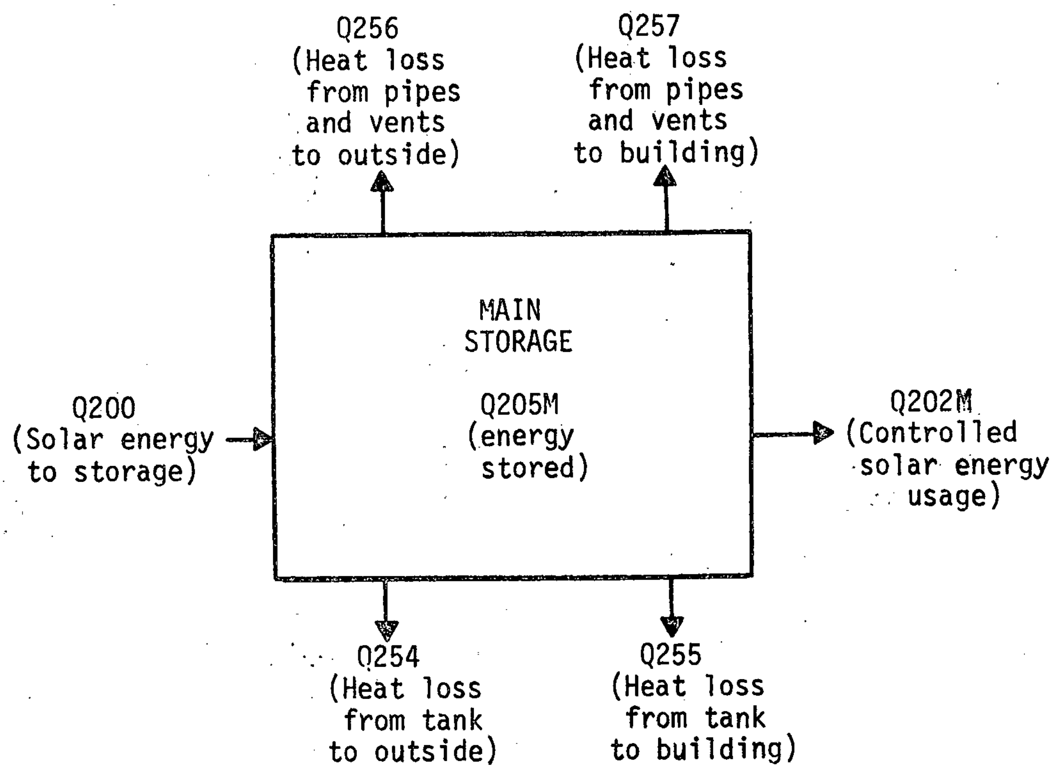
Figure 5-2H. Collection System Energy Flows, Winter 1978-1979




NOTES:

E120, E121, and E303 are measured collectively
E103 = E120 + E121
Q151 = Q154 + Q155
Q153 = Q156 + Q157 + Q159 + Q161 + Q163
Energy stored in the collection system, Q105, is generally lost overnight
Q150 = Q155 + Q157 + Q159 + Q161 + Q163
Q152 = Q154 + Q156
Q104 = Q150 + Q152
In summer 1979 performance calculations Q112 is used as "Solar energy delivered to main storage" in place of Q200

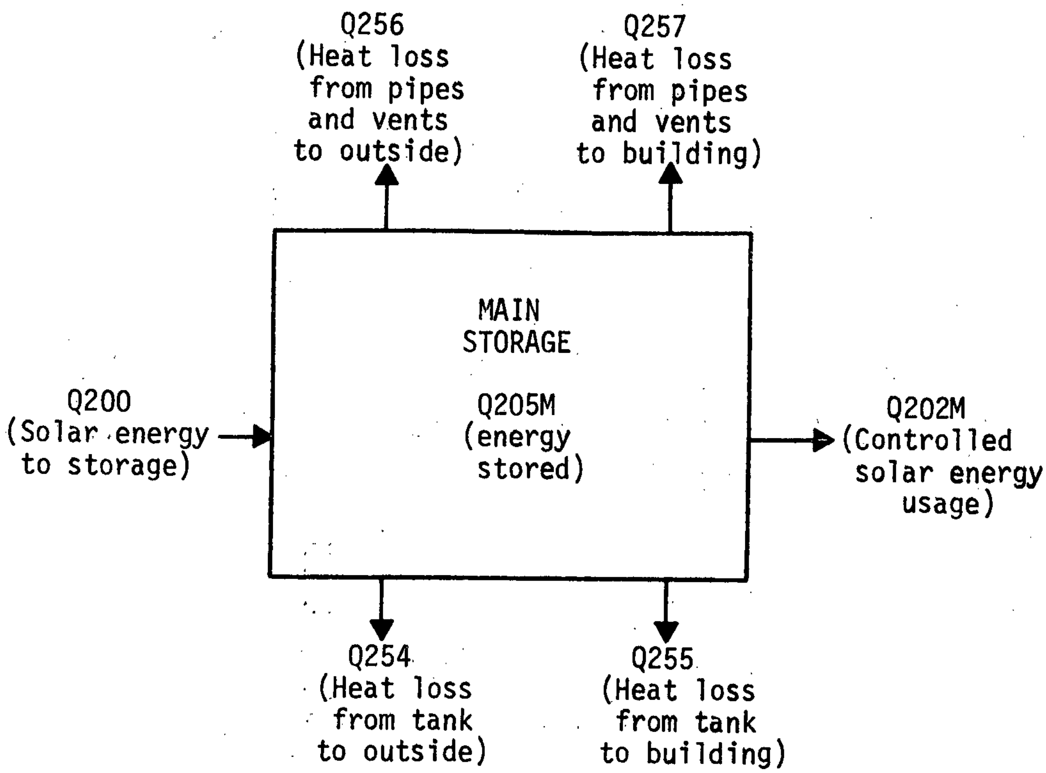
Figure 5-2C. Collection System Energy Flows, Summer 1979




NOTES:

Q112 is used as "solar energy to storage" in place of Q200
Q202 = Q412 + Q312
Q204M = Q211M - ΔQ205M - Q411M - Q310M
Q204E is calculated using loss coefficients determined by overnight heat loss experiments with the vents closed
Q250 = Q255 + Q257
Q252 = Q254 + Q256
Q250 = Q204M if space heating is performed during the day and is zero otherwise
Q252 = Q204 - Q250

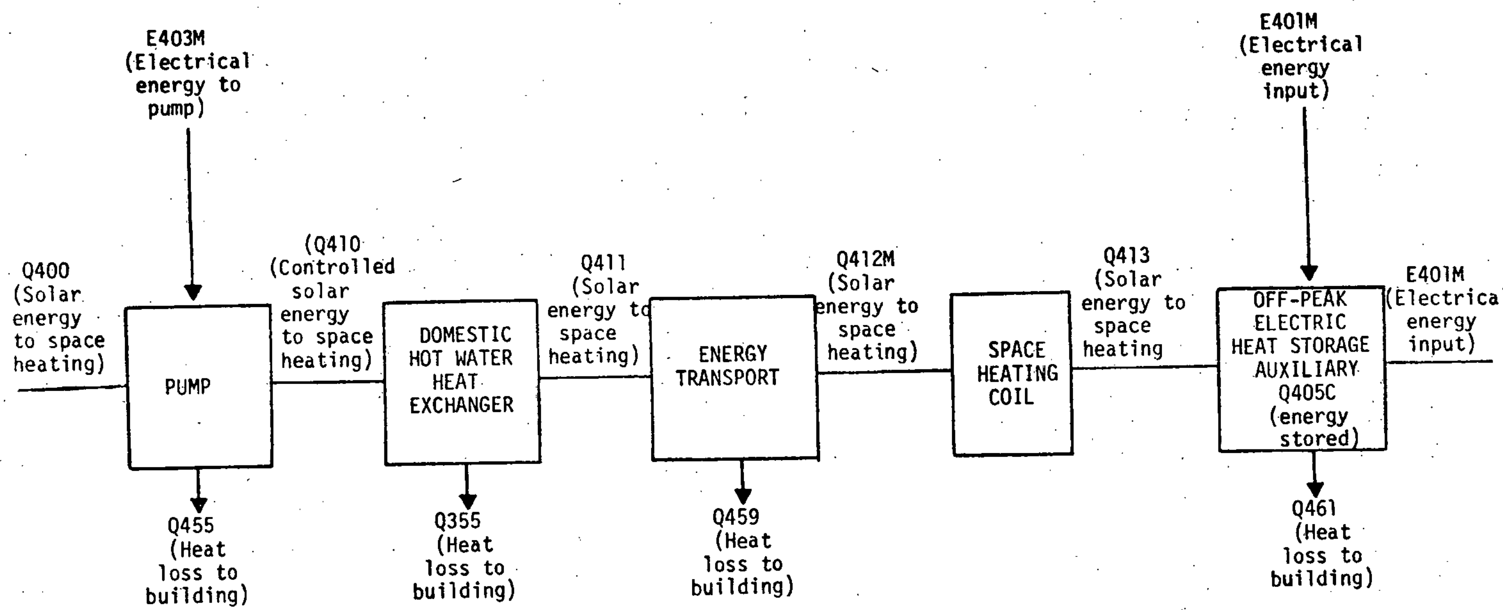
Figure 5-3H. Storage System Energy Flows, Winter 1978-1979




NOTES:

Q112 is used as "solar energy to storage" in place of Q200
Q202 = Q412 + Q312
Q204M = Q211M - ΔQ205M - Q411M - Q310M
Q204E is calculated using loss coefficients determined by overnight heat loss experiments with the vents closed
Q250 = Q255 + Q257
Q252 = Q254 + Q256
Q250 = Q204
Q252 = 0

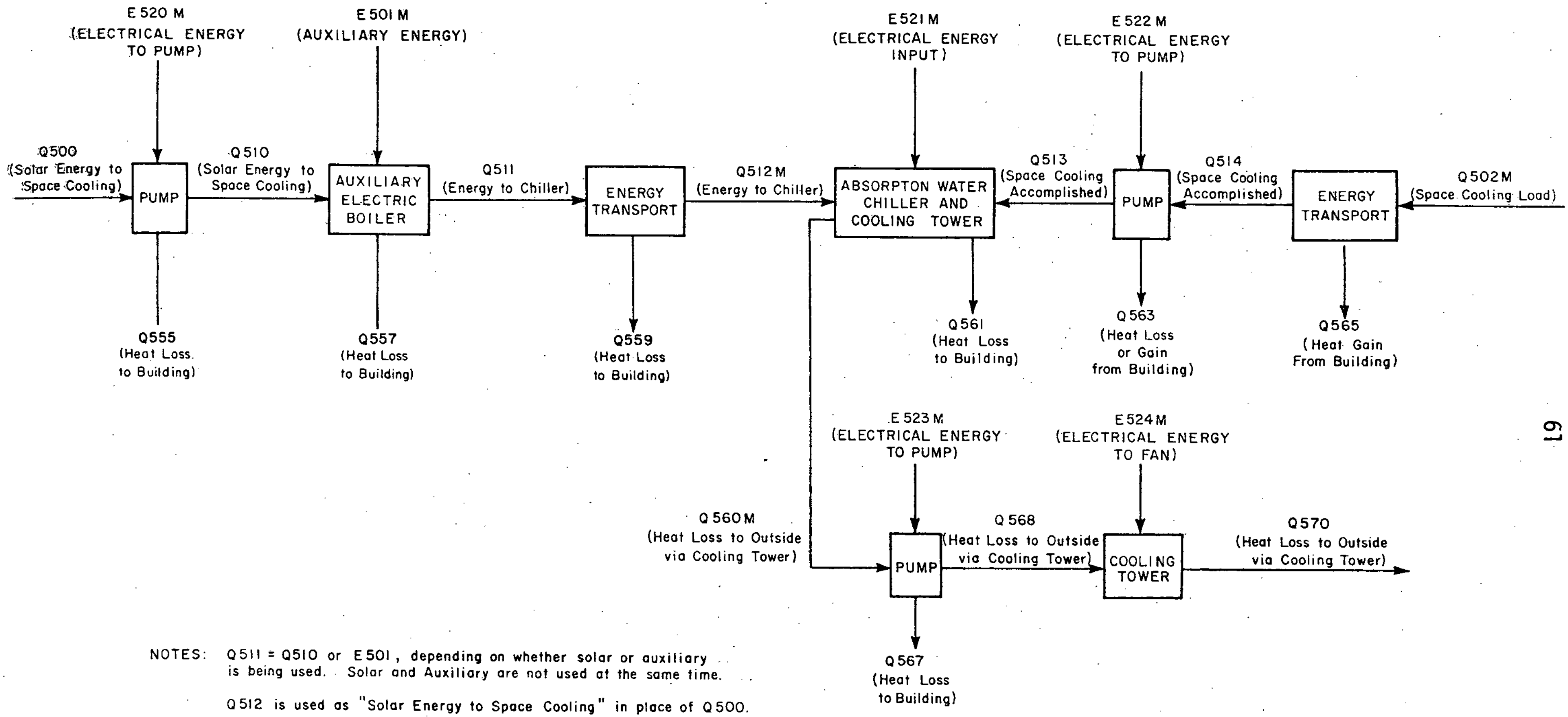
Figure 5-3C. Storage System Energy Flows, Summer 1979




NOTES:

Q412 is used as "Solar energy to space heating" in place of Q400.
Q461 is considered to be zero and all of E401 is eventually apportioned to Q402, though with some lag, for the winter 1978-1979 performance calculations

Figure 5-4H. Space Heating System Energy Flows, Winter 1978-1979




NOTES: Q511 = Q510 or E501, depending on whether solar or auxiliary is being used. Solar and Auxiliary are not used at the same time.

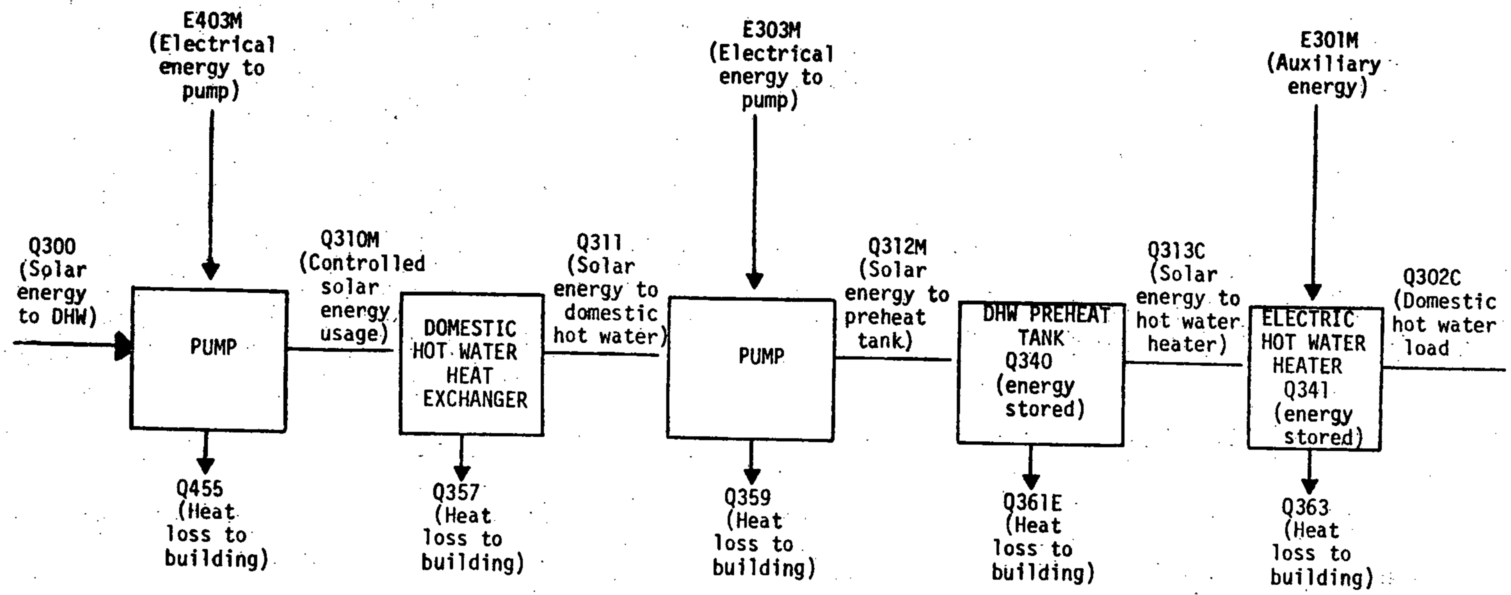
Q512 is used as "Solar Energy to Space Cooling" in place of Q500.

E503 = E521 + E522 + E523 + E524

Q540 solar space cooling = Q512 - E501

Q541 solar cooling supplied = Q502 When Solar Energy is Used

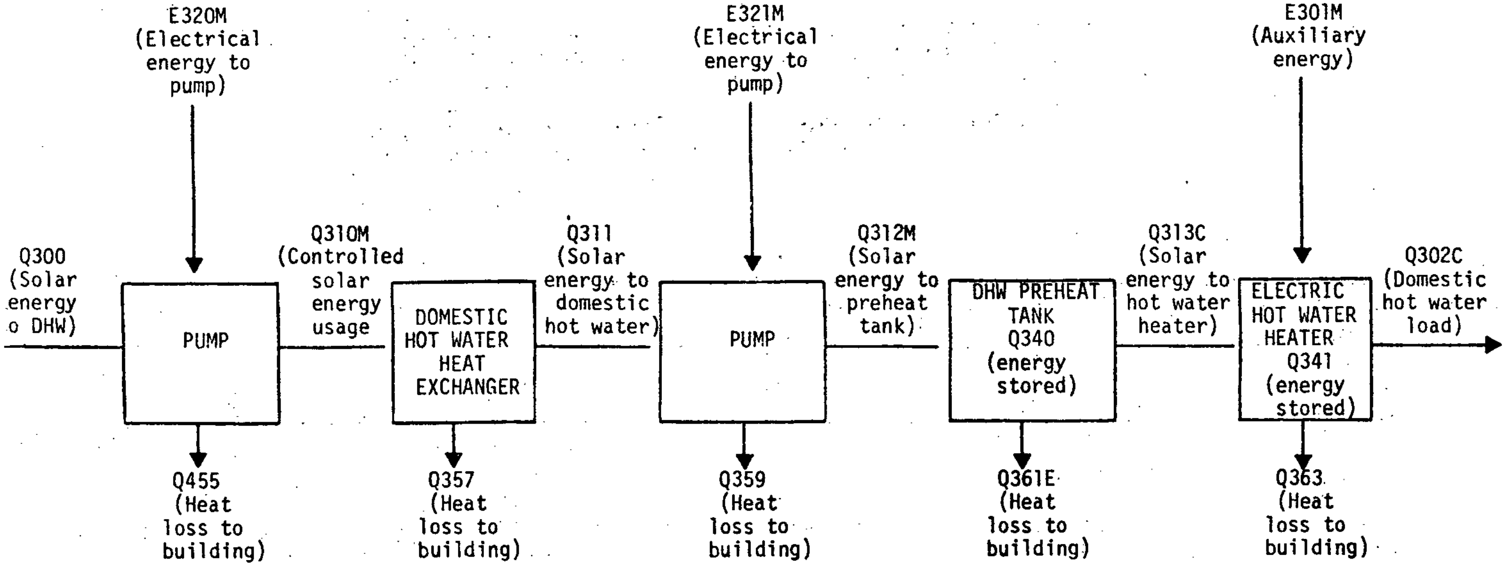
Figure 5-4C. Space Cooling System Energy Flows, Summer 1979




NOTES:

Q313 = Q312 - Q361
Q305 = Q340 + Q341
E303, E120 and E 121 are measured collectively
Q312 is used as "Solar energy to the preheat tank" in place of Q300
Q350 = Q361
Energy can only be sent to the domestic hot water preheat tank when energy is flowing to the space heating load. When energy is being sent to the preheat tank, only a portion of the energy flow from storage, Q202, flows to preheat.

Figure 5-5H. Domestic Hot Water System Energy Flows, Winter 1978-1979




NOTES:

E303 = E320 + E321
E303, E120 and E121 are measured collectively
Q305 = Q340 + Q341
Q312 is used as "Solar energy to the preheat tank" in place of Q300
Q305 = Q361

Figure 5-5C. Domestic Hot Water System Energy Flows, Summer 1979

## Table 5-5H. Solar House I Reported Energy Quantities, Winter 1978-1979

| IEA Acronym | CSU Acronym | Definition | Calculation Period Hour | Day | Month |
|---|---|---|---|---|---|
| | | Collection and Storage Subsystems | | | |
| S001 | S45 | Total solar incident in the aperture plane per unit area | | x | x |
| S003 | S450 | Total solar incident in the aperture plane while collecting per unit area | | x | |
| S005 | S45 | Total solar incident in the aperture plane on the collector aperture (S001 x $A_a$) | | | x |
| S006 | | Total solar incident in the aperture plane on the collector (S001 x $A_c$) | | | x |
| S007 | S450 | Total solar incident in the aperture plane on the collector aperture while collecting (S003 x $A_a$) | x | | x |
| S008 | | Solar incident in the aperture plane on the collector while collecting (S003 x $A_c$) | x | | x |
| Q100 | | Solar energy collected | | | |
| E103 | ELECS* | Operating energy for solar collection | | x | x |
| Q111 | QU | Solar energy delivered to the collector/storage heat exchanger (includes a minor energy contribution from the collector pump) | x | x | x |
| Q153 | | Heat loss occurring between collector and main storage tank | | | |
| Q202 | QSOLAR | Controlled solar energy used for space heating and hot water | | x | |
| Q204E | QTLOSS | Heat loss from main storage tank, estimated | | x | x |
| Q204M | | Heat loss from main storage tank, measured (Q112 - ΔQ203 - Q412 - Q312) | | | x |
| Q212 | QSHB | Storage energy transferred to the load subsystems in a controlled manner calculated by a heat balance (Q112 - ΔQ203 - Q204) | | x | |
| | | Energy Conversion and Distribution Subsystems | | | |
| E301 | QHWE | Auxiliary energy delivered to the domestic hot water heater | x | x | x |
| E303 | ELECS* | Operating energy for delivery of energy to the preheat tank | | x | x |
| ΔQ305 | DELQPH | Change in service hot water system stored energy | | x | |
| Q312 | QPH | Solar energy delivered to the domestic hot water system (preheat tank) | x | x | |
| Q313 | QSHWS | Energy transferred from the preheat tank to the service hot water tank | x | x | |
| Q340 | HBPH | Heat balance on preheat tank (Q312 - Q313 - ΔQ305 - Q350) | | x | |
| Q350 | QPHL | Usable heat loss from the service hot water system, heat loss from the preheat tank, estimated | | x | x |
| Q352 | QHWL | Nonusable heat loss from the service hot water system, heat loss from the service hot water heater tank, estimated | | x | x |
| E401 | | Energy to the off-peak auxiliary | x | x | x |
| Q402 | QLOAD & HLDM | "Controlled" energy to space heating load (loss from the off-peak unit is included) | | x | x |
| Q412 | QPCS | Solar energy to space heating | | | x |
| Q442C | QPCE & QAUX | Auxiliary energy to space heating; apportioned from E401, with some lag, using off-peak core storage temperature measurements (loss from off-peak unit is included) | | x | x |
| | | Building and Summary | | | |
| Q600 | | Controlled energy to building (Q402 + Q302) | | x | x |
| Q601 | | Total auxiliary energy (Q401 + Q301) | | x | x |
| Q603 | | Total operating energy (Q103 + Q300) | | | |
| Q604C | SLA | Calculated heat loss (Q204M + Q305E) | | x | x |
| Q604E | | Calculated heat loss based on estimates (Q204E + Q350E) | | | |
| Q606 | | Total energy supplied (Q610 + Q302) | | | |
| Q607 | | Total solar energy supplied (Q611 + Q313) | | x | x |
| Q610 | | Calculated energy delivered to space heating (Q611 + Q442) | | x | x |
| Q611 | | Calculated solar energy delivered to space heating (Q412 + Q650C) | | x | x |
| E613 | | Operating energy for the solar energy system (E103 + E320) | | x | x |
| Q650C | USLA | Useful calculated heat loss (equal to Q604C if space heating was required during the day and equal to zero otherwise) | | x | x |
| Q650E | | Useful calculated heat loss based on estimates (equal to Q604E if space heating was required during the day and equal to zero otherwise) | | | |

*ELECS includes both solar collection and solar delivery to service hot water

Note: Most of the summary and indicator quantities have been defined from directly measured quantities as and where measured. No corrections have been made to bring them into closer correspondence with the IEA data requirements documentation [11].

## Table 5-5C. Solar House I Reported Energy Quantities, Summer 1979

| IEA Acronym | CSU Acronym | Definition | Calculation Period: Hour | Day | Month |
|---|---|---|---|---|---|
| | | <u>Collection and Storage Subsystems</u> | | | |
| S001 | S45 | Total solar incident in the aperture plane per unit area | | X | X |
| S003 | S450 | Total solar incident in the aperture plane while collecting per unit area | | X | |
| S005 | S45 | Total solar incident in the aperture plane on the collector aperture (Q001 x $A_a$) | | | X |
| S006 | | Total solar incident in the aperture plane on the collector (Q001 x $A_c$) | | | X |
| S007 | S450 | Total solar incident in the aperture plane on the collector aperture while collecting (Q003 x $A_a$) | X | | X |
| S008 | | Solar incident in the aperture plane on the collector while collecting (Q003 x $A_c$) | X | | X |
| Q100 | | Solar energy collected | | | |
| E103 | ELECS* | Operating energy for solar collection | | X | X |
| Q111 | QU | Solar energy delivered to the collector/storage heat exchanger (includes a minor energy contribution from the collector pump) | X | X | X |
| Q153 | | Heat loss occurring between collector and main storage tank | | | |
| Q202 | QSOLAR | Controlled solar energy used for space cooling and hot water | | X | |
| Q204E | QTLOSS | Heat loss from main storage tank, estimated | | X | X |
| Q204M | | Heat loss from main storage tank, measured (Q112 - ΔQ203 - Q412 - Q311) | | | X |
| Q212 | QSHB | Storage energy transferred to the load subsystems in a controlled manner calculated by a heat balance (Q112 - ΔQ203 - Q204) | | X | |
| | | <u>Energy Conversion and Distribution Subsystems</u> | | | |
| E301 | QSHWG | Auxiliary energy delivered to the domestic hot water heater | X | X | X |
| E303 | ELECS* | Operating energy for delivery of energy to the preheat tank | | X | X |
| ΔQ305 | DELQPH | Change in service hot water system stored energy | | X | |
| Q311 | QPH | Solar energy delivered to the domestic hot water system (preheat tank) | X | X | |
| Q313 | QSHWS | Energy transferred from the preheat tank to the service hot water tank | X | X | |
| Q340 | HBPH | Heat balance on preheat tank (Q311 - Q313 - ΔQ305 - Q350) | | X | |
| Q350 | QPHL | Usable heat loss from the service hot water system, heat loss from the preheat tank, estimated | | X | X |
| Q352 | QHWL | Nonusable heat loss from the service hot water system, heat loss from the service hot water heater tank, estimated | | X | X |
| Q501 | QAIRCG & QAUX | Auxiliary energy to space cooling | | X | X |
| Q502 | QCOOL & CLDM | Space cooling load | X | X | X |
| Q512 | | Energy delivered to space cooling | | X | X |
| Q540 | QAIRCS | Solar energy to space cooling | | | X |
| Q541 | QCOOLS | Space cooling by solar | X | X | X |
| Q560 | QCTR | Heat loss to outside via cooling tower | X | | |
| | | <u>Building and Summary</u> | | | |
| Q600 | | Controlled energy to building (Q502 + Q302) | | X | X |
| Q601 | | Total auxiliary energy (Q501 + Q301) | | X | X |
| Q603 | | Total operating energy (Q103 + Q300) | | | |
| Q604C | SLA | Calculated heat loss (Q204M + Q305E) | | X | X |
| Q604E | | Calculated heat loss based on estimates (Q204E + Q350E) | | | |
| Q606 | | Total energy supplied (Q512 + Q302) | | | |
| Q607 | | Total solar energy supplied (Q540 + Q313) | | X | X |
| E613 | | Operating energy for the solar system (E103 + E320) | | X | X |
| Q650C | USLA | Useful calculated heat loss (equal to Q604C if space heating was required during the day and equal to zero otherwise) | | X | X |
| Q650E | | Useful calculated heat loss based on estimates (equal to Q604E is space heating was required during the day and equal to zero otherwise) | | | |

*ELECS includes both solar collection and solar delivery to service hot water

Note: Most of the summary and indicator quantities have been defined from directly measured quantities as and where measured. No corrections have been made to bring them into closer correspondence with the IEA data requirements documentation [11].

Table 5-6H. Solar House I Thermal Performance Indicators
Winter 1978-1979

| IEA Acronym | CSU Acronym | Definition and Formula | | Calculated period Hour | Day | Month |
|---|---|---|---|---|---|---|
| N100 | | Collector efficiency (aperture basis) | (Q100/S005) | | | |
| N101 | | Collector efficiency (gross area basis) | (Q100/S006) | | | |
| N103 | EFFT, & CE | System collection efficiency (aperture basis) | (Q111/S005) | | X | X |
| N104 | EFFO | System collection "collector on" efficiency (aperture basis) | (Q111/S007) | | X | X |
| N105 | | System collection efficiency (gross area basis) | (Q111/S006) | | X | X |
| N106 | | System collection "collector on" efficiency (gross area basis) | (Q111/S008) | | X | X |
| N401 | PCTHTS | Solar fraction space heating | (Q611/Q610) | | X | X |
| N301 | PCTSHWS | Solar fraction service hot water | (Q313/Q302) | | X | X |
| N601 | | Total solar fraction | [(Q313 + Q611)/Q606] | | X | X |

Table 5-6C. Solar House I Thermal Performance Indicators
Summer 1979

| IEA Acronym | CSU Acronym | Definition and Formula | | Calculated period Hour | Day | Month |
|---|---|---|---|---|---|---|
| N100 | | Collector efficiency (aperture basis) | (Q100/S005) | | | |
| N101 | | Collector on efficiency (gross area basis) | (Q100/S006) | | | |
| N103 | EFFT, & CE | System collection efficiency (aperture basis) | (Q111/S005) | | X | X |
| N104 | EFFO | System collection "collector on" efficiency (aperture basis) | (Q111/S007) | | X | X |
| N105 | | System collection efficiency (gross area basis) | (Q111/S006) | | X | X |
| N106 | | System collection "collector on" efficiency (gross area basis) | (Q111/S008) | | X | X |
| N301 | PCTSHWS | Solar fraction service hot water | (Q313/Q302) | | X | X |
| N501 | PCTARCS | Solar fraction space cooling | (Q540/Q512) | | X | X |
| N502 | | Solar fraction cooling supplied | (Q541/Q502) | | X | X |
| N503 | | Thermal cooling COP | (Q502/Q610) | | X | X |
| N601 | | Total solar fraction | [(Q313 + Q540)/Q606] | | X | X |

### 5.1.3 Temperatures and Miscellaneous Quantities

Table 5-7 provides definitions and descriptions of temperatures and additional quantities used in the evaluation of thermal performance during the heating season. A complete list of measurements on which thermal performance computations are based is shown in Table 5-8.

## 5.2 MONITORING SYSTEM

Data monitoring was accomplished both in batch and real time modes. Both systems are described in this section. The primary purpose of the real time mode is to facilitate the detection of faults in data procurement and system operation. Faults are identified primarily by visual inspection of the data, but a statistically based approach is being developed for automatically comparing the measured values of key variables with their expected values.

To improve the accuracy and continuity of the results, several important variables were verified by readings with redundant instrumentation. Collector flow rate was measured by use of individual flowmeters in each of the three collector subarrays and another in the total flow conduit. Temperature difference measurements were made across the collector and across both sides of the collector/storage heat exchanger. An additional flowmeter is located on the storage side of the collector/storage heat exchanger loop. Additional identical pyranometers are positioned at the same slope on adjacent Solar Houses II and III to provide checks on Solar House I radiation measurements. More sensor redundancies are planned for the next reporting period.

### 5.2.1 Instrumentation

Solar radiation was measured with an Eppley precision pyranometer placed in the center of the collector array and aligned with the collector aperture plane. Fluid flow rate was measured by Cox turbine flowmeters, and temperatures and temperature differences were measured by copper-constantan reference thermocouples and five junction thermopiles. The accuracy of the instruments used in the investigation is shown in Table 5-9. Figure 5-6H shows the location of the sensors during the 1978-79 winter, and Figure 5-6C provides the same information for the 1979 summer season.

Table 5-7. Solar House I Temperatures and Other Quantities
1978-1979

| IEA Acronym | CSU Acronym | Definition | Calculated period Hour | Day | Month |
|---|---|---|---|---|---|
| T113 | TOD | Average ambient dry bulb temperature | X | X | X |
| T406 | THD | Average indoor dry bulb temperature | X | X | X |
| T114 | TODO | Average ambient dry bulb temperature while collecting weighted by incident energy while collecting | | X | X |
| T200 | TSTOR | Average main storage temperature | X | X | X |
| T201 | TSTORO | Average main storage temperature while collecting weighted by incident energy while collecting | | X | X |
| | HOURO | Collector operating hours | | X | X |
| | HWLIT | Hot water usage in liters | X | | |

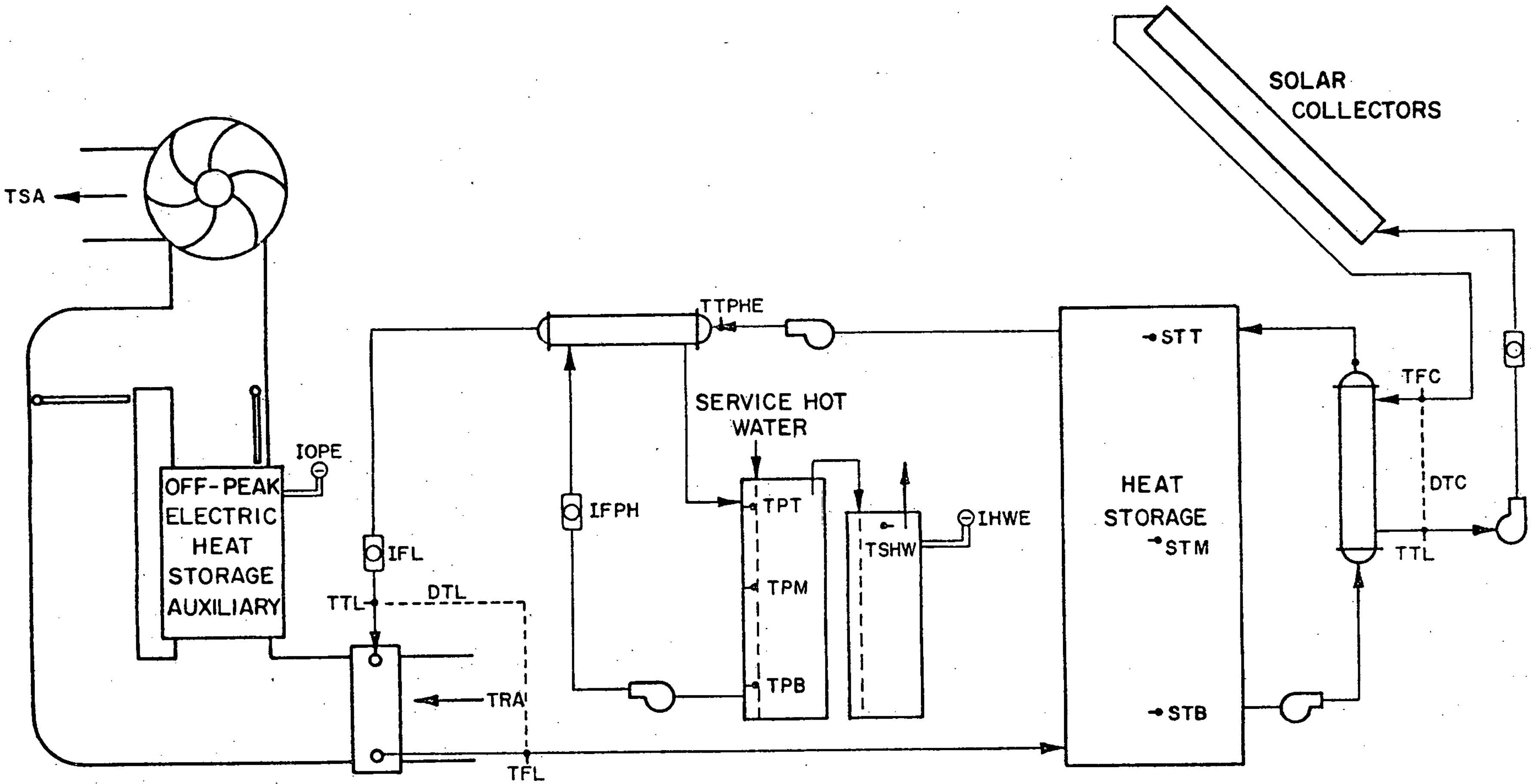
## Table 5-8. Data Collected

| CSU Acronym | IEA Acronym | Description |
|---|---|---|
| IBE | E501 | Integrated boiler electric |
| ISH45 | S001 | Integrated solar radiation at 45° - Test Bed (TB) |
| ISH45FP | S001 | Integrated solar radiation at 45° - Flat-Plate (FP) |
| IFC | W111 | Integrated flow collector (TB) |
| IFA3 | W100 | Integrated flow array 3 |
| IFA2 | W100 | Integrated flow array 2 |
| IFA1 | W100 | Integrated flow array 1 |
| IFCFP | W111 | Integrated flow collector (FP) |
| IFHR | - | Integrated flow heat rejector |
| IOPEL | E401 | Integrated off-peak electric |
| IFCT | W560 | Integrated flow cooling tower |
| IFCH | W512 | Integrated flow chiller |
| IFL | W411,500 | Integrated flow load |
| DTCHX | ΔT111 | Thermopile across collector heat exchanger |
| IHWEL | E301 | Integrated hot water electric |
| IP1EL | E420 | Integrated pump 1 (load pump) electricity |
| ISEL | E120+ E121+ E303 | Integrated solar electric |
| IFPEL | - | Integrated flat-plate electric |
| DTA3 | ΔT100 | Thermopile across array 3 |
| DTA2 | ΔT100 | Thermopile across array 2 |
| DTA1 | ΔT100 | Thermopile across array 1 |
| DTL | ΔT412,ΔT512 | Thermopile across the load heat exchanger |
| IWIND | W009 | Integrated wind |
| IP3OT | - | Integrated pump 3 on time - storage heat exch pump |
| HWBTU | - | P6 indicator ON/OFF, Hot water heat exchanger pump |
| P7IND | - | P7 indicator ON/OFF, Auxiliary boiler pump |
| V3IND | - | V3 indicator ON/OFF, Load = 0, By-pass = 180 mV |
| V2IND | - | V2 indicator position, Solar = 0, Auxiliary = 180 mV |
| TTPH | T310 | Temperature to preheat heat exchanger (tank room) |
| TTALL | - | Temperature trailer ambient liquid-liquid |
| TBTTL | - | Temperature bottom tank liquid-liquid |
| TCTLL | - | Temperature center tank liquid-liquid |
| TTTLL | - | Temperature top tank liquid-liquid |
| TRA | T600 | Temperature of return air |
| TSA | T402 | Temperature of supply air |
| TDP | - | Temperature dew point |
| TOD | T001 | Temperature of the outside air (dry bulb) |
| THD | T600 | Temperature of the house air |
| TPM | | Temperature of preheat middle |
| TSHW | T302 | Temperature service hot water |
| TFCT | T560 | Temperature from cooling tower |
| TTCT | T560 | Temperature to cooling tower |
| TFAC | - | Temperature to alternate coil |
| TTAC | - | Temperature to alternate coil |
| TFL | T412,T512 | Temperature from load |
| TTL | T412,T512 | Temperature to load |
| TRT | - | Tank room temperature |
| TFHR | - | Temperature from heat rejector |
| DTPH | ΔT310 | Thermopile across preheat heat exchanger |
| IFHW | W302 | Integrated flow of hot water |

| CSU Acronym | IEA Acronym | Description |
|---|---|---|
| TTHR | - | Temperature to heat rejector |
| STB | T205 | Storage tank bottom temperature |
| STM | T205 | Storage tank middle temperature |
| STT | T205 | Storage tank top temperature |
| TPB | - | Temperature preheat tank bottom |
| TP | - | Temperature preheat tank top |
| TM2L | T100 | Temperature module #2 lower interior |
| ST10 | T205 | Storage tank #10 (top) |
| ST9 | T205 | Storage tank #9 |
| ST8 | T205 | Storage tank #8 |
| ST7 | T205 | Storage tank #7 |
| ST6 | T205 | Storage tank #6 |
| ST5 | T205 | Storage tank #5 |
| ST4 | T205 | Storage tank #4 |
| ST3 | T205 | Storage tank #3 |
| ST2 | T205 | Storage tank #2 |
| ST1 | T205 | Storage tank #1 bottom (cold) |
| TTSHX | T111 | Temperature to storage heat exchanger |
| DTSHX | ΔT111 | Thermopile across storage heat exchanger |
| TFC | T111 | Temperature from collector (TB) |
| TTC | T111 | Temperature to collector (TB) |
| OPCM | - | Off-peak core (mV) |
| IFSHX | W111 | Integrated flow to storage heat exchanger |
| TTA3 | T100 | Temperature to array 3 |
| TTA2 | T100 | Temperature to array 2 |
| TTA1 | T100 | Temperature to array 1 |
| TM6U | T100 | TM6 upper interior thermocouple |
| TM5U | T100 | TM5 upper interior thermocouple |
| TM3U | T100 | TM3 upper interior thermocouple |
| TM1U | T100 | TM1 upper interior thermocouple |
| TTCFP | T111 | Temperature to flat-plate collector |
| TT1FP | T408 | Temperature to #1 flat-plate collector |
| TT9FP | T100 | Temperature to #9 flat-plate collector |
| TT13FP | T100 | Temperature to #13 flat-plate collector |
| TF13FP | T100 | Temperature from #13 flat-plate collector |
| TF12FP | T100 | Temperature from #12 flat-plate collector |
| TF11FP | T100 | Temperature from #11 flat-plate collector |
| TF10FP | T100 | Temperature from #10 flat-plate collector |
| TF9FP | T100 | Temperature from #9 flat-plate collector |
| TF8FP | T100 | Temperature from #8 flat-plate collector |
| TF7FP | T100 | Temperature from #7 flat-plate collector |
| TF6FP | T100 | Temperature from #6 flat-plate collector |
| TF5FP | T100 | Temperature from #5 flat-plate collector |
| TF4FP | T100 | Temperature from #4 flat-plate collector |
| TF3FP | T100 | Temperature from #3 flat-plate collector |
| TF2FP | T100 | Temperature from #2 flat-plate collector |
| TF1FP | T100 | Temperature from #1 flat-plate collector |
| TFCFP | T100 | Temperature from flat-plate collectors |
| TSHW | T302 | Temperature to service hot water |
| DTCT | ΔT560 | Thermopile across cooling tower |

Table 5-9. Solar House I Sensor Accuracy

| INSTRUMENT TYPE | ACCURACY ACCORDING TO MANUFACTURERS SPECIFICATIONS |
|---|---|
| Pyranometer<br>Eppley PSP | ±1% at direct sunlight incidence angles close to normal<br>3 to 4% at higher incidence angles |
| Flow Meters<br>Cox Turbine, Series 21<br>3/4"-30 gpm & 1/2"-15 gpm | ±0.5% of full scale reading within the 8% to 100% linear flow range |
| Thermocouples<br>Type T; Special limits | ±0.5° Celsius or 0.4% of reading |
| Thermopiles<br>Type T; 5 junction | 2% |
| Electric Meters<br>Westinghouse - Watt-hr meters | -0.5% |




FLOWMETER

THERMOPILE WITH REFERENCE THERMOCOUPLE

ELECTRIC METER

THERMOCOUPLE

NOTE: REFER TO FIGURE 1-2H FOR ADDITIONAL COMPONENT LABELS

Figure 5-6H. Sensors in Solar Heating System Winter, 1978-79

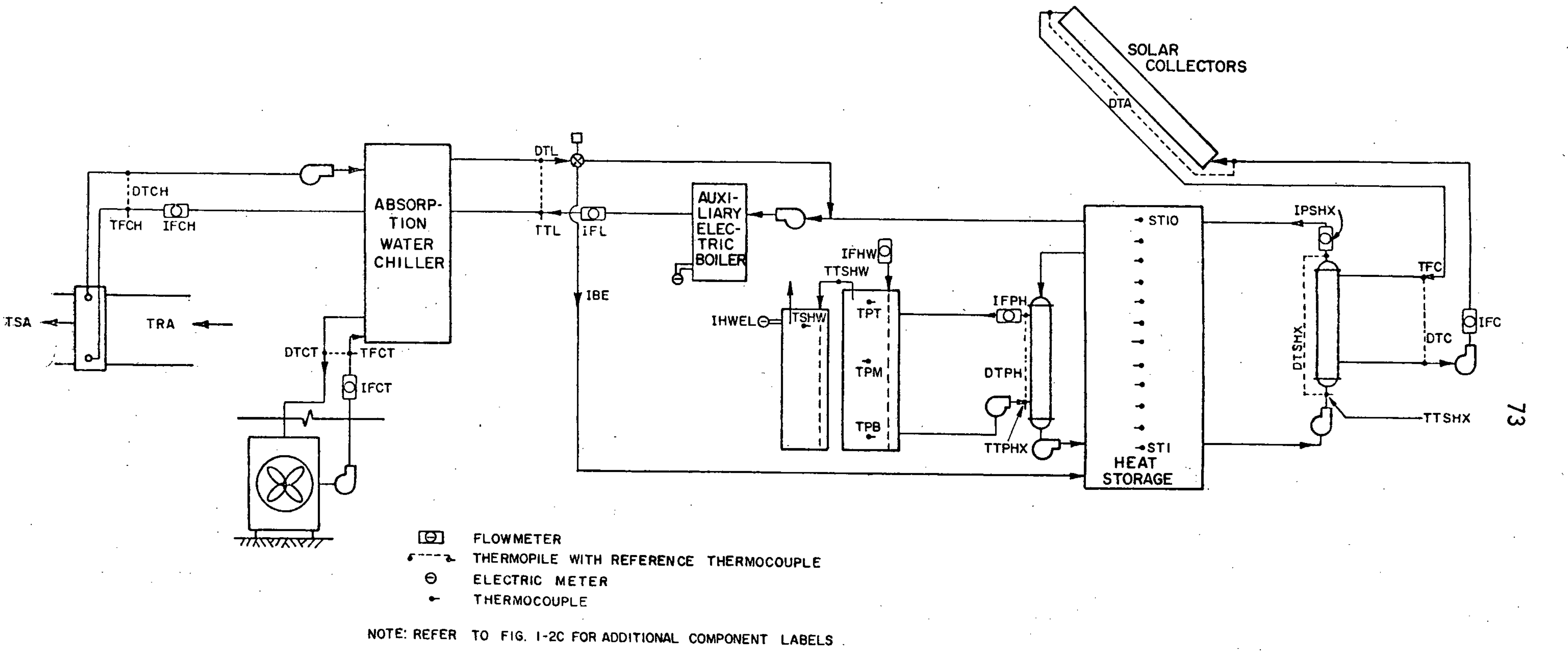



Figure 5-6C. Sensors in Solar Cooling System, Summer 1979

### 5.2.2 Data Acquisition

The data acquisition system shown in Figure 5-7 consists of a Doric data logger which scans 100 channels of data every ten minutes. The channel readings consist of temperatures from 45 thermocouples, temperature differences from 13 thermopiles, 12 integrated liquid flows, and 15 other integrated values (from electric meters, and thermal energy meters). The analog signals are digitized by the data logger. The data logger also linearizes the signals from the thermocouples and converts them to degrees Celsius. The data are stored on magnetic tape by a Kennedy seven track tape recorder and are processed monthly by a CDC Cyber 172 computer.

Simultaneously with recording on tape, the information from the data logger is input via an RS-232 interface controller to a Wang model 2200T minicomputer with a dual floppy disc, CRT/keyboard, plotter, and printer. Every ten minutes the Wang program analyzes the data and prints selected channel values, calculated energies, heat and mass flow balances, and warnings of unusual values. Summaries of data are also printed each hour and at the end of the day. Early detection of faulty system operation and of faulty data due to sensor or integrator failure is provided by computer comparison with predetermined statistical results. A real time load simulation for the second collector/storage system is also supplied by the Wang minicomputer.

## 5.3 DATA REDUCTION METHODS

Magnetic tape data are processed monthly. The energy quantities listed in Table 5-5H and 5-5C and the quantities listed in Tables 5-6H, 5-6C, and 5-7 were calculated by the primary data processing program. IEA nomenclature in Table 5-8 can be used to locate the measurements by finding the energy quantities in Figures 5-1H through 5-5H and 5-1C through 5-5C with numbers that correspond.

Thermal energy quantities transferred through the hydronic system are calculated by an approximation to the equation:

$$Q = \iint \dot{M}\, C_p dt\, dT = \iint \rho\, \dot{V} C_p\, dt\, dT \quad .$$

Density and heat capacity are approximated by first order polynomial fits (maximum error = 0.5%) to National Bureau of Standards data for

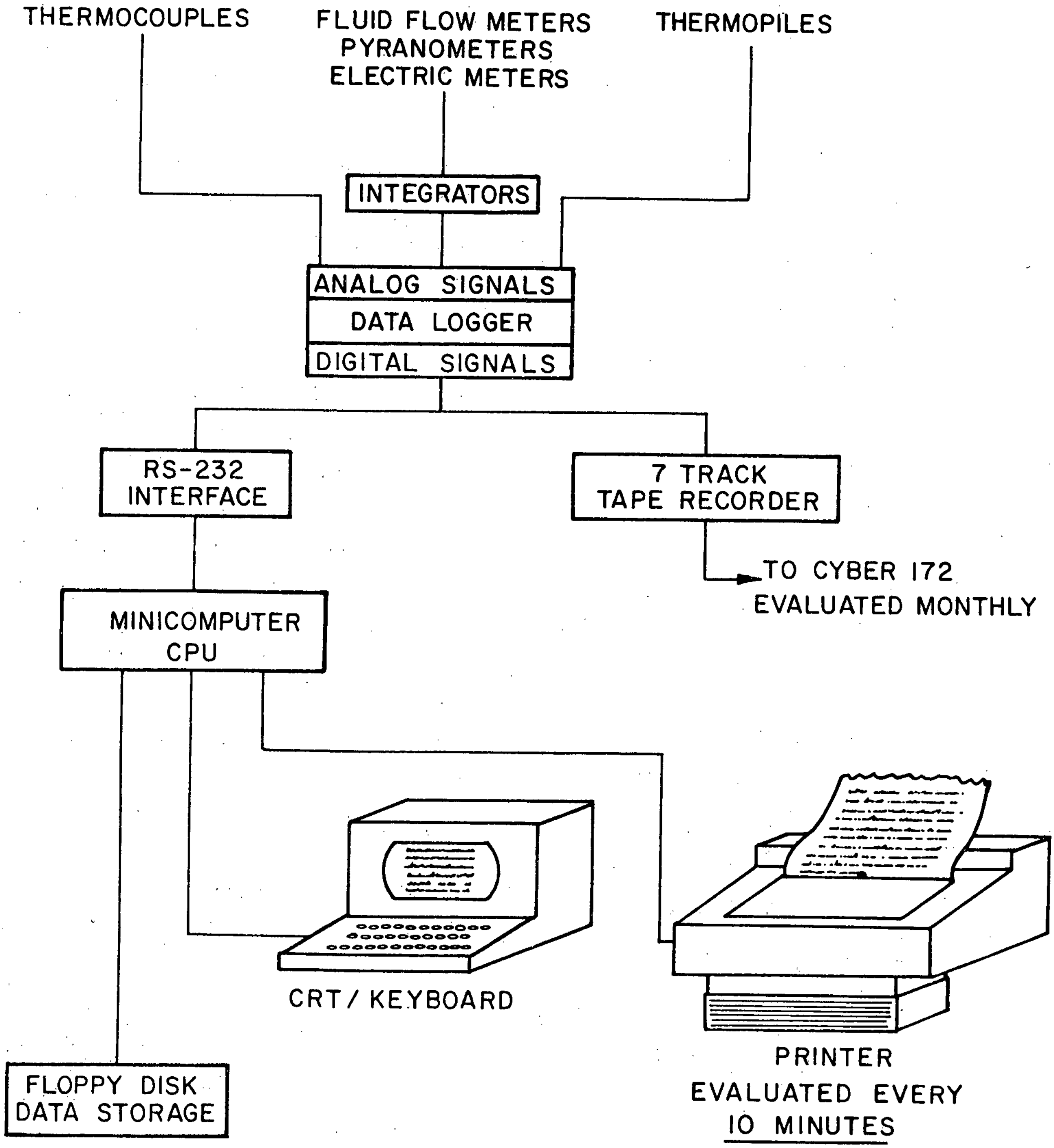



Figure 5-7. Solar House I Data System

ethylene glycol solutions. Total flow for ten minutes and instantaneous temperatures are used to approximate energy rate by the equation:

$$Q = \int_{T_i}^{T_o} \rho(T)C_p(T)\, dT \int_{t_1}^{t_2} \dot{V}(t)\, dt .$$

The validity of energy flow calculations is checked by daily heat balances on the storage tanks. Overall heat balances usually close to within a few percent. Heat balances on the storage tanks are made by comparing actual storage losses with estimated storage losses. The difference between the two is the unaccounted for energy for the day. Definitions and equations used for the energy quantities are shown in Appendix B.

With the exception of ΔQ205 and ΔQ305, energy quantities are calculated for each ten-minute period and then added for hourly, daily, and monthly data summaries. The quantities of energy in the storage and domestic hot water preheat tanks (ΔQ205 and ΔQ305) are calculated at the end of each day (midnight) and used in the daily heat balance.

A list of the hourly data printed and a sample printout are presented in Table 5-10. Definitions of quantities in Table 5-10 are given in Tables 5-5C, 5-6C, and 5-7C. Hourly data are used for observation of performance and operation of the solar and instrumentation systems as well as for examination of the data processing itself. Modifications to the data are made, or alternate sensors are used in accordance with entries in the daily operations log. When discrepancies are noted, scan-by-scan printouts of the pertinent data channels are analyzed. If the discrepancies cannot be resolved or if adequate data are not available, a data gap is recorded and the performance for this period is not reported.

When preliminary processing is complete, a secondary processing program is used to generate a detailed day by day monthly summary and two final monthly summary tables. The detailed day by day monthly summary listing is shown in Table 5-11. Definitions of quantities in this Table are given in Tables 5-5C, 5-6C, and 5-7C.

At this point, the data are carefully reviewed for validity and consistency. Days for which less than 24 hours of data are available must either be completed by interpolation or omitted, because energy which cannot be accounted for may have been collected or used during the missing period. Data required for calculation of a primary heat flow rate may also be incorrect or missing due to a temporary instrument failure. Interpolation is possible for one- to two-hour intervals by estimating collector performance from radiation levels measured in CSU Solar Houses II and III and observing the main storage tank energy change. When load data are missing, auxiliary supply is estimated and solar contribution is estimated by energy change in the main storage tank. Unless the heating or cooling load can reasonably be assumed constant during the gap, interpolation is not possible if solar heat is being collected and used simultaneously. In the case of an instrument failure, primary heat flow rates may be estimated if the system heat balance is satisfactory both before and after the failure.

After the data have been reviewed, each day is classified into one of four categories:

(1) Partial days -- days for which 24 hours of data are not present and interpolation is not possible

(2) Omitted days -- days for which the data are inaccurate as determined by the heat balance

(3) Included days with comment -- days for which data have been interpolated or to which some important comment pertains

(4) Included days without comment -- days for which the data are complete and reasonably accurate as determined by heat balances to which no comments pertain.

Days in categories (3) and (4) are then used to form the two final monthly summary tables which appear in Chapter 7 of this report.

Table 5-10. Sample of Measured and Computed Hourly Data

DATE 8 1 79

| HR | T100 | S001 | S003 | T600 | TFC T111 | TEC T111 | TSTR | TP T215 | T302 | QU Q111 | QLOAD Q402 | QAUX Q442C | QBG | QWEL | HWLIT | Q311 | QHWS | QHWG | QCOOL Q502 | QCOOLS Q540 | QCTR Q560 | QSTR | ELECS E103 | CF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 16.8 | 0.0 | 0.0 | 26.2 | 38.0 | 36.8 | 79.5 | 61.4 | 54.6 | 0.0 | 0.0 | 0.0 | 0.0 | .0 | .0 | .1 | .0 | 0.0 | -.0 | -.0 | -.0 | 1047. | .1 | |
| 1 | 16.4 | 0.0 | 0.0 | 26.1 | 35.8 | 34.9 | 79.4 | 61.4 | 53.3 | 0.0 | 0.0 | 0.0 | 0.0 | .0 | .0 | .1 | .0 | 0.0 | -.0 | -.0 | -.0 | 1048. | .1 | |
| 2 | 16.2 | 0.0 | 0.0 | 25.8 | 33.8 | 32.8 | 79.2 | 61.5 | 54.4 | 0.0 | 0.0 | 0.0 | 0.0 | 1.4 | .0 | .1 | .0 | 0.0 | -.0 | -.0 | -.0 | 1042. | .1 | |
| 3 | 15.8 | 0.0 | 0.0 | 25.4 | 32.1 | 31.3 | 79.0 | 61.5 | 54.8 | 0.0 | 0.0 | 0.0 | 0.0 | .0 | .0 | .1 | .0 | 0.0 | -.0 | -.0 | -.0 | 1042. | .2 | |
| 4 | 15.6 | 0.0 | 0.0 | 25.0 | 30.7 | 30.0 | 78.9 | 61.6 | 55.4 | 0.0 | 0.0 | 0.0 | 0.0 | .0 | 7.9 | .1 | 1.6 | 0.0 | -.0 | -.0 | -.0 | 1037. | .1 | |
| 5 | 16.3 | 5.8 | 0.0 | 24.6 | 29.8 | 28.8 | 78.1 | 61.3 | 57.3 | 0.0 | 0.0 | 0.0 | 0.0 | 1.1 | 43.1 | 13.4 | 7.9 | 0.0 | -.0 | -.0 | -.0 | 1023. | .2 | |
| 6 | 16.7 | 13.7 | 0.0 | 24.5 | 28.2 | 27.6 | 77.9 | 61.4 | 56.0 | 0.0 | 0.0 | 0.0 | 0.0 | .5 | 1.8 | .1 | .4 | 0.0 | -.0 | -.0 | -.0 | 1023. | .1 | |
| 7 | 18.8 | 50.4 | 0.0 | 24.9 | 28.6 | 25.0 | 77.6 | 61.3 | 57.4 | 0.0 | 0.0 | 0.0 | 0.0 | 5.4 | 4.7 | 2.1 | 1.0 | 0.0 | -.0 | -.0 | -.0 | 1016. | .1 | |
| 8 | 21.6 | 84.9 | 0.0 | 24.7 | 24.3 | 26.8 | 77.4 | 61.4 | 58.1 | 0.0 | 0.0 | 0.0 | 0.0 | 5.5 | 10.9 | .1 | 2.2 | 0.0 | -.0 | -.0 | -.0 | 1014. | .1 | |
| 9 | 24.1 | 116.6 | 98.5 | 25.1 | 69.4 | 70.1 | 76.9 | 60.8 | 56.0 | 18.5 | 0.0 | 0.0 | 0.0 | 2.4 | 42.4 | 13.4 | 7.9 | 0.0 | -.0 | -.0 | -.0 | 1016. | 1.1 | 1 |
| 10 | 27.0 | 135.7 | 135.7 | 26.0 | 80.2 | 83.3 | 79.5 | 61.2 | 53.1 | 60.4 | 0.0 | 0.0 | 0.0 | 2.4 | .1 | .1 | .0 | 0.0 | -.0 | -.0 | -.0 | 1074. | 2.0 | 4 |
| 11 | 29.4 | 155.2 | 155.2 | 26.0 | 84.5 | 89.0 | 81.4 | 61.2 | 54.3 | 89.1 | 49.8 | 0.0 | 0.0 | .0 | .2 | .0 | .0 | 0.0 | 22.6 | 22.6 | 72.4 | 1095. | 2.0 | 5 |
| 12 | 30.5 | 157.0 | 157.0 | 25.4 | 86.6 | 91.6 | 82.2 | 61.1 | 56.9 | 84.1 | 77.5 | 0.0 | 0.0 | 1.1 | 8.1 | .6 | 1.6 | 0.0 | 25.8 | 25.8 | 103.3 | 1098. | 2.0 | 5 |
| 13 | 31.8 | 146.6 | 146.6 | 25.6 | 87.2 | 92.0 | 82.5 | 61.1 | 57.8 | 80.6 | 53.5 | 0.0 | 0.0 | 3.2 | 7.0 | .4 | 1.4 | 0.0 | 17.0 | 17.0 | 70.6 | 1117. | 2.0 | 5 |
| 14 | 32.3 | 105.5 | 105.5 | 25.7 | 85.1 | 88.4 | 83.3 | 61.3 | 55.7 | 56.1 | 75.2 | 0.0 | 0.0 | 3.9 | .3 | .1 | .1 | 0.0 | 24.3 | 24.3 | 99.5 | 1105. | 2.0 | 5 |
| 15 | 31.9 | 56.1 | 56.1 | 25.6 | 81.2 | 82.4 | 90.9 | 61.0 | 57.2 | 3.5 | 58.5 | 0.0 | 0.0 | .8 | 6.1 | .1 | 1.2 | 0.0 | 20.3 | 20.3 | 78.8 | 1060. | 1.3 | |
| 16 | 30.5 | 33.0 | 3.6 | 25.6 | 76.0 | 74.7 | 78.7 | 61.1 | 56.0 | 0.0 | 48.9 | 0.0 | 0.0 | .6 | .3 | .1 | .0 | 0.0 | 21.2 | 21.2 | 70.1 | 1014. | .3 | |
| 17 | 30.5 | 22.0 | 9.4 | 25.9 | 71.4 | 73.5 | 76.7 | 61.3 | 54.2 | 0.0 | 23.8 | 0.0 | 0.0 | .0 | .0 | .0 | .0 | 0.0 | 13.6 | 13.6 | 42.5 | 984. | .3 | |
| 18 | 28.4 | 4.9 | 0.0 | 25.6 | 69.0 | 67.3 | 74.9 | 61.1 | 54.0 | 0.0 | 28.6 | 0.0 | 0.0 | .0 | .1 | 1.4 | .0 | 0.0 | 12.0 | 12.0 | 40.6 | 957. | .2 | |
| 19 | 27.1 | 0.0 | 0.0 | 25.8 | 62.0 | 61.0 | 73.4 | 61.0 | 54.4 | 0.0 | 22.7 | 0.0 | 0.0 | .1 | 8.2 | .1 | 1.7 | 0.0 | 10.5 | 10.5 | 33.2 | 933. | .1 | |
| 20 | 25.8 | 0.0 | 0.0 | 26.0 | 56.9 | 55.5 | 71.5 | 60.8 | 56.2 | 0.0 | 10.6 | 0.0 | 0.0 | 1.6 | 43.8 | 9.5 | 8.2 | 0.0 | 5.4 | 5.4 | 16.0 | 907. | .2 | |
| 21 | 24.0 | 0.0 | 0.0 | 25.7 | 53.0 | 51.5 | 70.5 | 61.1 | 54.0 | 0.0 | 30.1 | 0.0 | 0.0 | 1.2 | .1 | .0 | .0 | 0.0 | 15.2 | 15.2 | 45.3 | 879. | .2 | |
| 22 | 21.7 | 0.0 | 0.0 | 25.9 | 49.4 | 47.9 | 69.5 | 61.4 | 57.6 | 0.0 | 2.3 | 0.0 | 0.0 | 1.3 | 3.3 | 1.6 | .7 | 0.0 | .8 | .8 | 3.2 | 877. | .2 | |
| 23 | 20.1 | 0.0 | 0.0 | 26.1 | 45.9 | 44.8 | 69.5 | 61.2 | 54.0 | 0.0 | 0.0 | 0.0 | 0.0 | .0 | -.0 | .0 | -.0 | 0.0 | -.0 | -.0 | -.0 | 876. | .2 | |
| TOTALS | 1087.5 | 867.7 | | | | | | | | 392.4 | 486.6 | 0.0 | 0.0 | 32.6 | 188.6 | 44.4 | 35.9 | 32.6 | 188.7 | 188.7 | 675.3 | | 15.3 | |

DATE 8 2 79

| HR | TOD T100 | SAS S001 | SASO S003 | T600 | TFC T111 | TEC T111 | TSTR | TP T215 | T302 | QU Q111 | QLOAD Q402 | QAUX Q442C | QBG | QWEL | HWLIT | Q311 | QHWS | QHWG | QCOOL Q502 | QCOOLS Q540 | QCTR Q560 | QSTR | ELECS E103 | CF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 20.7 | 0.0 | 0.0 | 26.1 | 41.8 | 42.4 | 69.4 | 61.3 | 52.7 | 0.0 | 0.0 | 0.0 | 0.0 | .0 | .0 | .1 | .0 | 0.0 | -.0 | -.0 | -.0 | 875. | .2 | |
| 1 | 18.9 | 0.0 | 0.0 | 25.2 | 30.2 | 32.4 | 69.3 | 61.3 | 52.9 | 0.0 | 0.0 | 0.0 | 0.0 | 2.2 | .0 | .1 | .0 | 0.0 | -.0 | -.0 | -.0 | 973. | .2 | |
| 2 | 18.2 | 0.0 | 0.0 | 24.8 | 27.3 | 32.4 | 69.2 | 61.4 | 53.6 | 0.0 | 0.0 | 0.0 | 0.0 | 1.6 | .0 | .1 | .0 | 0.0 | -.0 | -.0 | -.0 | 869. | .2 | |
| 3 | 16.5 | 0.0 | 0.0 | 24.3 | 23.9 | 28.4 | 69.0 | 61.3 | 54.4 | 0.0 | 0.0 | 0.0 | 0.0 | .1 | .1 | .0 | .0 | 0.0 | -.0 | -.0 | -.0 | 864. | .2 | |
| 4 | 17.2 | 0.0 | 0.0 | 24.5 | 22.2 | 25.2 | 68.9 | 61.3 | 55.7 | 0.0 | 0.0 | 0.0 | 0.0 | .1 | 7.8 | .0 | 1.6 | 0.0 | -.0 | -.0 | -.0 | 862. | .2 | |
| 5 | 17.3 | 3.6 | 0.0 | 24.4 | 21.2 | 23.6 | 68.1 | 60.5 | 57.3 | 0.0 | 0.0 | 0.0 | 0.0 | 1.6 | 41.6 | 8.9 | 8.5 | 0.0 | -.0 | -.0 | -.0 | 847. | .4 | |
| 6 | 19.4 | 16.6 | 0.0 | 24.4 | 21.2 | 23.1 | 67.9 | 61.3 | 57.3 | 0.0 | 0.0 | 0.0 | 0.0 | .0 | 3.1 | .1 | .6 | 0.0 | -.0 | -.0 | -.0 | 844. | .2 | |
| 7 | 23.7 | 49.6 | 0.0 | 25.0 | 22.2 | 22.7 | 67.9 | 61.1 | 56.7 | 0.0 | 0.0 | 0.0 | 0.0 | .2 | 7.3 | .0 | 1.5 | 0.0 | -.0 | -.0 | -.0 | 843. | .4 | |
| 8 | 27.8 | 84.0 | 0.0 | 25.6 | 25.0 | 33.1 | 67.8 | 60.6 | 57.2 | 0.0 | 0.0 | 0.0 | 0.0 | .0 | 15.5 | 0.0 | 3.1 | 0.0 | -.0 | -.0 | -.0 | 845. | 0.0 | |
| 9 | 29.0 | 116.1 | 98.7 | 26.0 | 63.7 | 68.4 | 67.7 | 57.7 | 57.0 | 34.5 | 30.0 | 30.0 | 30.0 | .1 | 42.2 | 19.1 | 8.4 | 0.0 | 11.1 | -.0 | 41.3 | 853. | 1.8 | 3 |
| 10 | 30.3 | 141.7 | 141.7 | 25.9 | 74.7 | 79.2 | 70.3 | 61.2 | 53.9 | 74.2 | 39.9 | 32.0 | 32.0 | .6 | .3 | .1 | .1 | 0.0 | 24.6 | 4.6 | 68.9 | 913. | 1.9 | 5 |
| 11 | 31.1 | 155.0 | 155.0 | 26.0 | 79.0 | 84.2 | 72.5 | 61.4 | 53.2 | 85.7 | 55.2 | 0.0 | 0.0 | .0 | -.0 | 1.2 | -.0 | 0.0 | 24.9 | 24.9 | 80.1 | 935. | 2.0 | 5 |
| 12 | 31.2 | 157.8 | 157.9 | 26.2 | 81.0 | 86.4 | 74.0 | 61.8 | 53.2 | 89.6 | 52.3 | 0.0 | 0.0 | 1.7 | 1.4 | .1 | .3 | 0.0 | 27.1 | 27.1 | 79.5 | 972. | 1.9 | 5 |
| 13 | 31.0 | 147.3 | 147.3 | 25.5 | 80.5 | 85.6 | 76.2 | 61.4 | 54.8 | 83.4 | 49.1 | 0.0 | 0.0 | .7 | .0 | .0 | .0 | 0.0 | 24.4 | 24.4 | 73.5 | 1002. | 1.9 | 5 |
| 14 | 31.5 | 119.5 | 119.5 | 25.8 | 78.8 | 83.1 | 77.8 | 61.2 | 56.0 | 63.6 | 41.2 | 0.0 | 0.0 | .3 | .9 | .0 | .2 | 0.0 | 19.6 | 19.6 | 60.9 | 1031. | 1.8 | 5 |
| 15 | 31.2 | 73.7 | 73.7 | 25.8 | 75.6 | 77.4 | 78.4 | 61.2 | 55.3 | 27.8 | 39.1 | .7 | .7 | .3 | 1.6 | .1 | .3 | 0.0 | 21.3 | 16.9 | 68.1 | 1019. | 1.8 | 3 |
| 16 | 31.1 | 55.0 | 55.0 | 25.4 | 75.7 | 75.9 | 76.1 | 61.2 | 54.6 | 3.0 | 59.5 | 0.0 | 0.0 | 1.4 | .0 | .1 | -.0 | 0.0 | 25.7 | 25.7 | 85.2 | 970. | 1.0 | |
| 17 | 30.3 | 19.1 | 9.8 | 25.7 | 72.2 | 71.2 | 73.9 | 61.2 | 54.0 | 0.0 | 26.7 | 0.0 | 0.0 | 2.2 | .0 | .1 | .0 | 0.0 | 12.0 | 12.0 | 38.5 | 941. | .2 | |
| 18 | 27.4 | 3.0 | 0.0 | 25.6 | 65.6 | 64.2 | 72.3 | 61.0 | 53.5 | 0.0 | 19.0 | 0.0 | 0.0 | .4 | .0 | .1 | .0 | 0.0 | 10.2 | 10.2 | 29.2 | 922. | .1 | |
| 19 | 24.9 | 0.0 | 0.0 | 25.5 | 59.5 | 58.4 | 70.9 | 61.1 | 54.3 | 0.0 | 29.3 | 0.0 | 0.0 | 3.4 | 8.1 | .1 | 1.6 | 0.0 | 14.1 | 14.1 | 43.3 | 893. | .1 | |
| 20 | 24.7 | 0.0 | 0.0 | 25.8 | 54.7 | 53.7 | 69.3 | 60.1 | 56.6 | 0.0 | 19.0 | 0.0 | 0.0 | .9 | 44.3 | 13.8 | 6.1 | 0.0 | 8.7 | 8.7 | 27.9 | 856. | .3 | |
| 21 | 23.9 | 0.0 | 0.0 | 25.4 | 50.2 | 50.2 | 68.0 | 61.1 | 54.3 | 0.0 | 20.1 | 10.4 | 10.4 | .0 | .0 | .0 | .0 | 0.0 | 10.7 | 5.6 | 32.9 | 849. | .1 | |
| 22 | 21.7 | 0.0 | 0.0 | 25.7 | 47.3 | 45.7 | 67.8 | 61.2 | 55.9 | 0.0 | 0.0 | 0.0 | 0.0 | .0 | .3 | 2.3 | .1 | 0.0 | -.0 | -.0 | -.0 | 846. | .2 | |
| 23 | 19.6 | 0.0 | 0.0 | 25.4 | 43.5 | 43.1 | 67.8 | 61.2 | 55.0 | 0.0 | 0.0 | 0.0 | 0.0 | .1 | 1.6 | 1.3 | .3 | 0.0 | -.0 | -.0 | -.0 | 844. | .2 | |
| TOTALS | 1143.0 | 958.5 | | | | | | | | 462.0 | 480.5 | 73.1 | 73.1 | 18.0 | 176.2 | 47.7 | 32.6 | 18.0 | 234.3 | 193.8 | 729.2 | | 17.2 | |

## Table 5-11. Sample of Measured and Computed Daily Data

| DATE | T100 TOD | T114 TIOD | T600 THD | T200 TSTOR | T201 TSTOR1 | HDEGDA | CDEGDA | WIND | WINDD | HOURS | S001 S45 | S003 S450 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (DEGREES CELSIUS) | | | | | | | (KM/HR) | | (HRS) | (MJ/DAY/SQM) | |
| 8 1 79 | 23.7 | 29.8 | 25.5 | 77.4 | 80.9 | 1. | 3. | 15.3 | -.2 | 7.333 | 24.3 | 19.4 |
| 8 2 79 | 24.9 | 30.8 | 25.4 | 70.8 | 74.2 | 0. | 3. | 17.2 | -.2 | 8.167 | 25.6 | 21.4 |
| 8 3 79 | 26.5 | 32.5 | 25.4 | 70.5 | 73.6 | 0. | 4. | 18.2 | -.2 | 8.167 | 26.1 | 22.4 |
| 8 4 79 | 29.1 | 35.5 | 25.9 | 72.1 | 75.7 | 0. | 6. | 17.6 | -.2 | 8.167 | 26.5 | 22.9 |
| 8 5 79 | 27.5 | 34.1 | 25.8 | 71.3 | 74.9 | 0. | 5. | 18.4 | -.2 | 8.333 | 26.6 | 23.1 |
| 8 6 79 | 27.5 | 34.3 | 25.7 | 70.8 | 74.1 | 0. | 5. | 17.2 | -.2 | 7.833 | 24.1 | 20.1 |
| 8 7 79 | 28.1 | 32.7 | 25.7 | 69.0 | 71.8 | 0. | 5. | 18.0 | -.2 | 8.167 | 25.5 | 22.1 |
| 8 8 79 | 24.3 | 28.2 | 25.7 | 68.5 | 70.2 | 0. | 1. | 14.3 | -.2 | 6.500 | 19.0 | 15.0 |
| 8 9 79 | 22.5 | 28.1 | 25.4 | 68.1 | 69.3 | 0. | 1. | 10.4 | -.2 | 4.167 | 12.1 | 7.9 |
| 8 10 79 | 18.0 | 20.4 | 23.7 | 66.8 | 67.3 | 1. | 0. | 10.7 | -.2 | 3.833 | 12.4 | 8.2 |
| 8 11 79 | 22.0 | 27.4 | 22.8 | 75.7 | 77.1 | 1. | 2. | 18.4 | -.2 | 7.833 | 26.5 | 21.7 |
| 8 12 79 | 24.1 | 30.1 | 24.5 | 83.3 | 84.6 | 0. | 2. | 11.4 | -.2 | 5.000 | 14.6 | 9.2 |
| 8 13 79 | 19.5 | 20.7 | 25.1 | 77.7 | 76.7 | 0. | 0. | 3.4 | -.2 | .167 | 4.2 | .1 |
| 8 14 79 | 14.3 | 0.0 | 23.8 | 71.9 | 0.0 | 4. | 0. | 3.4 | 0.0 | 0.000 | 7.8 | 0.0 |
| 8 15 79* | 16.0 | 19.9 | 22.5 | 69.8 | 69.6 | 3. | 0. | 7.2 | -.2 | 3.000 | 17.7 | 6.0 |
| 8 16 79 | 21.5 | 26.0 | 24.4 | 71.8 | 74.2 | 0. | 1. | 14.6 | -.2 | 6.500 | 27.6 | 17.1 |
| 8 17 79 | 23.0 | 26.9 | 24.5 | 77.5 | 79.8 | 0. | 1. | 15.2 | -.2 | 6.833 | 28.5 | 21.1 |
| 8 18 79 | 23.5 | 25.4 | 24.6 | 82.3 | 82.3 | 0. | 1. | 10.4 | -.2 | 4.000 | 14.1 | 10.5 |
| 8 19 79 | 20.9 | 23.9 | 22.8 | 81.3 | 81.0 | 0. | 0. | 6.5 | -.2 | 1.500 | 8.2 | 3.8 |
| 8 20 79 | 19.9 | 22.8 | 23.0 | 79.7 | 79.6 | 0. | 0. | 10.7 | -.2 | 4.667 | 13.9 | 8.7 |
| 8 21 79 | 21.8 | 25.9 | 24.2 | 81.0 | 81.5 | 0. | 1. | 13.0 | -.2 | 6.167 | 16.0 | 12.3 |
| 8 22 79 | 22.3 | 26.8 | 24.0 | 83.5 | 84.1 | 0. | 1. | 15.3 | -.2 | 6.833 | 21.8 | 17.1 |
| 8 23 79 | 21.7 | 25.7 | 24.7 | 81.3 | 83.0 | 0. | 1. | 12.8 | -.2 | 5.500 | 19.5 | 13.9 |
| 8 24 79 | 22.2 | 25.9 | 24.1 | 72.9 | 73.6 | 0. | 1. | 12.5 | -.2 | 6.167 | 16.3 | 11.8 |
| 8 25 79 | 19.5 | 22.9 | 22.9 | 71.3 | 72.5 | 1. | 0. | 15.4 | -.2 | 6.500 | 19.1 | 14.1 |
| 8 26 79 | 19.5 | 23.6 | 22.6 | 77.8 | 78.4 | 1. | 0. | 12.9 | -.2 | 5.833 | 17.1 | 11.9 |
| 8 27 79* | 19.4 | 23.9 | 22.9 | 79.1 | 80.6 | 2. | 0. | 11.8 | -.2 | 6.333 | 18.4 | 15.0 |
| 8 28 79* | 24.9 | 27.0 | 23.5 | 69.8 | 71.2 | 0. | 2. | 14.7 | -.2 | 7.333 | 18.9 | 15.1 |
| 8 29 79 | 24.1 | 29.3 | 23.6 | 69.3 | 72.0 | 0. | 2. | 18.7 | -.2 | 8.500 | 25.6 | 22.5 |
| 8 30 79 | 22.8 | 28.8 | 24.0 | 69.0 | 71.1 | 0. | 1. | 14.5 | -.2 | 6.000 | 17.9 | 14.3 |
| 8 31 79 | 23.8 | 29.9 | 24.2 | 70.2 | 73.0 | 1. | 3. | 18.5 | -.2 | 8.167 | 24.7 | 21.5 |
| TOTAL | | | | | | 10. | 50. | 384.9 | -5.4 | 166.834 | 545. | 414. |
| MEAN | 22.8 | 26.7 | 24.4 | 74.4 | 73.4 | 0. | 2. | 13.7 | -.2 | 5.958 | 19. | 15. |
| STD.DEV | 3.24 | 6.57 | 1.03 | 5.27 | 15.14 | .83 | 1.79 | 4.28 | .04 | 2.37 | 6.80 | 6.95 |

* DATA ARE AVAILABLE ONLY FOR PART OF THIS DAY, DAY OMITTED FROM PERFORMANCE SUMMARIES, SEE COMMENT BELOW
$ SEE COMMENT BELOW FOR THIS DAY
a DAY OMITTED FROM PERFORMANCE SUMMARIES, SEE COMMENT BELOW

DAILY TOTAL HEAT RATES (MJ/DAY)

| DATE | Q111 QJ | Q311 QPH | Q313 QSHWS | Q512C QAIRCS | Q402 QPCS | QHWE | QBE | E301 QHWE | Q501 QAIRCE | Q442C QPCE | HLDOD | HLDM | CLDOD | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 1 79 | 392.4 | 44.4 | 35.9 | 485.6 | 0.0 | 32.6 | 0.0 | 32.6 | 0.0 | 0.0 | 20.7 | 0.0 | 87.5 | 4 |
| 8 2 79 | 462.0 | 47.7 | 32.6 | 407.4 | 0.0 | 18.0 | 73.1 | 18.0 | 73.1 | 0.0 | 6.3 | 0.0 | 100.1 | 4 |
| 8 3 79 | 480.0 | 40.6 | 28.9 | 375.5 | 0.0 | 3.8 | 45.0 | 8.8 | 45.0 | 0.0 | 9.4 | 0.0 | 148.7 | 4 |
| 8 4 79 | 498.4 | 43.3 | 28.2 | 425.4 | 0.0 | .9 | 52.4 | .9 | 52.4 | 0.0 | 0.0 | 0.0 | 192.9 | 4 |
| 8 5 79 | 492.5 | 44.5 | 27.8 | 390.6 | 0.0 | .2 | 26.4 | .2 | 26.4 | 0.0 | .1 | 0.0 | 153.9 | 4 |
| 8 6 79 | 444.8 | 41.2 | 29.1 | 397.9 | 0.0 | .8 | 79.3 | .8 | 79.3 | 0.0 | 2.0 | 0.0 | 167.4 | 4 |
| 8 7 79 | 490.4 | 44.7 | 33.9 | 398.7 | 0.0 | 3.5 | 246.7 | 3.5 | 246.7 | 0.0 | 0.0 | 0.0 | 154.2 | 6 |
| 8 8 79 | 302.9 | 48.8 | 25.7 | 194.8 | 0.0 | 5.7 | 163.2 | 5.7 | 163.2 | 0.0 | 0.0 | 0.0 | 47.8 | 3 |
| 8 9 79 | 137.2 | 47.0 | 29.2 | 74.1 | 0.0 | 5.9 | 185.2 | 5.9 | 185.2 | 0.0 | 1.0 | 0.0 | 35.1 | 2 |
| 8 10 79 | 112.5 | 49.7 | 28.8 | 0.0 | 0.0 | 9.2 | 0.0 | 9.2 | 0.0 | 0.0 | 28.5 | 0.0 | 0.0 | |
| 8 11 79 | 403.0 | 44.9 | 25.0 | 0.0 | 0.0 | 11.4 | 0.0 | 11.4 | 0.0 | 0.0 | 40.9 | 0.0 | 58.5 | |
| 8 12 79 | 98.8 | 34.6 | 33.3 | 52.1 | 0.0 | 12.7 | 0.0 | 12.7 | 0.0 | 0.0 | .2 | 0.0 | 73.3 | |
| 8 13 79 | 0.0 | 32.0 | 38.4 | 0.0 | 0.0 | 26.2 | 0.0 | 26.2 | 0.0 | 0.0 | .3 | 0.0 | 0.0 | |
| 8 14 79 | 0.0 | 32.4 | 26.1 | 0.0 | 0.0 | 2.8 | 0.0 | 2.8 | 0.0 | 0.0 | 136.7 | 0.0 | 0.0 | |
| 8 15 79* | 55.3 | 34.6 | 4.3 | 0.0 | 0.0 | .8 | .1 | .8 | .1 | 0.0 | 94.0 | 0.0 | 0.0 | |
| 8 16 79 | 248.8 | 40.6 | 33.7 | 104.7 | 0.0 | 5.9 | .4 | 6.9 | .4 | 0.0 | 16.5 | 0.0 | 20.1 | 1 |
| 8 17 79 | 412.5 | 37.4 | 31.5 | 132.3 | 0.0 | 1.3 | 0.0 | 1.3 | 0.0 | 0.0 | 4.2 | 0.0 | 35.3 | 1 |
| 8 18 79 | 211.0 | 26.8 | 31.5 | 75.9 | 0.0 | .8 | .8 | .8 | .8 | 0.0 | 0.0 | 0.0 | 37.9 | |
| 8 19 79 | 58.0 | 31.8 | 31.6 | 0.0 | 0.0 | 1.0 | 1.3 | 1.0 | 1.3 | 0.0 | 2.2 | 0.0 | 14.6 | |
| 8 20 79 | 97.1 | 42.3 | 34.7 | 0.0 | 0.0 | 5.3 | 1.5 | 5.4 | 1.5 | 0.0 | 13.4 | 0.0 | .3 | |
| 8 21 79 | 156.3 | 29.0 | 35.5 | 0.0 | 0.0 | 19.6 | 1.4 | 19.6 | 1.4 | 0.0 | 3.2 | 0.0 | 21.0 | |
| 8 22 79 | 340.0 | 41.0 | 34.0 | 229.6 | 0.0 | 5.8 | 1.4 | 6.8 | 1.4 | 0.0 | 3.5 | 0.0 | 35.8 | 2 |
| 8 23 79 | 265.8 | 39.5 | 43.6 | 259.3 | 0.0 | 1.8 | .9 | 1.8 | .9 | 0.0 | 8.1 | 0.0 | 20.1 | 2 |
| 8 24 79 | 199.5 | 29.1 | 35.5 | 304.0 | 0.0 | .7 | 9.9 | .7 | 9.9 | 0.0 | 8.6 | 0.0 | 21.9 | 3 |
| 8 25 79 | 244.5 | 54.3 | 28.5 | 0.0 | 0.0 | .7 | .8 | .7 | .8 | 0.0 | 31.4 | 0.0 | 3.2 | |
| 8 26 79 | 172.2 | 39.4 | 30.3 | 0.0 | 0.0 | .7 | .8 | .7 | .8 | 0.0 | 34.6 | 0.0 | 6.4 | |
| 8 27 79* | 258.5 | 26.4 | 24.8 | 299.2 | 0.0 | 5.1 | 0.0 | 6.1 | 0.0 | 0.0 | 55.4 | 0.0 | 14.1 | 2 |
| 8 28 79* | 289.5 | 35.6 | 21.1 | 253.1 | 0.0 | 1.0 | 66.2 | 1.0 | 66.2 | 0.0 | 0.0 | 0.0 | 59.7 | 3 |
| 8 29 79 | 490.7 | 48.8 | 35.1 | 392.9 | 0.0 | 1.3 | 46.3 | 1.3 | 46.3 | 0.0 | 5.4 | 0.0 | 78.0 | 4 |
| 8 30 79 | 302.5 | 52.3 | 25.5 | 203.9 | 0.0 | 3.0 | 7.5 | 3.0 | 7.5 | 0.0 | 6.2 | 0.0 | 45.9 | 2 |
| 8 31 79 | 449.5 | 48.8 | 29.9 | 342.8 | 0.0 | 1.1 | 0.0 | 1.1 | 0.0 | 0.0 | 19.9 | 0.0 | 87.1 | 3 |
| TOTAL | 7963.5 | 1156.9 | 885.5 | 5249.4 | 0.0 | [illegible] | 944.3 | 189.7 | 944.3 | 0.0 | 403.4 | 0.0 | 1515.9 | 51 |

Table 5-11 (continued)

* DATA ARE AVAILABLE ONLY FOR PART OF THIS DAY, DAY OMMITTED FROM PERFORMANCE SUMMARIES, SEE COMMENT BELOW
$ SEE COMMENT BELOW FOR THIS DAY
@ DAY OMMITTED FROM PERFORMANCE SUMMARIES, SEE COMMENT BELOW

| | | | Q212 | Q202 | | E103 | Q502 | Q540 | N103 | N104 | | N301 | N501 | N401 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | DAILY TOTAL HEAT RATES (MJ/DAY) | | | | | | EFFICIENCY | | | RATIO SUPPLIED BY SOLAR | | | |
| DATE | QSTOR (MJ) | DELQST | QSHB | QSOLAR | HBPH | ELECS | QCOOL | QCOOLS | EFFT | EFFO | COP | PCTHWS | PCTARCS | PCTHTS | SOLCOOL |
| 8 1 79 | 1051.9 | -184.9 | 538.7 | 530.9 | -7.2 | 15.3 | 188.7 | 188.7 | .361 | .452 | .388 | .524 | 1.000 | 0.000 | 1.000 |
| 8 2 79 | 873.0 | -30.7 | 459.1 | 455.0 | 1.2 | 17.2 | 234.3 | 193.8 | .404 | .482 | .488 | .644 | .848 | 0.000 | .827 |
| 8 3 79 | 842.0 | 24.8 | 421.8 | 417.1 | .4 | 18.2 | 204.7 | 183.3 | .411 | .479 | .486 | .767 | .893 | 0.000 | .895 |
| 8 4 79 | 863.3 | -7.5 | 471.6 | 468.7 | 5.4 | 17.5 | 206.4 | 182.2 | .421 | .487 | .432 | .968 | .890 | 0.000 | .883 |
| 8 5 79 | 852.5 | 24.3 | 434.4 | 435.1 | 7.8 | 18.4 | 179.5 | 166.2 | .414 | .477 | .430 | .992 | .937 | 0.000 | .926 |
| 8 6 79 | 877.0 | -43.8 | 455.3 | 439.1 | 1.5 | 17.2 | 224.8 | 183.1 | .413 | .496 | .471 | .972 | .834 | 0.000 | .814 |
| 8 7 79 | 839.3 | -5.5 | 464.0 | 443.4 | -.8 | 18.0 | 339.3 | 202.7 | .430 | .497 | .526 | .907 | .613 | 0.000 | .597 |
| 8 8 79 | 836.5 | 23.6 | 247.7 | 243.6 | 9.9 | 14.3 | 194.6 | 105.8 | .357 | .453 | .544 | .826 | .544 | 0.000 | .549 |
| 8 9 79 | 858.3 | -26.1 | 131.8 | 121.2 | 8.1 | 10.4 | 137.7 | 37.2 | .254 | .391 | .531 | .833 | .285 | 0.000 | .270 |
| 8 10 79 | 831.1 | 19.5 | 62.0 | 49.7 | 9.3 | 10.7 | -.0 | -.0 | .204 | .309 | 0.000 | .758 | 0.000 | 0.000 | 1.000 |
| 8 11 79 | 847.7 | 291.6 | 73.5 | 44.9 | 10.4 | 18.4 | -.0 | -.0 | .340 | .415 | 0.000 | .686 | 0.000 | 0.000 | 1.000 |
| 8 12 79 | 1129.5 | -60.7 | 116.4 | 86.7 | -10.1 | 11.4 | 16.6 | 15.6 | .152 | .241 | .318 | .724 | 1.000 | 0.000 | 1.000 |
| 8 13 79 | 1077.2 | -116.5 | 77.4 | 32.0 | -18.6 | 3.4 | -.0 | -.0 | 0.000 | 0.000 | 0.000 | .594 | 0.000 | 0.000 | 1.000 |
| 8 14 79 | 962.0 | -72.2 | 36.6 | 32.4 | 9.9 | 3.4 | -.0 | -.0 | 0.000 | 0.000 | 0.000 | .902 | 0.000 | 0.000 | 1.000 |
| 8 15 79* | 890.5 | -21.7 | 47.1 | 34.6 | 9.4 | 7.2 | -.0 | -.0 | .070 | .207 | -.100 | .835 | 0.000 | 0.000 | 1.000 |
| 8 16 79 | 872.4 | 54.6 | 159.2 | 145.4 | -3.9 | 14.5 | 48.9 | 46.9 | .202 | .325 | .465 | .829 | .995 | 0.000 | 1.000 |
| 8 17 79 | 925.3 | 164.1 | 209.7 | 169.7 | -3.3 | 15.2 | 40.5 | 40.5 | .323 | .437 | .306 | .961 | 1.000 | 0.000 | 1.000 |
| 8 18 79 | 1080.0 | 25.6 | 143.0 | 102.7 | -15.0 | 10.4 | 20.3 | 20.3 | .336 | .443 | .264 | .976 | .990 | 0.000 | 1.000 |
| 8 19 79 | 1103.0 | -48.9 | 64.6 | 31.9 | -11.5 | 6.5 | -.0 | -.0 | .159 | .341 | -.008 | .970 | 0.000 | 0.000 | 1.000 |
| 8 20 79 | 1054.4 | -6.8 | 62.7 | 42.3 | -4.9 | 10.7 | -.0 | -.0 | .156 | .250 | -.013 | .866 | 0.000 | 0.000 | 1.000 |
| 8 21 79 | 1046.2 | 72.3 | 42.3 | 29.0 | -16.0 | 13.0 | -.0 | -.0 | .219 | .284 | -.014 | .644 | 0.000 | 0.000 | 1.000 |
| 8 22 79 | 1113.3 | 3.5 | 292.9 | 270.6 | -4.3 | 15.3 | 98.3 | 98.3 | .348 | .445 | .426 | .833 | .994 | 0.000 | 1.000 |
| 8 23 79 | 1116.5 | -101.0 | 325.1 | 298.8 | -14.8 | 12.8 | 78.3 | 78.3 | .305 | .428 | .301 | .960 | .997 | 0.000 | 1.000 |
| 8 24 79 | 1022.1 | -206.4 | 370.0 | 333.1 | -22.0 | 12.5 | 136.5 | 131.3 | .273 | .379 | .435 | .982 | .958 | 0.000 | .962 |
| 8 25 79 | 822.0 | 167.0 | 42.3 | 54.3 | 15.7 | 15.4 | -.0 | -.0 | .287 | .388 | -.013 | .977 | 0.000 | 0.000 | 1.000 |
| 8 26 79 | 983.3 | 69.1 | 52.9 | 39.4 | -.2 | 12.9 | -.0 | -.0 | .226 | .324 | -.013 | .978 | 0.000 | 0.000 | 1.000 |
| 8 27 79* | 1044.8 | -70.4 | 299.2 | 325.7 | -2.6 | 11.8 | 101.3 | 101.3 | .314 | .387 | .339 | .804 | 1.000 | 0.000 | 1.000 |
| 8 28 79* | 864.9 | -17.1 | 282.3 | 288.6 | 5.4 | 14.7 | 156.1 | 121.7 | .343 | .428 | .469 | .953 | .793 | 0.000 | .780 |
| 8 29 79 | 846.2 | 1.1 | 456.2 | 441.7 | 1.5 | 18.7 | 199.0 | 180.7 | .429 | .485 | .453 | .964 | .895 | 0.000 | .908 |
| 8 30 79 | 850.0 | -.2 | 269.7 | 255.1 | 15.6 | 14.5 | 101.4 | 94.6 | .378 | .472 | .480 | .895 | .964 | 0.000 | .933 |
| 8 31 79 | 847.9 | 25.2 | 390.6 | 391.5 | 5.4 | 18.5 | 137.3 | 137.3 | .407 | .467 | .401 | .966 | 1.000 | 0.000 | 1.000 |
| TOTAL | 26424.0 | 54.8 | 6881.1 | 6406.3 | -30.5 | 384.9 | 2786.9 | 2290.5 | | | | | | | |
| MEAN | 943.7 | 2.0 | 245.8 | 228.8 | -1.1 | 13.7 | 99.5 | 81.8 | .327 | .430 | .450 | .824 | .848 | 0.000 | .822 |

* DATA ARE AVAILABLE ONLY FOR PART OF THIS DAY, DAY OMMITTED FROM PERFORMANCE SUMMARIES, SEE COMMENT BELOW
$ SEE COMMENT BELOW FOR THIS DAY
@ DAY OMMITTED FROM PERFORMANCE SUMMARIES, SEE COMMENT BELOW

# 6. OPERATIONS HISTORY - PROBLEMS, CORRECTIONS, AND SYSTEMS DEVELOPMENT

In addition to the continuous record provided by the previously described data acquisition systems, a daily log of events, unusual conditions, and special investigations is maintained. The purposes of this record are (1) to present qualitative information on system characteristics, (2) to identify and explain anomalies, problems, failures, and corrective measures in system operation, (3) to provide information which may be needed for an understanding and explanation of the quantitative data.

This section of the report is based directly on the operating log. The entries are in chronological sequence under each subsystem heading.

## 6.1 COLLECTION

6.1.1 The Philips collector system was closely monitored throughout September and October 1978. A preliminary analysis of the data indicated that system collection efficiency (N104) appeared to be about two-thirds of the collector efficiency obtained by Philips Research Laboratories in Aachen. The difference was too great to be explained by transport losses. The reasons for the lower collector efficiency were investigated.

6.1.2 Analysis of thermopile data for the Philips collector and storage heat exchanger in Solar House I showed that heat losses in piping were three to six percent of the energy collected. At an average value for $T_{fluid} - T_{ambient}$ of 53.5°C, the effective heat loss coefficient of the pipe insulation was calculated to be k = 0.057 $W/m^2 °C$. The manufacturer's value is k = 0.048 $W/m^2 °C$.

6.1.3 System monitoring and data analysis continued in Solar House I during November. September performance results were rechecked and were found to confirm a collector system efficiency about 30 percent below that measured by Philips. Measurements with the platinum RTD temperature sensors showed a maximum absorber plate temperature variation of 0.5°C in the six collector modules, confirming uniform flow distribution through the collector. The daily system heat balance closed within one percent for 29 days in September.

6.1.4 A representative from Philips Research Laboratory arrived on January 26th to assist in the investigation of collector performance discrepancies. He verified that the steady-state efficiency of the collector (N101) at CSU was seven to eight percentage points lower than that indicated by Philips test data.

6.1.5 An intensive one-week investigation by the Philips representative and members of the SEAL staff resolved the difference between collector efficiencies (N101) measured in Aachen and at CSU. Several minor causes of differences in collector performance were found, but the main cause of the discrepancy was a difference in the solar transmittance of the cover glass, measured at about 83 percent at CSU, compared with 89 percent in Aachen.

6.1.6 On 5 and 6 July, personnel from Philips Research Laboratories, Aachen, and the Solar Energy Applications Laboratory installed new cover glass on the Philips evacuated tubular collectors. The new glass, with 90 percent solar transmission, replaced the original cover glass which had deteriorated on exposure to ultraviolet light to a measured transmittance of only 83 percent. Selected mid-day readings showed that the instantaneous system efficiency improvement (N104) due to the new cover glass was on the order of eight percentage points.

6.1.7 The Philips collector operated in a pressurized mode during September. It was nominally charged to 20 psig at the top of the collector when filled. Periodic repressurization was required because the pressure slowly bled off through the pump seal and valve.

6.1.8 Although there were many October days with high solar radiation and low heat demand, the heat storage tank boiled only once, requiring heat to be dumped through the heat rejection facility.

6.1.9 As of November, new thermocouples had been installed at the inlet and outlet of each collector array and across the heat exchanger to determine if there was excessive heat loss from the pipes leading to and from the collector. Thermopiles with readings accurate to the nearest 0.1°C were installed in the collector and heat exchanger in November/December. All subsequent collector performance results were calculated from the $\Delta T$ values measured with the precision thermopiles. The useful heat delivered to storage was also calculated from the heat exchanger $\Delta T$ data recorded by the thermopile in the heat exchanger. The piping losses could then be calculated as the difference between these two quantities.

6.1.10 A snowstorm on December 29th covered the Philips collector with about two inches of snow which prevented collection for two and one-half days.

6.1.11 The solar system in Solar House I was shut down on 1 May for extensive remodeling. To avoid damage by prolonged high temperature stagnation, the Philips collectors were covered.

6.1.12 On 28 August, 160 ml of water were removed from the space between the cover and the evacuated tubes in the eastern-most Philips collector. Condensation under the cover glass had been noticed for several months prior to the installation of the new cover and also after the installation. Rain penetration around the edge of the cover appeared to be the most likely source of moisture.

## 6.2 STORAGE

6.2.1 A stratified heat storage experiment began in April 1979, after direct contact heat exchanger experiments with the Miromit flat-plate collectors were completed. The objectives of the experiment were a comparison of the solar load fraction with stratified storage and that obtained with mixed storage in both heating and cooling modes. The existing storage tank inside the building and the roof-mounted Miromit flat-plate collectors were used in the stratified storage experiments. Preparations for the experiment began in mid-March, and data were obtained by operating the system alternately with mixed and stratified storage throughout April.

6.2.2 On 19 March, badly deteriorated insulation on the basement storage tank (with a thermal resistance of only R-3) was removed. Four to five inches of sprayed-on cellulose insulation with a theoretical R-14 to R-16 (English Units) value were applied. The resulting insulating value of the tank, as determined by overnight heat loss experiments, was improved, but only to a level of about R-5.

6.2.3 Several changes in the outdoor tank room were also made. The outdoor tank was used with the Philips collector to supply energy to the house for a few days while the indoor tank was provided with new insulation, instrumentation, and piping for the stratified storage experiment. A tip sensitive thermocouple tree was installed within the tank. The Philips collector was then recoupled to the indoor tank and house load for operation of the system with stratified storage. Operation of the new flat-plate collector was continued with the direct contact liquid-liquid storage unit and heat rejection coil.

6.2.4 During switching of the tanks it was found that the load pump had a leaky seal, so it was replaced. The new heat exchanger pump, rated at 11 gpm, could not supply sufficient head when operating from the outdoor storage tank, so it was replaced with a pump of 14 gpm capacity.

6.2.5 Thirty days of space heating and water heating data were recorded during April, 1979. During most of the month, the Philips evacuated tube collectors supplied heat to this tank in the stratified mode. The tank was operated as a fully mixed heat storage facility for the last three days of the month.

6.2.6 For subsequent use in data analysis, the R-value of the insulation on the basement tank was determined by measuring the tank temperature decay rate during several days in April when no heat was supplied to or withdrawn from the tank. Following this measurement, the wall of the tank room was removed, all old wiring and plumbing were removed, and the main storage tank was stripped of insulation and removed.

6.2.7 The new built-up heat storage chamber supplied by Bally Manufacturing, Inc. was installed in mid-May. The only problem encountered with installation of the Bally tank was with one connecting latch. The tank was assembled in about 4 man-hours, a period which included carrying the separate panels into the building and final assembly. The vinyl liner was installed in the tank and another vinyl sheet was applied to the underside of the tank cover.

6.2.8 Final fittings for the Bally storage tank, including perforated vertical diffuser pipes for temperature stratification, were completed in mid-June, and the unit, which holds 1130 gallons (5.136 $m^3$), was leak-tested. No problems were encountered. During the last week of the month, the Philips evacuated tubular collectors were uncovered, and solar heat was supplied from them to the new tank.

6.2.9 Full operation and data collection in Solar House I were resumed on 30 June after a two-month shutdown for installation of the Bally storage chamber and total repiping and reinstrumentation of the system.

6.2.10 Early in July, there were significant storage heat losses due to thermosiphoning in the tank inlet/outlet loops. Check valves were therefore installed, and piping and component insulation was begun early in the month. On 19 July, a tank loss coefficient of 0.029 MJ/hr·°C was measured with the vent open, no fluid flows in or out of the tank, and insulation on most of the piping but not on the heat exchangers. After insulating the piping and heat exchangers late in July, the loss coefficient was measured at 0.022 MJ/hr·°C (corresponding to an R value of 14 $ft^2$·°F·hr/Btu). The measured heat loss coefficient includes direct losses through the tank walls, conduction losses to system piping, and heat loss by evaporation from the tank and subsequent condensation of most of the vapor in the 2-inch vent.

6.2.11 Good temperature stratification in storage was obtained in July and August, about 4°C to 6°C during periods of simultaneous collector and chiller operations. Stratification was increased to 12°C when a portion of the return flow from the generator was run through a manual by-pass valve and mixed with water from storage to provide a constant 74°C supply. An automatic tempering valve circuit was therefore designed.

6.2.12 A bowing of the sides of the Bally tank occurred over a period of several months. The deflection became serious enough that it was decided it would be necessary to provide additional exterior retention beams or "whalers". Four whalers were therefore installed at suitable levels. Even though the tank was emptied when the whalers were installed, considerable force had to be applied with a jack in order to maintain the square tank shape at all three levels. In replacing the tank top, some trouble was experienced in closing the latches, and it was not possible to fasten the last latch. This condition does not create any particular problem, but it is recommended that instructions to the installers include the use of at least two whalers for a tank of this height.

6.2.13 The tank had been used since 1 July with internal temperatures usually exceeding 80°C (176°F). Exceptional temperature stratification in the tank had been achieved by use of vertical perforated baffles, and temperature differences as high as 15°C have been obtained between top and bottom of the tank. It is not known if the square shape has any influence on stratification, but improved performance is clearly obtained.

## 6.3 SPACE HEATING

6.3.1 During September and October, 1978, the ductwork connecting the off-peak electrical storage unit with the ventilation system was completed. After testing, the unit was integrated into the central heat distribution system.

6.3.2 In December the TPI off-peak unit was modified so that power consumption could be recorded directly on the Doric data logger. Early in the month a control transformer in the unit failed (a fuse blew in the control circuit), causing the air distribution blower in the house to be down for one day during which time the house temperature decreased to a minimum of 11°C. Transformer and fuse were replaced, and the off-peak unit resumed normal operation within the next 24 hours.

6.3.3 Two computer programs were written to facilitate the analysis of data collected in this study. One program provides the daily on-peak and off-peak energy consumption and peak power demand for each of the components in the furnace. The second program performs an energy balance on the furnace by use of temperatures and energies recorded continuously on a stripchart recorder. The instrumentation was modified during the month by connecting one channel of off-peak furnace core temperature data to the central data logging system for the house. A new stripchart recorder was also installed to record system temperatures for the heat balance work.

6.3.4 The stripchart data program was used to complete a detailed energy balance of the off-peak furnace over a two day operating period and to calculate the effective heat storage capacity of the furnace in terms of a mean storage core temperature. Analysis of the stripchart recorded data was continued for additional days to increase the confidence level in the results.

6.3.5 The automatic data acquisition program was written so that the amount of energy supplied to the house each day could be calculated and so that daily heat balances on the house could be performed. The quantities of energy consumed as determined by periodic manual readings of the power meter and by the results of this program, were shown to be in agreement during most of the heating season. When there was disagreement, the cause was a gap in the automatic acquisition system information. Manually collected data are sufficient to offset these gaps and a complete set of off-peak furnace performance data for the heating season can be compiled.

6.3.6 Testing of the off-peak furnace as an auxiliary heat source for Solar House I terminated in April.

6.3.7 In addition to the replacement of the gas-fired auxiliary boiler with the off-peak electric resistance furnace (215 kW-hr TPI system) for space heating, an electric boiler was installed for auxiliary cooling use.

6.3.8 During the months of June and July, a by-pass duct and damper were installed so that when auxiliary heat was not needed, there would be no air flow through the off-peak furnace. This by-pass arrangement is expected to substantially reduce furnace heat losses during periods when solar heat is available and should result in a significant improvement in furnace performance during the next heating season.

6.3.9 A scheme for implementing an improved off-peak furnace charging strategy during the next heating season was also identified. The intention is to minimize electric utility charges, and the scheme will therefore utilize improved energy demand predictions. It is anticipated that the charging control algorithm will be incorporated into the Wang computer used in Solar House I.

6.3.10 Also in July, the TPI control was removed for testing and calibration. It was found to meet all specifications and will be reinstalled in the furnace before the next heating season commences. A decision was also made to remove the brickwork in the TPI unit, install a resistance wire sensor, and replace the brickwork during September. The sensor should result in more accurate measurement of the thermal energy content of the brick storage.

6.3.11 Work continued during July and August on the development of a new digital electronic control system for the TPI unit. The new system will control each of the eleven heater elements separately and will result in more even heating of the entire core. The controller will also permit more precise night-time charging to be achieved and should thus minimize the peak power demand on a month-by-month basis. At the end of August the unit was being wired and packaged.

6.4 COOLING

6.4.1 Cooling system performance in September 1978 was slightly lower than expected because the Arkla unit was frequently over-fired during solar operation, and the excess heat was rejected by the cooling tower.

6.4.2 In early August, the chiller control was modified to permit chiller operation to continue for a few minutes after heat supply to the generator is discontinued. This change, recommended by the manufacturer, provides additional cooling rather than added heat loss by internal conduction. Although the chiller usually runs continuously after first starting each day, cooling output and COP are increased by this modification under conditions of light loading and frequent on-off cycling.

6.4.3 A portion of the return flow from the generator was run through a manual by-pass valve and mixed with water from storage to maintain a constant 74°C supply temperature. By this arrangement, the COP can be maximized at a minimum temperature (see Figure 3-10). Installation of an automatic tempering valve was therefore planned.

6.4.4 The maximum COP achieved has been only slightly over 0.6. This value is much below the 0.72 maximum COP achieved during the summer of 1978. Measured COP's are considerably lower than predicted (see Figure 3-10) particularly in the middle temperature range. Such an alteration in performance could be caused by build up of contaminants in the chiller, or non-condensable gas accumulation could result in an insufficient vacuum pressure. The chiller was pumped down without noticeable performance improvement, so the latter possibility did not appear likely. Other possible causes are a lowered air flow rate across the cooling duct coil or instrumentation faults. The matter is being investigated. (Subsequently, low air flow rate was identified as the primary cause of decreased COP levels).

## 6.5 OTHER OPERATIONS

6.5.1 Several minor control difficulties were encountered during September. The electronics of the $\Delta T$ controller for the storage pump were modified to ensure proper operation.

6.5.2 The domestic hot water preheat system was also modified. In the previous design, a three-way valve was operated so that hot water was circulated from main storage either to the space heating exchanger or to the DHW exchanger. This operation was changed because the three-way by-pass valve leaked, and because that particular mode required excessive pumping power. In the new design, the preheat heat exchanger was placed in series with the heating/cooling load on the tube side, where the pressure drop is negligible (less than 0.2 psi). Heat was transferred to the DHW preheat tank only when solar was also being delivered to the heating/cooling load.

6.5.3 Another addition to the system was a new Gormann Rupp collector pump with a wire-to-water efficiency of 50 percent (compared with the previous 13 percent).

6.5.4 Construction and system modifications during February included repair of the heat rejector unit (which had sustained some freeze damage), repiping and valving in the basement tank room to permit quick change-over between indoor and outdoor storage and heat exchange systems, reinsulation of outdoor storage tank, installation of pumps for load and storage circuits in the outdoor system, completion of new flat-plate system including controller and flowmeter, and realignment of all channels in the Doric data logging equipment. The heat rejector was connected as the load for the direct contact liquid-liquid heat exchanger/storage experiment. The flowmeter in this circuit was recalibrated and reinstalled.

6.5.5 During June, system changes were either completed or nearing completion, and several subsystems, including collection/storage and domestic hot water heating, were started. Work accomplished included installation of the new blower, minor ductwork modification, insulation of the outdoor storage tank room, and power and instrumentation rewiring. The instrumentation system was completely operational, and recorded measurements indicate that the changed system components were operating at design point or better.

## 6.6 INSTRUMENTATION AND DATA COLLECTION

6.6.1 Secondary technical difficulties have hindered the efficient collection and analysis of data in Solar House I. Early in December, the Wang typewriter failed. On-line thermopile data for the Philips collector and heat exchanger system could therefore not be immediately evaluated. At least a month was required for processing magnetic tape data records at the CSU central computer system.

6.6.2 The Deltec Uninterruptible Power Supply system required repairs in January, so the data system was operated without this back-up source of power. The simulator program hardware was functional during this period, although restarting required use of the Texas Instruments interactive terminal.

6.6.3 Data were recorded nearly continuously during February, the only major interruption being a power failure on 9 February. A defect in a terminal block was found, corrected, and realignment of all channels was performed.

6.6.4 During March, the data system continued to be operated without the uninterruptible power supply. A problem was traced to the AC breaker switch within the UPS and the unit was repaired and put back in service.

## 6.7 DIRECT CONTACT LIQUID-TO-LIQUID HEAT EXCHANGER

6.7.1 The direct contact liquid-liquid heat exchanger was connected to the original flat-plate collectors on House I in October. Repeated efforts to achieve the desired flow rate of diethyl phthalate through the collectors were unsuccessful largely because they were designed and site-built for water/antifreeze collector fluids.

6.7.2 Replacement of the site-built flat-plate collectors on Solar House I began on November 27, 1978. Single-glazed Miromit collectors with large steel absorber tubes were selected. The tubing is suitable for circulating diethyl phthalate (DEP) at the flow rate required for optimum collector/storage performance. The Miromit collectors were donated to the university by American Heliothermal Corporation.

6.7.3 Although collector replacement was completed in December, severe weather delayed completion of the outdoor solder connections.

6.7.4 Data collection from the DCLLHE system began in January. The flow rate of DEP through the collector was set at 25 gpm, equivalent in heat capacity to a water/ethylene glycol flow rate of about 15 gpm.

6.7.5 Data on the Direct Contact Liquid-Liquid Heat Exchanger experiment were obtained in February, March and April. Extensive revision in the mechanical room piping in May terminated these tests.

6.7.6 The simulator program driving the Miromit flat-plate collectors and the direct contact unit was updated for the Wang minicomputer in House I. The updating was required to conform to the reconfiguration of the system within the house.

6.7.7 A separate report will be issued on the direct contact system.

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# 7. QUANTITATIVE RESULTS

The measured quantities of solar and auxiliary energy supplied and used are reported in tabular and graphical form, and temperatures in the building, the atmosphere, and the heat storage system are tabulated. A table and two charts in Section 7.2 contain total energy quantities subdivided by months in the table. Section 7.3 comprises a sample table of monthly energy totals, a table of monthly electricity use, and five charts showing incident solar energy, heat collection, and heat use.

Section 7.4 contains a sample monthly table of measured daily energy supplied and used, totaled for the month. Complete sets of monthly and daily tables of data are presented in Appendix B and Appendix C, respectively. Graphs and charts in other subsections show examples of hourly energy quantities, correlations of solar collection with radiation intensity and operating temperature differences, energy supply and use in off-peak electric heat storage unit, and comparisons of solar heat collection in House I with that in Houses II and III and with F Chart computations.

## 7.1 BUILDING PERFORMANCE - TEMPERATURES IN THE BUILDING

As may be seen in the hourly results in Section 7.5, the typical light construction of the building makes heating and cooling demand very responsive to changes in ambient temperature and solar gain. Tables 7-1H, 7-1C and Section 7.5 show that building air temperatures, the principal measure of occupant comfort, are maintained close to the thermostat setting under most load conditions by forced air space conditioning.

Thermostat settings are also shown in Tables 7-1H and 7-1C, and though maintained constant over long periods, they were changed from time to time to accommodate the needs of the experiment. For example, air conditioning loads are lower with the new highly insulated storage tank than with the previous tank, so a lower thermostat setting provides a load more comparable to that in previous summers.

# Table 7-1H. Daily Average Winter Temperature

| DAY | NOVEMBER | | | DECEMBER | | | JANUARY | | | FEBRUARY | | | MARCH | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | OUTDOOR AIR TEMPERATURE | BUILDING AIR TEMPERATURE | THERMOSTAT SET TEMPERATURE | OUTDOOR AIR TEMPERATURE | BUILDING AIR TEMPERATURE | THERMOSTAT SET TEMPERATURE | OUTDOOR AIR TEMPERATURE | BUILDING AIR TEMPERATURE | THERMOSTAT SET TEMPERATURE | OUTDOOR AIR TEMPERATURE | BUILDING AIR TEMPERATURE | THERMOSTAT SET TEMPERATURE | OUTDOOR AIR TEMPERATURE | BUILDING AIR TEMPERATURE | THERMOSTAT SET TEMPERATURE |
| 1 | 14.5 | 26.9 | 21.0 | -.2 | 21.6 | 21.0 | -17.7 | 16.6 | 21.0 | | | | 5.1 | 21.9 | 21.0 |
| 2 | 12.3 | 23.9 | 21.0 | -13.2 | 19.8 | 21.0 | -14.4 | 17.5 | 21.0 | -10.5 | 20.7 | 22.0 | 2.1 | 21.8 | 21.0 |
| 3 | 13.1 | 23.9 | 21.0 | -10.9 | 19.7 | 21.0 | -8.9 | 19.3 | 21.0 | -8.2 | 21.4 | 22.0 | -2.7 | 21.2 | 21.0 |
| 4 | 12.1 | 22.7 | 21.0 | -4.7 | 20.5 | 21.0 | -13.9 | 19.2 | 21.0 | -6.2 | 22.2 | 22.0 | 1.0 | 21.2 | 21.0 |
| 5 | 5.1 | 20.6 | 21.0 | -5.9 | 20.7 | 21.0 | -15.8 | 19.6 | 21.0 | -6.5 | 22.4 | 22.0 | 5.2 | 22.0 | 21.0 |
| 6 | | | 21.0 | -12.9 | 19.0 | 21.0 | -8.8 | 19.2 | 21.0 | -.7 | 22.3 | 22.0 | 8.7 | 22.5 | 21.0 |
| 7 | | | 21.0 | -18.4 | 18.6 | 21.0 | -14.6 | 19.5 | 21.0 | .1 | 21.1 | 21.0 | | | 21.0 |
| 8 | 15.0 | 23.9 | 21.0 | -19.1 | 18.4 | 21.0 | -9.8 | 21.0 | 21.0 | -4.5 | 21.1 | 21.0 | 1.4 | 22.1 | 21.0 |
| 9 | 11.4 | 20.7 | 21.0 | -12.4 | 18.6 | 21.0 | -6.8 | 20.8 | 21.0 | | | 21.0 | -2.2 | 21.5 | 21.0 |
| 10 | | | 21.0 | -3.4 | 19.6 | 21.0 | -12.2 | 19.8 | 21.0 | | | 21.0 | 1.1 | 21.2 | 21.0 |
| 11 | | | 21.0 | -3.5 | 20.5 | 21.0 | -3.3 | 20.6 | 21.0 | | | 21.0 | 9.5 | 21.9 | 21.0 |
| 12 | | | 21.0 | 2.9 | 21.3 | 21.0 | -6.6 | 20.4 | 21.0 | | | 21.0 | | | 21.0 |
| 13 | 1.8 | 21.3 | 21.0 | -4.9 | 21.3 | 21.0 | -12.3 | 19.7 | 21.0 | | | 21.0 | | | 21.0 |
| 14 | -5.5 | 20.5 | 21.0 | .5 | 21.6 | 21.0 | -12.9 | 19.4 | 21.0 | | | 21.0 | | | 21.0 |
| 15 | | | 21.0 | 1.5 | 22.0 | 21.0 | -.2 | 21.4 | 21.0 | | | 21.0 | | | 21.0 |
| 16 | | | 21.0 | -4.2 | 20.8 | 21.0 | | | 21.0 | | | 21.0 | | | 21.0 |
| 17 | | | 21.0 | -3.6 | 20.1 | 21.0 | 2.7 | 21.8 | 21.0 | | | 21.0 | | | 21.0 |
| 18 | | | 21.0 | 2.7 | 20.7 | 21.0 | 1.1 | 21.8 | 21.0 | | | 21.0 | | | 21.0 |
| 19 | | | 21.0 | 2.9 | 21.4 | 21.0 | -.2 | 21.9 | 21.0 | 4.7 | 21.8 | 21.0 | | | 21.0 |
| 20 | -7.7 | 19.5 | 21.0 | -3.8 | 20.5 | 21.0 | 1.5 | 21.8 | 21.0 | 3.7 | 21.8 | 21.0 | | | 21.0 |
| 21 | -4.6 | 20.0 | 21.0 | -.2 | 21.0 | 21.0 | 1.4 | 22.1 | 21.0 | | | 21.0 | | | 21.0 |
| 22 | 1.9 | 19.5 | 21.0 | -2.2 | 21.7 | 21.0 | -3.9 | 21.8 | 21.0 | | | 21.0 | | | 21.0 |
| 23 | 6.3 | 20.9 | 21.0 | -1.1 | 18.8* | 21.0 | -9.3 | 20.8 | 21.0 | -4.5 | 21.3 | 21.0 | | | 21.0 |
| 24 | 2.2 | 20.9 | 21.0 | 1.8 | 15.6* | 21.0 | -4.5 | 21.2 | 21.0 | -1.1 | 20.9 | 21.0 | | | 21.0 |
| 25 | .2 | 20.4 | 21.0 | -2.9 | 13.7* | 21.0 | -5.3 | 20.5 | 21.0 | .8 | 21.2 | 21.0 | | | 21.0 |
| 26 | -2.2 | 20.0 | 21.0 | -7.6 | 14.9* | 21.0 | -10.6 | 20.9 | 21.0 | 6.1 | 21.9 | 21.0 | | | 21.0 |
| 27 | -2.9 | 20.6 | 21.0 | -3.9 | 20.6 | 21.0 | -12.9 | 20.8 | 21.0 | 2.2 | 21.4 | 21.0 | | | 21.0 |
| 28 | 1.3 | 20.6 | 21.0 | -1.5 | 21.0 | 21.0 | -12.7 | 20.8 | 21.0 | 1.7 | 21.4 | 21.0 | | | 21.0 |
| 29 | 1.5 | 21.2 | 21.0 | -16.7 | 19.1 | 21.0 | -14.3 | 20.2 | 21.0 | | | | | | 21.0 |
| 30 | 2.9 | 21.6 | 21.0 | -19.3 | 17.7 | 21.0 | | | 21.0 | | | | | | 21.0 |
| 31 | | | | -18.2 | 17.2 | 21.0 | | | 21.0 | | | | | | 21.0 |

*Auxiliary was not functioning

Table 7-1C. Daily Average Summer Temperature

| DAY | JULY | | | AUGUST | | | SEPTEMBER | | | OCTOBER | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | OUTDOOR AIR TEMPERATURE | BUILDING AIR TEMPERATURE | THERMOSTAT SET TEMPERATURE | OUTDOOR AIR TEMPERATURE | BUILDING AIR TEMPERATURE | THERMOSTAT SET TEMPERATURE | OUTDOOR AIR TEMPERATURE | BUILDING AIR TEMPERATURE | THERMOSTAT SET TEMPERATURE | OUTDOOR AIR TEMPERATURE | BUILDING AIR TEMPERATURE | THERMOSTAT SET TEMPERATURE |
| 1 | 23.2 | 24.9 | 25.0 | 23.1 | 25.5 | 25.5 | 22.7 | 24.4 | 25.0 | 16.9 | 22.1 | 22.5 |
| 2 | 22.6 | 25.2 | 25.0 | 24.9 | 25.4 | 25.5 | 23.6 | 24.3 | 25.0 | 21.4 | 22.8 | 22.5 |
| 3 | 23.1 | 26.5 | 25.0 | 26.5 | 25.4 | 25.5 | 25.6 | 24.4 | 25.0 | 12.4 | 22.0 | 22.5 |
| 4 | 21.9 | 24.8 | 25.0 | 29.1 | 25.9 | 25.5 | 25.3 | 24.4 | 25.0 | 15.3 | 20.9 | 22.5 |
| 5 | 22.0 | 24.8 | 25.0 | 27.5 | 25.8 | 25.5 | | 24.4 | 25.0 | 22.3 | 21.4 | 22.5 |
| 6 | 21.6 | 25.2 | 25.0 | 27.6 | 25.7 | 25.5 | 22.2 | 24.3 | 25.0 | 19.2 | 20.8 | 22.5 |
| 7 | 24.4 | 24.6 | 25.0 | 28.1 | 25.7 | 25.5 | 23.7 | 24.5 | 25.0 | 21.8 | 21.4 | 22.5 |
| 8 | 24.0 | 26.5 | 25.0 | 24.3 | 25.7 | 25.5 | 25.4 | 24.4 | 25.0 | 17.9 | 22.5 | 22.5 |
| 9 | 24.0 | 27.4 | 25.0 | 22.6 | 25.4 | 25.5 | 26.7 | 24.5 | 25.0 | 4.2 | 21.5 | 22.5 |
| 10 | 26.0 | 27.3 | 25.0 | 18.0 | 23.7 | 25.5 | | 24.6 | 25.0 | 17.5 | 23.3 | 22.5 |
| 11 | 29.9 | 27.3 | 25.0 | 22.0 | 22.8 | 25.5 | 13.6 | 23.7 | 23.0 | 20.5 | 23.5 | 22.5 |
| 12 | 26.6 | 27.7 | 25.0 | 24.1 | 24.5 | 25.0 | 14.5 | 23.6 | 23.0 | 15.6 | 22.5 | 22.5 |
| 13 | 27.9 | 28.8 | 25.0 | 19.5 | 25.1 | 25.0 | 12.7 | 23.0 | 23.0 | 11.9 | 20.5 | 22.5 |
| 14 | 25.0 | 26.2 | 25.0 | 14.3 | 23.8 | 25.0 | 13.7 | 22.1 | 22.5 | 19.5 | 20.6 | 22.5 |
| 15 | 22.0 | 26.5 | 25.0 | | | | 18.7 | 21.0 | 22.5 | 19.2 | 22.5 | 22.5 |
| 16 | 20.1 | 24.1 | 25.0 | 21.5 | 24.4 | 25.0 | 20.2 | 21.0 | 22.5 | 13.6 | 22.5 | 22.5 |
| 17 | 22.9 | 25.0 | 25.0 | 23.0 | 24.5 | 25.0 | 22.8 | 22.8 | 22.5 | 11.1 | 22.3 | 22.5 |
| 18 | 21.8 | 25.6 | 25.0 | 23.5 | 24.6 | 25.0 | 19.2 | 22.6 | 22.5 | | | 22.5 |
| 19 | 22.9 | 25.5 | 25.0 | 20.9 | 22.8 | 25.0 | 20.2 | 22.6 | 22.5 | | | 22.5 |
| 20 | 23.6 | 24.4 | 25.0 | 19.9 | 23.0 | 25.0 | 18.3 | 22.3 | 22.5 | | | 22.5 |
| 21 | 23.0 | 24.2 | 25.0 | 21.8 | 24.2 | 25.0 | 17.8 | 22.3 | 22.5 | | | 22.5 |
| 22 | 23.7 | 24.4 | 25.0 | 22.8 | 24.0 | 25.0 | 22.9 | 22.1 | 22.5 | | | 22.5 |
| 23 | 23.4 | 25.2 | 25.5 | 21.7 | 24.7 | 25.0 | 24.5 | 22.3 | 22.5 | | | 22.5 |
| 24 | 23.4 | 25.4 | 25.5 | 22.2 | 24.1 | 25.0 | 21.9 | 22.5 | 22.5 | | | 22.5 |
| 25 | 23.5 | 25.4 | 25.5 | 19.6 | 22.9 | 25.0 | 20.3 | 22.6 | 22.5 | | | 22.5 |
| 26 | 22.3 | 25.9 | 25.5 | 19.6 | 22.6 | 25.0 | 20.0 | 22.8 | 22.5 | | | 22.5 |
| 27 | 25.3 | 25.8 | 25.5 | | | 25.0 | 20.5 | 22.5 | 22.5 | | | 22.5 |
| 28 | 26.4 | 25.8 | 25.5 | | | 25.0 | 19.9 | 22.2 | 22.5 | | | 22.5 |
| 29 | 21.1 | 25.7 | 25.5 | 24.1 | 23.6 | 25.0 | 22.0 | 21.8 | 22.5 | | | 22.5 |
| 30 | 19.2 | 24.6 | 25.5 | 22.8 | 24.0 | 25.0 | 22.3 | 22.1 | 22.5 | | | 22.5 |
| 31 | 23.7 | 25.5 | 25.5 | 23.8 | 24.2 | 25.0 | | | | | | 22.5 |

Loads are not typical of normal residential buildings because the building is used for offices. Tours, sometimes of 30 or more people, are frequent. Atypical electric equipment, such as typewriters, mini-computer, power conditioning equipment and data acquisition devices also produce considerable heat. Three hot water dumps per day are made in a pattern reflecting residential use. However, instrument and control problems sometimes made hot water demand irregular as may be seen in the daily results of Section 7.4. Except on four days when the auxiliary heater was not operating, the lowest daily average building temperature was 16.6°C. On four other days, average building temperature ranged from 16.6 to 17.7, and throughout the balance of the winter, average temperatures varied between 18.4 and 22.5°C.

In the summer months, Table 7-1C shows the maximum daily average temperature of the living space was 28.8°C, and on nine days, average temperature was above 26°C. During the balance of the summer, average daily building temperatures were not more than one degree above thermostat settings of 25.5°. 25.0°, or 22.5°C.

## 7.2 SEASONAL AND ANNUAL PERFORMANCE OF SOLAR HEATING, COOLING, AND HOT WATER SYSTEMS

Figures 7-1H and 7-1C show the distribution of the energy falling on the collector aperture during the heating and cooling seasons. The width of the arrows, except for very small energy values, is proportional to the energy flows. Monthly totals based on daily averages appearing in Section 7.3 and Appendix B were used to construct these figures. Percentages are portions of the total incident solar energy on the collector.

Table 7-2 contains monthly, seasonal, and annual totals of incident solar energy, energy collected, solar energy applied to heating, cooling, and hot water supply, electric auxiliary heat and electric energy for pumping, and other values based on those totals. Some of these energy quantities differ slightly from those shown in Figures 7-1H and 7-1C because the table includes net energy storage changes during data gaps whereas the charts do not.

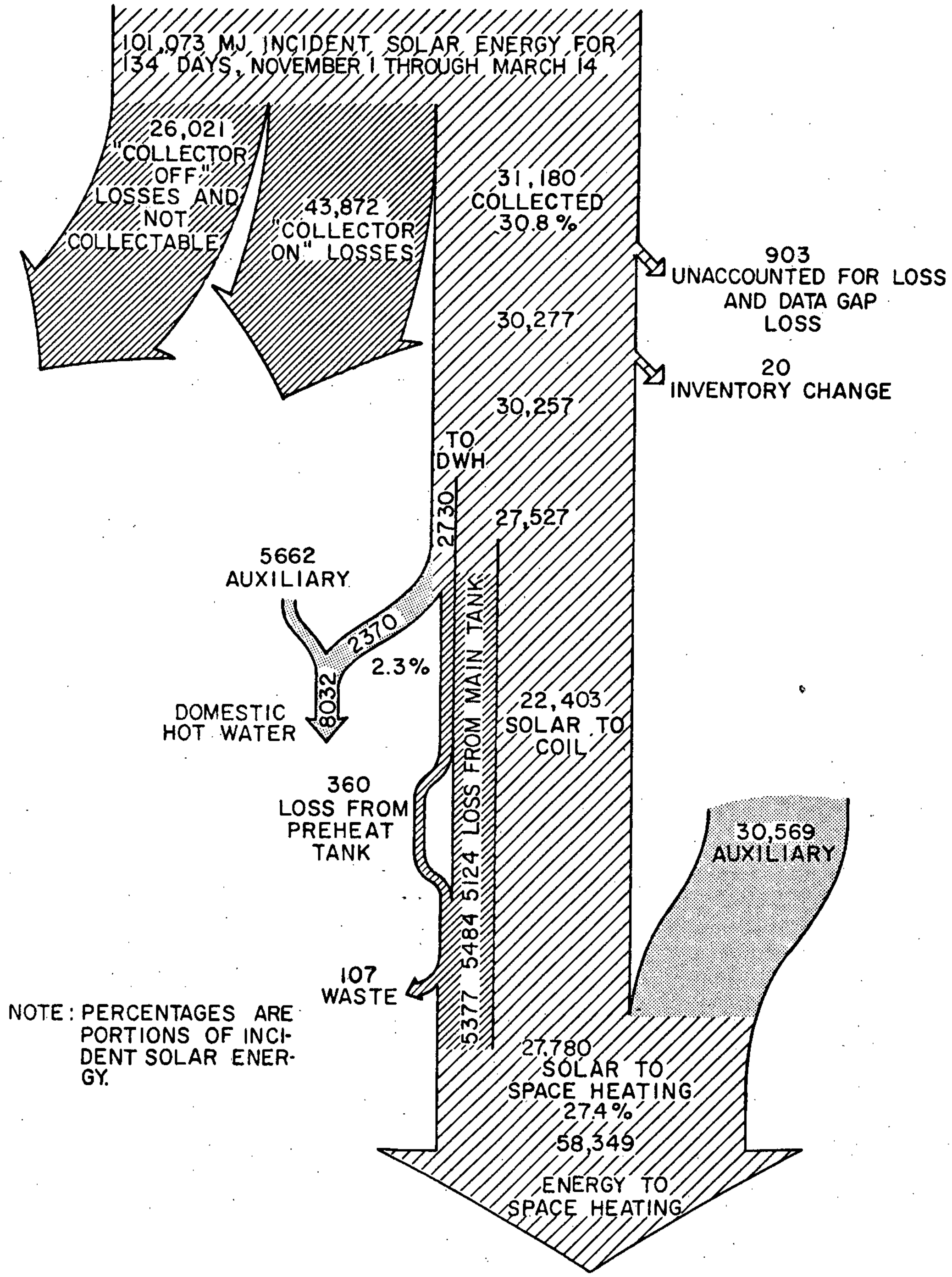



Figure 7-1H. 1978-79 Heating Season Energy Flows for Solar House I

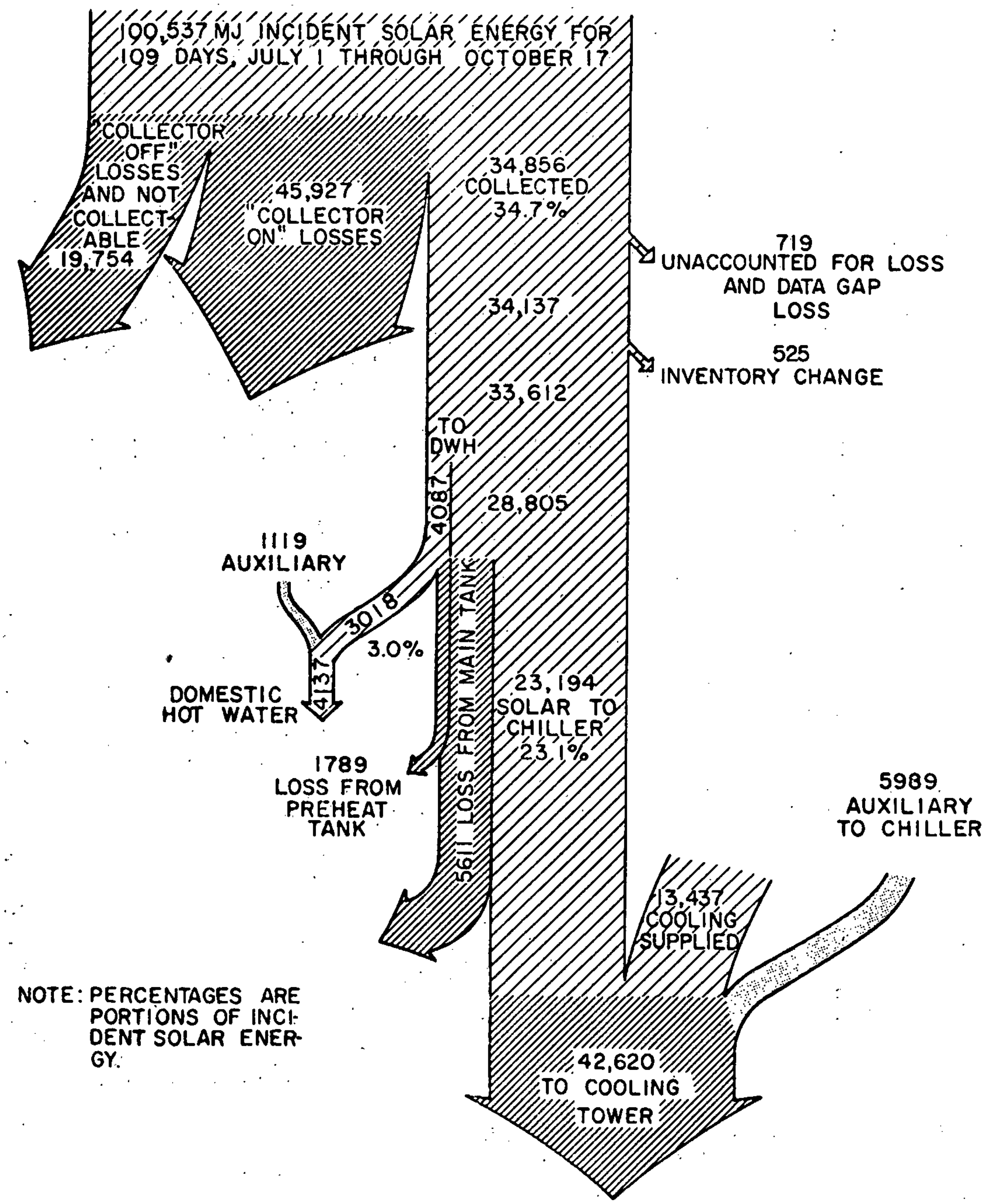



Figure 7-1C. 1979 Cooling Season Energy Flows for Solar House I

## Table 7-2. CSU Solar House Performance 1978-1979

| Month<br>Days of Data | Oct<br>29 | Nov<br>20 | Dec<br>31 | Jan<br>28 | Feb<br>15 | Mar<br>10 | Total<br>10/1<br>to<br>3/14 | July<br>31 | Aug<br>28 | Sept<br>30 | Oct<br>17 | Total<br>7/1<br>to<br>10/17 | Total<br>274<br>days | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Total solar on aperture | 928[1] | 642 | 708 | 704 | 888 | 942 | 129841[2] | 904 | 871 | 1000 | 914 | 100537[2] | 230378 | 44.7 $m^2$ aperture |
| 2. Solar when operating | 719 | 495 | 480 | 438 | 752 | 762 | 97340 | 709 | 661 | 856 | 743 | 80783 | 178123 | |
| 3. Energy collected (5) | 264 | 158 | 210 | 199 | 321 | 300 | 38792 | 297 | 281 | 379 | 320 | 34742 | 73534 | |
| 4. Collection efficiency (5) | 28.5% | 24.6% | 29.7% | 27.7% | 35.4% | 31.1% | 29.9% | 32.9% | 32.7% | 37.9% | 35.0% | 34.6% | 31.9% | (3)÷(1) |
| 5. Collection efficiency when operating (5) | 36.7% | 38.5% | 43.8% | 44.5% | 41.8% | 38.5% | 39.9% | 41.9% | 43.0% | 44.3% | 43.1% | 43.0% | 41.3% | (3)÷(2) |
| 6. Total space heating | 101 | 334 | 426 | 568 | 453 | 345 | 61481 | | | | | | 61481 | |
| 7. Solar space heating | 101 | 166 | 195 | 179 | 272 | 259 | 30911 | | | | | | 30911 | |
| 8. % solar heating | 100% | 49.5% | 45.7% | 31.6% | 59.9% | 75.1% | 50.3% | | | | | | 50.3% | (7)÷(6) |
| 9. Total heat for cooling | 207 | | | | | | 6431 | 230 | 221 | 362 | 254 | 29183 | 35614 | Supply to chiller |
| 10. Solar for cooling | 119 | | | | | | 3680 | 170 | 188 | 272 | 233 | 23194 | 26874 | |
| 11. % solar for cooling | 57.2% | | | | | | 57.2% | 73.6% | 84.8% | 75.1% | 91.8% | 79.5% | 75.5% | (10)÷(9) |
| 12. Total hot water | 8 | 20 | 57 | 84 | 106 | 7 | 8032 | 28 | 38 | 46 | 40 | 4137 | 12169 | |
| 13. Solar for hot water | 0 | 10 | 24 | 16 | 26 | 7 | 2370 | 18 | 32 | 34 | 28 | 3008 | 5378 | |
| 14. % solar hot water | 0% | 52.0% | 41.7% | 19.3% | 24.4% | 100% | 29.5% | 62.7% | 82.4% | 73.1% | 69.4% | 72.7% | 44.2% | (13)÷(12) |
| 15. Total loads | 317 | 354 | 483 | 652 | 559 | 352 | 75944 | 259 | 260 | 409 | 294 | 33320 | 109264 | (6)+(9)+(12) |
| 16. Total solar to loads | 220 | 176 | 218 | 196 | 297 | 266 | 36961 | 187 | 219 | 306 | 261 | 26202 | 63163 | (7)+(10)+(13) |
| 17. % solar, total | 69% | 49.7% | 45.2% | 30.0% | 53.2% | 75.5% | 48.7% | 72.4% | 84.4% | 74.9% | 88.8% | 78.6% | 57.8% | (16)÷(15) |
| 18. System efficiency | 23.7% | 27.4% | 30.8% | 27.8% | 33.4% | 28.2% | 28.5% | 20.7% | 25.1% | 30.6% | 28.6% | 26.1% | 27.4% | (16)÷(1) |
| 19. Total cooling supplied | 77 | | | | | | 2383 | 111 | 100 | 161 | 124 | 13437 | | Output of chiller |
| 20. Cooling from solar | 47 | | | | | | 1444 | 77 | 82 | 117 | 114 | 10363 | | |
| 21. % cooling by solar | 60.6% | | | | | | 60.6% | 70.0% | 82.0% | 73.1% | 91.9% | 77.1% | | (20)÷(19) |
| 22. Total cooling COP | 0.37 | | | | | | 0.37 | 0.48 | 0.45 | 0.44 | 0.49 | 0.46 | | (19)÷(9) |
| 23. Solar cooling COP | 0.39 | | | | | | 0.39 | 0.46 | 0.44 | 0.43 | 0.49 | 0.45 | | (20)÷(10) |
| 24. Collector pumping energy (3) | 20.6 | 12.2[4] | 9.0 | 9.5 | 13.1 | 11.1 | 2101 | 15.1 | 13.7 | 16.2 | 14.8 | 1631 | 3732 | Total elec. use other than aux. |
| 25. Solar use/collection pumps | 10.7 | 14.4 | 24.2 | 20.6 | 22.7 | 24.0 | 17.6 | 12.4 | 16.0 | 18.9 | 17.6 | 16.1 | 16.9 | (16)÷(25) |
| 26. Mean storage temp °C | 75 | 53.2 | 40.3 | 39.2 | 40.8 | 48.1 | | 73.6 | 75.8 | 75.1 | 77.0 | | | |
| 27. Mean ambient temp °C | 10 | 9.5 | 1.1 | -5.0 | 1.3 | 7.1 | | 28.7 | 29.0 | 26.1 | 22.7 | | | |

Notes:
(1) All monthly energy quantities in megajoules per day
(2) All seasonal and annual total energy quantities in megajoules for entire period
(3) October-March by visual meter readings. July-October by data logger
(4) Pump change November 18
(5) Values corrected for gain or loss during data gaps

## 7.3 MONTHLY PERFORMANCE OF THE SOLAR HEATING, COOLING, AND HOT WATER SYSTEMS

Daily averages and extrapolated monthly totals of the most important thermal performance indicators for solar collection, thermal storage, space heating, water heating, and space conditioning appear in Appendix B, Tables B-1H through B-5H (heating) and B-1C through B-4C (cooling). An example (November) is also shown in this section as Table 7-3H. For November through February and July through September, the totals that appear in the tables are extrapolated to a full month from the daily averages shown in Section 7.4. However, the totals for March and October are for parts of those months. Quantities listed in the tables are defined in Table 7-4 in terms of the items calculated and measured.

It may be seen in the tables that there is a difference between "energy collected" and "apparent energy delivered to storage". During data gaps, some net gain or loss was an excess or deficiency caused by solar operations during those intervals. Net storage energy gain for the month includes net energy gains (or losses) during data gaps since that energy may be used later. These net gains and losses are computed by hand and entered into the program manually.

Key thermal performance quantity and indicator values for the collection subsystem from Tables B-1H through B-5H and B-1C through B-4C are displayed in Figures 7-2H and 7-2C. Weighted average temperatures of storage and of outdoor ambient air are also shown. These averages are calculated by weighting the temperatures according to daily "collector on" incident solar energy. Figures 7-3H, 7-3C and 7-4C display key quantities and indicators for the space heating and cooling subsystems. October 1978 values in the figures are from the 1977-1978 Solar House I report [9]. Figure 7-3H includes values only from October 17 through the end of the month. The first part of October is omitted because cooling was the predominant mode. Figure 7-2H, however, includes values for the entire month.

Electricity for operating pumps used for solar collection, transfer to storage, and transfer to the service hot water preheat tank was continuously measured and recorded, but data logging problems prevented procurement of accurate results during the heating season. Monthly

Table 7-3H. Daily Averages and Extrapolated Monthly Totals, November 1978

CSU SOLAR HOUSE I

DAILY AVERAGES AND EXTRAPOLATED MONTHLY TOTALS

NOVEMBER 1978

| | MONTHLY TOTALS | DAILY AVERAGES |
|---|---|---|
| DAYS OF DATA | 20 | 20 |
| AVERAGE DAILY ENERGY FLUX (PER SQ.M) | 14.4 | 14.4 |
| TOTAL INCIDENT SOLAR ON 44.7 SQ.M APERTURE AREA | 19259. | 642.3 |
| TOTAL INCIDENT SOLAR ON 54.2 SQ.M COLLECTOR AREA | 23364. | 778.8 |
| INCIDENT SOLAR 'ON' (APERTURE AREA) | 14851. | 495.0 |
| INCIDENT SOLAR 'ON' (COLLECTOR AREA) | 18007. | 600.2 |
| SOLAR ENERGY COLLECTED | 5713. | 190.5 |
| NET STORAGE ENERGY GAIN DURING DATA GAPS | -984. | -32.8 |
| APPARENT ENERGY DELIVERED TO STORAGE | 4730. | 157.7 |
| NET STORAGE ENERGY GAIN FOR MONTH | -635. | -21.2 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-APERTURE) | .297 | .297 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-COLLECTOR) | .245 | .245 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -APERTURE) | .385 | .385 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -COLLECTOR) | .317 | .317 |
| SPACE HEATING LOAD (COIL) | 8736. | 291.2 |
| SPACE HEATING BY SOLAR (COIL) | 3676. | 122.5 |
| SOLAR SPACE HEATING (COIL) FRACTION | .421 | .421 |
| SOLAR ENERGY LOST FROM STORAGE | 1397. | 46.6 |
| USEFUL SOLAR ENERGY LOST FROM STORAGE | 1290. | 43.0 |
| TOTAL SPACE HEATING LOAD | 10026. | 334.2 |
| TOTAL SOLAR SPACE HEATING | 4966. | 165.5 |
| TOTAL SOLAR SPACE HEATING FRACTION | .495 | .495 |
| SPACE COOLING LOAD | 0. | 0.0 |
| SOLAR SPACE COOLING | 0. | 0.0 |
| SOLAR SPACE COOLING FRACTION | 0.000 | 0.000 |
| TOTAL COOLING SUPPLIED | 0. | 0.0 |
| SOLAR COOLING SUPPLIED | 0. | 0.0 |
| SOLAR FRACTION OF COOLING SUPPLIED | 0.000 | 0.000 |
| SOLAR ENERGY DELIVERED TO PREHEAT TANK | 365. | 12.2 |
| TOTAL ENERGY TO SERVICE HOT WATER | 588. | 19.6 |
| SOLAR ENERGY TO SERVICE HOT WATER | 306. | 10.2 |
| SOLAR HOT WATER FRACTION | .520 | .520 |
| TOTAL LOAD | 10614. | 353.8 |
| TOTAL LOAD BY SOLAR | 5272. | 175.7 |
| SOLAR TOTAL FRACTION | .497 | .497 |
| ENERGY SAVINGS FOR DOMESTIC HOT WATER | 2163. | 72.1 |
| ENERGY SAVINGS FOR SPACE HEATING | 4956. | 165.5 |
| ENERGY SAVINGS FOR SPACE COOLING | 0. | 0.0 |
| ENERGY SAVINGS FOR SPACE COOLING,EXCLUDING LOSSES | 0. | 0.0 |
| TOTAL ENERGY SAVINGS | 7129. | 237.6 |
| TOTAL ENERGY SAVINGS,EXCLUDING LOSSES | 7129. | 237.6 |
| UNACCOUNTABLE ENERGY LOST FROM MAIN STORAGE | -103. | |
| UNACCOUNTABLE ENERGY LOST, PCT. OF TOTAL COLLECTED | -2.2 | |
| UNACCOUNTABLE ENERGY LOST FROM PREHEAT TANK | -55. | |
| UNACCOUNTABLE ENERGY LOST, PCT. OF TOTAL INPUT | 0.0 | |

ALL DATA IN MEGAJOULES

## Table 7-4. Definition of Items Calculated in Monthly Summaries

| Item | Description |
|---|---|
| Days of data | Number of included days |
| Average daily energy flux (per square meter) | Q001 |
| Total incident solar on 44.7 sq. meter aperture area | S005 |
| Total incident solar on 54.2 sq. meter collector area | S006 |
| Incident solar "on" (aperture area) | S007 |
| Incident solar "on" (collector area) | S008 |
| Solar energy collected | Q111 |
| Net storage energy gain during data gaps | Net storage gain for month, (Net storage energy gain, included days) x (Days in month/Days of data) |
| Apparent energy delivered to storage | Q200 + (Net storage energy gain during data gaps) |
| Net storage energy gain for month | ΔQ205 |
| System collection efficiency (Total incident, aperture) | N103 |
| System collection efficiency (Total incident, collector) | N105 |
| System collection efficiency (Incident "on", aperture) | N104 |
| System collection efficiency (Incident "on", collector) | N106 |
| Space heating load (coil) | Q402 |
| Space heating by solar (coil) | Q412 |
| Solar space heating (coil) fraction | Q402/Q411 |
| Solar energy lost from storage | Q604M |
| Useful solar energy lost from storage | Q650C |
| Total space heating load | Q610 |
| Total solar space heating | Q611 |
| Total solar space heating fraction | N401 |
| Space cooling load | Q512 |
| Solar space cooling | Q540 |
| Solar space cooling fraction | N501 |
| Total cooling supplied | Q502 |
| Solar cooling supplied | Q541 |
| Solar fraction of cooling supplied | N502 |
| Solar energy delivered to preheat tank | Q312 |
| Total energy to service hot water | Q302 |
| Solar energy to service hot water | Q313 |
| Solar hot water fraction | N301 |
| Total load | Q606 |
| Total load by solar | Q607 |
| Solar total fraction | N601 |

*$\eta_B$ and $\eta_{HW}$ are the boiler and hot water burning efficiences and COP is the chiller coefficient of performance

visual readings of electric meters were threfore used in the analysis of the October-March operation and automatic recordings were used in the July-October period. Monthly totals of these electric energy quantities and solar energy usage per unit of electric energy for collection are tabulated. Readings of other electric meters were periodically recorded, and monthly electric usage for other system pumps was calculated. Table 7-5 contains monthly, electric energy consumption for solar collection distribution of solar and auxiliary heat, and chiller operation, as well as solar energy delivered to uses and the corresponding ratios.

Table 7-5. Solar and Pumping Energy (MJ/day)

| Month | Solar Energy Used | Electric Energy for Collection(1) | Solar Use ÷ Electric for Collection (SCOP) | Solar Plus Auxiliary Used | Electric Energy for Distillation(2) | Total Energy Use ÷ for Distrib. |
|---|---|---|---|---|---|---|
| October 1978 | 220 | 20.6 | 10.7 | 317 | 9.4 | 33.7 |
| November | 176 | 12.2 | 14.4 | 354 | (3) | |
| December | 218 | 9.0 | 24.2 | 483 | 13.6 | 35.5 |
| January 1979 | 196 | 9.5 | 20.6 | 652 | 9.4 | 69.4 |
| February | 297 | 13.1 | 22.7 | 559 | 9.8 | 57.0 |
| March | 266 | 11.1 | 24.0 | 352 | (3) | |
| July 1979 | 187 | 15.1 | 12.4 | 259 | (3) | |
| August | 219 | 13.7 | 16.0 | 260 | 20.1 (4) | 12.9 (5) |
| September | 306 | 16.2 | 18.9 | 409 | 50.8 (4) | 8.1 (5) |
| October | 261 | 14.8 | 17.6 | 294 | (3) | |

(1) For collector pump, storage heat exchanger pump, hot water preheat pump.

(2) Pump for water to heating coil or chiller generator. In July-Oct, includes also chilled water pump, cooling water pump, cooling tower fan, LiBr solution.

(3) Data not available.

(4) Based on electric meter readings August 6-27 and September 4-25.

(5) Values of total cooling delivered ÷ total electric usage for collection, distribution, and chiller operation are 2.96 and 2.40 in August and September. If solar heat usage for hot water had also been used for cooling, total solar cooling delivered ÷ total electric usage would have been 3.37 in August and 2.63 in September.

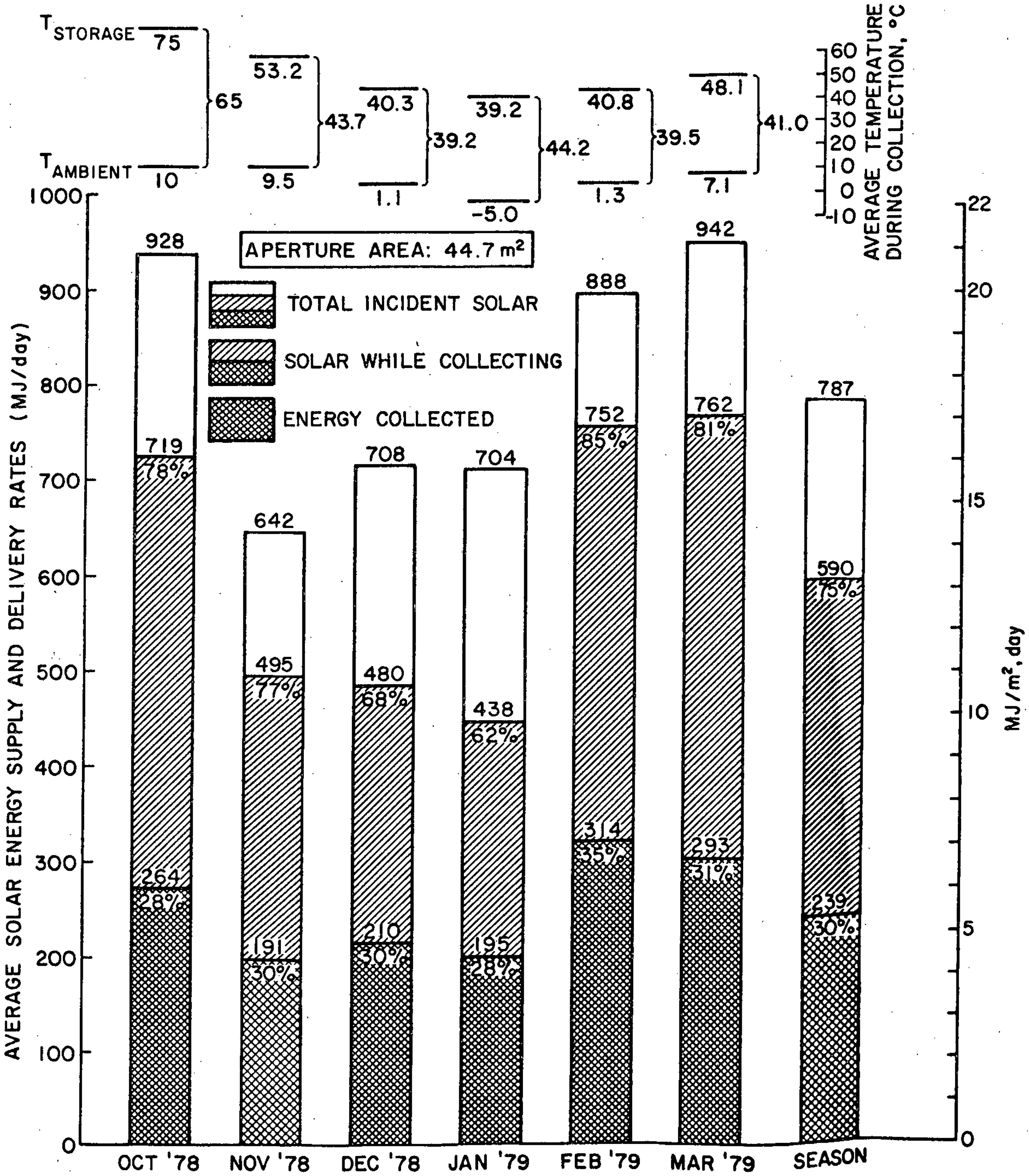



Figure 7-2H. Solar Energy Monthly Availability and Collection for the Heating Season

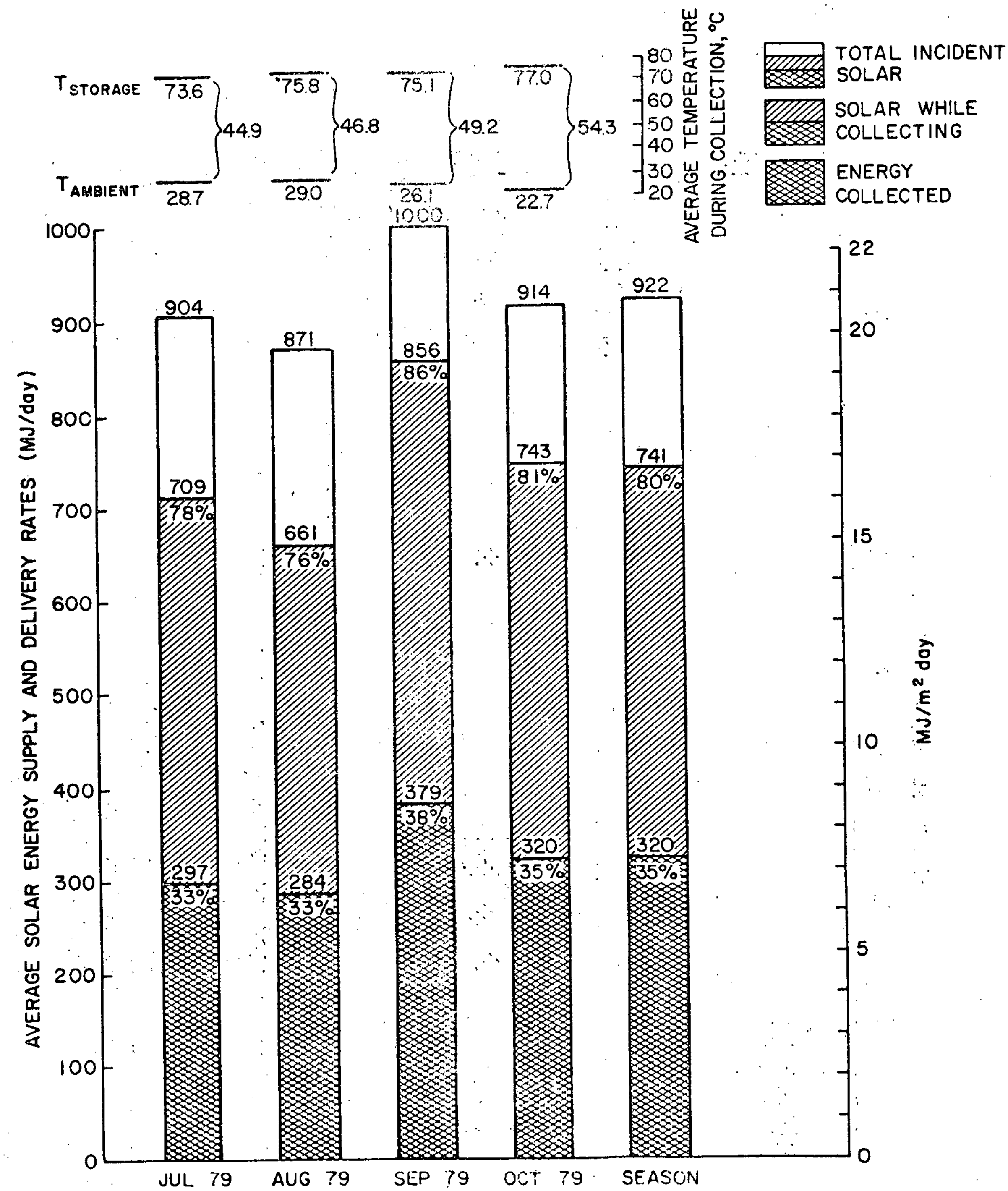



Figure 7-2C. Solar Energy Monthly Availability and Collection for the Cooling Season

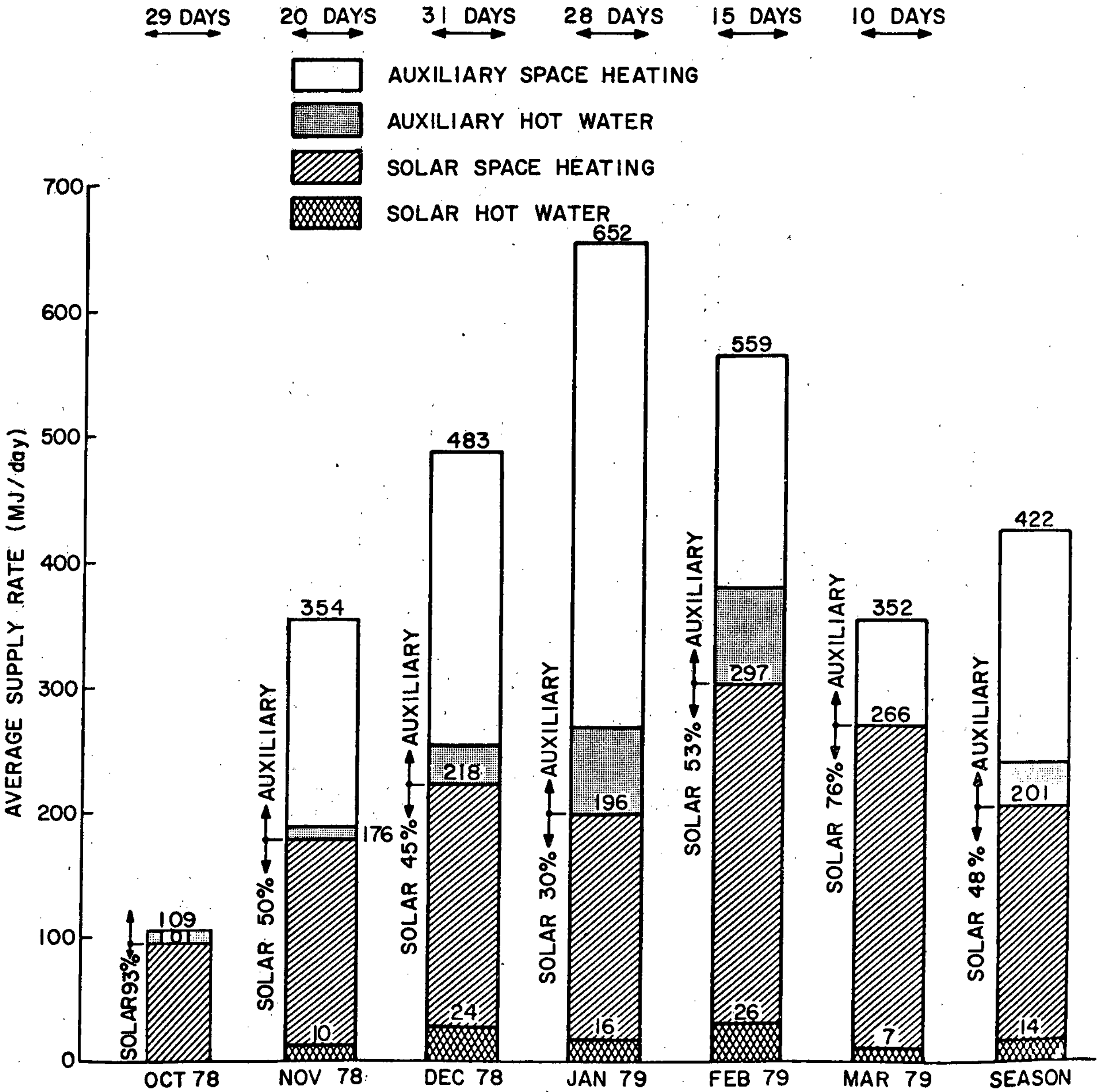



Figure 7-3H. Solar and Auxiliary Energy Use During Heating Season

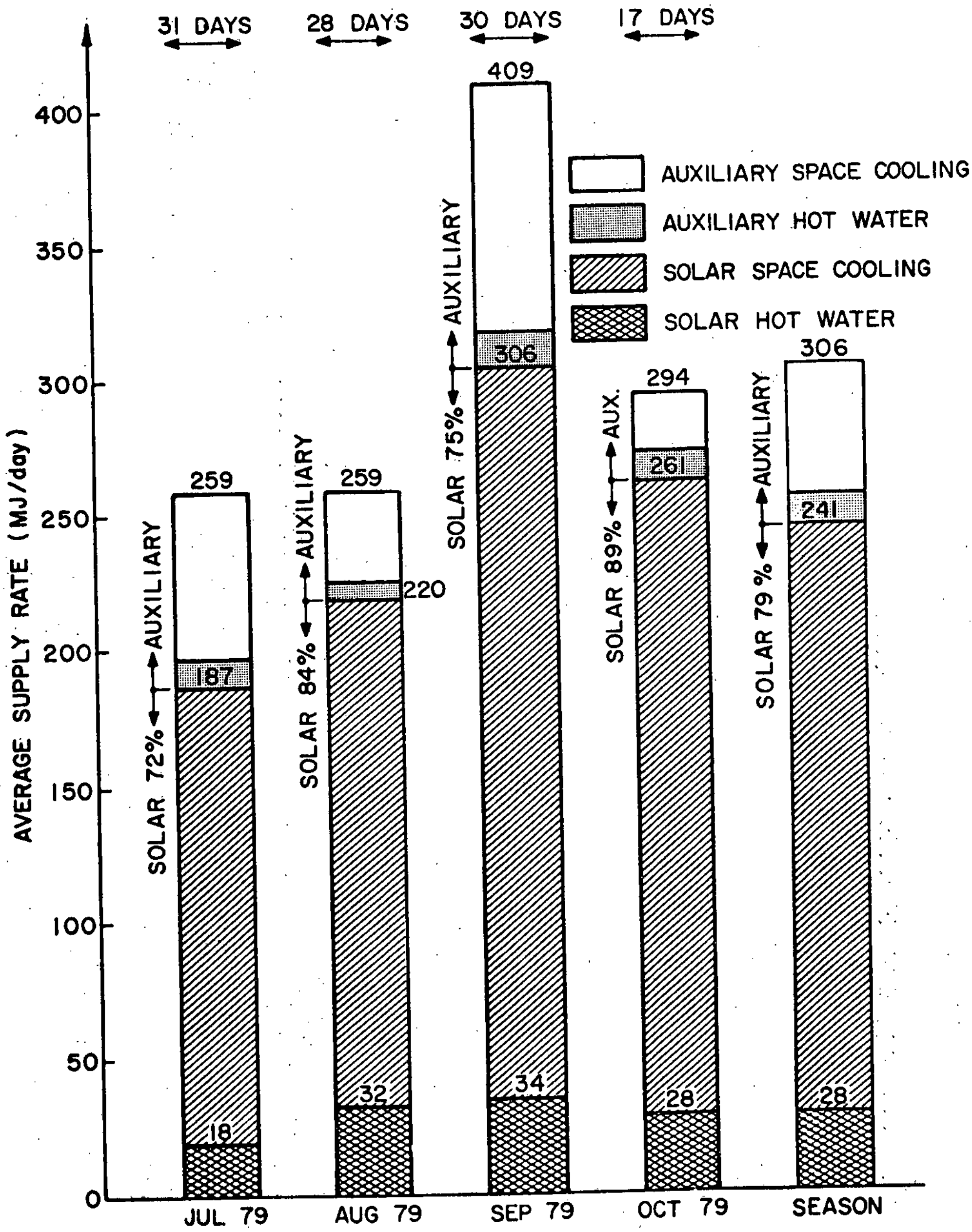



Figure 7-3C. Solar and Auxiliary Energy Use During Cooling Season

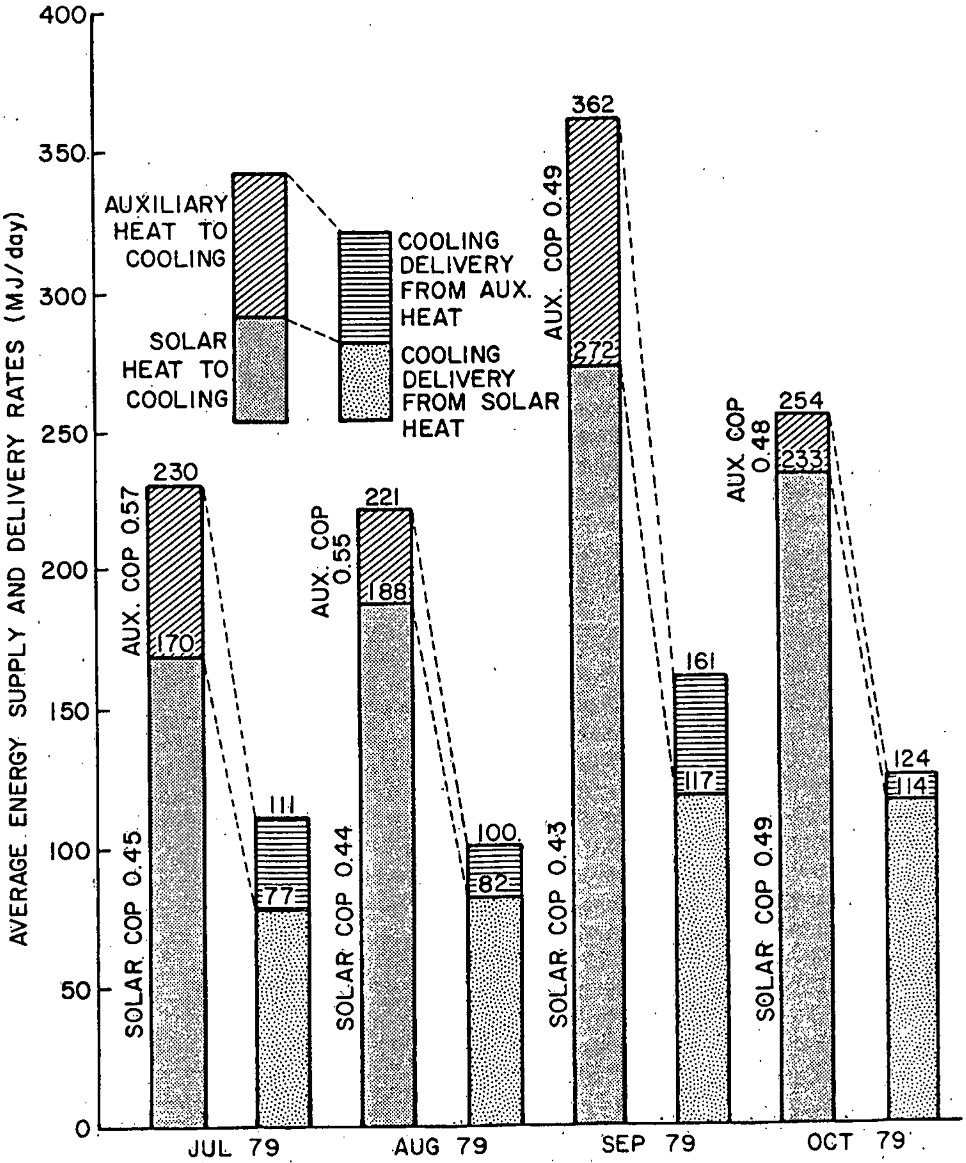



Figure 7-4C. Chiller Performance with Solar and Auxiliary Heat

## 7.4 DAILY PERFORMANCE OF THE SOLAR HEATING, COOLING AND HOT WATER SYSTEMS

Monthly summaries of daily system performance are presented in Appendix C, as Tables C-1H through C-5H (heating) and C-1C through C-4C (cooling), for the period 1 November 1978-31 October 1979. An example (November) is also shown in this section as Tables 7-6H. The definitions of the quantities in the monthly summaries are given in Chapter 5 of this report. In the last lines of each table, the daily values are totaled and divided by the number of days of data to obtain daily averages. These averages are then multiplied by the number of days in the month to obtain monthly totals which are also given in Section 7.3. Totals for March and October are based on the portions of each month during which the solar systems operated. This procedure is based on the assumption that the days for which data are available are representative of the entire month. It was shown in the 1977-78 Solar House I report [9] that this is a satisfactory approximation of the full month. Comments pertaining to the data appearing in the tables are presented in Appendix A.

Figures 7-5H, 7-6H, 7-5C and 7-6C are plots of daily energy collected versus daily incident energy. The effect on performance of the temperature difference between storage and ambient is partially recognized by segregating the data into a set for which $\Delta T$ was less than 45° and another set for which $\Delta T$ was greater than 45°. Points representing unusually high and low $\Delta T$ values are identified by numbers representing the difference. A regression analysis of the equation, Q111 = a + b(S005) yielded correlation coefficients of about 0.97.

## 7.5 HOURLY PERFORMANCE OF THE SOLAR HEATING, COOLING AND HOT WATER SYSTEMS

Figure 7-7C displays several important hourly thermal and temperature quantities for a three day period in the cooling season. Many of the control and timing aspects of cooling systems operation are shown. A typical auxiliary and solar supply sequence is shown. On many evenings, cooling demand persists beyond the time when storage

## Table 7-6H. CSU Solar House I System Performance for Month of November, 1978

| DAY | ENERGY REQUIRED | | | | SOLAR ENERGY USED | | | | | | | AUXILIARY ENERGY USED | | | | SOLAR FRACTION | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q610 SPACE HEATING | Q512 SPACE COOLING | Q312 HOT WATER HEATING | Q606 TOTAL | Q402 SPACE HEATING | Q604C ACTUAL STORAGE LOSSES | Q611 TOTAL USEFUL HEATING | Q604E STORAGE LOSSES ESTIMATED | Q540 SPACE COOLING | Q313 HOT WATER HEATING | Q612 TOTAL USEFUL ENERGY | Q442 SPACE HEATING | Q501 SPACE COOLING | Q301 HOT WATER HEATING | Q601 TOTAL | N401 SPACE HEATING | N501 SPACE COOLING | N301 HOT WATER HEATING |
| 1 | 215.9 | 0.0 | 12.2 | 228.1 | 115.0 | 100.9 | 215.9 | 114.3 | 0.0 | 5.0 | 220.9 | 0.0 | 0.0 | 7.2 | 7.2 | 1.000 | 0.000 | .410 |
| 2 | 158.0 | 0.0 | 10.9 | 168.9 | 3.2 | 154.8 | 158.0 | 127.3 | 0.0 | 3.4 | 161.4 | 0.0 | 0.0 | 7.5 | 7.5 | 1.000 | 0.000 | .312 |
| 3 | 216.6 | 0.0 | 9.7 | 226.3 | 25.1 | 191.5 | 216.6 | 139.1 | 0.0 | 2.6 | 219.2 | 0.0 | 0.0 | 7.1 | 7.1 | 1.000 | 0.000 | .268 |
| 4 | 175.0 | 0.0 | 7.8 | 182.8 | 18.0 | 157.0 | 175.0 | 127.3 | 0.0 | .9 | 175.9 | 0.0 | 0.0 | 6.9 | 6.9 | 1.000 | 0.000 | .115 |
| 5 | 660.8 | 0.0 | 23.2 | 684.0 | 563.5 | 97.3 | 660.8 | 85.5 | 0.0 | 16.8 | 677.6 | 0.0 | 0.0 | 6.4 | 6.4 | 1.000 | 0.000 | .724 |
| 6 | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | | | |
| 8 | 111.1 | 0.0 | 9.5 | 120.6 | .6 | 86.0 | 86.6 | 106.1 | 0.0 | .9 | 87.5 | 24.4 | 0.0 | 8.6 | 33.0 | .780 | 0.000 | .095 |
| 9 | 0.0 | 0.0 | 8.8 | 8.8 | 0.0 | 71.0 | 0.0 | 105.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.8 | 8.8 | 0.000 | 0.000 | 0.000 |
| 10 | | | | | | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | | | | | |
| 13 | 710.7 | 0.0 | 49.8 | 760.5 | 61.7 | 17.7 | 79.4 | 23.5 | 0.0 | 38.5 | 117.9 | 630.4 | 0.0 | 11.3 | 641.7 | .112 | 0.000 | .773 |
| 14 | 507.3 | 0.0 | 23.5 | 530.8 | 233.9 | 9.5 | 243.4 | 23.7 | 0.0 | 13.5 | 256.9 | 260.6 | 0.0 | 10.0 | 270.6 | .480 | 0.000 | .574 |
| 15 | | | | | | | | | | | | | | | | | | |
| 16 | | | | | | | | | | | | | | | | | | |
| 17 | | | | | | | | | | | | | | | | | | |
| 18 | | | | | | | | | | | | | | | | | | |
| 19 | | | | | | | | | | | | | | | | | | |
| 20 | 433.3 | 0.0 | 16.0 | 449.3 | 110.0 | -57.9 | 42.1 | -6.6 | 0.0 | 4.4 | 46.5 | 390.2 | 0.0 | 11.6 | 401.8 | .097 | 0.000 | .275 |
| 21 | 402.8 | 0.0 | 11.6 | 414.4 | 27.7 | -21.5 | 6.2 | -5.3 | 0.0 | 0.0 | 6.2 | 396.4 | 0.0 | 11.6 | 408.0 | .015 | 0.000 | 0.000 |
| 22 | 167.7 | 0.0 | 37.1 | 204.8 | 106.0 | -48.1 | 57.9 | 6.9 | 0.0 | 25.6 | 83.5 | 108.4 | 0.0 | 11.5 | 119.9 | .346 | 0.000 | .690 |
| 23 | 344.6 | 0.0 | 32.5 | 377.1 | 162.2 | 28.9 | 191.1 | 26.1 | 0.0 | 22.3 | 213.4 | 150.8 | 0.0 | 10.2 | 161.0 | .555 | 0.000 | .686 |
| 24 | 416.6 | 0.0 | 18.5 | 435.1 | 222.3 | 32.5 | 254.8 | 21.7 | 0.0 | 9.0 | 263.8 | 158.6 | 0.0 | 9.5 | 168.1 | .612 | 0.000 | .486 |
| 25 | 367.1 | 0.0 | 12.6 | 379.7 | 143.8 | -25.2 | 118.6 | 6.1 | 0.0 | 2.6 | 121.2 | 246.8 | 0.0 | 10.0 | 256.8 | .323 | 0.000 | .206 |
| 26 | 367.7 | 0.0 | 13.2 | 380.9 | 74.0 | .7 | 74.7 | -.7 | 0.0 | 2.8 | 77.5 | 293.1 | 0.0 | 10.4 | 303.5 | .203 | 0.000 | .212 |
| 27 | 340.9 | 0.0 | 34.4 | 375.3 | 117.6 | 17.9 | 135.4 | 18.3 | 0.0 | 23.5 | 158.9 | 203.8 | 0.0 | 10.9 | 214.7 | .397 | 0.000 | .683 |
| 28 | 466.5 | 0.0 | 21.0 | 487.5 | 202.3 | 38.6 | 240.8 | 15.1 | 0.0 | 9.0 | 249.8 | 223.0 | 0.0 | 12.0 | 235.0 | .516 | 0.000 | .429 |
| 29 | 347.5 | 0.0 | 30.1 | 377.6 | 129.6 | 44.7 | 174.3 | 29.5 | 0.0 | 17.9 | 192.2 | 171.5 | 0.0 | 12.2 | 183.7 | .501 | 0.000 | .595 |
| 30 | 274.3 | 0.0 | 9.6 | 283.9 | 134.1 | 45.0 | 179.1 | 36.1 | 0.0 | 5.2 | 184.3 | 93.1 | 0.0 | 4.4 | 97.5 | .653 | 0.000 | .543 |
| TOTAL | 6684. | 0. | 392. | 7076. | 2450. | 931. | 3311. | 1000. | 0. | 204. | 3515. | 3351. | 0. | 188. | 3539. | .495 | 0.000 | .520 |
| DAILY | 334.2 | 0.0 | 19.6 | 353.8 | 122.5 | 46.6 | 165.5 | 50.0 | 0.0 | 10.2 | 175.7 | 167.6 | 0.0 | 9.4 | 177.0 | .495 | 0.000 | .520 |
| MONTH | 10025. | 0. | 588. | 10614. | 3676. | 1397. | 4966. | 1500. | 0. | 306. | 5272. | 5027. | 0. | 282. | 5309. | .495 | 0.000 | .520 |

ALL DATA IN MEGAJOULES

* BASED ON 54.2 SQ.M COLLECTOR AREA

## Table 7-6H (continued)

| DAY | ---- | ---COLLECTOR PERFORMANCE--- | | | | -CHILLER PERFORMANCE- | | | |
|---|---|---|---|---|---|---|---|---|---|
| | N601 TOTAL | S006 TOTAL SOLAR* | S008 SOLAR* WHEN COLLECTING | Q111 HEAT DELIVERED | N100 AVERAGE EFFICIENCY | Q502 TOTAL OUTPUT | Q541 SOLAR OUTPUT | N502 FRACTION BY SOLAR | |
| 1 | .958 | 955.2 | 809.2 | 210.3 | .220 | 0.0 | 0.0 | 0.000 | 3.7 |
| 2 | .956 | 1315.1 | 1113.5 | 299.3 | .228 | 0.0 | 0.0 | 0.000 | 3.3 |
| 3 | .969 | 1212.0 | 1021.8 | 281.3 | .232 | 0.0 | 0.0 | 0.000 | 7.8 |
| 4 | .962 | 915.2 | 609.3 | 139.2 | .152 | 0.0 | 0.0 | 0.000 | 3.5 |
| 5 | .991 | 672.1 | 451.9 | 140.0 | .208 | 0.0 | 0.0 | 0.000 | 8.1 |
| 6 | | | | | | | | | |
| 7 | | | | | | | | | |
| 8 | .726 | 700.6 | 395.5 | 107.7 | .154 | 0.0 | 0.0 | 0.000 | 3.4 |
| 9 | 0.000 | 825.4 | 509.7 | 135.7 | .164 | 0.0 | 0.0 | 0.000 | 3.1 |
| 10 | | | | | | | | | |
| 11 | | | | | | | | | |
| 12 | | | | | | | | | |
| 13 | .155 | 1366.6 | 1290.0 | 476.9 | .349 | 0.0 | 0.0 | 0.000 | 6.8 |
| 14 | .484 | 32.6 | 3.6 | -.4 | -.013 | 0.0 | 0.0 | 0.000 | 9.0 |
| 15 | | | | | | | | | |
| 16 | | | | | | | | | |
| 17 | | | | | | | | | |
| 18 | | | | | | | | | |
| 19 | | | | | | | | | |
| 20 | .104 | 54.2 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.000 | 13.1 |
| 21 | .015 | 605.7 | 8.7 | .1 | .000 | 0.0 | 0.0 | 0.000 | 7.3 |
| 22 | .408 | 892.3 | 740.9 | 246.7 | .276 | 0.0 | 0.0 | 0.000 | 7.2 |
| 23 | .566 | 1322.4 | 1175.5 | 436.8 | .330 | 0.0 | 0.0 | 0.000 | 9.0 |
| 24 | .606 | 537.0 | 290.9 | 91.4 | .170 | 0.0 | 0.0 | 0.000 | 8.2 |
| 25 | .319 | 87.2 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.000 | 9.7 |
| 26 | .203 | 392.3 | 244.3 | 59.5 | .152 | 0.0 | 0.0 | 0.000 | 11.0 |
| 27 | .424 | 1233.3 | 1153.5 | 391.9 | .318 | 0.0 | 0.0 | 0.000 | 7.5 |
| 28 | .513 | 533.3 | 446.8 | 131.0 | .245 | 0.0 | 0.0 | 0.000 | 9.5 |
| 29 | .509 | 924.2 | 834.7 | 326.5 | .353 | 0.0 | 0.0 | 0.000 | 7.2 |
| 30 | .649 | 999.0 | 904.5 | 335.3 | .336 | 0.0 | 0.0 | 0.000 | 6.2 |
| TOTAL | .497 | 15576. | 12005. | 3809. | .245 | 0.0 | 0.0 | 0.000 | 144.6 |
| DAILY | .497 | 778.8 | 600.2 | 190.5 | .245 | 0.0 | 0.0 | 0.000 | 7.2 |
| MONTH | .497 | 23364. | 18007. | 5713. | .245 | 0.0 | 0.0 | 0.000 | 216.9 |

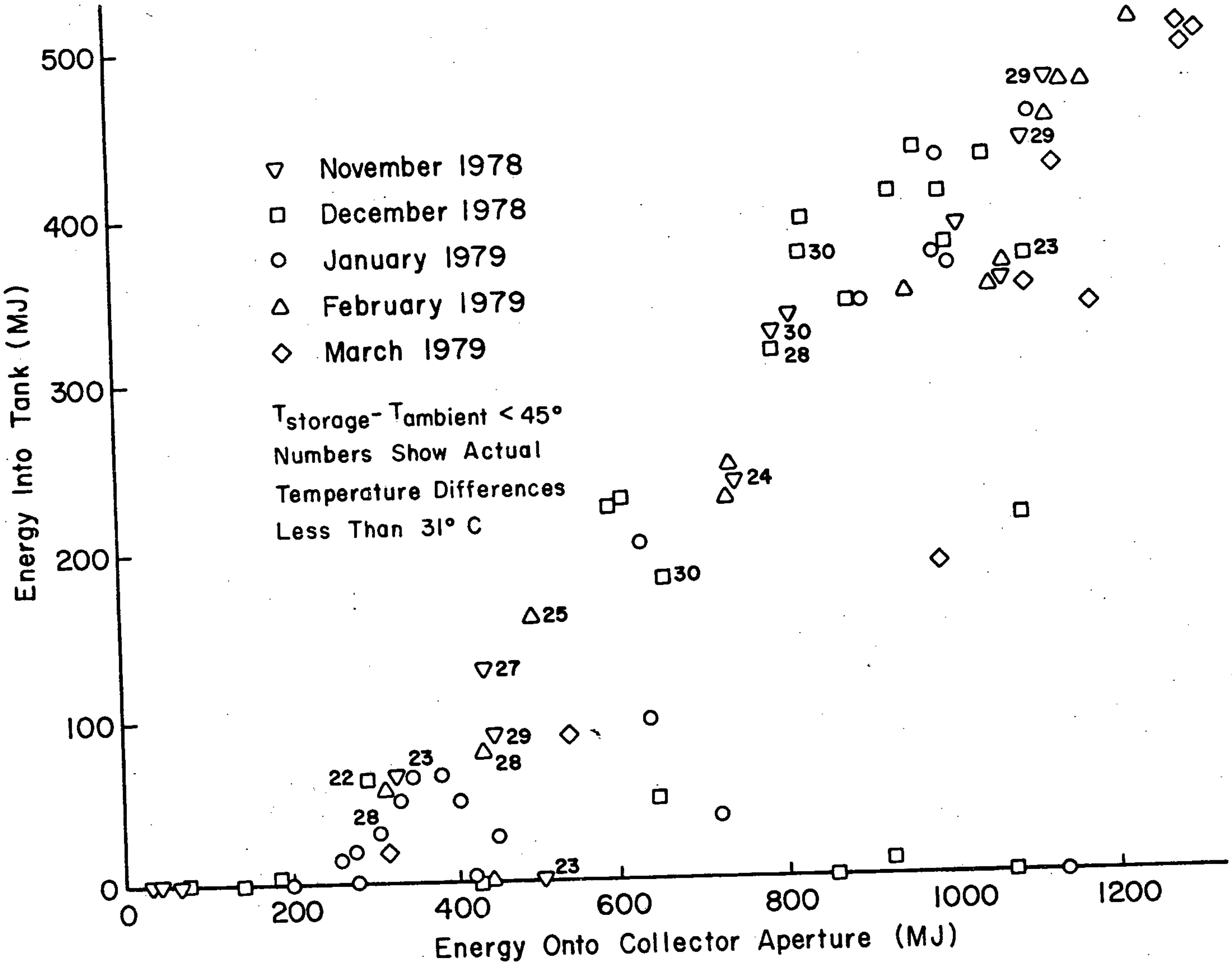



Figure 7-5H. Daily Solar Radiation and Energy Collection During Heating Season, 1978-79

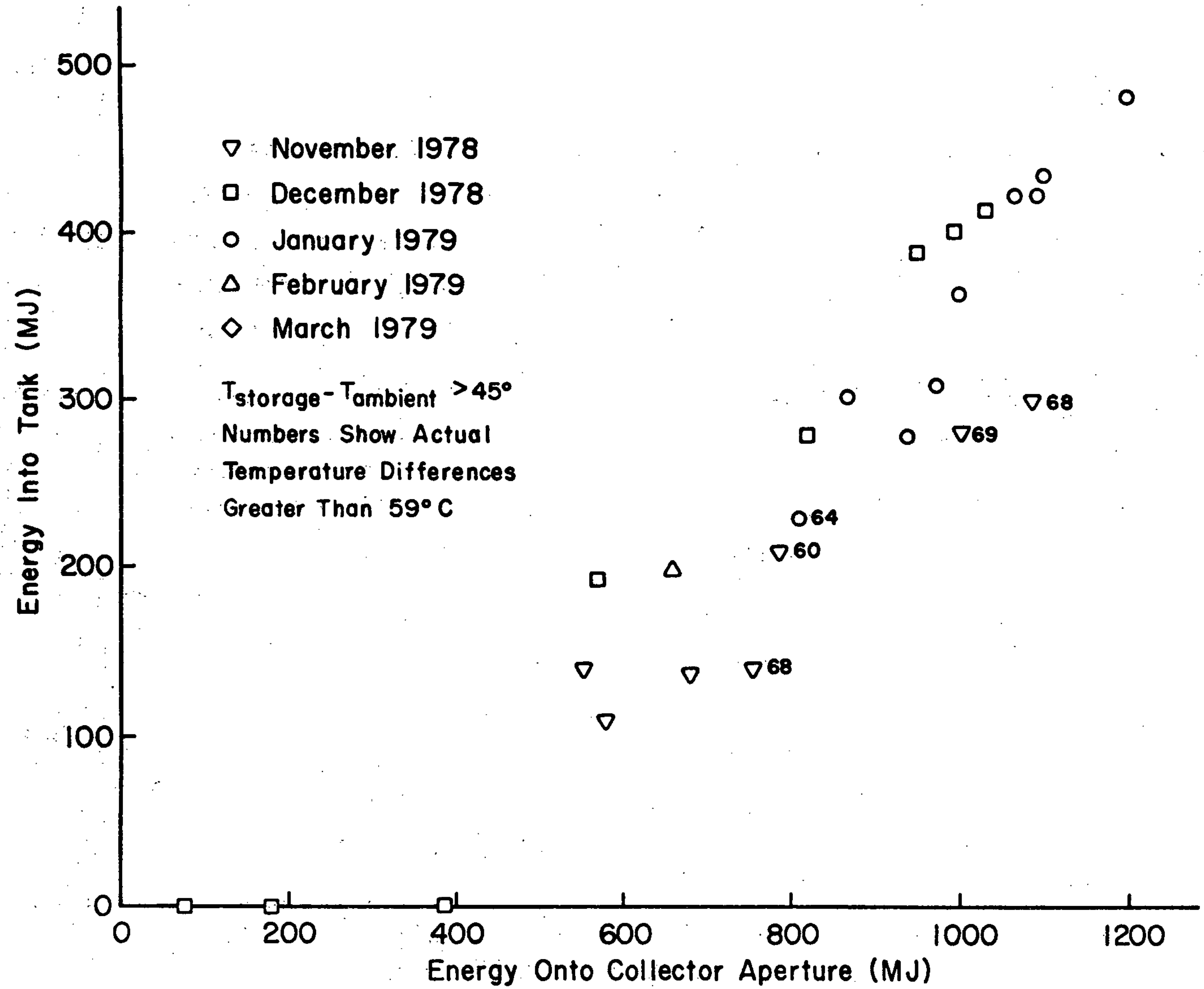



Figure 7-6H. Daily Solar Radiation and Energy Collection During Heating Season, 1978-79

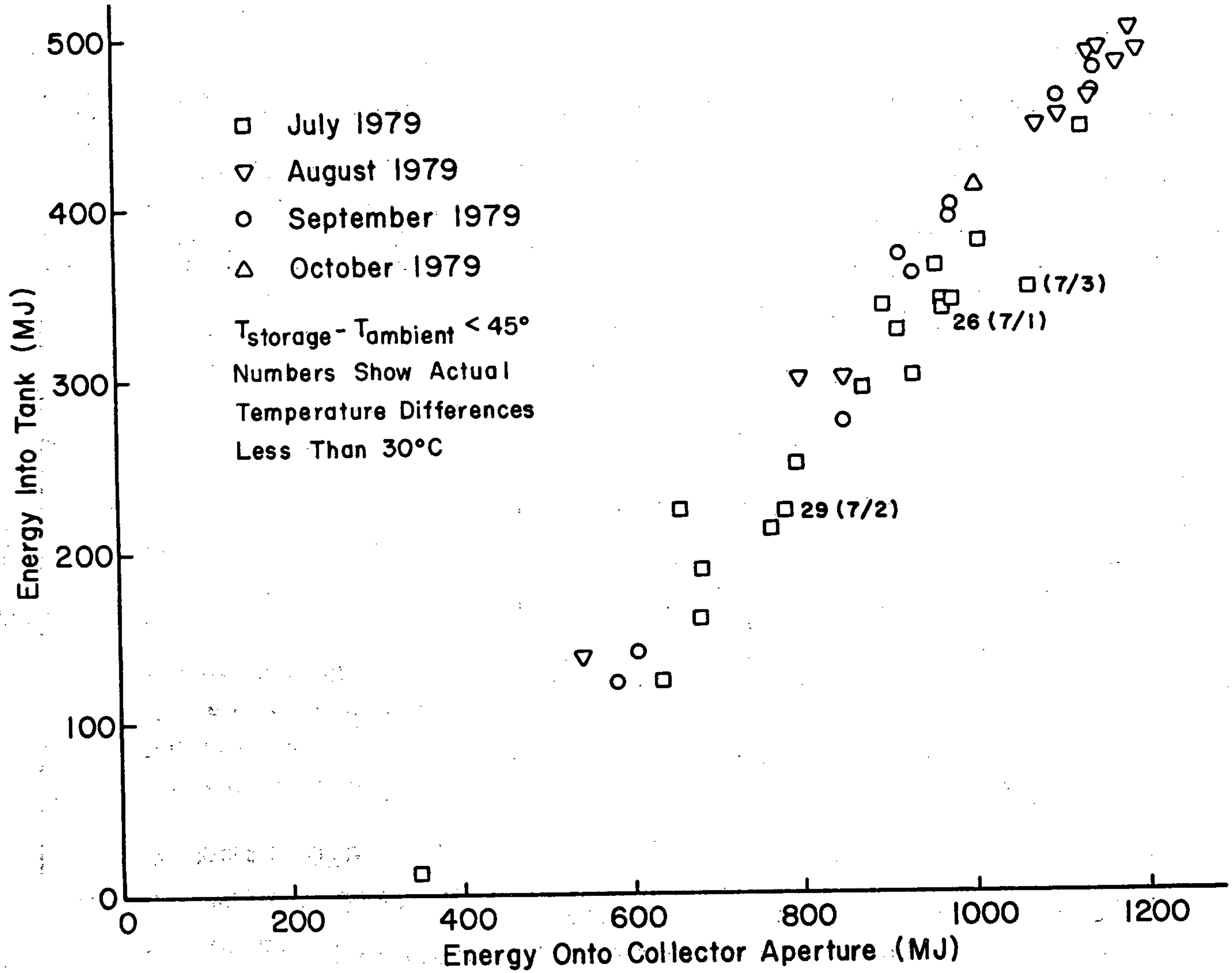



Figure 7-5C. Daily Solar Radiation and Energy Collection During Cooling Season, 1979

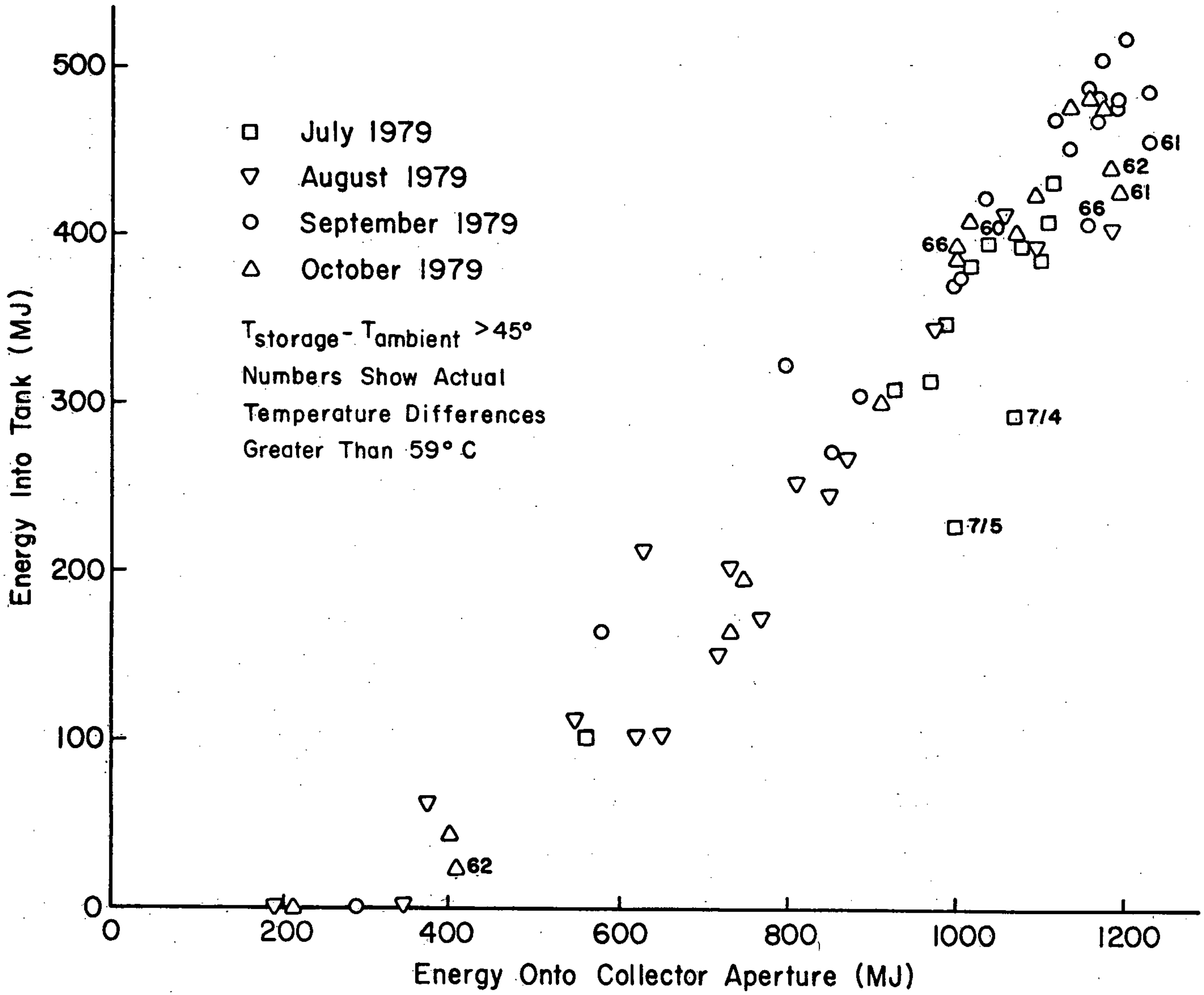



Figure 7-6C. Daily Solar Radiation and Energy Collection During Cooling Season, 1979

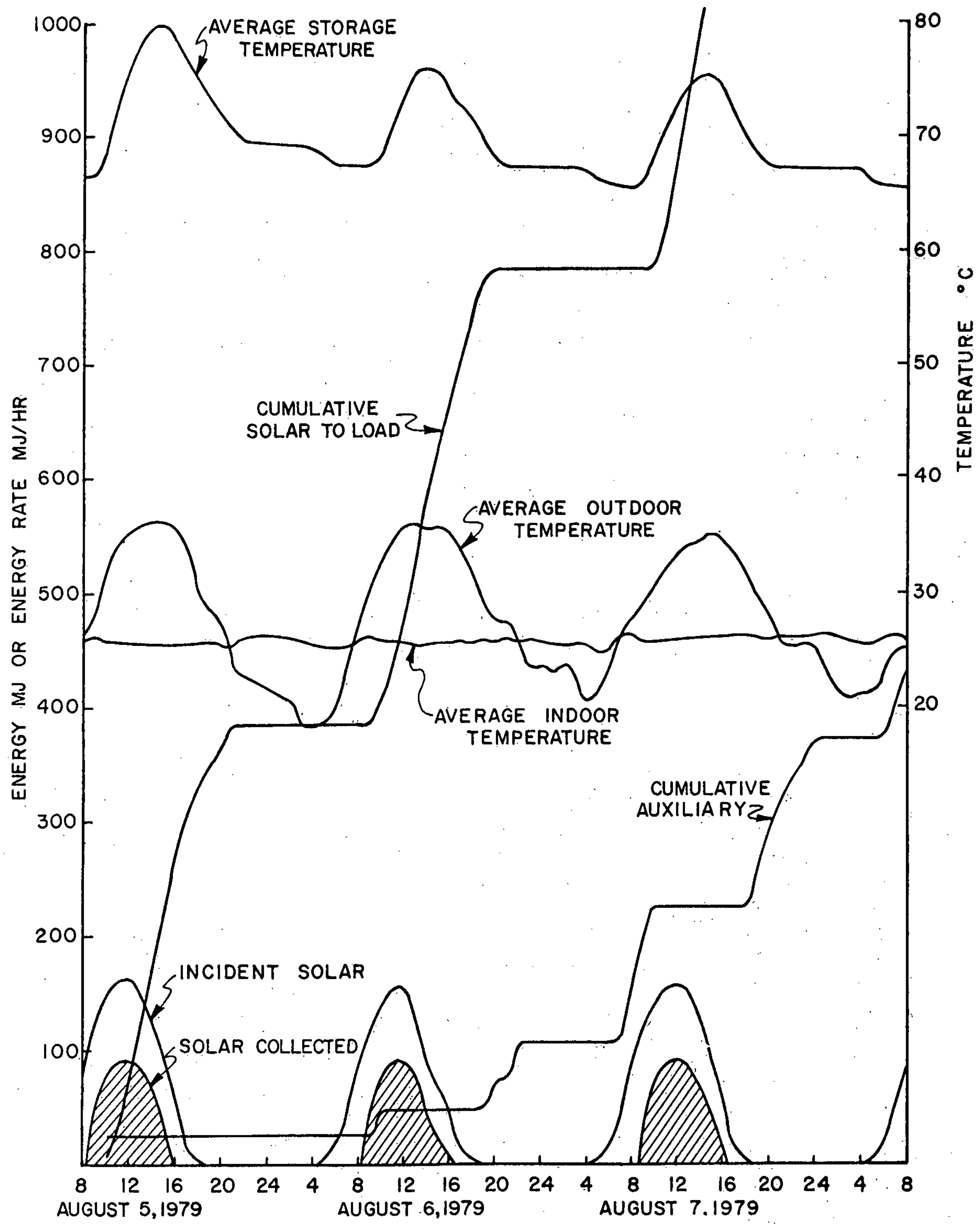



Figure 7-7C. Hourly Cooling System Performance, August 5-August 8, 1979 temperature is sufficient to provide energy to the generator, so auxiliary heat is then used. Auxiliary heat is also frequently the energy source for supplying cooling when first needed the next day. This operation is often brief because the air conditioning load usually lags rising insolation levels and ambient temperature, so that storage temperature can rise to the 75° switchover point and solar operation can commence.

When cooling is being supplied at night by use of auxiliary heat, the storage temperature decreases slowly because of heat loss from the tank and because of solar heat use for hot water heating.

The demand for air conditioning is usually coupled to the total daily insolation, so solar energy is capable of supplying most of the load. However, when solar intensity decreases late in the day while a high demand for cooling exists, the capability of solar to meet the requirements is rapidly reduced. Figure 7-7C shows that the storage temperature profiles do not reach levels on the second and third days as high as on the first day.

A figure comparable to 7-7C for heating was not developed because hourly values of auxiliary usage were not available. The off-peak contribution to space heating, estimated from core temperature changes, was available only on a daily basis.

Figure 7-8C shows the improvement in instantaneous system collection efficiency (based on hourly mid-day data) that was achieved by replacing the original cover glass in July 1979 with one having about eight percentage points higher solar transmittance. It is seen, however, that measured collection efficiency, even after cover replacement, did not reach the levels attained in manufacturer's testing. Heat capacitance effects and less effective contact between tubes and heat transfer plates may be primary causes of the differences.

Performance of the off-peak electric heat storage unit was continuously monitored through the heating season. After initial adjustment, it operated reliably and effectively. Control improvements were found to be needed, however, for minimizing auxiliary electric requirements. During the start-up period in November, 1978, 1315 kW-hr of off-peak electric energy was stored in this unit for use during

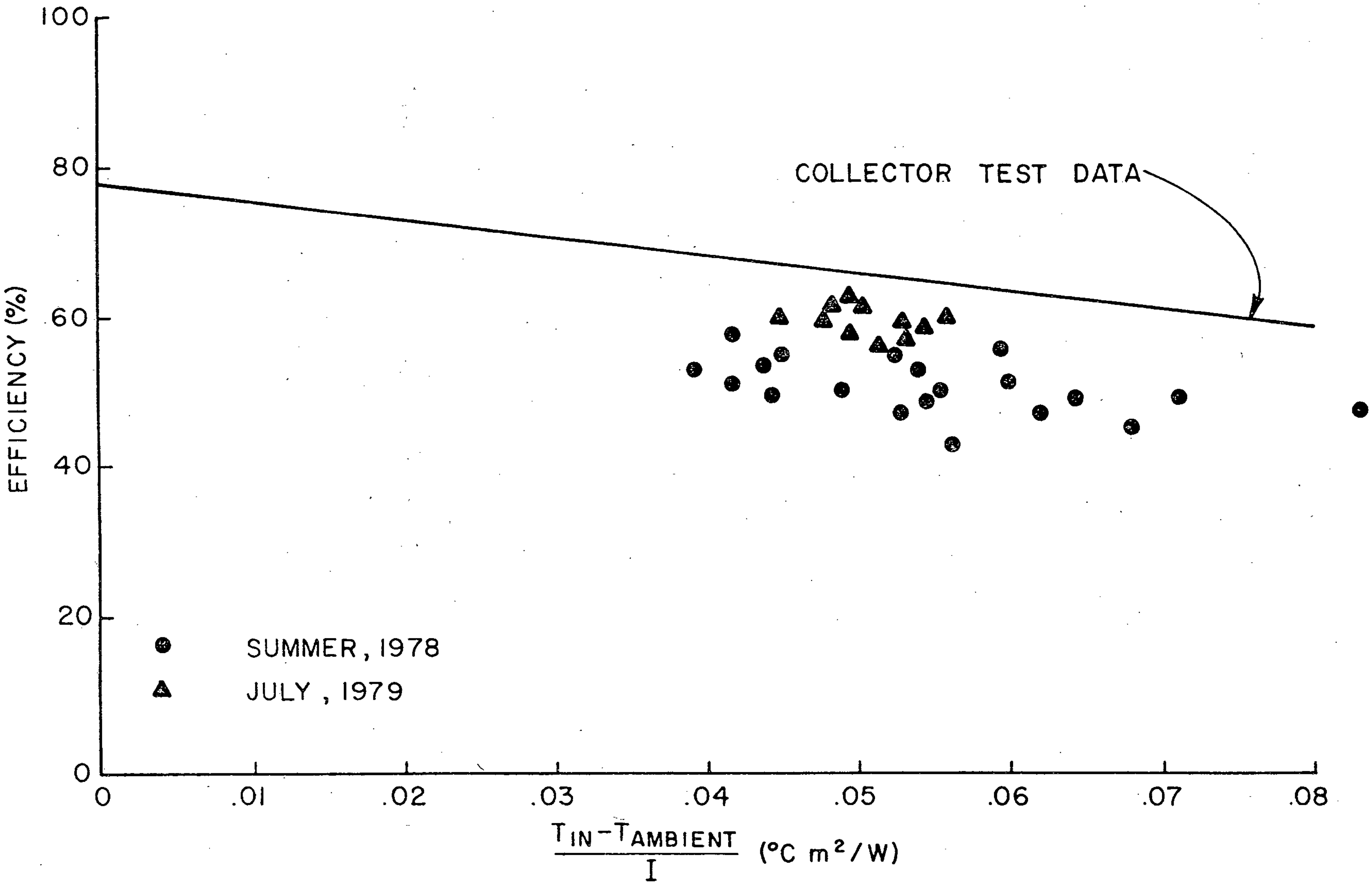
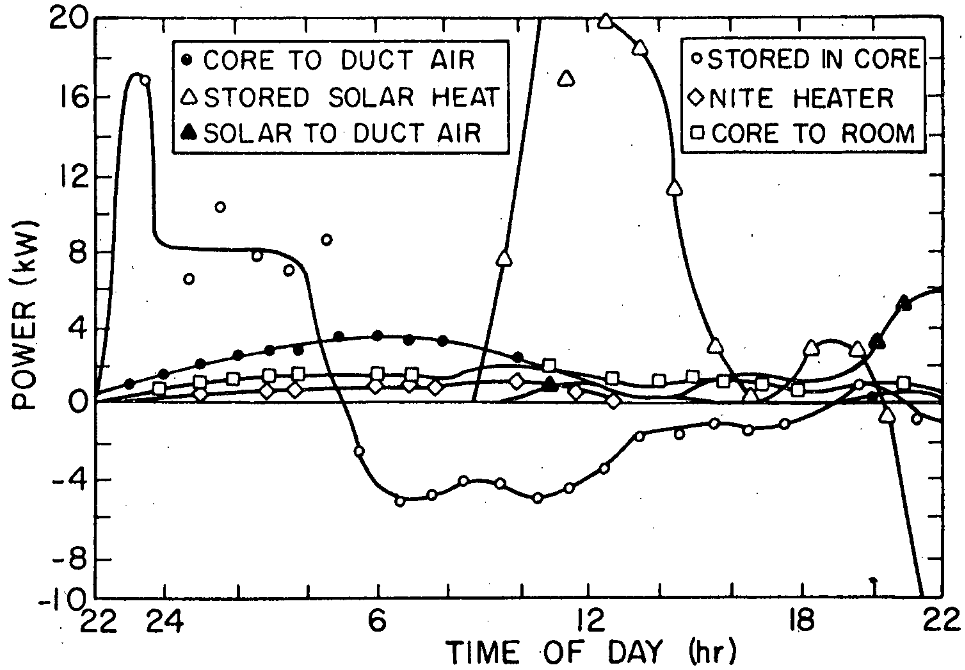



Figure 7-8C. Selected Midday Hourly System Solar Collection Efficiencies Based on Absorber Area daytime periods when stored solar heat was inadequate. Maximum nighttime charging rate was 15.6 kW. During that month, only 151 kW-hr of electricity were used during the day-time (on-peak) at a maximum rate of 1.0 kW for operation of pump and blower motors.

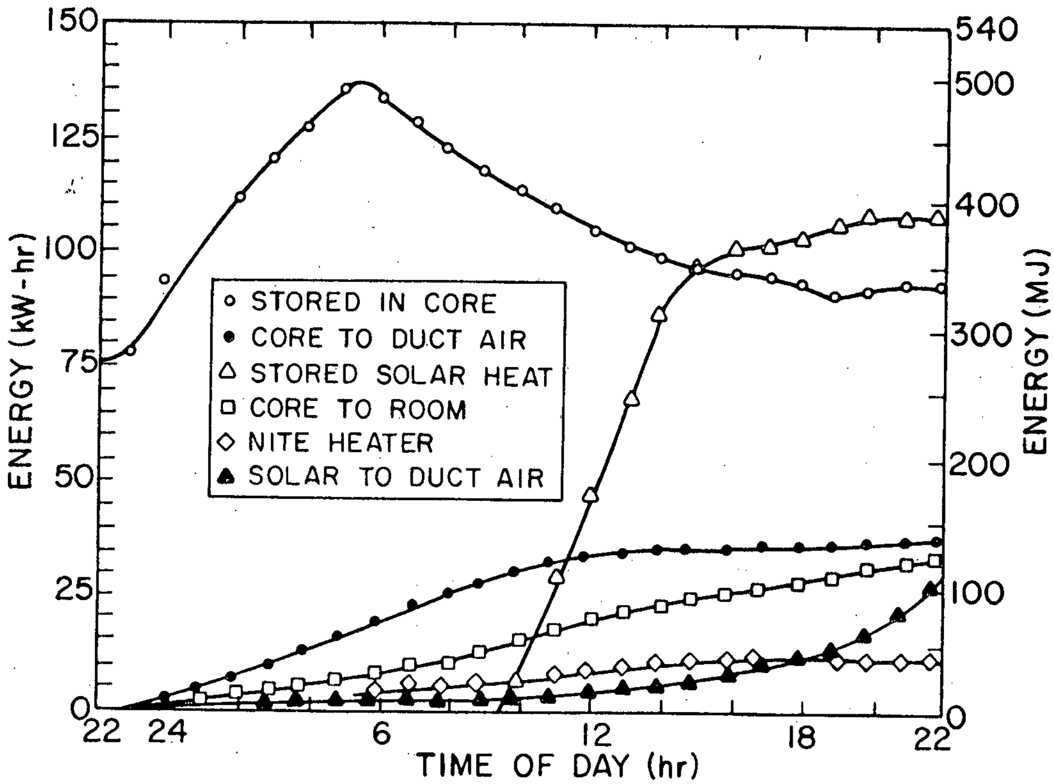
Typical and detailed performance of the off-peak auxiliary heat storage system is shown in Figure 7-9 (a and b). Figure 7-9 shows results for a typical November day. Power input and losses from the solar and off-peak storage units (Figure 7-9a) as well as the energy content and cumulative energy loss from these reservoirs (Figure 7-9b) are shown. At the start of the off-peak power period (22 hours), the off-peak furnace contained 75 kW-hr and solar storage was essentially depleted. The off-peak furnace heaters came on at a 17 kW power level at this time and remained at that level for about one and one-half hours before dropping to an 8 kW input. The power remained at the 8 kW level until 4:00 a.m. to 5:00 am, at which time the energy flow to the off-peak furnace went negative. The negative state indicated the heaters had been turned off and extraction of energy from the storage core had started. During the period from 22 hours to 6 hours, a small amount of energy was supplied to the house as a result of heat leakage from the furnace core and from the night heater. Although the purpose of the night heater is to supply electric heat directly to circulating air during off-peak periods, there is some leakage of heat from the core to air passing through this unit at night.

As the day progressed, the sun rose and energy input to the solar storage increased. Solar energy supplied to the house reached about 30 kW-hr at 22 hours, the end of the on-peak period. Energy in solar storage at this time was approximately 110 kW-hr.

Two undesirable aspects of the off-peak furnace operation involve (1) the unintentional leakage of heat to the room and duct air and (2) the change in the core storage heating power level from 17 kW to about 8 kW and then to zero during the off-peak period. The heat leakage rate from the core to the duct air circulated through the night heater (designated by "h" points and a dotted line in Figure 7-9a) is observed to reach a maximum of about 1 kW when the core energy reached its peak. This loss occurs primarily because of damper leakage in the furnace.




a. Typical Power Distribution




b. Typical Energy Distribution

Figure 7-9. Off-Peak Auxiliary Furnace Performance I

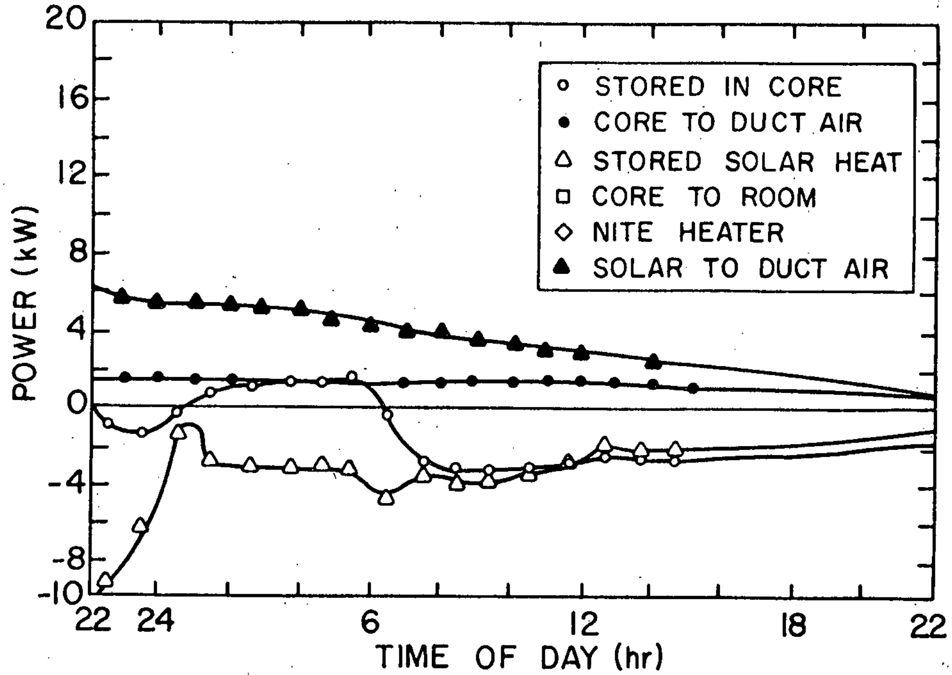
The rate of heat loss directly to the room in which the off-peak furnace is located (designated by "r" points and a dashed line) rose to a maximum value of about 2 kW at about eight hours. By the end of the day, heat supply to the house from these two sources is observed in Figure 7-9b to have reached about 10 kW-hr and 35 kW-hr, respectively. The fact that the sum of these unintentional electric heat supplies is slightly more than the intentional heating of duct air (line d) in the furnace core indicates that heat leakage rates are excessive.

The decrease in the core storage heating power level from 17 kW to 8 kW to zero is undesirable because utility charges are often based on both an energy charge and a more substantial monthly demand (peak power) charge. Operation at an 8 kW power level throughout the off-peak period would have resulted in about the same level of energy input to the core but, because of lower maximum demand, would have cost about half as much as did operation in the irregular fashion shown in Figure 7-9a.

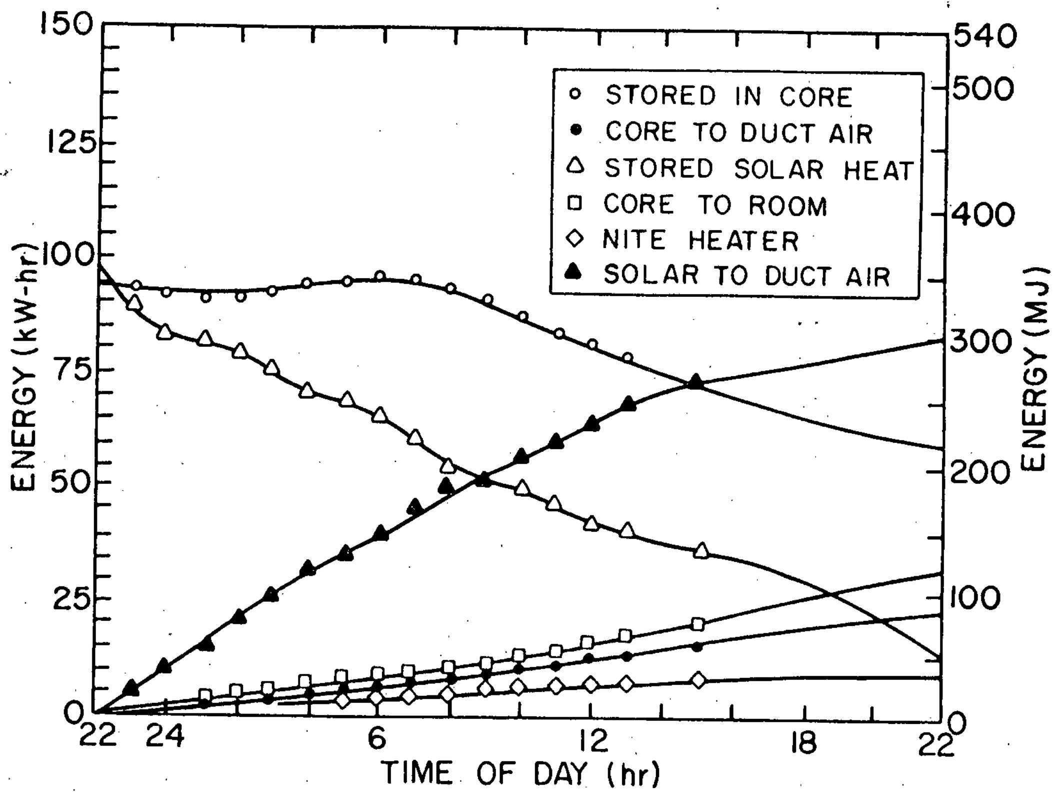
Figure 7-10 shows operation on another typical day. In this case, both solar and off-peak furnace storage levels were so high that no energy additions to the core were needed during the off-peak period. During the day, energies stored in the solar tank and the furnace core were sufficient to meet the demand. Again, heat losses from the furnace core to the room and duct air were substantial, although solar heat delivered to the duct air provided most of the house heat.

The observed changes in the off-peak power supplied to the storage core (Figure 7-10a) suggest that the controller is changing power demand as a result of changes in temperature of the furnace core and the outside atmosphere during the night.

In Figure 7-11, the fraction of full charge that should be stored in the off-peak unit as a function of outside ambient temperature is shown as a solid line. The data points show that the amount of energy actually supplied to the core is almost always less than indicated by the control curve. Power to the core heaters is apparently being terminated before the programmed energy storage level is reached. Due to the failure of the controller to minimize peak power demand and associated cost, design of a new controller for the next heating season was initiated.




a. Typical Power Distribution




b. Typical Energy Distribution

Figure 7-10. Off-Peak Auxiliary Furnace Performance II

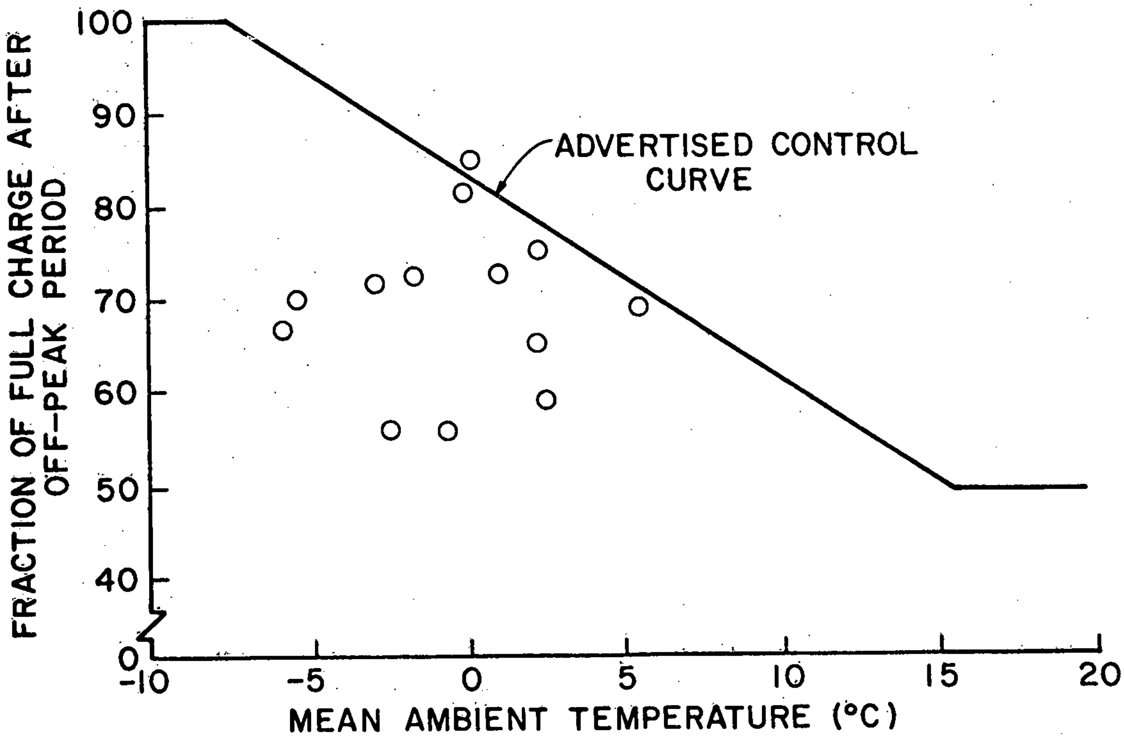



Figure 7-11. Controller Performance

## 7.6 PERFORMANCE COMPARISON

In Figure 7-12H, system collection performance during the heating season in Solar Houses I, II and III is compared. The three solar houses are of identical style and size and are constructed of essentially the same materials. The only significant differences are in the solar energy systems. The air system in Solar House II has a Solaron flat plate collector with a selective absorber and single cover. Heat storage is in a vertical rock bed. The liquid system in Solar House III has a flat plate Chamberlain collector with single glazing and selective absorber. A horizontal cylindrical storage tank with sprayed-on insulation is located in a contiguous structure that can be vented either to the atmosphere or to the building. Solar House III also has a Yazaki 2.3 ton lithium bromide absorption

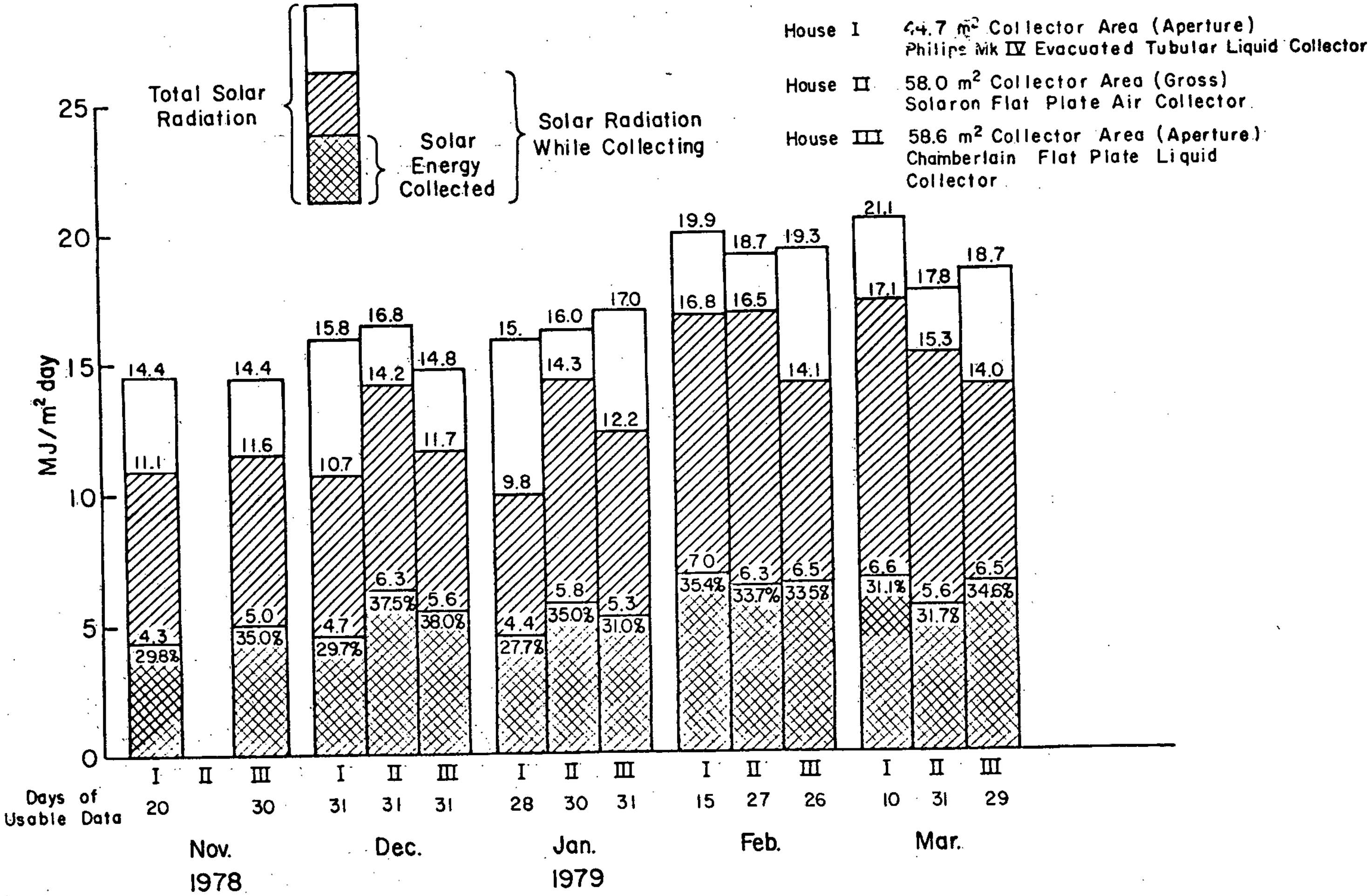



Figure 7-12H. Comparison of Winter Season Results chiller and an air-to-air heat pump in parallel with the solar system for auxiliary heating and cooling.

The 45° slope of all collectors results in levels of incident radiation that do not differ greatly month-to-month. Generally clear skies and favorable solar incidence angles provide winter radiation levels nearly as high as the spring.

Only in February is the system collection efficiency of Solar House I seen to be greater than that of the other two houses. Prolonged retention of snow on the cover plates occurs because of low upward heat losses from evacuated tubular collectors. Snow may be retained for one or more days while insolation causes melting of a thin layer of snow and rapid sliding from the conventional collectors on the other houses. Inspection of the data shows that even though solar radiation was being received, there was no collection in Solar House I on part or all of one day in November, seven days in December, five day in January, three days in February, and four days in March. Exclusion of those days from calculation of averages shows system collection efficiencies of 32.5%, 38.0%, 32.4%, 37.5%, and 34.8% for November through March, respectively. The first three days in November were also excluded because of abnormally high storage temperatures.

Figure 7-12C shows a comparison between cooling system performance in Solar House I during 1979 and that of Solar House III in 1978 and one month in 1979. Although not for identical periods, it is seen that in comparable months, system performance in House I, with evacuated tubular collector exceeded that in House III with flat plate type.

## 7.7 COMPARISON WITH COMPUTER MODEL

The actual solar heat supplied for space heating and hot water is compared in Figure 7-13H with the output computed by use of a mathematical model. The model, known as F-chart, requires collector performance characteristics supplied by the manufacturer or obtained by measurement. Other system parameters included in the model are the heat capacity of storage, effectiveness of heat exchanger between collector and storage, and effectiveness of heat exchanger between

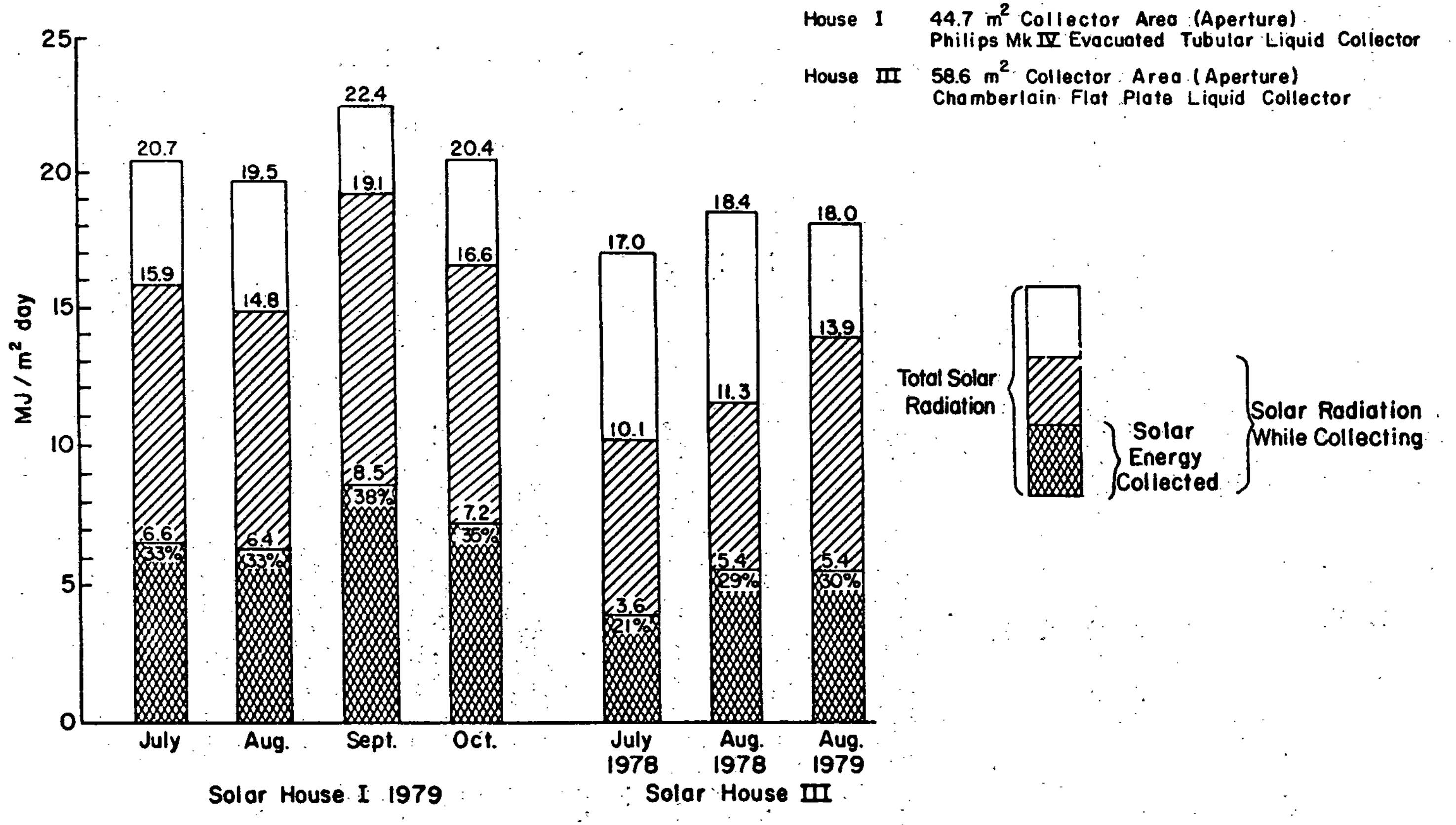



Figure 7-12C. Comparison of Summer Season Results

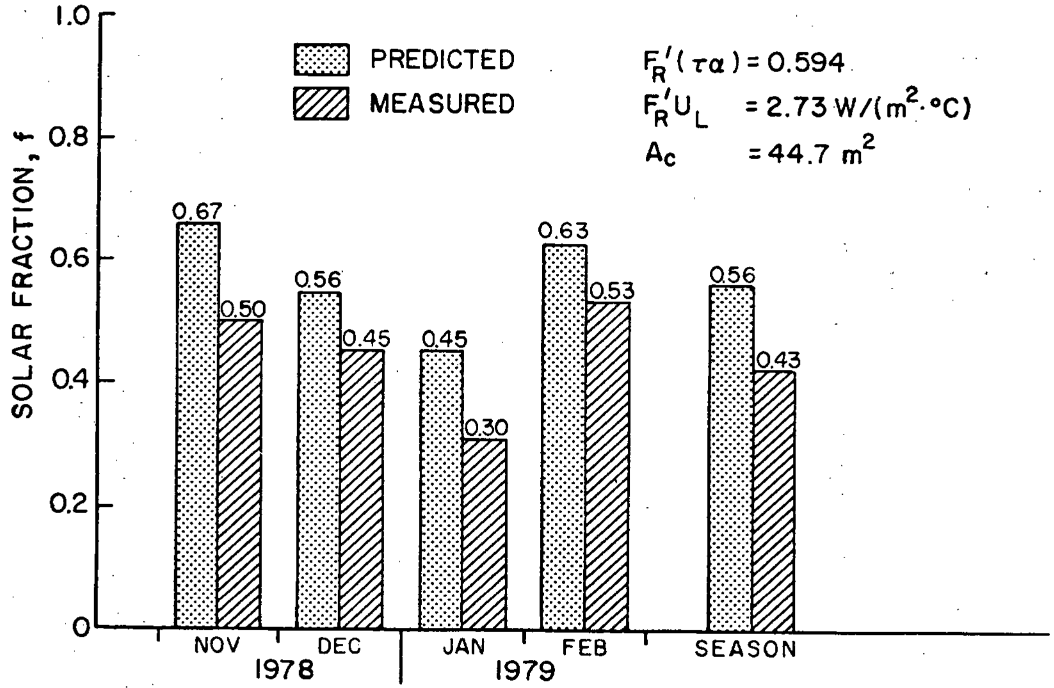



Figure 7-13H. Comparison of F-Chart Predicted and Measured Solar Fractions for Space Heating and Hot Water in CSU Solar House I (1978-79) stored hot water and room air. Fractions of monthly heating and hot water demands supplied by solar were hand-calculated by formulas and charts equivalent to the computer version known as F-Chart-3.

Rather than some other mathematical model, F-Chart was used in the comparison because of its widespread adoption for sizing solar heating systems and predicting their performance. It is a convenient empirical equivalent of the more precise TRNSYS model which has been well validated. Experimental results reported herein may be used on a daily basis or monthly basis in comparisons with other models. Instead of the long-term temperature and solar averages normally employed in system design work, actual measured monthly average ambient temperatures and solar radiation levels were used in the calculation of expected solar heat delivery.

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# 8. ECONOMICS

The costs of experimental and prototype components are quite different from those of the equivalent mass-produced versions. Moreover, the added complexities of instrumention and one-of-a-kind designs in experimental systems involve substantially higher installation costs. Since there is no firm basis for meaningful projection of the cost of future, mass-produced systems evaluated in this project, no estimates are presented.

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# 9. DISCUSSION

## 9.1 COLLECTION

The effect of cover glass transmittance on solar collection is clearly illustrated by Figure 7-8C. The approximately eight percentage point improvement in transmittance translates directly into almost the same percentage point increase in midday system collection efficiency. This effect may also be seen in Figures 7-5C and 7-6C where the points for July 1 through 5, obtained before cover glass replacement, are clearly below subsequent points.

Figure 7-8C shows maximum system collection efficiency with the higher transmittance cover glass about 5 to 7 percentage points below instantaneous steady state efficiencies based on collector test data. The difference is due mainly to about three to four percentage points heat capacitance effect and to about three percentage points piping heat loss. Measurements of energy collected are made at the storage tank and thus include heat losses in the piping between collector and storage. The capacitance effect is caused by storage of some of the collected energy in the collector system, the temperature of the entire collection system progressively rising during the greater part of a typical day. This effect, which can be calculated from the known heat capacity of the collector system, was observed experimentally during the testing of cover glass transmittance. In this experiment, cold water from the main was blended with supply water from storage to maintain an unchanging collector inlet temperature over a sustained period. Measured system collection efficiency was found to increase about four percentage points in these tests.

The effect of increased cover glass transmittance, while clearly evident in the comparison of summer performance in 1978 and 1979, is not observed when efficiencies in the winter of 1978-79 (Figures 7-5H and 7-6H) are compared with those of the 1979 summer (Figures 7-5C and 7-6C). It is speculated that sky temperature differences and incidence angle effects may be responsible for a six to eight percentage point superiority in winter performance. This issue is being investigated.

The low upward heat loss coefficient in a selective evacuated collector is sometimes a disadvantage because of the slow rate of snow melting and sliding. As the discussion in Section 7.5 indicates, collection efficiencies were lowered two to eight points during the five winter months in 1978-79. These effects can also be seen in Figure 7-5H, where there are ten snow cover days with incident energy in excess of 600 MJ. On four days, complete snow cover resulted in no collection, and on six days, partial snow cover caused subnormal collection.

In comparisons with previous Solar House I collectors [9], system collection performance in 1978-79 was substantially higher than that of the system with site-built double glazed collectors, but lower than that of the system with the Corning evacuated tubular collector. The latter represents what is felt to be the highest efficiencies practically attainable in solar collectors. In a comparison of the experimental House I collector with the single glazed selective, state-of-the-art, flat plate collectors on Solar House III, Figure 7-12C shows the Philips Mark IV collector to have a performance advantage in summer operation. The low rate of heat loss from the evacuated tubular collector, evidenced by the low slope of the efficiency curve, results in greater collection. If snow can be removed by some practical means, the discussion in Section 7.6 shows the Philips collector to have a slight performance advantage in winter also.

Electric power usage for collection is seen in Table 7-2 and 7-5 to be acceptably low solar heat delivery averaging about 17 times the electricity used. Electric consumption for collection is thus about 6 percent of solar heat delivery. Table 7-5 shows that electricity use for heat distribution to space heating and hot water is only 2 to 3% of total heat delivered to loads, and about 10% of heat supply to cooling.

## 9.2 STORAGE

The sectional insulated container shown in Figure 3-6 represents a significant improvement in thermal storage tanks. Tank erection including placement of the linear was accomplished in four hours. Although, the measured thermal resistance of 2.4 $m^2 \cdot °C/W$ did not equal the rated $6 m^2 \cdot °C/W$, it is much higher than that of previous tanks. Their poor performance was due primarily to inferior insulation on the tank walls, bottom, and top (see [9]). In the new tank, most of the remaining heat losses are by conduction through thirteen connecting pipes entering the top of the tank. The large vent pipe to the outside, necessary in a nonpressurized system, was probably a major factor. Fewer connections would be needed in a non-experimental installation. Heat and vapor losses from the vent will be studied and measures will be taken to reduce them.

Significant thermosyphoning was observed in some of the tank piping circuits before check valves were installed. Tank losses would have been about twice as great without check valves. Reduction of these comparatively small losses becomes important when a well insulated tank offers the advantages of a very low loss system.

As long as most losses occur in a timely way into a heated space, heat loss reduction measures may not pay for themselves. But in the cooling season, when heat loss imposes additional demand, or when heating is required only at intervals, heat loss reduction measures are usually cost effective.

Temperature stratification manifolds (baffles) shown in Figure 3-7 have performed very well. After installation of tempering (by-pass) valves to regulate the temperature of hot water to the chiller, the average difference in temperature between the top and bottom of the storage tank during collection and use was about 12°C. Stratification increased collection efficiency by about three percent. Stratification also causes higher average temperature water to be supplied to the generator resulting in higher chiller COP's. A higher generator supply temperature results in increased chiller COP, greater uitlization of solar, and reduced auxiliary energy requirements.

## 9.3 HEATING

The off-peak electric heat storage auxiliary did not require daytime peak rate electricity at any time during the 1978-79 heating season. This experience demonstrates that present and prospective electricity pricing policies that would penalize solar can be successfully circumvented.

One of the design faults in the present off-peak unit is a high heat loss rate which averages about 25 percent of the total electric heat stored. This loss was not a serious problem in this climate during most of the heating season. It supplied part of the heating requirements of the house since, as can be seen in Table 7-1H, there was no significant indoor temperature rise above thermostat settings while the off-peak unit was in operation. In mild weather, however, this loss effectively reduces the demand for solar heat and increases auxiliary energy purchases. Means for decreasing the loss will be investigated.

Another design fault is the limited off-peak control capability that results in lower solar utilization and higher solar storage temperatures. Conventional two-stage thermostat control (upper point actuating solar supply, lower point adding, rather than substituting, auxiliary supply) did not function satisfactorily, so it was necessary to rely on the off-peak unit to supply heat whenever the solar storage tank fell below 25°C, whether or not such a solar supply temperature could satisfy space heating requirements. In mild weather, electric heat was therefore sometimes used when solar heat would have been adequate.
An advantage of the series-booster design where solar preheating and auxiliary boosting is used, is the effective utilization of solar heat at lower temperatures than in a parallel system. With lower average storage temperatures, collection efficiency is increased. Improvements in control system design are therefore planned. Leakage through dampers when off-peak heat is not being used can also have the same deleterious effect on average solar storage temperature and will therefore be investigated.

Along with improved control schemes to apportion heat from the off-peak unit more advantageously, better control in charging the unit is desirable. Also needed is two-stage thermostat control, with automatic by-passing of the entire off-peak unit when only the first stage is actuated. Second stage operation should then continue solar supply to the coil and auxiliary boosting in the off-peak unit. Microcomputer-based approaches by which ambient temperatures are predicted and the charging of the unit accordingly adjusted are being developed for implementation next heating season.

## 9.4 COOLING

Heat losses from storage have decreased substantially since the installation of the Bally tank. Figure 7-1H and 7-1C show the losses to be nearly the same fraction of the energy input to the tank. When average storage temperatures shown in Figures 7-2H and 7-2C are compared with indoor temperatures of about 21°C in winter and 25°C in summer, it is seen that the temperature difference between tank contents and the room is about 2.5 times as great in the summer as in the winter. Summer heat loss would therefore have been about 14000 MJ rather than 5611 MJ if the old tank had not been replaced. The effect on cooling demand would have been almost a doubling of the 13,437 MJ cooling actually required. These high cooling requirements and storage losses had previously been encountered as can be seen in the 1977-78 Solar House I report [9].

Figure 7-4C shows that COP's for both auxiliary and solar chiller operation during 1979, though higher than the 0.4 levels in 1978, did not reach the 0.6 values usually measured in 1977. The most likely reason for lower COP is a decreased rate of air flow through the duct coil through which chilled water is circulated. At the lowered heat transfer rate, "overfiring" of the chiller can occur with decreased COP. (Air flow rates were subsequently increased and performance improvement was observed). Other means for increasing COP's are being investigated.

A manual tempering valve and later an automatic tempering valve were installed in the hot water pipe to the generator so that supply temperature could be limited to 80°C and overfiring avoided. Figure 3-10 shows maximum COP levels are realized by preventing higher generator supply temperatures. By use of a tempering valve, solar cooling can be provided for greater portions of the day, less auxiliary heat is required, and increased collector efficiency is obtained by improved storage temperature stratification that results from lower flow rate from tank to chiller. A previous conclusion, [9] that the cost of a tempering valve could not be justified by the benefits, was not based on a system having stratification enhancement. It is now concluded that such a valve is cost effective for the chiller characteristic shown in Figure 3-10.

Although thermal COP values are acceptable both with solar supply and auxiliary supply, and overall conversion of solar radiation to cooling is satisfactory, Table 7-5 shows that electric energy usage for cooling is excessive. Parasitic power consumption, particularly for supply and rejection of heat to and from the chiller approaches electric requirements for conventional vapor-compression air conditioning.

### 9.5 HOT WATER

Figures 7-1H and 7-1C show that about 25 percent more solar hot water was obtained in the summer when the system design corresponded to that in Figure 1-2C rather than in the winter design shown in Figure 1-2H. No conclusions as to design preference can be drawn from these results because other factors were not comparable. Summer operation is at higher temperature levels, so a greater hot water fraction should be possible. In winter operation, the heating coil bypass was not used, thus limiting hot water heating to periods in which space heating was also required. Finally, the total hot water demands were not comparable. Differences in performance of these systems are being studied by simulation methods.

### 9.6 INSTRUMENTATION AND DATA COLLECTION

In the 1978-79 heating season, there was no instrumentation for measurement of air flow and air temperature rise through the off peak auxiliary unit. It had previously been concluded that recorded core temperature changes could be used to calculate the hourly energy supplied to the air stream. It was subsequently found that this calculation was inaccurate for periods shorter than one day. There was some uncertainty even in the daily estimate, one day's energy addition perhaps being understated and the next overstated. Instrumentation for measuring energy received by the air stream has been ordered for the 1979-80 heating season.

### 9.7 COMPARISON WITH MODEL

Comparison of measured and computed fractions of the monthly heat requirements supplied by solar energy shows that the model overstates the performance of the system with the Philips collector. Differences of 10 to 17 percentage points in the load fraction carried by solar may be observed. The seasonal heating fraction actually supplied by solar was 13 percentage points below the computer estimate. This difference is equivalent to overpredicting the seasonal solar heat supply by 30 percent.

The model itself probably does not closely conform to the system because the collector loss parameter values are not within the stated range of model validity. How closely the model resembles actual system operation is also a question. For example, snow cover contributed to the differences and heat loss from the off-peak electric auxiliary heater into the building reduced the need for, and use of, solar heat. Although the rough agreement of the model may be adequate for sizing solar heating systems in individual residences, more detailed methods are required for guiding the design of larger commercial systems. The results of this comparison do not provide a basis for judging the validity of the model or the quality of the experimental results.

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# 10. CONCLUSIONS AND RECOMMENDATIONS

## 10.1 CLASSIFICATION

The conclusions are divided into three categories. The first, Definitive Findings, includes conclusions which are broadly based on important results of the investigation. These major points are derived both from the quantitative measurements and from practical observations.

The second category comprises conclusions on the quantitative performance of systems developed during the period covered by this report and comparisons with other systems and with performance models. The third category includes conclusions on various topics not covered in the previous two groups.

## 10.2 DEFINITIVE FINDINGS

- Solar Cooling Improvement

  Although solar cooling delivered by the Philips Mark IV experimental collector, Arkla WF36 chiller, and well-insulated stratified storage was not as high as that attained with the system employing the Corning evacuated tube collector in 1977, the fraction of the total cooling demand met by solar was higher, actually above 75%, in every month of the 1979 summer. This major increase in load fraction carried by solar was due primarily to the decreased total cooling demand resulting from substantial reduction in heat losses from storage.

- Elimination of Peak-Load Problem with Electric Auxiliary Heat

  A serious obstacle to use of electric auxiliary heat with solar heating systems has been effectively removed by successful combination and use of an off-peak electric storage unit with the solar heating system. Although improvements in the commercial off-peak unit are needed to maximize its benefits, operation of the system through an entire winter was achieved without once requiring electric back-up during daytime (peak) hours. This result is demonstrable proof that electric auxiliary for solar heating does not need to be a problem for the public utilities and that, on the contrary, system benefits can be obtained. Closer control and better thermal design will enhance these benefits.

- <u>Doubling of Long-Term Solar Heat Delivery per Unit Collector Area</u>
  A doubling of typical useful solar heat delivery over extended periods has been achieved by use of evacuated tube collectors. "Fine tuning" of the solar heating and cooling system has resulted in an annual solar collection and utilization as high as 2100 MJ/m$^2$ (approx. 200,000 Btu/ft$^2$). This total is believed to be the highest attained in any solar heating and cooling system supplying as much as two-thirds of the annual energy requirements of a building, although comparable deliveries have been reported for systems in which smaller load fractions were met by solar.
- <u>Cost-Effective Solution to Heat Losses from Storage</u>
  A "breakthough" in solar heat storage can now be asserted as a result of providing in a solar heating and cooling system a greatly improved sectionalized container for hot water storage. In addition to installation economies achieved by modular design, measurements show that heat loss from storage at about 75°C was reduced from over 100 MJ/day dissipated from the site-insulated tank into a well-insulated equipment room to less than 60 MJ/day from the new tank into an area open to the entire living space. Since the R-34 (engineering units) insulation of the container permits a conduction loss of only 15 MJ/day at this temperature, further reductions require control of vapor loss, conduction through piping, and thermosiphon circulation.
- <u>Successful Temperature Stratification in Heat Storage Unit</u>
  Outstanding benefits are being realized by use of a system for obtaining effective temperature stratification in liquid solar storage. By use of specially designed perforated feeder and delivery conduits submerged in the tank, consistent temperature differences of 7°C are obtained between the bottom and top of the tank. Under best conditions, differences greater

than 10°C prevail. Improvement of solar collection efficiency and higher temperatures in the supply to use (particularly important for absorption air conditioner operation) are advantageous.

- Continuity of System Operation and Data Procurement

  The system was operated during the 12-month period nearly continuously. On only one day out of 396 days did the heating, cooling, or hot water system fail to supply sufficient solar and/or auxiliary heat to meet the full demand. The continuity of operation was intentionally interrupted several times for system modification, installation of measuring sensors, and the like. Data acquisition was also satisfactory, only 35 days out of a total of 274 operating days requiring omission from calculation because of incomplete data or system shut-down.

## 10.3 QUANTITATIVE COMPARISONS

- Solar Collection Efficiency

  Of 5154 MJ solar energy received per square meter of collector aperture during the 10-months of operation, 1645 MJ were collected and delivered to use in the building. Of 2905 MJ incident solar radiation during the heating season, from October 1, 1978, to March 14, 1979, 30%, equivalent to 868 MJ, were collected for use. During 109 days in summer and fall, 2249 MJ of solar radiation were received per square meter, of which 777 MJ, or 35% were collected for cooling and hot water use.

- Solar and Auxiliary Utilization

  Of 61481 MJ total space heating demands between October 1, 1978 and March 14, 1979, 50%, equivalent to 30911 MJ were supplied by solar energy. For cooling, between July 1 and October 17, 1979, 23194 MJ, equivalent to 79 percent of the total 29183 MJ energy supply for cooling, were supplied by solar. When cooling with solar energy, the average coefficient of performance was 0.45. Total cooling supplied was 13437 MJ, of which 77%

were from solar. During the 10 months of operation, the energy required for water heating was 12169 MJ, of which 5378 MJ, or 44% were supplied by solar.

- Electric Energy Consumption

  Electricity usage ("parasitic power") for collection of solar energy was acceptably low, averaging 6% of heat collected and used. Electricity for distribution of solar and auxiliary heat to space heating, hot water, and cooling equipment was only 2 to 3% of the total loads, but power requirements of the chiller and accessories were over 10% of heat supply to the cooling system. Low electric COP, (total cooling supplied per unit of electric energy used for collection, distribution, and chiller operation) in the 2.6 to 3.4 range is a severe system penalty.

- Performance Comparisons

  Although not as high as the solar energy delivery by the system supplied with solar heat from the Corning evacuated tube collector, (1977), the system in which the Philips collectors were used provided substantially more energy than did the site-built flat plate collector and associated components in CSU Solar House I. For space heating and water heating, average solar collection efficiency based on the flat absorber plate area in the site-built collectors was 18%, whereas the corresponding figure for the Philips evacuated tube collectors based on aperture area is 30%. Efficiency of heat delivery from the site-built, flat plate collector for cooling and hot water supply was about 17%, whereas the efficiency with the Philips evacuated tube system for the same service (but in different years) was about 35%.

- Relative Performance of Three Solar Heating Systems

  Comparisons of solar collection for space heating show that the system with the Philips collector supplied an average of 5.26 MJ per $m^2$·day at 30% efficiency, the system with site-built flat-plate collector provided 2.89 MJ per $m^2$·day at an efficiency of 18%, and the system with the Corning collector supplied 7.92 MJ per $m^2$·day at an efficiency of 56%.

- <u>Relative Performance of Three Solar Cooling Systems</u>
  For cooling and summer hot water supply, the present system output of 7.12 MJ/m$^2$ day corresponding to 35% efficiency, is much higher than the output of the system with site-built flat-plate collectors, which averaged 3.13 MJ/m$^2$·day at an efficiency of 17%, but is less than the output of the previously evaluated evacuated tube system producing 9.98 MJ/m$^2$·day at 52% efficiency.
- <u>Comparison of Three Heating Systems in Simultaneous Operation</u>
  Comparison of heating performance of the evacuated tube collector system in CSU Solar House I, the solar air system in CSU House II, and the flat-plate solar liquid system in CSU Solar House III, all operating during the same period of time and under the same solar and environmental conditions shows that 5.60, 5.94, and 5.91 MJ/m$^2$·day were the average values in CSU Solar Houses I, II, and III respectively. Corresponding solar collector efficiencies are 31.5%, 34.6%, and 34.2%.
- <u>Comparison of Cooling Performance During Simultaneous Operation of Two Systems</u>
  Solar heat delivered in August, 1979, to simultaneous cooling operations in CSU Solar Houses I and III was 4.2 and 4.1 MJ/m$^2$·day, respectively. In this limited comparison, the solar cooling system with flat plate collectors in House III and the system with the evacuated tube collectors in House I performed equally well.
- <u>Comparison of Performance and Models</u>
  Comparison of measured solar heating performance with values computed by an F-chart model shows monthly differences of 10 to 17 percentage points. Seasonal performance comparisons show that the F-chart model overstates the solar fraction of total heat supply for space heating and hot water by 30%; that is, 43% of the load was actually met by solar, whereas 56% is computed by F-chart based on the weather and solar conditions that prevailed from November 1 through February 28. It is

concluded that the F-chart model does not satisfactorily represent the performance of this system, even though it was operated and controlled by procedures which should have maximized its heat output.

## 10.4 MISCELLANEOUS CONCLUSIONS

- Consistent Cooling Operation

  Dependability of the solar cooling system was substantially improved over that achieved in previous years. On only 3 days out of a 109-day cooling season was operation interrupted by system faults.

- Diagnostic Data Program

  The use of a diagnostic program associated with on-line continuous system monitoring permitted immediate recognition of operational and data logging faults and their prompt correction. Without such capability, as in previous years, faults could have gone undetected for periods as long as 3 weeks.

- Location and Operation of Water Heating Coil

  Operation of the service water heat exchanger independently of the space heating and cooling operations resulted in an increase in solar water heating from an average of 17.7 MJ/day to 27.6 MJ/day. The magnitude of the increase is affected, however, by the difference in weather and solar operation under winter and summer conditions. It is concluded that the loss in solar water heating capability resulting from use of the service water exchanger and the space heating exchanger in series is too great to justify the saving of a small circulating pump for the service hot water in the parallel system. Although not tested, operation of the series system with a capability for water heating even when space heating is not required does not appear to offer significant advantage over the system involving the two heat exchangers in separate loops.

- Hail Resistance

  On July 30, 1979, an intense hailstorm passed through Fort Collins, causing property damage of approximately $50 million. Among 11 solar heating systems in the path of hail stones as large as 10 cm (3.5 inches), the flat plate and evacuated tube collectors at CSU Solar House I were undamaged. There was no damage to any of the five collectors in the CSU Solar Village, and of nearly 1000 collectors in the hail path, only 11 cover glasses were broken. It is concluded that the risk of hail damage to collectors with tempered glass covers is negligible.

- Overall Evaluation

  Solar heating, cooling and hot water systems developed and evaluated in the 1978-79 year provided highly reliable performance data and operational experience. Although the solar collectors did not prove to be a significant improvement over other types, the performance of the integrated system was substantially improved over that of previous configurations. Data reliability and system performance provide criteria against which commercial systems in practical residential applications can be compared.

- Further Evaluations

  Although system reliability and performance were improved in 1978-79, further improvements are clearly possible and desirable. The cost of solar heat can be further reduced by application of improved equipment and its integration into effective systems and its closely controlled operation. Evaluation of newly developed components in well functioning integrated systems controlled to maximize solar delivery and utilization is critically needed.

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# APPENDIX A

# DATA COMMENTS

# DATA COMMENTS

| DATE | | | COMMENT |
|---|---|---|---|
| General-November | | | Auxiliary energy from TPI furnace. QPG entered manually for each day of the month. HLDM was adjusted accordingly. QSHWS was corrected manually to properly account for losses from preheat tank. |
| 11 | 15-16 | 78 | Qu corrected manually. |
| General-December | | | Auxiliary energy from TPI furnace, QPCG, entered manually for each day of the month. HLDM was adjusted accordingly. QSHWS was corrected manually to properly account for losses from preheat tank. |
| 12 | 1,4,5,14, 15,17,20, 21,22,24, 25,27 | 78 | Load flowmeter integrator suspect due to noise problem. QPCS and QSOLAR manually corrected to enforce an energy balance. |
| 12 | 20,24,26 | 78 | Pyranometer\|integrator error, Solar House III values taken for S45. S450 taken as fraction of S45 indicated by original data. |
| 12 | 26,29 | 78 | TOD/and HLDDD error, manually adjusted. |
| General-January | | | Auxiliary energy from TPI furnace, QPCG, entered manually for each day of the month. HLDM was adjusted accordingly. Single measurements available for the following periods; 1-2, 6-9, 17-24, 25-31. Daily auxiliary energy was apportioned based on degree day heating load for these periods. Insolation values suspect due to pyranometer/integrator error, average of Solar House II and III values were used for S45 for each day of the month. S450 was taken as fraction of S45 indicated by original data. QSHWS was corrected manually to properly account for losses from preheat tank. |
| 01 | 10,11,12, 13,14,16, 27 | 79 | Load flowmeter integrator suspect due to noise problem. QPCS and QSOLAR manually corrected to enforce an energy balance. |
| 01 | 15 | 79 | Day omitted due to unreconciled energy balance discrepancy. |
| 01 | 31 | 79 | Day omitted; invalid data due to collector testing. |
| General-February | | | Auxiliary energy from TPI furnace, QPCG, entered manually for each day of the month. HLDM was adjusted accordingly. Insolation values suspect due to pyranometer integrator error; the average of Solar House II and III values were used for S45. S450 was taken as the fraction of S45 indicated by original data. QSHWS was corrected manually to properly account for losses from preheat tank. |
| 02 | 1 | 79 | Day omitted; invalid data due to collector testing. |
| 02 | 2 | 79 | Discrepancy between QSTR and QU between hours 8 and 11 AM. Manual correction applied to QU. |
| 02 | 9,10 | 79 | Partial days due to power failure and subsequent Doric problems. |
| 02 | 11-14 | 79 | Days omitted due to suspect data logging system. |
| 02 | 21,22 | 79 | Days omitted due; unreconciled energy balance. |
| 02 | 23-28 | 79 | QPH, QSHWS, QPCS, QSOLAR all include correction for load flowmeter integrator noise. |
| General-March | | | QSHWS was corrected manually to properly account for losses from preheat tank. |
| 03 | 15 | 79 | Switched to outside storage tank to begin stratified storage experiments. |
| General-July | | | Collector and load loop piping was progressively insulated throughout the first half at the month. No corrections were made for higher heat losses during first half of the month so actual storage losses appear much greater than estimated storage losses. QPH is much greater than QSHWS during first several days because it is being charged from an initial temperature of 10°C. |
| 07 | 1,2,5,13, 19,26,27, 28,29,30 | 79 | Corrections were made for the problems encountered throughout the month in measuring QPH. |
| 08 | | 79 | No significant data problems were noted. |
| 09 | | 79 | No significant data problems were noted. |
| 10 | | 79 | No significant data problems were noted. |

# APPENDIX B

## TABULATED MONTHLY PERFORMANCE OF THE SOLAR HEATING, COOLING, AND HOT WATER SYSTEMS

Table B-1H. Daily Averages and Extrapolated Monthly Totals, November 1978

CSU SOLAR HOUSE I

DAILY AVERAGES AND EXTRAPOLATED MONTHLY TOTALS

NOVEMBER 1978

| | MONTHLY TOTALS | DAILY AVERAGES |
|---|---|---|
| DAYS OF DATA | 20 | 20 |
| AVERAGE DAILY ENERGY FLUX (PER SQ.M) | 14.4 | 14.4 |
| TOTAL INCIDENT SOLAR ON 44.7 SQ.M APERTURE AREA | 19269. | 642.3 |
| TOTAL INCIDENT SOLAR ON 54.2 SQ.M COLLECTOR AREA | 23364. | 778.8 |
| INCIDENT SOLAR 'ON' (APERTURE AREA) | 14851. | 495.0 |
| INCIDENT SOLAR 'ON' (COLLECTOR AREA) | 18007. | 600.2 |
| SOLAR ENERGY COLLECTED | 5713. | 190.5 |
| NET STORAGE ENERGY GAIN DURING DATA GAPS | -984. | -32.8 |
| APPARENT ENERGY DELIVERED TO STORAGE | 4730. | 157.7 |
| NET STORAGE ENERGY GAIN FOR MONTH | -635. | -21.2 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-APERTURE) | .297 | .297 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-COLLECTOR) | .245 | .245 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -APERTURE) | .385 | .385 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -COLLECTOR) | .317 | .317 |
| SPACE HEATING LOAD (COIL) | 8736. | 291.2 |
| SPACE HEATING BY SOLAR (COIL) | 3676. | 122.5 |
| SOLAR SPACE HEATING (COIL) FRACTION | .421 | .421 |
| SOLAR ENERGY LOST FROM STORAGE | 1397. | 46.6 |
| USEFUL SOLAR ENERGY LOST FROM STORAGE | 1290. | 43.0 |
| TOTAL SPACE HEATING LOAD | 10026. | 334.2 |
| TOTAL SOLAR SPACE HEATING | 4966. | 165.5 |
| TOTAL SOLAR SPACE HEATING FRACTION | .495 | .495 |
| SPACE COOLING LOAD | 0. | 0.0 |
| SOLAR SPACE COOLING | 0. | 0.0 |
| SOLAR SPACE COOLING FRACTION | 0.000 | 0.000 |
| TOTAL COOLING SUPPLIED | 0. | 0.0 |
| SOLAR COOLING SUPPLIED | 0. | 0.0 |
| SOLAR FRACTION OF COOLING SUPPLIED | 0.000 | 0.000 |
| SOLAR ENERGY DELIVERED TO PREHEAT TANK | 365. | 12.2 |
| TOTAL ENERGY TO SERVICE HOT WATER | 588. | 19.6 |
| SOLAR ENERGY TO SERVICE HOT WATER | 306. | 10.2 |
| SOLAR HOT WATER FRACTION | .520 | .520 |
| TOTAL LOAD | 10614. | 353.8 |
| TOTAL LOAD BY SOLAR | 5272. | 175.7 |
| SOLAR TOTAL FRACTION | .497 | .497 |

Table B-2H. Daily Averages and Extrapolated Monthly Totals, December 1978

CSU SOLAR HOUSE I

DAILY AVERAGES AND EXTRAPOLATED MONTHLY TOTALS

DECEMBER 1978

| | MONTHLY TOTALS | DAILY AVERAGES |
|---|---|---|
| DAYS OF DATA | 31 | 31 |
| AVERAGE DAILY ENERGY FLUX (PER SQ.M) | 15.8 | 15.8 |
| TOTAL INCIDENT SOLAR ON 44.7 SQ.M APERTURE AREA | 21942. | 707.8 |
| TOTAL INCIDENT SOLAR ON 54.2 SQ.M COLLECTOR AREA | 26606. | 858.3 |
| INCIDENT SOLAR 'ON' (APERTURE AREA) | 14884. | 480.1 |
| INCIDENT SOLAR 'ON' (COLLECTOR AREA) | 18047. | 582.2 |
| SOLAR ENERGY COLLECTED | 6516. | 210.2 |
| NET STORAGE ENERGY GAIN DURING DATA GAPS | -0. | -.0 |
| APPARENT ENERGY DELIVERED TO STORAGE | 6516. | 210.2 |
| NET STORAGE ENERGY GAIN FOR MONTH | -315. | -10.1 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-APERTURE) | .297 | .297 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-COLLECTOR) | .245 | .245 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -APERTURE) | .438 | .438 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -COLLECTOR) | .351 | .361 |
| SPACE HEATING LOAD (COIL) | 12134. | 391.4 |
| SPACE HEATING BY SOLAR (COIL) | 4972. | 160.4 |
| SOLAR SPACE HEATING (COIL) FRACTION | .410 | .410 |
| SOLAR ENERGY LOST FROM STORAGE | 1057. | 34.1 |
| USEFUL SOLAR ENERGY LOST FROM STORAGE | 1057. | 34.1 |
| TOTAL SPACE HEATING LOAD | 13191. | 425.5 |
| TOTAL SOLAR SPACE HEATING | 6029. | 194.5 |
| TOTAL SOLAR SPACE HEATING FRACTION | .457 | .457 |
| SPACE COOLING LOAD | 0. | 0.0 |
| SOLAR SPACE COOLING | 0. | 0.0 |
| SOLAR SPACE COOLING FRACTION | 0.000 | 0.000 |
| TOTAL COOLING SUPPLIED | 0. | 0.0 |
| SOLAR COOLING SUPPLIED | 0. | 0.0 |
| SOLAR FRACTION OF COOLING SUPPLIED | 0.000 | 0.000 |
| SOLAR ENERGY DELIVERED TO PREHEAT TANK | 848. | 27.4 |
| TOTAL ENERGY TO SERVICE HOT WATER | 1776. | 57.3 |
| SOLAR ENERGY TO SERVICE HOT WATER | 741. | 23.9 |
| SOLAR HOT WATER FRACTION | .417 | .417 |
| TOTAL LOAD | 14967. | 482.8 |
| TOTAL LOAD BY SOLAR | 6770. | 218.4 |
| SOLAR TOTAL FRACTION | .452 | .452 |

Table B-3H. Daily Averages and Extrapolated Monthly Totals, January 1979

CSU SOLAR HOUSE I

DAILY AVERAGES AND EXTRAPOLATED MONTHLY TOTALS

JANUARY 1979

| | MONTHLY TOTALS | DAILY AVERAGES |
|---|---|---|
| DAYS OF DATA | 28 | 28 |
| AVERAGE DAILY ENERGY FLUX (PER SQ.M) | 15.7 | 15.7 |
| TOTAL INCIDENT SOLAR ON 44.7 SQ.M APERTURE AREA | 21824. | 704.0 |
| TOTAL INCIDENT SOLAR ON 54.2 SQ.M COLLECTOR AREA | 26462. | 853.6 |
| INCIDENT SOLAR 'ON' (APERTURE AREA) | 13592. | 438.4 |
| INCIDENT SOLAR 'ON' (COLLECTOR AREA) | 16480. | 531.6 |
| SOLAR ENERGY COLLECTED | 6045. | 195.0 |
| NET STORAGE ENERGY GAIN DURING DATA GAPS | 125. | 4.0 |
| APPARENT ENERGY DELIVERED TO STORAGE | 6170. | 199.0 |
| NET STORAGE ENERGY GAIN FOR MONTH | 16. | .5 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-APERTURE) | .277 | .277 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-COLLECTOR) | .228 | .228 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -APERTURE) | .445 | .445 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -COLLECTOR) | .367 | .367 |
| SPACE HEATING LOAD (COIL) | 16577. | 534.7 |
| SPACE HEATING BY SOLAR (COIL) | 4527. | 146.0 |
| SOLAR SPACE HEATING (COIL) FRACTION | .273 | .273 |
| SOLAR ENERGY LOST FROM STORAGE | 1035. | 33.4 |
| USEFUL SOLAR ENERGY LOST FROM STORAGE | 1035. | 33.4 |
| TOTAL SPACE HEATING LOAD | 17612. | 568.1 |
| TOTAL SOLAR SPACE HEATING | 5561. | 179.4 |
| TOTAL SOLAR SPACE HEATING FRACTION | .316 | .316 |
| SPACE COOLING LOAD | 0. | 0.0 |
| SOLAR SPACE COOLING | 0. | 0.0 |
| SOLAR SPACE COOLING FRACTION | 0.000 | 0.000 |
| TOTAL COOLING SUPPLIED | 0. | 0.0 |
| SOLAR COOLING SUPPLIED | 0. | 0.0 |
| SOLAR FRACTION OF COOLING SUPPLIED | 0.000 | 0.000 |
| SOLAR ENERGY DELIVERED TO PREHEAT TANK | 586. | 18.9 |
| TOTAL ENERGY TO SERVICE HOT WATER | 2614. | 84.3 |
| SOLAR ENERGY TO SERVICE HOT WATER | 505. | 16.3 |
| SOLAR HOT WATER FRACTION | .193 | .193 |
| TOTAL LOAD | 20226. | 652.4 |
| TOTAL LOAD BY SOLAR | 6066. | 195.7 |
| SOLAR TOTAL FRACTION | .300 | .300 |

Table B-4H. Daily Averages and Extrapolated Monthly Totals, February 1979

CSU SOLAR HOUSE I

DAILY AVERAGES AND EXTRAPOLATED MONTHLY TOTALS

FEBRUARY 1979

| | MONTHLY TOTALS | DAILY AVERAGES |
|---|---|---|
| DAYS OF DATA | 15 | 15 |
| AVERAGE DAILY ENERGY FLUX (PER SQ.M) | 19.9 | 19.9 |
| TOTAL INCIDENT SOLAR ON 44.7 SQ.M APERTURE AREA | 24849. | 887.5 |
| TOTAL INCIDENT SOLAR ON 54.2 SQ.M COLLECTOR AREA | 30130. | 1076.1 |
| INCIDENT SOLAR 'ON' (APERTURE AREA) | 21051. | 751.8 |
| INCIDENT SOLAR 'ON' (COLLECTOR AREA) | 25525. | 911.6 |
| SOLAR ENERGY COLLECTED | 8798. | 314.2 |
| NET STORAGE ENERGY GAIN DURING DATA GAPS | 197. | 7.0 |
| APPARENT ENERGY DELIVERED TO STORAGE | 8995. | 321.3 |
| NET STORAGE ENERGY GAIN FOR MONTH | 546. | 19.5 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-APERTURE) | .354 | .354 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-COLLECTOR) | .292 | .292 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -APERTURE) | .418 | .418 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -COLLECTOR) | .345 | .345 |
| SPACE HEATING LOAD (COIL) | 11568. | 413.2 |
| SPACE HEATING BY SOLAR (COIL) | 6475. | 231.3 |
| SOLAR SPACE HEATING (COIL) FRACTION | .560 | .560 |
| SOLAR ENERGY LOST FROM STORAGE | 1126. | 40.2 |
| USEFUL SOLAR ENERGY LOST FROM STORAGE | 1126. | 40.2 |
| TOTAL SPACE HEATING LOAD | 12695. | 453.4 |
| TOTAL SOLAR SPACE HEATING | 7601. | 271.5 |
| TOTAL SOLAR SPACE HEATING FRACTION | .599 | .599 |
| SPACE COOLING LOAD | 0. | 0.0 |
| SOLAR SPACE COOLING | 0. | 0.0 |
| SOLAR SPACE COOLING FRACTION | 0.000 | 0.000 |
| TOTAL COOLING SUPPLIED | 0. | 0.0 |
| SOLAR COOLING SUPPLIED | 0. | 0.0 |
| SOLAR FRACTION OF COOLING SUPPLIED | 0.000 | 0.000 |
| SOLAR ENERGY DELIVERED TO PREHEAT TANK | 837. | 29.9 |
| TOTAL ENERGY TO SERVICE HOT WATER | 2957. | 105.6 |
| SOLAR ENERGY TO SERVICE HOT WATER | 721. | 25.8 |
| SOLAR HOT WATER FRACTION | .244 | .244 |
| TOTAL LOAD | 15651. | 559.0 |
| TOTAL LOAD BY SOLAR | 8323. | 297.2 |
| SOLAR TOTAL FRACTION | .532 | .532 |

Table B-5H. Daily Averages and Extrapolated Monthly Totals, March 1979

CSU SOLAR HOUSE I

DAILY AVERAGES AND EXTRAPOLATED MONTHLY TOTALS

MARCH 1979

| | MONTHLY TOTALS | DAILY AVERAGES |
|---|---|---|
| DAYS OF DATA | 10 | 10 |
| AVERAGE DAILY ENERGY FLUX (PER SQ.M) | 21.1 | 21.1 |
| TOTAL INCIDENT SOLAR ON 44.7 SQ.M APERTURE AREA | 13189. | 942.0 |
| TOTAL INCIDENT SOLAR ON 54.2 SQ.M COLLECTOR AREA | 15992. | 1142.3 |
| INCIDENT SOLAR 'ON' (APERTURE AREA) | 10674. | 762.4 |
| INCIDENT SOLAR 'ON' (COLLECTOR AREA) | 12943. | 924.5 |
| SOLAR ENERGY COLLECTED | 4108. | 293.4 |
| NET STORAGE ENERGY GAIN DURING DATA GAPS | 88. | 6.3 |
| APPARENT ENERGY DELIVERED TO STORAGE | 4196. | 299.7 |
| NET STORAGE ENERGY GAIN FOR MONTH | 408. | 29.1 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-APERTURE) | .311 | .311 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-COLLECTOR) | .257 | .257 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -APERTURE) | .385 | .385 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -COLLECTOR) | .317 | .317 |
| SPACE HEATING LOAD (COIL) | 3957. | 282.6 |
| SPACE HEATING BY SOLAR (COIL) | 2753. | 196.6 |
| SOLAR SPACE HEATING (COIL) FRACTION | .696 | .696 |
| SOLAR ENERGY LOST FROM STORAGE | 869. | 62.1 |
| USEFUL SOLAR ENERGY LOST FROM STORAGE | 869. | 62.1 |
| TOTAL SPACE HEATING LOAD | 4825. | 344.7 |
| TOTAL SOLAR SPACE HEATING | 3622. | 258.7 |
| TOTAL SOLAR SPACE HEATING FRACTION | .751 | .751 |
| SPACE COOLING LOAD | 0. | 0.0 |
| SOLAR SPACE COOLING | 0. | 0.0 |
| SOLAR SPACE COOLING FRACTION | 0.000 | 0.000 |
| TOTAL COOLING SUPPLIED | 0. | 0.0 |
| SOLAR COOLING SUPPLIED | 0. | 0.0 |
| SOLAR FRACTION OF COOLING SUPPLIED | 0.000 | 0.000 |
| SOLAR ENERGY DELIVERED TO PREHEAT TANK | 94. | 6.7 |
| TOTAL ENERGY TO SERVICE HOT WATER | 97. | 6.9 |
| SOLAR ENERGY TO SERVICE HOT WATER | 97. | 6.9 |
| SOLAR HOT WATER FRACTION | 1.000 | 1.000 |
| TOTAL LOAD | 4922. | 351.6 |
| TOTAL LOAD BY SOLAR | 3719. | 265.6 |
| SOLAR TOTAL FRACTION | .755 | .755 |

# Table B-1C. Daily Averages and Extrapolated Monthly Totals, July 1979

CSU SOLAR HOUSE I

DAILY AVERAGES AND EXTRAPOLATED MONTHLY TOTALS

JULY 1979

| | MONTHLY TOTALS | DAILY AVERAGES |
|---|---|---|
| DAYS OF DATA | 31 | 31 |
| AVERAGE DAILY ENERGY FLUX (PER SQ.M) | 20.2 | 20.2 |
| TOTAL INCIDENT SOLAR ON 44.7 SQ.M APERTURE AREA | 28009. | 903.5 |
| TOTAL INCIDENT SOLAR ON 54.2 SQ.M COLLECTOR AREA | 33961. | 1095.5 |
| INCIDENT SOLAR 'ON' (APERTURE AREA) | 21990. | 709.3 |
| INCIDENT SOLAR 'ON' (COLLECTOR AREA) | 26663. | 860.1 |
| SOLAR ENERGY COLLECTED | 9216. | 297.3 |
| NET STORAGE ENERGY GAIN DURING DATA GAPS | 0. | .0 |
| APPARENT ENERGY DELIVERED TO STORAGE | 9216. | 297.3 |
| NET STORAGE ENERGY GAIN FOR MONTH | 463. | 14.9 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-APERTURE) | .329 | .329 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-COLLECTOR) | .271 | .271 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -APERTURE) | .419 | .419 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -COLLECTOR) | .346 | .346 |
| SPACE HEATING LOAD (COIL) | 0. | 0.0 |
| SPACE HEATING BY SOLAR (COIL) | 0. | 0.0 |
| SOLAR SPACE HEATING (COIL) FRACTION | 0.000 | 0.000 |
| SOLAR ENERGY LOST FROM STORAGE | 2523. | 81.4 |
| USEFUL SOLAR ENERGY LOST FROM STORAGE | 0. | 0.0 |
| TOTAL SPACE HEATING LOAD | 0. | 0.0 |
| TOTAL SOLAR SPACE HEATING | 0. | 0.0 |
| TOTAL SOLAR SPACE HEATING FRACTION | 0.000 | 0.000 |
| SPACE COOLING LOAD | 7139. | 230.3 |
| SOLAR SPACE COOLING | 5255. | 169.5 |
| SOLAR SPACE COOLING FRACTION | .736 | .736 |
| TOTAL COOLING SUPPLIED | 3429. | 110.6 |
| SOLAR COOLING SUPPLIED | 2400. | 77.4 |
| SOLAR FRACTION OF COOLING SUPPLIED | .700 | .700 |
| SOLAR ENERGY DELIVERED TO PREHEAT TANK | 1280. | 41.3 |
| TOTAL ENERGY TO SERVICE HOT WATER | 880. | 28.4 |
| SOLAR ENERGY TO SERVICE HOT WATER | 552. | 17.8 |
| SOLAR HOT WATER FRACTION | .627 | .627 |
| TOTAL LOAD | 8019. | 258.7 |
| TOTAL LOAD BY SOLAR | 5807. | 187.3 |
| SOLAR TOTAL FRACTION | .724 | .724 |

Table B-2C. Daily Averages and Extrapolated Monthly Totals, August 1979

CSU SOLAR HOUSE I

DAILY AVERAGES AND EXTRAPOLATED MONTHLY TOTALS

AUGUST 1979

| | MONTHLY TOTALS | DAILY AVERAGES |
|---|---|---|
| DAYS OF DATA | 28 | 28 |
| AVERAGE DAILY ENERGY FLUX (PER SQ.M) | 19.5 | 19.5 |
| TOTAL INCIDENT SOLAR ON 44.7 SQ.M APERTURE AREA | 26988. | 870.6 |
| TOTAL INCIDENT SOLAR ON 54.2 SQ.M COLLECTOR AREA | 32724. | 1055.6 |
| INCIDENT SOLAR 'ON' (APERTURE AREA) | 20498. | 661.2 |
| INCIDENT SOLAR 'ON' (COLLECTOR AREA) | 24853. | 801.7 |
| SOLAR ENERGY COLLECTED | 8817. | 284.4 |
| NET STORAGE ENERGY GAIN DURING DATA GAPS | -115. | -3.7 |
| APPARENT ENERGY DELIVERED TO STORAGE | 8702. | 280.7 |
| NET STORAGE ENERGY GAIN FOR MONTH | -54. | -1.8 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-APERTURE) | .327 | .327 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-COLLECTOR) | .269 | .269 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -APERTURE) | .430 | .430 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -COLLECTOR) | .355 | .355 |
| SPACE HEATING LOAD (COIL) | 0. | 0.0 |
| SPACE HEATING BY SOLAR (COIL) | 0. | 0.0 |
| SOLAR SPACE HEATING (COIL) FRACTION | 0.000 | 0.000 |
| SOLAR ENERGY LOST FROM STORAGE | 2010. | 64.8 |
| USEFUL SOLAR ENERGY LOST FROM STORAGE | 0. | 0.0 |
| TOTAL SPACE HEATING LOAD | 0. | 0.0 |
| TOTAL SOLAR SPACE HEATING | 0. | 0.0 |
| TOTAL SOLAR SPACE HEATING FRACTION | 0.000 | 0.000 |
| SPACE COOLING LOAD | 6857. | 221.2 |
| SOLAR SPACE COOLING | 5812. | 187.5 |
| SOLAR SPACE COOLING FRACTION | .848 | .848 |
| TOTAL COOLING SUPPLIED | 3086. | 99.5 |
| SOLAR COOLING SUPPLIED | 2536. | 81.8 |
| SOLAR FRACTION OF COOLING SUPPLIED | .822 | .822 |
| SOLAR ENERGY DELIVERED TO PREHEAT TANK | 1281. | 41.3 |
| TOTAL ENERGY TO SERVICE HOT WATER | 1191. | 38.4 |
| SOLAR ENERGY TO SERVICE HOT WATER | 981. | 31.7 |
| SOLAR HOT WATER FRACTION | .824 | .824 |
| TOTAL LOAD | 8049. | 259.6 |
| TOTAL LOAD BY SOLAR | 6793. | 219.1 |
| SOLAR TOTAL FRACTION | .844 | .844 |

Table B-3C. Daily Averages and Extrapolated Monthly Totals, September 1979

CSU SOLAR HOUSE I

DAILY AVERAGES AND EXTRAPOLATED MONTHLY TOTALS

SEPTEMBER 1979

| | MONTHLY TOTALS | DAILY AVERAGES |
|---|---|---|
| DAYS OF DATA | 30 | 30 |
| AVERAGE DAILY ENERGY FLUX (PER SQ.M) | 22.4 | 22.4 |
| TOTAL INCIDENT SOLAR ON 44.7 SQ.M APERTURE AREA | 30005. | 1000.2 |
| TOTAL INCIDENT SOLAR ON 54.2 SQ.M COLLECTOR AREA | 36382. | 1212.7 |
| INCIDENT SOLAR 'ON' (APERTURE AREA) | 25671. | 855.7 |
| INCIDENT SOLAR 'ON' (COLLECTOR AREA) | 31127. | 1037.6 |
| SOLAR ENERGY COLLECTED | 11378. | 379.3 |
| NET STORAGE ENERGY GAIN DURING DATA GAPS | 0. | .0 |
| APPARENT ENERGY DELIVERED TO STORAGE | 11378. | 379.3 |
| NET STORAGE ENERGY GAIN FOR MONTH | 161. | 5.4 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-APERTURE) | .379 | .379 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-COLLECTOR) | .313 | .313 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -APERTURE) | .443 | .443 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -COLLECTOR) | .366 | .366 |
| SPACE HEATING LOAD (COIL) | 0. | 0.0 |
| SPACE HEATING BY SOLAR (COIL) | 0. | 0.0 |
| SOLAR SPACE HEATING (COIL) FRACTION | 0.000 | 0.000 |
| SOLAR ENERGY LOST FROM STORAGE | 1861. | 62.0 |
| USEFUL SOLAR ENERGY LOST FROM STORAGE | 0. | 0.0 |
| TOTAL SPACE HEATING LOAD | 0. | 0.0 |
| TOTAL SOLAR SPACE HEATING | 0. | 0.0 |
| TOTAL SOLAR SPACE HEATING FRACTION | 0.000 | 0.000 |
| SPACE COOLING LOAD | 10869. | 362.3 |
| SOLAR SPACE COOLING | 8161. | 272.0 |
| SOLAR SPACE COOLING FRACTION | .751 | .751 |
| TOTAL COOLING SUPPLIED | 4819. | 160.6 |
| SOLAR COOLING SUPPLIED | 3494. | 116.5 |
| SOLAR FRACTION OF COOLING SUPPLIED | .725 | .725 |
| SOLAR ENERGY DELIVERED TO PREHEAT TANK | 1535. | 51.2 |
| TOTAL ENERGY TO SERVICE HOT WATER | 1390. | 46.3 |
| SOLAR ENERGY TO SERVICE HOT WATER | 1016. | 33.9 |
| SOLAR HOT WATER FRACTION | .731 | .731 |
| TOTAL LOAD | 12259. | 408.6 |
| TOTAL LOAD BY SOLAR | 9177. | 305.9 |
| SOLAR TOTAL FRACTION | .749 | .749 |

Table B-4C. Daily Averages and Extrapolated Monthly Totals, October 1979

CSU SOLAR HOUSE I

DAILY AVERAGES AND EXTRAPOLATED MONTHLY TOTALS

OCTOBER 1979

| | MONTHLY TOTALS | DAILY AVERAGES |
|---|---|---|
| DAYS OF DATA | 17 | 17 |
| AVERAGE DAILY ENERGY FLUX (PER SQ.M) | 20.4 | 20.4 |
| TOTAL INCIDENT SOLAR ON 44.7 SQ.M APERTURE AREA | 15535. | 913.8 |
| TOTAL INCIDENT SOLAR ON 54.2 SQ.M COLLECTOR AREA | 18837. | 1108.1 |
| INCIDENT SOLAR 'ON' (APERTURE AREA) | 12624. | 742.6 |
| INCIDENT SOLAR 'ON' (COLLECTOR AREA) | 15307. | 900.4 |
| SOLAR ENERGY COLLECTED | 5445. | 320.3 |
| NET STORAGE ENERGY GAIN DURING DATA GAPS | -0. | -.0 |
| APPARENT ENERGY DELIVERED TO STORAGE | 5445. | 320.3 |
| NET STORAGE ENERGY GAIN FOR MONTH | -45. | -2.6 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-APERTURE) | .350 | .350 |
| COLLECTION EFFICIENCY (TOTAL INCIDENT-COLLECTOR) | .289 | .289 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -APERTURE) | .431 | .431 |
| COLLECTION EFFICIENCY (INCIDENT 'ON' -COLLECTOR) | .356 | .356 |
| SPACE HEATING LOAD (COIL) | 0. | 0.0 |
| SPACE HEATING BY SOLAR (COIL) | 0. | 0.0 |
| SOLAR SPACE HEATING (COIL) FRACTION | 0.000 | 0.000 |
| SOLAR ENERGY LOST FROM STORAGE | 1006. | 59.2 |
| USEFUL SOLAR ENERGY LOST FROM STORAGE | 0. | 0.0 |
| TOTAL SPACE HEATING LOAD | 0. | 0.0 |
| TOTAL SOLAR SPACE HEATING | 0. | 0.0 |
| TOTAL SOLAR SPACE HEATING FRACTION | 0.000 | 0.000 |
| SPACE COOLING LOAD | 4318. | 254.0 |
| SOLAR SPACE COOLING | 3966. | 233.3 |
| SOLAR SPACE COOLING FRACTION | .918 | .918 |
| TOTAL COOLING SUPPLIED | 2103. | 123.7 |
| SOLAR COOLING SUPPLIED | 1933. | 113.7 |
| SOLAR FRACTION OF COOLING SUPPLIED | .919 | .919 |
| SOLAR ENERGY DELIVERED TO PREHEAT TANK | 711. | 41.8 |
| TOTAL ENERGY TO SERVICE HOT WATER | 676. | 39.8 |
| SOLAR ENERGY TO SERVICE HOT WATER | 469. | 27.6 |
| SOLAR HOT WATER FRACTION | .694 | .694 |
| TOTAL LOAD | 4995. | 293.8 |
| TOTAL LOAD BY SOLAR | 4436. | 260.9 |
| SOLAR TOTAL FRACTION | .888 | .888 |

# APPENDIX C

Tabulated Daily Performance of the Solar Heating, Cooling, and Hot Water Systems

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## Table C-1H. CSU Solar House I System Performance for Month of November, 1978

| DAY | ENERGY REQUIRED | | | | SOLAR ENERGY USED | | | | | | | AUXILIARY ENERGY USED | | | | SOLAR FRACTION | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q610 SPACE HEATING | Q512 SPACE COOLING | Q312 HOT WATER HEATING | Q606 TOTAL | Q402 SPACE HEATING | Q604C ACTUAL STORAGE LOSSES | Q611 TOTAL USEFUL HEATING | Q604E STORAGE LOSSES ESTIMATED | Q540 SPACE COOLING | Q313 HOT WATER HEATING | Q612 TOTAL USEFUL ENERGY | Q442 SPACE HEATING | Q501 SPACE COOLING | Q301 HOT WATER HEATING | Q601 TOTAL | N401 SPACE HEATING | N501 SPACE COOLING | N301 HOT WATER HEATING |
| 1 | 215.9 | 0.0 | 12.2 | 228.1 | 115.0 | 100.9 | 215.9 | 114.3 | 0.0 | 5.0 | 220.9 | 0.0 | 0.0 | 7.2 | 7.2 | 1.000 | 0.000 | .410 |
| 2 | 158.0 | 0.0 | 10.9 | 168.9 | 3.2 | 154.8 | 158.0 | 127.3 | 0.0 | 3.4 | 161.4 | 0.0 | 0.0 | 7.5 | 7.5 | 1.000 | 0.000 | .312 |
| 3 | 216.6 | 0.0 | 9.7 | 226.3 | 25.1 | 191.5 | 216.6 | 139.1 | 0.0 | 2.6 | 219.2 | 0.0 | 0.0 | 7.1 | 7.1 | 1.000 | 0.000 | .268 |
| 4 | 175.0 | 0.0 | 7.8 | 182.8 | 18.0 | 157.0 | 175.0 | 127.3 | 0.0 | .9 | 175.9 | 0.0 | 0.0 | 6.9 | 6.9 | 1.000 | 0.000 | .115 |
| 5 | 660.8 | 0.0 | 23.2 | 684.0 | 563.5 | 97.3 | 660.8 | 85.5 | 0.0 | 16.8 | 677.6 | 0.0 | 0.0 | 6.4 | 6.4 | 1.000 | 0.000 | .724 |
| 6 | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | | | |
| 8 | 111.1 | 0.0 | 9.5 | 120.6 | .6 | 86.0 | 86.6 | 106.1 | 0.0 | .9 | 87.5 | 24.4 | 0.0 | 8.6 | 33.0 | .780 | 0.000 | .095 |
| 9 | 0.0 | 0.0 | 8.8 | 8.8 | -0.0 | 71.0 | 0.0 | 105.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.8 | 8.8 | 0.000 | 0.000 | 0.000 |
| 10 | | | | | | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | | | | | |
| 13 | 710.7 | 0.0 | 49.8 | 760.5 | 61.7 | 17.7 | 79.4 | 23.5 | 0.0 | 38.5 | 117.9 | 630.4 | 0.0 | 11.3 | 641.7 | .112 | 0.000 | .773 |
| 14 | 507.3 | 0.0 | 23.5 | 530.8 | 233.9 | 9.5 | 243.4 | 23.7 | 0.0 | 13.5 | 256.9 | 260.6 | 0.0 | 10.0 | 270.6 | .480 | 0.000 | .574 |
| 15 | | | | | | | | | | | | | | | | | | |
| 16 | | | | | | | | | | | | | | | | | | |
| 17 | | | | | | | | | | | | | | | | | | |
| 18 | | | | | | | | | | | | | | | | | | |
| 19 | | | | | | | | | | | | | | | | | | |
| 20 | 433.3 | 0.0 | 16.0 | 449.3 | 110.0 | -67.9 | 42.1 | -6.6 | 0.0 | 4.4 | 46.5 | 390.2 | 0.0 | 11.6 | 401.8 | .097 | 0.000 | .275 |
| 21 | 402.8 | 0.0 | 11.6 | 414.4 | 27.7 | -21.5 | 6.2 | -5.3 | 0.0 | 0.0 | 6.2 | 396.4 | 0.0 | 11.6 | 408.0 | .015 | 0.000 | 0.000 |
| 22 | 167.7 | 0.0 | 37.1 | 204.8 | 106.0 | -48.1 | 57.9 | 6.9 | 0.0 | 25.6 | 83.5 | 108.4 | 0.0 | 11.5 | 119.9 | .346 | 0.000 | .690 |
| 23 | 344.6 | 0.0 | 32.5 | 377.1 | 162.2 | 28.9 | 191.1 | 26.1 | 0.0 | 22.3 | 213.4 | 150.8 | 0.0 | 10.2 | 161.0 | .555 | 0.000 | .686 |
| 24 | 416.6 | 0.0 | 18.5 | 435.1 | 222.3 | 32.5 | 254.8 | 21.7 | 0.0 | 9.0 | 263.8 | 158.6 | 0.0 | 9.5 | 168.1 | .612 | 0.000 | .486 |
| 25 | 367.1 | 0.0 | 12.6 | 379.7 | 143.8 | -25.2 | 118.6 | 6.1 | 0.0 | 2.6 | 121.2 | 246.8 | 0.0 | 10.0 | 256.8 | .323 | 0.000 | .206 |
| 26 | 367.7 | 0.0 | 13.2 | 380.9 | 74.0 | .7 | 74.7 | -.7 | 0.0 | 2.8 | 77.5 | 293.1 | 0.0 | 10.4 | 303.5 | .203 | 0.000 | .212 |
| 27 | 340.9 | 0.0 | 34.4 | 375.3 | 117.6 | 17.9 | 135.4 | 18.3 | 0.0 | 23.5 | 158.9 | 203.8 | 0.0 | 10.9 | 214.7 | .397 | 0.000 | .683 |
| 28 | 466.5 | 0.0 | 21.0 | 487.5 | 202.3 | 38.6 | 240.8 | 15.1 | 0.0 | 9.0 | 249.8 | 223.0 | 0.0 | 12.0 | 235.0 | .516 | 0.000 | .429 |
| 29 | 347.5 | 0.0 | 30.1 | 377.6 | 129.6 | 44.7 | 174.3 | 29.5 | 0.0 | 17.9 | 192.2 | 171.5 | 0.0 | 12.2 | 183.7 | .501 | 0.000 | .595 |
| 30 | 274.3 | 0.0 | 9.6 | 283.9 | 134.1 | 45.0 | 179.1 | 36.1 | 0.0 | 5.2 | 184.3 | 93.1 | 0.0 | 4.4 | 97.5 | .653 | 0.000 | .543 |
| TOTAL | 6684. | 0. | 392. | 7076. | 2450. | 931. | 3311. | 1000. | 0. | 204. | 3515. | 3351. | 0. | 188. | 3539. | .495 | 0.000 | .520 |
| DAILY | 334.2 | 0.0 | 19.6 | 353.8 | 122.5 | 46.6 | 165.5 | 50.0 | 0.0 | 10.2 | 175.7 | 167.6 | 0.0 | 9.4 | 177.0 | .495 | 0.000 | .520 |
| MONTH | 10025. | 0. | 588. | 10614. | 3676. | 1397. | 4966. | 1500. | 0. | 306. | 5272. | 5027. | 0. | 282. | 5309. | .495 | 0.000 | .520 |

ALL DATA IN MEGAJOULES

* BASED ON 54.2 SQ.M COLLECTOR AREA

Table C-1H (continued)

| DAY | N601 TOTAL | S006 TOTAL SOLAR* | S008 SOLAR* WHEN COLLECTING | Q111 HEAT DELIVERED | N100 AVERAGE EFFICIENCY | Q502 TOTAL OUTPUT | Q541 SOLAR OUTPUT | N502 FRACTION BY SOLAR | |
|---|---|---|---|---|---|---|---|---|---|
| | | ---COLLECTOR PERFORMANCE--- | | | | -CHILLER PERFORMANCE- | | | |
| 1 | .968 | 955.2 | 809.2 | 210.3 | .220 | 0.0 | 0.0 | 0.000 | 3.7 |
| 2 | .956 | 1315.1 | 1113.5 | 299.3 | .228 | 0.0 | 0.0 | 0.000 | 3.3 |
| 3 | .969 | 1212.0 | 1021.8 | 281.3 | .232 | 0.0 | 0.0 | 0.000 | 7.8 |
| 4 | .962 | 915.2 | 609.3 | 139.2 | .152 | 0.0 | 0.0 | 0.000 | 3.5 |
| 5 | .991 | 672.1 | 451.9 | 140.0 | .208 | 0.0 | 0.0 | 0.000 | 8.1 |
| 6 | | | | | | | | | |
| 7 | | | | | | | | | |
| 8 | .726 | 700.6 | 395.5 | 107.7 | .154 | 0.0 | 0.0 | 0.000 | 3.4 |
| 9 | 0.000 | 825.4 | 509.7 | 135.7 | .164 | 0.0 | 0.0 | 0.000 | 3.1 |
| 10 | | | | | | | | | |
| 11 | | | | | | | | | |
| 12 | | | | | | | | | |
| 13 | .155 | 1366.6 | 1290.0 | 476.9 | .349 | 0.0 | 0.0 | 0.000 | 6.8 |
| 14 | .484 | 32.6 | 3.6 | -.4 | -.013 | 0.0 | 0.0 | 0.000 | 9.0 |
| 15 | | | | | | | | | |
| 16 | | | | | | | | | |
| 17 | | | | | | | | | |
| 18 | | | | | | | | | |
| 19 | | | | | | | | | |
| 20 | .104 | 54.2 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.000 | 13.1 |
| 21 | .015 | 605.7 | 8.7 | .1 | .000 | 0.0 | 0.0 | 0.000 | 7.3 |
| 22 | .408 | 892.3 | 740.9 | 246.7 | .276 | 0.0 | 0.0 | 0.000 | 7.2 |
| 23 | .566 | 1322.4 | 1175.5 | 436.8 | .330 | 0.0 | 0.0 | 0.000 | 9.0 |
| 24 | .606 | 537.0 | 290.9 | 91.4 | .170 | 0.0 | 0.0 | 0.000 | 8.2 |
| 25 | .319 | 87.2 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.000 | 9.7 |
| 26 | .203 | 392.3 | 244.3 | 59.5 | .152 | 0.0 | 0.0 | 0.000 | 11.0 |
| 27 | .424 | 1233.3 | 1153.5 | 391.9 | .318 | 0.0 | 0.0 | 0.000 | 7.5 |
| 28 | .513 | 533.3 | 446.8 | 131.0 | .245 | 0.0 | 0.0 | 0.000 | 9.5 |
| 29 | .509 | 924.2 | 834.7 | 326.5 | .353 | 0.0 | 0.0 | 0.000 | 7.2 |
| 30 | .649 | 999.0 | 904.5 | 335.3 | .336 | 0.0 | 0.0 | 0.000 | 6.2 |
| TOTAL | .497 | 15576. | 12005. | 3809. | .245 | 0.0 | 0.0 | 0.000 | 144.6 |
| DAILY | .497 | 778.8 | 600.2 | 190.5 | .245 | 0.0 | 0.0 | 0.000 | 7.2 |
| MONTH | .497 | 23364. | 18007. | 5713. | .245 | 0.0 | 0.0 | 0.000 | 216.9 |

ALL DATA IN MEGAJOULES
*BASED ON 54.2 SQ.M COLLECTOR AREA

# Table C-2H. CSU Solar House I System Performance for Month of December, 1978

| DAY | ENERGY REQUIRED | | | | SOLAR ENERGY USED | | | | | | | AUXILIARY ENERGY USED | | | | SOLAR FRACTION | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q610 SPACE HEATING | Q512 SPACE COOLING | Q312 HOT WATER HEATING | Q606 TOTAL | Q402 SPACE HEATING | Q604C ACTUAL STORAGE LOSSES | Q611 TOTAL USEFUL HEATING | Q604E STORAGE LOSSES ESTIMATED | Q540 SPACE COOLING | Q313 HOT WATER HEATING | Q612 TOTAL USEFUL ENERGY | Q442 SPACE HEATING | Q501 SPACE COOLING | Q301 HOT WATER HEATING | Q601 TOTAL | N401 SPACE HEATING | N501 SPACE COOLING | N301 HOT WATER HEATING |
| 1 | 310.5 | 0.0 | 31.2 | 341.7 | 219.0 | 50.5 | 269.5 | 41.7 | 0.0 | 28.6 | 298.1 | 41.0 | 0.0 | 2.6 | 43.6 | .868 | 0.000 | .917 |
| 2 | 488.2 | 0.0 | 8.7 | 496.9 | 269.5 | 13.7 | 283.2 | 21.0 | 0.0 | 6.1 | 289.3 | 205.0 | 0.0 | 2.6 | 207.6 | .580 | 0.000 | .701 |
| 3 | 471.4 | 0.0 | 2.5 | 474.0 | 60.8 | -2.6 | 58.2 | 4.5 | 0.0 | 0.0 | 58.2 | 414.0 | 0.0 | 2.6 | 416.6 | .124 | 0.000 | 0.000 |
| 4 | 402.1 | 0.0 | 17.2 | 419.3 | 57.3 | 3.8 | 61.1 | 21.2 | 0.0 | 14.5 | 75.6 | 341.0 | 0.0 | 2.7 | 343.7 | .152 | 0.000 | .843 |
| 5 | 263.2 | 0.0 | 11.3 | 274.5 | 179.1 | 39.1 | 217.2 | 21.0 | 0.0 | 8.7 | 225.9 | 64.0 | 0.0 | 2.6 | 66.6 | .825 | 0.000 | .770 |
| 6 | 461.0 | 0.0 | 79.5 | 540.5 | 56.5 | 14.5 | 70.9 | 5.7 | 0.0 | 0.0 | 70.9 | 390.0 | 0.0 | 79.5 | 469.5 | .154 | 0.000 | 0.000 |
| 7 | 494.3 | 0.0 | 173.6 | 667.9 | 0.0 | 3.3 | 3.3 | 8.5 | 0.0 | 0.0 | 3.3 | 491.0 | 0.0 | 173.6 | 664.6 | .007 | 0.000 | 0.000 |
| 8 | 512.9 | 0.0 | 144.3 | 657.2 | 46.2 | -9.3 | 36.8 | 10.5 | 0.0 | 12.3 | 49.1 | 476.0 | 0.0 | 132.0 | 608.0 | .072 | 0.000 | .085 |
| 9 | 591.5 | 0.0 | 36.3 | 627.8 | 110.1 | -3.6 | 106.5 | 14.5 | 0.0 | 36.3 | 142.8 | 485.0 | 0.0 | 0.0 | 485.0 | .180 | 0.000 | 1.000 |
| 10 | 600.9 | 0.0 | 31.2 | 632.1 | 148.6 | 9.3 | 157.9 | 5.5 | 0.0 | 31.2 | 189.1 | 443.0 | 0.0 | 0.0 | 443.0 | .263 | 0.000 | 1.000 |
| 11 | 381.6 | 0.0 | 44.6 | 426.2 | 108.0 | 46.5 | 154.5 | 17.7 | 0.0 | 44.6 | 199.1 | 227.0 | 0.0 | 0.0 | 227.0 | .405 | 0.000 | 1.000 |
| 12 | 317.4 | 0.0 | 43.1 | 360.5 | 132.2 | 50.2 | 182.4 | 25.7 | 0.0 | 43.1 | 225.5 | 135.0 | 0.0 | 0.0 | 135.0 | .575 | 0.000 | 1.000 |
| 13 | 435.7 | 0.0 | 37.9 | 473.6 | 208.3 | 47.4 | 255.7 | 37.9 | 0.0 | 37.9 | 293.6 | 180.0 | 0.0 | 0.0 | 180.0 | .587 | 0.000 | 1.000 |
| 14 | 400.5 | 0.0 | 36.7 | 437.2 | 248.6 | 28.9 | 277.5 | 48.9 | 0.0 | 36.7 | 314.2 | 123.0 | 0.0 | 0.0 | 123.0 | .693 | 0.000 | 1.000 |
| 15 | 393.5 | 0.0 | 83.2 | 476.7 | 261.8 | 70.7 | 332.5 | 49.5 | 0.0 | 56.2 | 388.7 | 61.0 | 0.0 | 27.0 | 88.0 | .845 | 0.000 | .675 |
| 16 | 612.5 | 0.0 | 35.8 | 648.3 | 365.2 | 76.3 | 441.5 | 47.2 | 0.0 | 35.8 | 477.3 | 171.0 | 0.0 | 0.0 | 171.0 | .721 | 0.000 | 1.000 |
| 17 | 527.1 | 0.0 | 7.1 | 534.2 | 294.4 | 38.7 | 333.1 | 20.0 | 0.0 | 7.1 | 340.2 | 194.0 | 0.0 | 0.0 | 194.0 | .632 | 0.000 | 1.000 |
| 18 | 342.3 | 0.0 | 4.3 | 346.6 | 68.2 | 27.1 | 95.3 | 2.4 | 0.0 | 4.3 | 99.6 | 247.0 | 0.0 | 0.0 | 247.0 | .278 | 0.000 | 1.000 |
| 19 | 281.8 | 0.0 | 60.2 | 342.0 | 72.1 | 30.7 | 102.7 | 18.4 | 0.0 | 25.1 | 127.8 | 179.0 | 0.0 | 35.1 | 214.1 | .365 | 0.000 | .417 |
| 20 | 470.9 | 0.0 | 82.5 | 553.4 | 256.8 | 52.1 | 308.9 | 37.4 | 0.0 | 37.1 | 346.0 | 162.0 | 0.0 | 45.4 | 207.4 | .656 | 0.000 | .450 |
| 21 | 441.5 | 0.0 | 85.0 | 526.5 | 221.7 | 56.8 | 278.5 | 42.6 | 0.0 | 31.0 | 309.5 | 163.0 | 0.0 | 54.0 | 217.0 | .631 | 0.000 | .365 |
| 22 | 338.3 | 0.0 | 79.1 | 417.4 | 262.6 | 53.7 | 316.3 | 50.1 | 0.0 | 38.2 | 354.5 | 22.0 | 0.0 | 40.9 | 62.9 | .935 | 0.000 | .483 |
| 23 | 209.3 | 0.0 | 66.2 | 275.5 | 133.0 | 76.3 | 209.3 | 42.1 | 0.0 | 34.3 | 243.6 | 0.0 | 0.0 | 31.9 | 31.9 | 1.000 | 0.000 | .518 |
| 24 | 167.7 | 0.0 | 96.1 | 263.8 | 99.6 | 68.0 | 167.7 | 57.1 | 0.0 | 61.5 | 229.2 | 0.0 | 0.0 | 34.6 | 34.6 | 1.000 | 0.000 | .640 |
| 25 | 137.2 | 0.0 | 66.9 | 204.1 | 69.7 | 67.5 | 137.2 | 58.3 | 0.0 | 33.8 | 171.0 | 0.0 | 0.0 | 33.1 | 33.1 | 1.000 | 0.000 | .505 |
| 26 | 428.8 | 0.0 | 71.5 | 500.3 | 366.8 | 27.0 | 393.8 | 44.5 | 0.0 | 32.5 | 426.3 | 95.0 | 0.0 | 39.0 | 134.0 | .918 | 0.000 | .455 |
| 27 | 769.6 | 0.0 | 57.6 | 827.1 | 256.9 | 32.7 | 289.5 | 18.8 | 0.0 | 12.2 | 301.7 | 480.0 | 0.0 | 45.4 | 525.4 | .376 | 0.000 | .212 |
| 28 | 493.9 | 0.0 | 82.4 | 576.3 | 178.2 | 54.7 | 232.9 | 34.6 | 0.0 | 30.9 | 263.8 | 261.0 | 0.0 | 51.5 | 312.5 | .471 | 0.000 | .375 |
| 29 | 391.3 | 0.0 | 61.2 | 452.5 | 220.7 | 14.6 | 235.3 | 21.2 | 0.0 | 1.0 | 236.3 | 156.0 | 0.0 | 60.2 | 216.2 | .601 | 0.000 | .016 |
| 30 | 536.5 | 0.0 | 69.5 | 606.0 | 0.0 | 11.5 | 11.5 | 20.6 | 0.0 | 0.0 | 11.5 | 525.0 | 0.0 | 69.5 | 594.5 | .021 | 0.000 | 0.000 |
| 31 | 517.8 | 0.0 | 69.3 | 587.1 | 0.0 | 7.8 | 7.8 | 19.6 | 0.0 | 0.0 | 7.8 | 510.0 | 0.0 | 69.3 | 579.3 | .015 | 0.000 | 0.000 |
| TOTAL | 13191. | 0. | 1776. | 14967. | 4972. | 1057. | 6029. | 869. | 0. | 741. | 6770. | 7241. | 0. | 1035. | 8276. | .457 | 0.000 | .417 |
| DAILY | 425.5 | 0.0 | 57.3 | 482.8 | 160.4 | 34.1 | 194.5 | 28.0 | 0.0 | 23.9 | 218.4 | 233.6 | 0.0 | 33.4 | 267.0 | .457 | 0.000 | .417 |
| MONTH | 13191. | 0. | 1776. | 14967. | 4972. | 1057. | 6029. | 869. | 0. | 741. | 5770. | 7241. | 0. | 1035. | 8276. | .457 | 0.000 | .417 |

* ALL DATA IN MEGAJOULES
* BASED ON 54.2 53.4 COLLECTOR AREA

Table C-2H (continued)

| DAY | ----- N601 TOTAL | ---COLLECTOR S006 TOTAL SOLAR* | PERFORMANCE S008 SOLAR* WHEN COLLECTING | Q111 HEAT DELIVERED | --- N100 AVERAGE EFFICIENCY | -CHILLER Q502 TOTAL OUTPUT | PERFORMANCE- Q541 SOLAR OUTPUT | N502 FRACTION BY SOLAR | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | .872 | 718.3 | 579.2 | 226.2 | .315 | 0.0 | 0.0 | 0.000 | 6.1 |
| 2 | .582 | 224.1 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.000 | 11.5 |
| 3 | .123 | 1129.3 | 76.4 | 6.8 | .006 | 0.0 | 0.0 | 0.000 | 8.5 |
| 4 | .180 | 1331.5 | 1197.9 | 370.9 | .279 | 0.0 | 0.0 | 0.000 | 3.9 |
| 5 | .823 | 85.2 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.000 | 5.6 |
| 6 | .131 | 171.3 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.000 | 5.0 |
| 7 | .005 | 506.8 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.000 | 3.3 |
| 8 | .075 | 781.6 | 176.8 | 49.1 | .063 | 0.0 | 0.0 | 0.000 | 3.5 |
| 9 | .227 | 1324.9 | 875.9 | 216.6 | .164 | 0.0 | 0.0 | 0.000 | 3.4 |
| 10 | .299 | 797.1 | 580.1 | 178.0 | .223 | 0.0 | 0.0 | 0.000 | 5.1 |
| 11 | .457 | 1072.5 | 834.6 | 342.0 | .319 | 0.0 | 0.0 | 0.000 | 3.2 |
| 12 | .626 | 913.3 | 745.0 | 317.1 | .347 | 0.0 | 0.0 | 0.000 | 2.6 |
| 13 | .620 | 1142.4 | 1092.1 | 408.3 | .357 | 0.0 | 0.0 | 0.000 | 2.9 |
| 14 | .719 | 1177.0 | 1097.6 | 438.5 | .373 | 0.0 | 0.0 | 0.000 | 2.4 |
| 15 | .815 | 1147.2 | 1064.8 | 388.5 | .339 | 0.0 | 0.0 | 0.000 | 2.1 |
| 16 | .736 | 1246.8 | 1127.8 | 415.0 | .333 | 0.0 | 0.0 | 0.000 | 2.8 |
| 17 | .637 | 239.7 | 99.8 | 8.0 | .033 | 0.0 | 0.0 | 0.000 | 3.6 |
| 18 | .287 | 355.0 | 244.2 | 66.2 | .186 | 0.0 | 0.0 | 0.000 | 3.0 |
| 19 | .374 | 1009.8 | 910.1 | 374.7 | .371 | 0.0 | 0.0 | 0.000 | 2.6 |
| 20 | .625 | 1278.0 | 1173.7 | 428.4 | .335 | 0.0 | 0.0 | 0.000 | 2.7 |
| 21 | .588 | 1015.5 | 976.6 | 394.2 | .388 | 0.0 | 0.0 | 0.000 | 2.6 |
| 22 | .849 | 1195.8 | 1084.2 | 404.4 | .338 | 0.0 | 0.0 | 0.000 | 1.8 |
| 23 | .884 | 690.2 | 528.4 | 196.2 | .284 | 0.0 | 0.0 | 0.000 | 4.4 |
| 24 | .869 | 1212.5 | 1105.8 | 373.5 | .308 | 0.0 | 0.0 | 0.000 | 5.2 |
| 25 | .838 | 90.1 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.000 | 5.1 |
| 26 | .652 | 994.3 | 897.3 | 279.2 | .281 | 0.0 | 0.0 | 0.000 | 6.0 |
| 27 | .365 | 731.8 | 605.7 | 226.5 | .309 | 0.0 | 0.0 | 0.000 | 6.8 |
| 28 | .458 | 1209.0 | 973.3 | 407.7 | .338 | 0.0 | 0.0 | 0.000 | 4.5 |
| 29 | .522 | 472.9 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.000 | 3.7 |
| 30 | .019 | 1304.3 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.000 | 1.6 |
| 31 | .013 | 1038.4 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.000 | 1.9 |
| TOTAL | .452 | 26606. | 18047. | 6516. | .245 | 0.0 | 0.0 | 0.000 | 127.4 |
| DAILY | .452 | 858.3 | 582.2 | 210.2 | .245 | 0.0 | 0.0 | 0.000 | 4.1 |
| MONTH | .452 | 26606. | 18047. | 6516. | .245 | 0.0 | 0.0 | 0.000 | 127.4 |

Note: Several very high solar radiation measurements resulting from snow reflection

ALL DATA IN MEGAJOULES
BASED ON 54.2 SQ. M COLLECTOR AREA

## Figure C-3H. CSU Solar House I System Performance for Month of January, 1979

| DAY | ENERGY REQUIRED Q610 SPACE HEATING | Q512 SPACE COOLING | Q312 HOT WATER HEATING | Q606 TOTAL | SOLAR ENERGY USED Q402 SPACE HEATING | Q604C ACTUAL STORAGE LOSSES | Q611 TOTAL USEFUL HEATING | Q604E STORAGE LOSSES ESTIMATED | Q540 SPACE COOLING | Q313 HOT WATER HEATING | Q612 TOTAL USEFUL ENERGY | AUXILIARY ENERGY USED Q442 SPACE HEATING | Q501 SPACE COOLING | Q301 HOT WATER HEATING | Q601 TOTAL | SOLAR FRACTION N401 SPACE HEATING | N501 SPACE COOLING | N301 HOT WATER HEATING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 549.6 | 0.0 | 80.5 | 630.1 | 0.0 | 7.2 | 7.2 | 16.5 | 0.0 | 1.6 | 8.8 | 542.4 | 0.0 | 78.9 | 621.3 | .013 | 0.000 | .020 |
| 2 | 501.1 | 0.0 | 94.1 | 595.2 | 0.0 | 7.5 | 7.5 | 16.6 | 0.0 | 1.6 | 9.1 | 493.6 | 0.0 | 92.5 | 586.1 | .015 | 0.000 | .017 |
| 3 | 981.1 | 0.0 | 82.4 | 1063.5 | .1 | 5.1 | 5.2 | 13.0 | 0.0 | 2.1 | 7.3 | 976.0 | 0.0 | 80.3 | 1056.3 | .005 | 0.000 | .025 |
| 4 | 560.8 | 0.0 | 107.6 | 668.4 | 0.0 | 4.7 | 4.7 | 19.8 | 0.0 | 2.2 | 7.0 | 556.0 | 0.0 | 105.4 | 661.4 | .008 | 0.000 | .021 |
| 5 | 676.8 | 0.0 | 87.3 | 764.0 | 230.2 | 3.8 | 234.0 | 29.0 | 0.0 | 30.3 | 264.3 | 443.0 | 0.0 | 57.0 | 500.0 | .346 | 0.000 | .347 |
| 6 | 482.0 | 0.0 | 61.1 | 543.1 | 57.3 | 13.1 | 70.4 | 20.3 | 0.0 | 1.7 | 72.1 | 411.6 | 0.0 | 59.4 | 471.0 | .146 | 0.000 | .028 |
| 7 | 820.0 | 0.0 | 100.7 | 920.6 | 316.4 | 3.2 | 319.6 | 29.8 | 0.0 | 41.9 | 361.5 | 500.4 | 0.0 | 58.8 | 559.2 | .390 | 0.000 | .416 |
| 8 | 716.9 | 0.0 | 94.1 | 811.0 | 243.2 | 47.5 | 290.7 | 30.9 | 0.0 | 34.7 | 325.4 | 426.2 | 0.0 | 59.4 | 485.6 | .405 | 0.000 | .369 |
| 9 | 560.2 | 0.0 | 69.4 | 629.6 | 155.3 | 23.1 | 178.4 | 23.4 | 0.0 | 4.2 | 182.7 | 381.8 | 0.0 | 65.2 | 447.0 | .319 | 0.000 | .061 |
| 10 | 648.4 | 0.0 | 73.3 | 721.7 | 50.0 | 23.4 | 73.4 | 39.5 | 0.0 | 1.8 | 75.2 | 575.0 | 0.0 | 71.5 | 646.5 | .113 | 0.000 | .025 |
| 11 | 558.7 | 0.0 | 85.7 | 644.4 | 25.0 | 48.7 | 73.7 | 42.7 | 0.0 | 3.3 | 77.0 | 485.0 | 0.0 | 82.4 | 567.4 | .132 | 0.000 | .038 |
| 12 | 498.0 | 0.0 | 74.6 | 572.6 | 55.0 | 7.0 | 62.0 | 36.9 | 0.0 | 2.8 | 64.8 | 436.0 | 0.0 | 71.8 | 507.8 | .124 | 0.000 | .038 |
| 13 | 589.0 | 0.0 | 73.3 | 662.3 | 63.0 | 35.0 | 98.0 | 51.7 | 0.0 | 2.9 | 100.9 | 491.0 | 0.0 | 70.3 | 561.3 | .166 | 0.000 | .040 |
| 14 | 769.5 | 0.0 | 86.5 | 856.0 | 139.0 | 59.5 | 198.5 | 58.5 | 0.0 | 3.5 | 202.0 | 571.0 | 0.0 | 83.0 | 654.0 | .258 | 0.000 | .040 |
| 15 | | | | | | | | | | | | | | | | | | |
| 16 | 425.7 | 0.0 | 68.2 | 493.9 | 328.5 | 48.2 | 376.7 | 40.8 | 0.0 | 15.2 | 391.9 | 49.0 | 0.0 | 53.0 | 102.0 | .885 | 0.000 | .223 |
| 17 | 445.3 | 0.0 | 87.9 | 533.3 | 180.7 | 31.9 | 212.7 | 20.4 | 0.0 | 27.5 | 240.2 | 232.7 | 0.0 | 60.4 | 293.1 | .478 | 0.000 | .313 |
| 18 | 331.8 | 0.0 | 92.2 | 424.0 | 122.8 | 18.0 | 140.7 | 10.3 | 0.0 | 11.9 | 152.6 | 191.0 | 0.0 | 80.3 | 271.3 | .424 | 0.000 | .129 |
| 19 | 372.0 | 0.0 | 110.5 | 482.5 | 127.8 | 38.5 | 166.3 | 20.7 | 0.0 | 50.0 | 216.3 | 205.7 | 0.0 | 60.5 | 266.2 | .447 | 0.000 | .452 |
| 20 | 508.6 | 0.0 | 79.8 | 588.4 | 279.5 | 43.1 | 322.5 | 31.9 | 0.0 | 41.0 | 363.5 | 186.0 | 0.0 | 38.8 | 224.8 | .634 | 0.000 | .514 |
| 21 | 501.9 | 0.0 | 84.5 | 586.4 | 266.7 | 48.1 | 314.7 | 41.4 | 0.0 | 40.0 | 354.7 | 187.1 | 0.0 | 44.5 | 231.6 | .627 | 0.000 | .473 |
| 22 | 517.5 | 0.0 | 70.5 | 588.0 | 203.4 | 67.5 | 270.9 | 27.0 | 0.0 | 13.6 | 284.5 | 246.6 | 0.0 | 56.9 | 303.5 | .524 | 0.000 | .193 |
| 23 | 605.2 | 0.0 | 87.5 | 692.7 | 237.7 | 61.4 | 299.0 | 20.5 | 0.0 | 17.1 | 316.1 | 306.1 | 0.0 | 70.4 | 376.5 | .494 | 0.000 | .195 |
| 24 | 399.7 | 0.0 | 75.4 | 475.1 | 95.0 | 51.9 | 146.9 | 31.2 | 0.0 | 4.0 | 150.9 | 252.8 | 0.0 | 71.4 | 324.2 | .368 | 0.000 | .053 |
| 25 | 349.9 | 0.0 | 78.2 | 428.1 | 0.0 | 71.6 | 71.6 | 49.6 | 0.0 | 0.0 | 71.6 | 278.3 | 0.0 | 78.2 | 356.5 | .205 | 0.000 | 0.000 |
| 26 | 517.1 | 0.0 | 107.8 | 624.9 | 148.0 | 28.1 | 176.0 | 36.5 | 0.0 | 28.1 | 204.1 | 341.0 | 0.0 | 79.7 | 420.7 | .340 | 0.000 | .261 |
| 27 | 713.3 | 0.0 | 83.3 | 796.6 | 283.9 | 61.4 | 345.3 | 29.0 | 0.0 | 31.4 | 376.7 | 368.0 | 0.0 | 51.9 | 419.9 | .484 | 0.000 | .377 |
| 28 | 733.1 | 0.0 | 86.7 | 819.8 | 310.8 | 56.2 | 367.0 | 27.8 | 0.0 | 31.5 | 398.5 | 366.1 | 0.0 | 55.2 | 421.3 | .501 | 0.000 | .363 |
| 29 | 574.3 | 0.0 | 78.1 | 652.4 | 169.4 | 20.0 | 189.4 | 9.2 | 0.0 | 10.0 | 199.4 | 384.9 | 0.0 | 68.1 | 453.0 | .330 | 0.000 | .128 |
| 30 | | | | | | | | | | | | | | | | | | |
| 31 | | | | | | | | | | | | | | | | | | |
| TOTAL | 15907. | 0. | 2361. | 18268. | 4089. | 935. | 5023. | 825. | 0. | 456. | 5479. | 10884. | 0. | 1905. | 12789. | .316 | 0.000 | .193 |
| DAILY | 568.1 | 0.0 | 84.3 | 652.4 | 146.0 | 33.4 | 179.4 | 29.5 | 0.0 | 16.3 | 195.7 | 388.7 | 0.0 | 68.0 | 456.8 | .316 | 0.000 | .193 |
| *MONTH | 17612. | 0. | 2614. | 20226. | 4527. | 1035. | 5561. | 913. | 0. | 505. | 6066. | 12050. | 0. | 2109. | 14160. | .316 | 0.000 | .193 |

ALL DATA IN MEGAJOULES
* BASED ON 54.2 SQ.M COLLECTOR AREA

Table C-3H (continued)

| DAY | ----- N601 TOTAL | ---COLLECTOR PERFORMANCE--- S006 TOTAL SOLAR* | S008 SOLAR* WHEN COLLECTING | Q111 HEAT DELIVERED | N100 AVERAGE EFFICIENCY | -CHILLER PERFORMANCE- Q502 TOTAL OUTPUT | Q541 SOLAR OUTPUT | N502 FRACTION BY SOLAR | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | .014 | 1393.2 | 26.7 | -.8 | -.001 | 0.0 | 0.0 | 0.000 | 2.0 |
| 2 | .015 | 498.3 | 5.5 | 1.3 | .003 | 0.0 | 0.0 | 0.000 | 2.1 |
| 3 | .007 | 542.0 | 206.1 | 35.5 | .065 | 0.0 | 0.0 | 0.000 | 1.9 |
| 4 | .010 | 774.8 | 341.9 | 94.0 | .121 | 0.0 | 0.0 | 0.000 | 2.3 |
| 5 | .346 | 1143.4 | 812.4 | 279.2 | .244 | 0.0 | 0.0 | 0.000 | 4.1 |
| 6 | .133 | 487.4 | 217.0 | 49.3 | .101 | 0.0 | 0.0 | 0.000 | 3.2 |
| 7 | .393 | 1327.7 | 1073.1 | 423.5 | .319 | 0.0 | 0.0 | 0.000 | 4.5 |
| 8 | .401 | 1333.8 | 1057.3 | 435.9 | .327 | 0.0 | 0.0 | 0.000 | 4.1 |
| 9 | .290 | 460.8 | 276.5 | 62.6 | .136 | 0.0 | 0.0 | 0.000 | 3.6 |
| 10 | .104 | 1051.3 | 948.2 | 302.1 | .287 | 0.0 | 0.0 | 0.000 | 2.2 |
| 11 | .120 | 309.2 | 162.5 | 18.2 | .059 | 0.0 | 0.0 | 0.000 | 2.1 |
| 12 | .113 | 298.3 | 124.9 | 15.6 | .052 | 0.0 | 0.0 | 0.000 | 2.0 |
| 13 | .152 | 1181.0 | 845.1 | 309.8 | .262 | 0.0 | 0.0 | 0.000 | 2.3 |
| 14 | .236 | 980.9 | 759.0 | 233.2 | .238 | 0.0 | 0.0 | 0.000 | 2.3 |
| 15 | | | | | | | | | |
| 16 | .793 | 379.5 | 76.4 | 29.6 | .078 | 0.0 | 0.0 | 0.000 | 14.2 |
| 17 | .450 | 759.0 | 526.2 | 206.0 | .271 | 0.0 | 0.0 | 0.000 | 3.9 |
| 18 | .360 | 335.9 | 146.7 | 63.5 | .189 | 0.0 | 0.0 | 0.000 | 16.0 |
| 19 | .448 | 1219.8 | 965.2 | 429.2 | .352 | 0.0 | 0.0 | 0.000 | 4.2 |
| 20 | .618 | 1349.5 | 1079.1 | 454.2 | .337 | 0.0 | 0.0 | 0.000 | 28.6 |
| 21 | .605 | 1105.8 | 802.7 | 345.0 | .312 | 0.0 | 0.0 | 0.000 | 3.6 |
| 22 | .484 | 395.3 | 129.7 | 47.9 | .121 | 0.0 | 0.0 | 0.000 | 3.9 |
| 23 | .456 | 1235.6 | 877.9 | 365.8 | .296 | 0.0 | 0.0 | 0.000 | 5.3 |
| 24 | .318 | 1230.7 | 948.2 | 373.4 | .303 | 0.0 | 0.0 | 0.000 | 3.5 |
| 25 | .167 | 325.0 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.000 | 2.0 |
| 26 | .327 | 877.9 | 276.5 | 37.5 | .043 | 0.0 | 0.0 | 0.000 | 3.5 |
| 27 | .473 | 1452.6 | 1224.7 | 483.6 | .333 | 0.0 | 0.0 | 0.000 | 5.3 |
| 28 | .486 | 1208.9 | 976.1 | 365.1 | .302 | 0.0 | 0.0 | 0.000 | 5.5 |
| 29 | .306 | 243.7 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.000 | 5.1 |
| 30 | | | | | | | | | |
| 31 | | | | | | | | | |
| TOTAL | .300 | 23901. | 14886. | 5460. | .228 | 0.0 | 0.0 | 0.000 | 143.3 |
| DAILY | .300 | 853.6 | 531.6 | 195.0 | .228 | 0.0 | 0.0 | 0.000 | 5.1 |
| MONTH | .300 | 26462. | 16480. | 6045. | .228 | 0.0 | 0.0 | 0.000 | 158.7 |

ALL DATA IN MEGAJOULES
*BASED ON 54.2 SQ. M COLLECTOR AREA

# Table C-4H. CSU Solar House I System Performance for Month of February, 1979

| DAY | ENERGY REQUIRED | | | | SOLAR ENERGY USED | | | | | | | AUXILIARY ENERGY USED | | | | SOLAR FRACTION | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q610 SPACE HEAT-ING | Q512 SPACE COOL-ING | Q312 HOT WATER HEAT-ING | Q606 TOTAL | Q402 SPACE HEAT-ING | Q604C ACTUAL STORAGE LOSSES | Q611 TOTAL USEFUL HEAT-ING | Q604E STORAGE LOSSES ESTI-MATED | Q540 SPACE COOL-ING | Q313 HOT WATER HEAT-ING | Q612 TOTAL USEFUL ENERGY | Q442 SPACE HEAT-ING | Q501 SPACE COOL-ING | Q301 HOT WATER HEAT-ING | Q601 TOTAL | N401 SPACE HEAT-ING | N501 SPACE COOL-ING | N301 HOT WATER HEAT-ING |
| 1 | | | | | | | | | | | | | | | | | | |
| 2 | 537.6 | 0.0 | 78.5 | 616.1 | 217.4 | 53.2 | 270.6 | 37.7 | 0.0 | 24.7 | 295.3 | 267.0 | 0.0 | 53.8 | 320.8 | .503 | 0.000 | .315 |
| 3 | 802.2 | 0.0 | 96.0 | 898.2 | 350.0 | 7.2 | 357.1 | 25.7 | 0.0 | 50.2 | 407.3 | 445.0 | 0.0 | 45.8 | 490.8 | .445 | 0.000 | .523 |
| 4 | 631.8 | 0.0 | 68.9 | 700.7 | 396.6 | 16.8 | 413.4 | 26.3 | 0.0 | 26.9 | 440.3 | 218.0 | 0.0 | 42.0 | 260.0 | .654 | 0.000 | .390 |
| 5 | 575.8 | 0.0 | 99.0 | 674.8 | 284.2 | 26.8 | 311.0 | 27.3 | 0.0 | 42.9 | 353.9 | 265.0 | 0.0 | 56.1 | 321.1 | .540 | 0.000 | .433 |
| 6 | 322.9 | 0.0 | 106.6 | 429.5 | 203.5 | 24.9 | 228.4 | 47.8 | 0.0 | 50.2 | 278.6 | 94.0 | 0.0 | 56.4 | 150.4 | .707 | 0.000 | .471 |
| 7 | 410.5 | 0.0 | 85.1 | 495.6 | 263.5 | 49.5 | 312.9 | 40.4 | 0.0 | 28.2 | 341.1 | 97.0 | 0.0 | 56.9 | 153.9 | .762 | 0.000 | .331 |
| 8 | 440.9 | 0.0 | 86.5 | 527.4 | 230.4 | 58.9 | 289.3 | 43.4 | 0.0 | 35.7 | 325.0 | 152.0 | 0.0 | 50.8 | 202.8 | .656 | 0.000 | .413 |
| 9 | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | | | | |
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| 16 | | | | | | | | | | | | | | | | | | |
| 17 | | | | | | | | | | | | | | | | | | |
| 18 | | | | | | | | | | | | | | | | | | |
| 19 | 305.3 | 0.0 | 83.3 | 388.6 | 191.0 | 88.3 | 279.3 | 62.0 | 0.0 | 38.6 | 317.9 | 26.0 | 0.0 | 44.7 | 70.7 | .915 | 0.000 | .453 |
| 20 | 291.7 | 0.0 | 130.8 | 422.5 | 195.1 | 57.7 | 252.8 | 62.6 | 0.0 | 40.0 | 292.8 | 39.0 | 0.0 | 90.8 | 129.8 | .867 | 0.000 | .306 |
| 21 | | | | | | | | | | | | | | | | | | |
| 22 | | | | | | | | | | | | | | | | | | |
| 23 | 432.1 | 0.0 | 126.7 | 558.8 | 275.3 | 54.1 | 329.4 | 44.0 | 0.0 | 8.6 | 338.0 | 103.0 | 0.0 | 118.1 | 221.1 | .762 | 0.000 | .068 |
| 24 | 519.6 | 0.0 | 124.5 | 644.1 | 246.0 | 25.6 | 271.6 | 30.1 | 0.0 | 11.9 | 283.5 | 248.0 | 0.0 | 112.6 | 360.6 | .523 | 0.000 | .096 |
| 25 | 370.7 | 0.0 | 111.8 | 482.5 | 248.2 | 41.7 | 289.9 | 35.0 | 0.0 | 8.2 | 298.1 | 81.0 | 0.0 | 103.6 | 184.6 | .782 | 0.000 | .073 |
| 26 | 307.4 | 0.0 | 140.8 | 448.2 | 90.9 | 31.4 | 122.3 | 31.1 | 0.0 | 5.3 | 127.6 | 185.0 | 0.0 | 135.5 | 320.5 | .398 | 0.000 | .038 |
| 27 | 355.8 | 0.0 | 123.4 | 479.2 | 143.5 | 26.8 | 170.3 | 24.3 | 0.0 | 8.3 | 178.6 | 185.0 | 0.0 | 115.1 | 300.1 | .479 | 0.000 | .067 |
| 28 | 496.6 | 0.0 | 122.1 | 618.5 | 133.4 | 40.4 | 173.8 | 32.9 | 0.0 | 6.7 | 180.5 | 323.0 | 0.0 | 115.4 | 438.4 | .350 | 0.000 | .055 |
| TOTAL | 5801. | 0. | 1584. | 8385. | 3469. | 603. | 4072. | 571. | 0. | 386. | 4459. | 2728. | 0. | 1198. | 3925. | .599 | 0.000 | .244 |
| DAILY | 453.4 | 0.0 | 105.6 | 559.0 | 231.3 | 40.2 | 271.5 | 38.0 | 0.0 | 25.8 | 297.2 | 181.9 | 0.0 | 79.8 | 261.7 | .599 | 0.000 | .244 |
| MONTH | 12695. | 0. | 2957. | 15651. | 6475. | 1126. | 7601. | 1065. | 0. | 721. | 8323. | 5092. | 0. | 2236. | 7328. | .599 | 0.000 | .244 |

All data in megajoules
*Based on 54.2 Sq. M. collector area

Table C-4H (continued)

| DAY | -----<br>N601<br>TOTAL | ---COLLECTOR PERFORMANCE---<br>S006<br>TOTAL SOLAR* | S008<br>SOLAR* WHEN COLLECTING | Q111<br>HEAT DELIVERED | N100<br>AVERAGE EFFICIENCY | -CHILLER PERFORMANCE-<br>Q502<br>TOTAL OUTPUT | Q541<br>SOLAR OUTPUT | N502<br>FRACTION BY SOLAR | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | |
| 2 | .479 | 802.7 | 671.7 | 203.1 | .253 | 0.0 | 0.0 | 0.000 | 9.8 |
| 3 | .454 | 1490.2 | 1360.5 | 511.7 | .343 | 0.0 | 0.0 | 0.000 | 0.0 |
| 4 | .628 | 1165.2 | 996.7 | 349.0 | .299 | 0.0 | 0.0 | 0.000 | 0.0 |
| 5 | .524 | 1398.0 | 1235.6 | 477.4 | .341 | 0.0 | 0.0 | 0.000 | 0.0 |
| 6 | .649 | 1235.5 | 1138.6 | 402.0 | .325 | 0.0 | 0.0 | 0.000 | 0.0 |
| 7 | .688 | 894.8 | 748.1 | 248.9 | .278 | 0.0 | 0.0 | 0.000 | 0.0 |
| 8 | .616 | 1430.8 | 1121.6 | 366.1 | .256 | 0.0 | 0.0 | 0.000 | .1 |
| 9 | | | | | | | | | |
| 10 | | | | | | | | | |
| 11 | | | | | | | | | |
| 12 | | | | | | | | | |
| 13 | | | | | | | | | |
| 14 | | | | | | | | | |
| 15 | | | | | | | | | |
| 16 | | | | | | | | | |
| 17 | | | | | | | | | |
| 18 | | | | | | | | | |
| 19 | .818 | 1284.1 | 1187.1 | 353.5 | .275 | 0.0 | 0.0 | 0.000 | .3 |
| 20 | .693 | 1425.9 | 1316.8 | 473.4 | .332 | 0.0 | 0.0 | 0.000 | .8 |
| 21 | | | | | | | | | |
| 22 | | | | | | | | | |
| 23 | .605 | 515.3 | 16.4 | -.2 | -.000 | 0.0 | 0.0 | 0.000 | 0.0 |
| 24 | .440 | 1376.2 | 1295.0 | 456.1 | .331 | 0.0 | 0.0 | 0.000 | 0.0 |
| 25 | .618 | 888.8 | 770.0 | 232.2 | .261 | 0.0 | 0.0 | 0.000 | 0.0 |
| 26 | .285 | 601.4 | 460.8 | 160.9 | .268 | 0.0 | 0.0 | 0.000 | .2 |
| 27 | .373 | 390.4 | 260.7 | 60.1 | .154 | 0.0 | 0.0 | 0.000 | 0.0 |
| 28 | .292 | 1241.6 | 1094.9 | 419.4 | .338 | 0.0 | 0.0 | 0.000 | 0.0 |
| TOTAL | .532 | 16141. | 13674. | 4713. | .292 | 0.0 | 0.0 | 0.000 | 11.2 |
| DAILY | .532 | 1076.1 | 911.6 | 314.2 | .292 | 0.0 | 0.0 | 0.000 | .7 |
| MONTH | .532 | 30130. | 25525. | 8798. | .292 | 0.0 | 0.0 | 0.000 | 20.9 |

ALL DATA IN MEGAJOULES
*BASED ON 54.2 SQ. M COLLECTOR AREA

Table C-5H. CSU Solar House I System Performance for Month of March, 1979

| DAY | ENERGY REQUIRED: Q610 SPACE HEATING | Q512 SPACE COOLING | Q312 HOT WATER HEATING | Q606 TOTAL | SOLAR ENERGY USED: Q402 SPACE HEATING | Q604C ACTUAL STORAGE LOSSES | Q611 TOTAL USEFUL HEATING | Q604E STORAGE LOSSES ESTIMATED | Q540 SPACE COOLING | Q313 HOT WATER HEATING | Q612 TOTAL USEFUL ENERGY | AUXILIARY ENERGY USED: Q442 SPACE HEATING | Q501 SPACE COOLING | Q301 HOT WATER HEATING | Q601 TOTAL | SOLAR FRACTION: N401 SPACE HEATING | N501 SPACE COOLING | N301 HOT WATER HEATING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 276.4 | 0.0 | 6.2 | 282.6 | 135.2 | 70.9 | 206.1 | 52.7 | 0.0 | 6.2 | 212.3 | 70.3 | 0.0 | 0.0 | 70.3 | .746 | 0.000 | 1.000 |
| 2 | 326.6 | 0.0 | 0.0 | 326.6 | 161.0 | 78.0 | 239.0 | 47.6 | 0.0 | 0.0 | 239.0 | 87.6 | 0.0 | 0.0 | 87.6 | .732 | 0.000 | 0.000 |
| 3 | 373.0 | 0.0 | 8.3 | 381.3 | 221.0 | 40.1 | 261.1 | 40.2 | 0.0 | 8.3 | 269.4 | 111.9 | 0.0 | 0.0 | 111.9 | .700 | 0.000 | 1.000 |
| 4 | 438.6 | 0.0 | 29.9 | 467.5 | 289.9 | 57.3 | 347.2 | 47.9 | 0.0 | 28.9 | 376.1 | 91.4 | 0.0 | 0.0 | 91.4 | .792 | 0.000 | 1.000 |
| 5 | 278.1 | 0.0 | 0.0 | 278.1 | 152.2 | 72.3 | 224.4 | 62.9 | 0.0 | 0.0 | 224.4 | 53.6 | 0.0 | 0.0 | 53.6 | .807 | 0.000 | 0.000 |
| 6 | 240.0 | 0.0 | 6.4 | 246.4 | 174.6 | 60.5 | 235.1 | 60.7 | 0.0 | 6.4 | 241.5 | 5.0 | 0.0 | 0.0 | 5.0 | .980 | 0.000 | 1.000 |
| 7 | | | | | | | | | | | | | | | | | | |
| 8 | 232.8 | 0.0 | 0.0 | 232.8 | 179.0 | 47.3 | 226.3 | 74.5 | 0.0 | 0.0 | 226.3 | 6.5 | 0.0 | 0.0 | 6.5 | .972 | 0.000 | 0.000 |
| 9 | 496.9 | 0.0 | 0.0 | 496.9 | 229.5 | 56.1 | 285.6 | 47.1 | 0.0 | 0.0 | 285.6 | 211.3 | 0.0 | 0.0 | 211.3 | .575 | 0.000 | 0.000 |
| 10 | 530.5 | 0.0 | 9.6 | 540.1 | 261.4 | 54.5 | 315.9 | 47.2 | 0.0 | 9.6 | 325.5 | 214.6 | 0.0 | 0.0 | 214.6 | .595 | 0.000 | 1.000 |
| 11 | 254.0 | 0.0 | 9.6 | 263.6 | 162.6 | 83.8 | 246.5 | 62.1 | 0.0 | 9.6 | 256.1 | 7.6 | 0.0 | 0.0 | 7.6 | .970 | 0.000 | 1.000 |
| 12 | | | | | | | | | | | | | | | | | | |
| 13 | | | | | | | | | | | | | | | | | | |
| 14 | | | | | | | | | | | | | | | | | | |
| TOTAL | 3447. | 0. | 69. | 3516. | 1966. | 621. | 2587. | 543. | 0. | 69. | 2656. | 860. | 0. | 0. | 860. | .751 | 0.000 | 1.000 |
| DAILY | 344.7 | 0.0 | 6.9 | 351.6 | 196.6 | 62.1 | 258.7 | 54.3 | 0.0 | 6.9 | 265.6 | 86.0 | 0.0 | 0.0 | 86.0 | .751 | 0.000 | 1.000 |
| MONTH | 4825. | 0. | 97. | 4922. | 2753. | 869. | 3622. | 760. | 0. | 97. | 3719. | 1204. | 0. | 0. | 1204. | .751 | 0.000 | 1.000 |

All data in megajoules
*Based on 54.2 Sq. M. collector area

Table C-5H (continued)

| DAY | ----- | ---COLLECTOR PERFORMANCE--- | | | | -CHILLER PERFORMANCE- | | | |
|---|---|---|---|---|---|---|---|---|---|
| | N601 TOTAL | S006 TOTAL SOLAR* | S008 SOLAR* WHEN COLLECTING | Q111 HEAT DELIVERED | N100 AVERAGE EFFICIENCY | Q502 TOTAL OUTPUT | Q541 SOLAR OUTPUT | N502 FRACTION BY SOLAR | |
| 1 | .751 | 1325.5 | 1208.4 | 354.0 | .267 | 0.0 | 0.0 | 0.000 | .2 |
| 2 | .732 | 387.2 | 218.1 | 24.2 | .062 | 0.0 | 0.0 | 0.000 | 0.0 |
| 3 | .707 | 1430.3 | 1183.7 | 345.7 | .242 | 0.0 | 0.0 | 0.000 | 0.0 |
| 4 | .805 | 1769.4 | 1584.4 | 503.2 | .284 | 0.0 | 0.0 | 0.000 | 0.0 |
| 5 | .807 | 1382.2 | 1208.6 | 426.6 | .309 | 0.0 | 0.0 | 0.000 | 0.0 |
| 6 | .980 | 655.9 | 10.2 | 91.2 | .139 | 0.0 | 0.0 | 0.000 | 0.0 |
| 7 | | | | | | | | | |
| 8 | .972 | 106.6 | 0.0 | 0.0 | 0.000 | 0.0 | 0.0 | 0.000 | 2.8 |
| 9 | .575 | 1200.3 | 944.8 | 192.2 | .160 | 0.0 | 0.0 | 0.000 | .2 |
| 10 | .603 | 1588.0 | 1443.6 | 501.9 | .316 | 0.0 | 0.0 | 0.000 | 0.0 |
| 11 | .971 | 1577.3 | 1443.0 | 495.4 | .314 | 0.0 | 0.0 | 0.000 | .2 |
| 12 | | | | | | | | | |
| 13 | | | | | | | | | |
| 14 | | | | | | | | | |
| TOTAL | .755 | 11423. | 9245. | 2934. | .257 | 0.0 | 0.0 | 0.000 | 3.4 |
| DAILY | .755 | 1142.3 | 924.5 | 293.4 | .257 | 0.0 | 0.0 | 0.000 | .3 |
| MONTH | .755 | 15992. | 12943. | 4108. | .257 | 0.0 | 0.0 | 0.000 | 4.8 |

ALL DATA IN MEGAJOULES
*BASED ON 54.2 SQ. M COLLECTOR AREA

## Table C-1C. CSU Solar House I System Performance for Month of July, 1979

| DAY | Q610 SPACE HEATING | Q512 SPACE COOLING | Q312 HOT WATER HEATING | Q606 TOTAL | Q402 SPACE HEATING | Q604C ACTUAL STORAGE LOSSES | Q611 TOTAL USEFUL HEATING | Q604E STORAGE LOSSES ESTIMATED | Q540 SPACE COOLING | Q313 HOT WATER HEATING | Q612 TOTAL USEFUL ENERGY | Q442 SPACE HEATING | Q501 SPACE COOLING | Q301 HOT WATER HEATING | Q601 TOTAL | N401 SPACE HEATING | N501 SPACE COOLING | N301 HOT WATER HEATING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ENERGY REQUIRED | | | | SOLAR ENERGY USED | | | | | | | AUXILIARY ENERGY USED | | | | SOLAR FRACTION | | |
| 1 | 0.0 | 0.0 | 1.4 | 1.4 | 0.0 | 107.3 | 0.0 | 26.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.4 | 1.4 | 0.000 | 0.000 | 0.000 |
| 2 | 0.0 | 0.0 | 3.9 | 3.9 | 0.0 | 49.7 | 0.0 | 27.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 3.9 | 3.9 | 0.000 | 0.000 | 0.000 |
| 3 | 0.0 | -7.1 | 4.0 | -3.1 | 0.0 | 50.6 | 0.0 | 29.3 | 7.1 | 0.0 | 7.1 | 0.0 | 0.0 | 4.0 | 4.0 | 0.000 | -1.001 | 0.000 |
| 4 | 0.0 | 0.0 | .9 | .9 | 0.0 | 129.9 | 0.0 | 42.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | .9 | .9 | 0.000 | 0.000 | 0.000 |
| 5 | 0.0 | -.7 | 8.9 | 8.2 | 0.0 | 150.0 | 0.0 | 37.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.9 | 8.9 | 0.000 | 0.000 | 0.000 |
| 6 | 0.0 | 102.4 | 40.4 | 142.8 | 0.0 | 155.1 | 0.0 | 86.5 | 196.0 | 25.7 | 221.7 | 0.0 | 0.0 | 14.7 | 14.7 | 0.000 | 1.914 | .636 |
| 7 | 0.0 | 105.0 | 21.4 | 126.4 | 0.0 | 152.4 | 0.0 | 38.4 | 105.0 | 0.0 | 105.0 | 0.0 | 0.0 | 21.4 | 21.4 | 0.000 | 1.000 | 0.000 |
| 8 | 0.0 | 0.0 | 1.0 | 1.0 | 0.0 | 171.8 | 0.0 | 41.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 1.0 | 0.000 | 0.000 | 0.000 |
| 9 | 0.0 | 235.2 | 55.5 | 291.6 | 0.0 | 155.7 | 0.0 | 43.2 | 236.2 | 50.7 | 286.9 | 0.0 | 0.0 | 4.8 | 4.8 | 0.000 | 1.000 | .914 |
| 10 | 0.0 | 345.5 | 10.5 | 356.1 | 0.0 | 48.2 | 0.0 | 27.3 | 345.5 | 3.6 | 349.1 | 0.0 | 0.0 | 7.0 | 7.0 | 0.000 | 1.000 | .341 |
| 11 | 0.0 | 340.7 | 5.5 | 346.2 | 0.0 | 37.0 | 0.0 | 24.0 | 340.7 | 2.5 | 343.2 | 0.0 | 0.0 | 3.0 | 3.0 | 0.000 | 1.000 | .457 |
| 12 | 0.0 | 266.7 | 4.0 | 270.7 | 0.0 | 55.2 | 0.0 | 30.3 | 266.7 | 1.1 | 267.8 | 0.0 | 0.0 | 2.9 | 2.9 | 0.000 | 1.000 | .275 |
| 13 | 0.0 | 70.9 | 17.6 | 88.5 | 0.0 | 39.5 | 0.0 | 40.4 | 70.9 | 2.6 | 73.5 | 0.0 | 0.0 | 15.0 | 15.0 | 0.000 | 1.000 | .148 |
| 14 | 0.0 | 582.1 | 10.5 | 592.6 | 0.0 | 10.0 | 0.0 | 43.1 | 582.1 | .5 | 582.6 | 0.0 | 0.0 | 10.1 | 10.1 | 0.000 | 1.000 | .048 |
| 15 | 0.0 | 296.6 | 17.0 | 313.6 | 0.0 | 59.8 | 0.0 | 39.4 | 296.6 | .8 | 297.4 | 0.0 | 0.0 | 16.2 | 16.2 | 0.000 | 1.000 | .047 |
| 16 | 0.0 | 13.1 | 28.6 | 41.7 | 0.0 | 74.0 | 0.0 | 27.7 | .5 | 19.2 | 19.7 | 0.0 | 12.6 | 9.4 | 22.0 | 0.000 | .037 | .672 |
| 17 | 0.0 | 23.3 | 30.3 | 53.6 | 0.0 | 54.4 | 0.0 | 36.3 | .1 | 21.0 | 21.1 | 0.0 | 23.2 | 9.3 | 32.5 | 0.000 | .004 | .693 |
| 18 | 0.0 | 294.5 | 23.0 | 317.5 | 0.0 | 48.9 | 0.0 | 38.0 | 280.3 | 12.0 | 292.2 | 0.0 | 14.3 | 11.0 | 25.3 | 0.000 | .951 | .520 |
| 19 | 0.0 | 411.1 | 44.1 | 455.2 | 0.0 | 57.1 | 0.0 | 38.0 | 228.0 | 29.5 | 257.5 | 0.0 | 183.1 | 14.6 | 197.7 | 0.000 | .555 | .669 |
| 20 | 0.0 | 328.5 | 48.8 | 377.5 | 0.0 | 78.1 | 0.0 | 38.0 | .2 | 30.4 | 30.6 | 0.0 | 328.4 | 18.4 | 346.8 | 0.000 | .001 | .623 |
| 21 | 0.0 | 254.3 | 48.3 | 303.1 | 0.0 | 64.2 | 0.0 | 39.3 | 254.3 | 28.3 | 282.7 | 0.0 | .5 | 20.0 | 20.4 | 0.000 | .998 | .587 |
| 22 | 0.0 | 525.1 | 37.5 | 563.7 | 0.0 | 67.3 | 0.0 | 40.3 | 54.8 | 33.6 | 88.4 | 0.0 | 471.2 | 4.1 | 475.3 | 0.000 | .104 | .892 |
| 23 | 0.0 | 562.5 | 34.3 | 596.9 | 0.0 | 52.8 | 0.0 | 40.5 | 287.5 | 31.4 | 318.9 | 0.0 | 275.1 | 2.9 | 278.0 | 0.000 | .511 | .915 |
| 24 | 0.0 | 369.9 | 32.7 | 402.6 | 0.0 | 58.2 | 0.0 | 28.0 | 326.7 | 30.4 | 357.1 | 0.0 | 43.2 | 2.3 | 45.5 | 0.000 | .883 | .930 |
| 25 | 0.0 | 377.3 | 34.5 | 411.8 | 0.0 | 73.8 | 0.0 | 61.0 | 176.7 | 31.6 | 208.2 | 0.0 | 200.7 | 2.9 | 203.6 | 0.000 | .468 | .915 |
| 26 | 0.0 | 294.4 | 37.7 | 332.6 | 0.0 | 53.6 | 0.0 | 37.1 | 122.9 | 32.2 | 155.1 | 0.0 | 171.9 | 5.5 | 177.4 | 0.000 | .417 | .854 |
| 27 | 0.0 | 346.3 | 76.9 | 423.2 | 0.0 | 42.8 | 0.0 | 38.1 | 265.6 | 28.6 | 294.2 | 0.0 | 80.7 | 48.3 | 129.0 | 0.000 | .767 | .372 |
| 28 | 0.0 | 325.3 | 40.8 | 366.1 | 0.0 | 56.5 | 0.0 | 37.7 | 225.1 | 32.0 | 258.1 | 0.0 | 99.8 | 8.8 | 108.5 | 0.000 | .694 | .785 |
| 29 | 0.0 | 185.3 | 42.2 | 228.0 | 0.0 | 52.9 | 0.0 | 26.4 | 98.2 | 31.6 | 129.8 | 0.0 | 87.6 | 10.6 | 98.2 | 0.000 | .528 | .749 |
| 30 | 0.0 | 0.0 | 49.5 | 49.5 | 0.0 | 67.5 | 0.0 | 30.6 | 0.0 | 36.5 | 36.5 | 0.0 | 0.0 | 13.1 | 13.1 | 0.000 | 0.000 | .736 |
| 31 | 0.0 | 486.6 | 68.4 | 555.0 | 0.0 | 68.9 | 0.0 | 43.7 | 486.6 | 35.9 | 522.5 | 0.0 | 0.0 | 32.6 | 32.6 | 0.000 | 1.000 | .524 |
| TOTAL | 0. | 7139. | 880. | 8019. | 0. | 2523. | 0. | 1189. | 5255. | 552. | 5807. | 0. | 1992. | 329. | 2321. | 0.000 | .735 | .527 |
| DAILY | 0.0 | 230.3 | 28.4 | 258.7 | 0.0 | 81.4 | 0.0 | 38.3 | 169.5 | 17.8 | 187.3 | 0.0 | 64.3 | 10.6 | 74.9 | 0.000 | .735 | .527 |
| MONTH | 0. | 7139. | 880. | 8019. | 0. | 2523. | 0. | 1189. | 5255. | 552. | 5807. | 0. | 1992. | 329. | 2321. | 0.000 | .735 | .527 |

ALL DATA IN MEGAJOULES
* BASED ON 54.2 SQ.M COLLECTOR AREA

Table C-1C (continued)

| DAY | ----- | ---COLLECTOR PERFORMANCE--- | | | | -CHILLER PERFORMANCE- | | | |
|---|---|---|---|---|---|---|---|---|---|
| | N601 TOTAL | S005 TOTAL SOLAR* | S007 SOLAR* WHEN COLLECTING | Q111 HEAT DELIVERED | N100 AVERAGE EFFICIENCY | Q502 TOTAL OUTPUT | Q541 SOLAR OUTPUT | N502 FRACTION BY SOLAR | E103 + E303 |
| 1 | 0.000 | 1164.3 | 920.2 | 339.3 | .291 | 0.0 | 0.0 | 0.000 | 18.7 |
| 2 | 0.000 | 943.0 | 705.9 | 225.7 | .239 | 0.0 | 0.0 | 0.000 | 16.9 |
| 3 | -2.261 | 1297.0 | 1084.7 | 354.1 | .273 | 0.0 | 0.0 | 0.000 | 16.1 |
| 4 | 0.000 | 1300.4 | 1011.7 | 291.0 | .224 | 0.0 | 0.0 | 0.000 | 16.6 |
| 5 | 0.000 | 1208.6 | 933.2 | 225.1 | .186 | 0.0 | 0.0 | 0.000 | 13.3 |
| 6 | 1.553 | 677.2 | 533.5 | 98.9 | .146 | 84.1 | 84.1 | 1.000 | 11.9 |
| 7 | .831 | 1360.5 | 1122.7 | 434.3 | .319 | 43.6 | 43.6 | 1.000 | 19.2 |
| 8 | 0.000 | 1099.2 | 832.9 | 331.3 | .301 | 0.0 | 0.0 | 1.000 | 14.8 |
| 9 | .984 | 1262.5 | 1026.8 | 394.3 | .312 | 107.5 | 107.5 | 1.000 | 16.7 |
| 10 | .980 | 1238.0 | 1064.6 | 379.6 | .307 | 121.1 | 121.1 | 1.000 | 16.3 |
| 11 | .991 | 1223.4 | 963.5 | 378.6 | .309 | 163.5 | 163.5 | 1.000 | 14.1 |
| 12 | .989 | 1162.5 | 885.1 | 364.8 | .314 | 150.7 | 150.7 | 1.000 | 13.7 |
| 13 | .831 | 1351.0 | 1147.4 | 407.9 | .302 | 28.2 | 28.2 | 1.000 | 17.5 |
| 14 | .983 | 1336.3 | 1122.9 | 382.8 | .286 | 280.2 | 280.2 | 1.000 | 16.1 |
| 15 | .948 | 1170.0 | 927.7 | 313.5 | .268 | 78.2 | 78.2 | 1.000 | 15.0 |
| 16 | .473 | 425.5 | 113.1 | 15.1 | .035 | 1.3 | .1 | .071 | 5.6 |
| 17 | .393 | 828.8 | 539.7 | 186.7 | .225 | 2.6 | 0.0 | 0.000 | 13.2 |
| 18 | .920 | 1186.1 | 968.4 | 347.4 | .293 | 98.5 | 95.1 | .966 | 14.4 |
| 19 | .566 | 1129.5 | 904.3 | 299.9 | .266 | 220.8 | 122.1 | .553 | 16.0 |
| 20 | .081 | 771.4 | 480.8 | 127.7 | .165 | 174.9 | 0.0 | 0.000 | 11.9 |
| 21 | .933 | 1088.1 | 922.4 | 341.8 | .314 | 124.1 | 124.1 | 1.000 | 14.9 |
| 22 | .157 | 826.2 | 622.3 | 158.2 | .191 | 293.9 | 33.7 | .115 | 14.0 |
| 23 | .534 | 1170.1 | 932.4 | 342.7 | .293 | 301.6 | 158.5 | .525 | 17.2 |
| 24 | .887 | 1370.0 | 1158.8 | 447.2 | .326 | 175.5 | 157.5 | .897 | 18.5 |
| 25 | .506 | 928.6 | 698.8 | 215.8 | .232 | 200.6 | 93.2 | .465 | 14.9 |
| 26 | .466 | 961.5 | 717.3 | 250.1 | .260 | 162.0 | 69.2 | .427 | 14.6 |
| 27 | .695 | 1178.8 | 945.8 | 345.0 | .293 | 168.5 | 132.0 | .783 | 17.7 |
| 28 | .704 | 1055.9 | 878.1 | 292.8 | .277 | 167.8 | 120.1 | .715 | 18.1 |
| 29 | .569 | 796.8 | 629.5 | 224.8 | .282 | 91.3 | 48.5 | .532 | 12.4 |
| 30 | .735 | 1131.8 | 816.5 | 307.1 | .271 | -.0 | -.0 | 1.000 | 13.3 |
| 31 | .941 | 1318.6 | 1052.1 | 392.4 | .298 | 188.7 | 188.7 | 1.000 | 15.3 |
| TOTAL | .724 | 33961. | 26663. | 9216. | .271 | 3429.2 | 2399.9 | .700 | 468.9 |
| DAILY | .724 | 1095.5 | 860.1 | 297.3 | .271 | 110.6 | 77.4 | .700 | 15.1 |
| MONTH | .724 | 33961. | 26663. | 9216. | .271 | 3429.2 | 2399.9 | .700 | 468.9 |

ALL DATA IN MEGAJOULES
*BASED ON 54.2 SQ. M COLLECTOR AREA

Table C-2C. CSU Solar House I System Performance for Month of August, 1979

| DAY | ENERGY REQUIRED Q610 SPACE HEATING | Q512 SPACE COOLING | Q312 HOT WATER HEATING | Q606 TOTAL | SOLAR ENERGY USED Q402 SPACE HEATING | Q604C ACTUAL STORAGE LOSSES | Q611 TOTAL USEFUL HEATING | Q604E STORAGE LOSSES ESTIMATED | Q540 SPACE COOLING | Q313 HOT WATER HEATING | Q612 TOTAL USEFUL ENERGY | AUXILIARY ENERGY USED Q442 SPACE HEATING | Q501 SPACE COOLING | Q301 HOT WATER HEATING | Q601 TOTAL | SOLAR FRACTION N401 SPACE HEATING | N501 SPACE COOLING | N301 HOT WATER HEATING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0 | 486.6 | 68.4 | 555.0 | 0.0 | 57.9 | 0.0 | 50.1 | 486.6 | 35.9 | 522.5 | 0.0 | 0.0 | 32.6 | 32.6 | 0.000 | 1.000 | .524 |
| 2 | 0.0 | 480.5 | 50.6 | 531.1 | 0.0 | 48.7 | 0.0 | 44.5 | 407.4 | 32.6 | 439.9 | 0.0 | 73.1 | 18.0 | 91.1 | 0.000 | .844 | .644 |
| 3 | 0.0 | 421.5 | 37.6 | 459.1 | 0.0 | 49.3 | 0.0 | 44.5 | 376.5 | 28.9 | 405.3 | 0.0 | 45.0 | 8.8 | 53.8 | 0.000 | .893 | .757 |
| 4 | 0.0 | 477.8 | 29.1 | 506.9 | 0.0 | 47.8 | 0.0 | 44.3 | 425.4 | 28.2 | 453.6 | 0.0 | 52.4 | .9 | 53.3 | 0.000 | .890 | .958 |
| 5 | 0.0 | 417.0 | 28.0 | 445.0 | 0.0 | 43.6 | 0.0 | 44.3 | 390.6 | 27.8 | 418.4 | 0.0 | 26.4 | .2 | 26.6 | 0.000 | .937 | .992 |
| 6 | 0.0 | 477.2 | 29.9 | 507.1 | 0.0 | 60.4 | 0.0 | 44.1 | 397.9 | 29.1 | 426.9 | 0.0 | 79.3 | .8 | 80.2 | 0.000 | .834 | .972 |
| 7 | 0.0 | 645.4 | 37.4 | 682.7 | 0.0 | 54.7 | 0.0 | 44.1 | 398.7 | 33.9 | 432.6 | 0.0 | 246.7 | 3.5 | 250.1 | 0.000 | .618 | .907 |
| 8 | 0.0 | 358.1 | 32.4 | 390.5 | 0.0 | 45.6 | 0.0 | 42.5 | 194.8 | 26.7 | 221.6 | 0.0 | 163.2 | 5.7 | 168.9 | 0.000 | .544 | .826 |
| 9 | 0.0 | 259.4 | 35.1 | 294.4 | 0.0 | 53.2 | 0.0 | 42.5 | 74.1 | 29.2 | 103.3 | 0.0 | 185.2 | 5.9 | 191.1 | 0.000 | .285 | .833 |
| 10 | 0.0 | 0.0 | 38.0 | 38.0 | 0.0 | 54.5 | 0.0 | 42.3 | 0.0 | 28.8 | 28.8 | 0.0 | 0.0 | 9.2 | 9.2 | 0.000 | 0.000 | .758 |
| 11 | 0.0 | 0.0 | 36.4 | 36.4 | 0.0 | 77.6 | 0.0 | 48.9 | 0.0 | 25.0 | 25.0 | 0.0 | 0.0 | 11.4 | 11.4 | 0.000 | 0.000 | .686 |
| 12 | 0.0 | 52.1 | 46.0 | 98.1 | 0.0 | 83.7 | 0.0 | 54.1 | 52.1 | 33.3 | 85.4 | 0.0 | 0.0 | 12.7 | 12.7 | 0.000 | 1.000 | .724 |
| 13 | 0.0 | 0.0 | 64.6 | 64.6 | 0.0 | 96.1 | 0.0 | 50.7 | 0.0 | 38.4 | 38.4 | 0.0 | 0.0 | 26.2 | 26.2 | 0.000 | 0.000 | .594 |
| 14 | 0.0 | 0.0 | 28.9 | 28.9 | 0.0 | 50.5 | 0.0 | 46.3 | 0.0 | 26.1 | 26.1 | 0.0 | 0.0 | 2.8 | 2.8 | 0.000 | 0.000 | .902 |
| 15 | | | | | | | | | | | | | | | | | | |
| 16 | 0.0 | 105.1 | 40.6 | 145.7 | 0.0 | 60.3 | 0.0 | 46.1 | 104.7 | 33.7 | 138.4 | 0.0 | .4 | 6.9 | 7.3 | 0.000 | .995 | .829 |
| 17 | 0.0 | 132.3 | 32.7 | 165.1 | 0.0 | 90.0 | 0.0 | 50.1 | 132.3 | 31.5 | 163.8 | 0.0 | 0.0 | 1.3 | 1.3 | 0.000 | 1.000 | .951 |
| 18 | 0.0 | 76.7 | 32.3 | 109.0 | 0.0 | 93.4 | 0.0 | 53.1 | 75.9 | 31.5 | 107.5 | 0.0 | .8 | .8 | 1.5 | 0.000 | .990 | .976 |
| 19 | 0.0 | 1.3 | 32.6 | 33.9 | 0.0 | 86.2 | 0.0 | 53.5 | 0.0 | 31.6 | 31.6 | 0.0 | 1.3 | 1.0 | 2.3 | 0.000 | 0.000 | .970 |
| 20 | 0.0 | 1.5 | 40.0 | 41.5 | 0.0 | 73.3 | 0.0 | 52.9 | 0.0 | 34.7 | 34.7 | 0.0 | 1.5 | 5.4 | 6.8 | 0.000 | 0.000 | .856 |
| 21 | 0.0 | 1.4 | 55.1 | 56.5 | 0.0 | 66.4 | 0.0 | 53.2 | 0.0 | 35.5 | 35.5 | 0.0 | 1.4 | 19.6 | 21.0 | 0.000 | 0.000 | .644 |
| 22 | 0.0 | 231.0 | 40.9 | 271.9 | 0.0 | 77.2 | 0.0 | 54.3 | 229.6 | 34.0 | 263.6 | 0.0 | 1.4 | 6.8 | 8.3 | 0.000 | .994 | .833 |
| 23 | 0.0 | 260.2 | 45.4 | 305.5 | 0.0 | 79.4 | 0.0 | 53.1 | 259.3 | 43.6 | 302.8 | 0.0 | .9 | 1.8 | 2.7 | 0.000 | .997 | .960 |
| 24 | 0.0 | 313.9 | 37.1 | 351.0 | 0.0 | 84.1 | 0.0 | 47.2 | 304.0 | 36.5 | 340.5 | 0.0 | 9.9 | .7 | 10.6 | 0.000 | .968 | .982 |
| 25 | 0.0 | .8 | 29.2 | 30.0 | 0.0 | 34.3 | 0.0 | 46.3 | 0.0 | 28.5 | 28.5 | 0.0 | .8 | .7 | 1.5 | 0.000 | 0.000 | .977 |
| 26 | 0.0 | .8 | 31.0 | 31.8 | 0.0 | 75.0 | 0.0 | 51.5 | 0.0 | 30.3 | 30.3 | 0.0 | .8 | .7 | 1.4 | 0.000 | 0.000 | .978 |
| 27 | | | | | | | | | | | | | | | | | | |
| 28 | | | | | | | | | | | | | | | | | | |
| 29 | 0.0 | 439.2 | 37.5 | 476.7 | 0.0 | 59.4 | 0.0 | 45.0 | 392.9 | 36.1 | 429.0 | 0.0 | 46.3 | 1.3 | 47.6 | 0.000 | .895 | .954 |
| 30 | 0.0 | 211.4 | 28.5 | 239.9 | 0.0 | 57.9 | 0.0 | 44.3 | 203.9 | 25.5 | 229.4 | 0.0 | 7.5 | 3.0 | 10.5 | 0.000 | .964 | .895 |
| 31 | 0.0 | 342.8 | 31.0 | 373.7 | 0.0 | 44.3 | 0.0 | 45.2 | 342.8 | 29.9 | 372.7 | 0.0 | 0.0 | 1.1 | 1.1 | 0.000 | 1.000 | .966 |
| TOTAL | 0. | 6194. | 1076. | 7270. | 0. | 1815. | 0. | 1341. | 5249. | 886. | 6136. | 0. | 944. | 190. | 1134. | 0.000 | .846 | .824 |
| DAILY | 0.0 | 221.2 | 38.4 | 259.6 | 0.0 | 64.8 | 0.0 | 47.9 | 187.5 | 31.7 | 219.1 | 0.0 | 33.7 | 6.8 | 40.5 | 0.000 | .848 | .824 |
| MONTH | 0. | 6857. | 1191. | 8049. | 0. | 2010. | 0. | 1484. | 5812. | 981. | 6793. | 0. | 1045. | 210. | 1255. | 0.000 | .843 | .824 |

ALL DATA IN MEGAJOULES
* BASED ON 54.2 SQ.M COLLECTOR AREA

Table C-2C (continued)

| | ----- | ---COLLECTOR PERFORMANCE--- | | | | -CHILLER PERFORMANCE- | | | |
|---|---|---|---|---|---|---|---|---|---|
| DAY | N601 TOTAL | S005 TOTAL SOLAR* | S007 SOLAR* WHEN COLLECTING | Q111 HEAT DELIVERED | N100 AVERAGE EFFICIENCY | Q502 TOTAL OUTPUT | Q541 SOLAR OUTPUT | N502 FRACTION BY SOLAR | E103 + E303 |
| 1 | .941 | 1318.5 | 1052.1 | 392.4 | .298 | 188.7 | 188.7 | 1.000 | 15.3 |
| 2 | .828 | 1385.9 | 1162.2 | 462.0 | .333 | 234.3 | 193.8 | .827 | 17.2 |
| 3 | .883 | 1414.3 | 1214.0 | 480.0 | .339 | 204.7 | 183.3 | .895 | 18.2 |
| 4 | .895 | 1436.5 | 1242.2 | 498.4 | .347 | 206.4 | 182.2 | .883 | 17.6 |
| 5 | .940 | 1442.2 | 1251.2 | 492.5 | .341 | 179.5 | 166.2 | .925 | 18.4 |
| 6 | .842 | 1306.1 | 1087.8 | 444.8 | .341 | 224.8 | 183.1 | .814 | 17.2 |
| 7 | .634 | 1382.6 | 1197.1 | 490.4 | .355 | 339.3 | 202.7 | .597 | 18.0 |
| 8 | .567 | 1028.0 | 811.2 | 302.9 | .295 | 194.6 | 106.8 | .549 | 14.3 |
| 9 | .351 | 655.3 | 425.8 | 137.2 | .209 | 137.7 | 37.2 | .270 | 10.4 |
| 10 | .758 | 670.2 | 441.8 | 112.6 | .168 | -.0 | -.0 | 1.000 | 10.7 |
| 11 | .686 | 1435.8 | 1176.4 | 403.0 | .281 | -.0 | -.0 | 1.000 | 18.4 |
| 12 | .871 | 789.5 | 497.0 | 98.8 | .125 | 16.6 | 16.6 | 1.000 | 11.4 |
| 13 | .594 | 225.0 | 2.9 | 0.0 | 0.000 | -.0 | -.0 | 1.000 | 3.4 |
| 14 | .902 | 420.5 | 0.0 | 0.0 | 0.000 | -.0 | -.0 | 1.000 | 3.4 |
| 15 | | | | | | | | | |
| 16 | .950 | 1493.3 | 927.1 | 248.8 | .167 | 48.9 | 48.9 | 1.000 | 14.6 |
| 17 | .992 | 1546.7 | 1143.5 | 412.6 | .267 | 40.5 | 40.5 | 1.000 | 15.2 |
| 18 | .986 | 762.2 | 577.0 | 211.0 | .277 | 20.3 | 20.3 | 1.000 | 10.4 |
| 19 | .932 | 442.8 | 206.4 | 58.0 | .131 | -.0 | -.0 | 1.000 | 6.5 |
| 20 | .835 | 754.5 | 471.6 | 97.1 | .129 | -.0 | -.0 | 1.000 | 10.7 |
| 21 | .628 | 866.5 | 666.2 | 156.3 | .180 | -.0 | -.0 | 1.000 | 13.0 |
| 22 | .970 | 1183.3 | 927.2 | 340.0 | .287 | 98.3 | 98.3 | 1.000 | 15.3 |
| 23 | .991 | 1056.6 | 752.6 | 265.8 | .252 | 78.3 | 78.3 | 1.000 | 12.8 |
| 24 | .970 | 884.7 | 637.7 | 199.5 | .226 | 136.5 | 131.3 | .962 | 12.5 |
| 25 | .952 | 1034.0 | 763.0 | 244.5 | .236 | -.0 | -.0 | 1.000 | 15.4 |
| 26 | .955 | 925.4 | 644.3 | 172.2 | .186 | -.0 | -.0 | 1.000 | 12.9 |
| 27 | | | | | | | | | |
| 28 | | | | | | | | | |
| 29 | .900 | 1388.0 | 1226.6 | 490.7 | .354 | 199.0 | 180.7 | .908 | 18.7 |
| 30 | .956 | 969.8 | 776.4 | 302.5 | .312 | 101.4 | 94.6 | .933 | 14.5 |
| 31 | .997 | 1338.5 | 1167.4 | 449.6 | .336 | 137.3 | 137.3 | 1.000 | 18.5 |
| TOTAL | .844 | 29557. | 22449. | 7963. | .269 | 2786.9 | 2290.5 | .822 | 384.9 |
| DAILY | .844 | 1055.6 | 801.7 | 284.4 | .269 | 99.5 | 81.8 | .822 | 13.7 |
| MONTH | .844 | 32724. | 24854. | 8817. | .269 | 3085.5 | 2535.9 | .822 | 426.1 |

*Errors discovered after compiling. Correct values are approximately 1210 and 1310, respectively. Effect on averages is not siginficant.

ALL DATA IN MEGJOULES
*BASED ON 54.2 SQ. M COLLECTOR AREA

Table C-3C. CSU Solar House I System Performance for Month of September, 1979

| DAY | ENERGY REQUIRED: Q610 SPACE HEATING | Q512 SPACE COOLING | Q312 HOT WATER HEATING | Q606 TOTAL | SOLAR ENERGY USED: Q402 SPACE HEATING | Q604C ACTUAL STORAGE LOSSES | Q611 TOTAL USEFUL HEATING | Q604E STORAGE LOSSES ESTIMATED | Q540 SPACE COOLING | Q313 HOT WATER HEATING | Q612 TOTAL USEFUL ENERGY | AUXILIARY ENERGY USED: Q442 SPACE HEATING | Q501 SPACE COOLING | Q301 HOT WATER HEATING | Q601 TOTAL | SOLAR FRACTION: N401 SPACE HEATING | N501 SPACE COOLING | N301 HOT WATER HEATING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0 | 102.8 | 34.0 | 136.8 | 0.0 | 71.6 | 0.0 | 42.9 | 102.8 | 29.7 | 132.5 | 0.0 | 0.0 | 4.3 | 4.3 | 0.000 | 1.000 | .874 |
| 2 | 0.0 | 275.4 | 45.6 | 321.1 | 0.0 | 81.9 | 0.0 | 45.7 | 275.4 | 36.5 | 311.9 | 0.0 | 0.0 | 9.2 | 9.2 | 0.000 | 1.000 | .799 |
| 3 | 0.0 | 537.9 | 58.1 | 596.1 | 0.0 | 67.8 | 0.0 | 42.2 | 537.9 | 36.6 | 574.5 | 0.0 | 0.0 | 21.6 | 21.6 | 0.000 | 1.000 | .629 |
| 4 | 0.0 | 427.4 | 51.3 | 478.7 | 0.0 | 87.9 | 0.0 | 39.0 | 401.7 | 31.8 | 433.5 | 0.0 | 25.7 | 19.5 | 45.1 | 0.000 | .940 | .620 |
| 5 | 0.0 | 426.6 | 70.9 | 497.5 | 0.0 | 34.0 | 0.0 | 38.2 | 375.7 | 40.2 | 415.9 | 0.0 | 50.9 | 30.7 | 81.6 | 0.000 | .881 | .567 |
| 6 | 0.0 | 303.2 | 42.3 | 345.5 | 0.0 | 50.8 | 0.0 | 38.3 | 284.9 | 35.3 | 320.1 | 0.0 | 18.3 | 7.1 | 25.3 | 0.000 | .940 | .833 |
| 7 | 0.0 | 407.5 | 32.5 | 440.0 | 0.0 | 51.3 | 0.0 | 38.0 | 371.7 | 30.1 | 401.8 | 0.0 | 35.8 | 2.4 | 38.2 | 0.000 | .912 | .926 |
| 8 | 0.0 | 315.4 | 33.3 | 348.7 | 0.0 | 57.4 | 0.0 | 37.9 | 253.5 | 30.3 | 283.8 | 0.0 | 61.8 | 3.0 | 64.8 | 0.000 | .804 | .911 |
| 9 | 0.0 | 332.6 | 29.9 | 362.5 | 0.0 | 59.8 | 0.0 | 37.9 | 310.6 | 28.8 | 339.5 | 0.0 | 22.0 | 1.1 | 23.1 | 0.000 | .934 | .964 |
| 10 | 0.0 | 541.3 | 44.2 | 585.5 | 0.0 | 60.7 | 0.0 | 38.2 | 0.0 | 40.0 | 40.0 | 0.0 | 541.3 | 4.2 | 545.5 | 0.000 | 0.000 | .905 |
| 11 | 0.0 | 69.4 | 36.8 | 106.2 | 0.0 | 53.9 | 0.0 | 37.7 | 0.0 | 32.8 | 32.8 | 0.0 | 69.4 | 4.1 | 73.5 | 0.000 | 0.000 | .890 |
| 12 | 0.0 | 98.5 | 52.0 | 150.5 | 0.0 | 52.8 | 0.0 | 38.2 | 97.8 | 30.9 | 128.7 | 0.0 | .7 | 21.1 | 21.8 | 0.000 | .993 | .595 |
| 13 | 0.0 | 4.4 | 61.9 | 66.3 | 0.0 | 69.0 | 0.0 | 41.2 | 3.7 | 33.9 | 37.7 | 0.0 | .7 | 28.0 | 28.7 | 0.000 | .842 | .548 |
| 14 | 0.0 | 192.9 | 51.6 | 244.5 | 0.0 | 81.4 | 0.0 | 45.2 | 192.0 | 35.9 | 227.9 | 0.0 | .9 | 15.7 | 16.6 | 0.000 | .996 | .695 |
| 15 | 0.0 | 197.9 | 70.6 | 268.4 | 0.0 | 132.4 | 0.0 | 46.8 | 196.9 | 66.6 | 263.5 | 0.0 | 1.0 | 4.0 | 5.0 | 0.000 | .995 | .943 |
| 16 | 0.0 | 508.2 | 40.6 | 548.8 | 0.0 | 91.0 | 0.0 | 45.6 | 507.8 | 31.1 | 538.9 | 0.0 | .4 | 9.6 | 10.0 | 0.000 | .999 | .764 |
| 17 | 0.0 | 687.5 | 44.2 | 731.7 | 0.0 | 53.5 | 0.0 | 41.6 | 528.5 | 31.1 | 559.6 | 0.0 | 158.9 | 13.1 | 172.0 | 0.000 | .769 | .704 |
| 18 | 0.0 | 487.7 | 48.8 | 536.5 | 0.0 | 50.4 | 0.0 | 40.4 | 387.7 | 33.4 | 421.2 | 0.0 | 99.9 | 15.4 | 115.3 | 0.000 | .795 | .684 |
| 19 | 0.0 | 433.3 | 44.9 | 478.2 | 0.0 | 59.9 | 0.0 | 40.1 | 366.8 | 32.9 | 399.7 | 0.0 | 66.5 | 12.0 | 78.5 | 0.000 | .847 | .733 |
| 20 | 0.0 | 321.1 | 48.4 | 369.5 | 0.0 | 56.0 | 0.0 | 39.7 | 232.2 | 32.9 | 265.0 | 0.0 | 88.9 | 15.6 | 104.5 | 0.000 | .723 | .679 |
| 21 | 0.0 | 281.6 | 44.9 | 326.4 | 0.0 | 57.1 | 0.0 | 40.2 | 276.5 | 28.7 | 305.2 | 0.0 | 5.1 | 16.2 | 21.3 | 0.000 | .982 | .640 |
| 22 | 0.0 | 342.1 | 40.6 | 382.6 | 0.0 | 54.5 | 0.0 | 41.5 | 283.6 | 29.0 | 312.6 | 0.0 | 58.5 | 11.6 | 70.0 | 0.000 | .829 | .715 |
| 23 | 0.0 | 403.6 | 43.8 | 447.4 | 0.0 | 56.4 | 0.0 | 39.8 | 330.8 | 27.1 | 358.0 | 0.0 | 72.8 | 16.6 | 89.4 | 0.000 | .820 | .620 |
| 24 | 0.0 | 453.7 | 43.5 | 497.2 | 0.0 | 61.0 | 0.0 | 39.4 | 272.7 | 30.5 | 303.2 | 0.0 | 181.0 | 13.0 | 194.0 | 0.000 | .601 | .702 |
| 25 | 0.0 | 499.6 | 46.6 | 546.2 | 0.0 | 34.9 | 0.0 | 38.8 | 200.9 | 30.6 | 231.5 | 0.0 | 298.7 | 16.0 | 314.7 | 0.000 | .402 | .656 |
| 26 | 0.0 | 434.4 | 42.2 | 476.6 | 0.0 | 48.6 | 0.0 | 39.1 | .3 | 30.1 | 30.4 | 0.0 | 434.1 | 12.1 | 446.2 | 0.000 | .001 | .713 |
| 27 | 0.0 | 701.2 | 40.6 | 741.9 | 0.0 | 59.6 | 0.0 | 40.7 | 420.8 | 31.0 | 451.9 | 0.0 | 280.4 | 9.6 | 290.0 | 0.000 | .600 | .764 |
| 28 | 0.0 | 481.6 | 48.5 | 530.0 | 0.0 | 25.1 | 0.0 | 40.8 | 347.2 | 33.8 | 381.1 | 0.0 | 134.3 | 14.6 | 148.9 | 0.000 | .721 | .698 |
| 29 | 0.0 | 224.1 | 46.8 | 270.9 | 0.0 | 58.9 | 0.0 | 43.1 | 224.1 | 33.2 | 257.3 | 0.0 | 0.0 | 13.6 | 13.6 | 0.000 | 1.000 | .710 |
| 30 | 0.0 | 376.1 | 50.5 | 426.6 | 0.0 | 80.7 | 0.0 | 46.1 | 376.1 | 40.9 | 417.1 | 0.0 | 0.0 | 9.6 | 9.6 | 0.000 | 1.000 | .811 |
| TOTAL | 0. | 10869. | 1390. | 12259. | 0. | 1861. | 0. | 1224. | 8161. | 1016. | 9177. | 0. | 2708. | 374. | 3082. | 0.000 | .751 | .731 |
| DAILY | 0.0 | 362.3 | 46.3 | 408.6 | 0.0 | 62.0 | 0.0 | 40.8 | 272.0 | 33.9 | 305.9 | 0.0 | 90.3 | 12.5 | 102.7 | 0.000 | .751 | .731 |
| MONTH | 0. | 10869. | 1390. | 12259. | 0. | 1861. | 0. | 1224. | 8161. | 1016. | 9177. | 0. | 2708. | 374. | 3082. | 0.000 | .751 | .731 |

ALL DATA IN MEGAJOULES
* BASED ON 54.2 SQ.M COLLECTOR AREA

Table C-3C (continued)

| DAY | ----- N601 TOTAL | ---COLLECTOR PERFORMANCE--- S005 TOTAL SOLAR* | S007 SOLAR* WHEN COLLECTING | Q111 HEAT DELIVERED | N100 AVERAGE EFFICIENCY | -CHILLER PERFORMANCE- Q502 TOTAL OUTPUT | Q541 SOLAR OUTPUT | N502 FRACTION BY SOLAR | E103 + E303 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | .969 | 1431.1 | 1238.2 | 467.6 | .327 | 26.5 | 26.5 | 1.000 | 18.7 |
| 2 | .971 | 1053.6 | 756.5 | 270.6 | .257 | 81.6 | 81.6 | 1.000 | 12.8 |
| 3 | .964 | 1437.2 | 1259.8 | 505.0 | .351 | 202.8 | 202.8 | 1.000 | 17.8 |
| 4 | .906 | 1327.4 | 1121.0 | 460.6 | .347 | 185.1 | 175.7 | .950 | 16.9 |
| 5 | .836 | 1404.5 | 1224.7 | 480.7 | .342 | 199.1 | 171.5 | .861 | 19.1 |
| 6 | .927 | 1227.3 | 1050.9 | 375.5 | .306 | 152.3 | 143.1 | .939 | 18.7 |
| 7 | .913 | 1383.3 | 1202.9 | 467.3 | .338 | 193.0 | 178.5 | .925 | 17.9 |
| 8 | .814 | 1134.8 | 931.2 | 359.7 | .317 | 146.1 | 113.7 | .778 | 15.1 |
| 9 | .936 | 1185.6 | 1005.9 | 398.3 | .336 | 149.4 | 139.1 | .931 | 16.9 |
| 10 | .068 | 712.4 | 1268.3 | 123.0 | .173 | 277.5 | -.0 | -.000 | 11.7 |
| 11 | .308 | 344.2 | 60.6 | 0.0 | 0.000 | 30.0 | .0 | .000 | 5.1 |
| 12 | .855 | 1085.5 | 919.9 | 304.4 | .280 | 45.8 | 45.8 | 1.000 | 18.2 |
| 13 | .568 | 728.4 | 548.2 | 162.6 | .223 | -.0 | -.0 | 1.000 | 13.5 |
| 14 | .932 | 1413.3 | 1194.9 | 404.4 | .286 | 43.9 | 43.9 | 1.000 | 17.9 |
| 15 | .981 | 1499.9 | 1294.3 | 455.4 | .304 | 42.2 | 42.2 | 1.000 | 18.4 |
| 16 | .982 | 1499.0 | 1304.0 | 484.8 | .323 | 132.8 | 132.8 | 1.000 | 18.6 |
| 17 | .765 | 1464.1 | 1254.1 | 515.6 | .352 | 262.2 | 191.6 | .731 | 18.1 |
| 18 | .785 | 1441.8 | 1234.2 | 487.8 | .338 | 240.7 | 190.6 | .792 | 17.8 |
| 19 | .836 | 1361.7 | 1153.8 | 466.0 | .342 | 218.7 | 186.1 | .851 | 16.6 |
| 20 | .717 | 969.5 | 845.3 | 321.8 | .332 | 159.4 | 112.2 | .704 | 13.9 |
| 21 | .935 | 1268.5 | 1124.0 | 420.8 | .332 | 140.6 | 135.4 | .962 | 16.6 |
| 22 | .817 | 1213.5 | 1009.8 | 369.7 | .305 | 154.8 | 126.6 | .818 | 15.8 |
| 23 | .800 | 1189.9 | 983.6 | 393.9 | .331 | 199.4 | 164.3 | .824 | 16.8 |
| 24 | .610 | 1114.6 | 927.5 | 371.2 | .333 | 227.0 | 135.3 | .596 | 14.8 |
| 25 | .424 | 1032.0 | 863.4 | 276.5 | .268 | 246.7 | 97.8 | .396 | 15.0 |
| 26 | .064 | 744.0 | 497.1 | 141.7 | .190 | 211.9 | .3 | .001 | 11.2 |
| 27 | .609 | 1427.0 | 1254.7 | 481.7 | .338 | 330.0 | 197.4 | .598 | 18.0 |
| 28 | .719 | 1391.5 | 1217.3 | 454.3 | .326 | 238.7 | 178.4 | .748 | 17.1 |
| 29 | .950 | 1448.6 | 1269.5 | 482.6 | .333 | 117.1 | 117.1 | 1.000 | 18.7 |
| 30 | .978 | 1447.4 | 1111.2 | 474.2 | .328 | 163.9 | 163.9 | 1.000 | 18.0 |
| TOTAL | .749 | 36382. | 31127. | 11378. | .313 | 4818.8 | 3494.0 | .725 | 485.7 |
| DAILY | .749 | 1212.7 | 1037.6 | 379.3 | .313 | 160.6 | 116.5 | .725 | 16.2 |
| MONTH | .749 | 36382. | 31127. | 11378. | .313 | 4818.8 | 3494.0 | .725 | 485.7 |

ALL DATA IN MEGAJOULES
*BASED ON 54.2 SQ. M COLLECTOR AREA

## Table C-4C. CSU Solar House I System Performance for Month of October, 1979

| DAY | ENERGY REQUIRED Q610 SPACE HEATING | ENERGY REQUIRED Q512 SPACE COOLING | ENERGY REQUIRED Q312 HOT WATER HEATING | ENERGY REQUIRED Q606 TOTAL | SOLAR ENERGY USED Q402 SPACE HEATING | SOLAR ENERGY USED Q604C ACTUAL STORAGE LOSSES | SOLAR ENERGY USED Q611 TOTAL USEFUL HEATING | SOLAR ENERGY USED Q604E STORAGE LOSSES ESTIMATED | SOLAR ENERGY USED Q540 SPACE COOLING | SOLAR ENERGY USED Q313 HOT WATER HEATING | SOLAR ENERGY USED Q612 TOTAL USEFUL ENERGY | AUXILIARY ENERGY USED Q442 SPACE HEATING | AUXILIARY ENERGY USED Q501 SPACE COOLING | AUXILIARY ENERGY USED Q301 HOT WATER HEATING | AUXILIARY ENERGY USED Q601 TOTAL | SOLAR FRACTIO N401 SPACE HEATING | SOLAR FRACTIO N501 SPACE COOLING | SOLAR FRACTIO N301 HOT WATER HEATING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0 | 295.9 | 47.3 | 343.2 | 0.0 | 75.1 | 0.0 | 46.5 | 295.1 | 35.4 | 330.5 | 0.0 | .8 | 11.9 | 12.7 | 0.000 | .997 | .748 |
| 2 | 0.0 | 470.0 | 42.3 | 512.3 | 0.0 | 66.0 | 0.0 | 44.2 | 404.7 | 31.8 | 436.5 | 0.0 | 65.3 | 10.5 | 75.8 | 0.000 | .861 | .752 |
| 3 | 0.0 | 190.4 | 45.4 | 235.8 | 0.0 | 69.3 | 0.0 | 42.5 | 190.4 | 34.3 | 224.7 | 0.0 | 0.0 | 11.1 | 11.1 | 0.000 | 1.000 | .756 |
| 4 | 0.0 | 281.9 | 46.3 | 328.2 | 0.0 | 79.0 | 0.0 | 45.9 | 281.9 | 37.0 | 318.9 | 0.0 | 0.0 | 9.3 | 9.3 | 0.000 | 1.000 | .799 |
| 5 | 0.0 | 643.5 | 49.6 | 693.1 | 0.0 | 63.7 | 0.0 | 43.7 | 516.4 | 37.7 | 554.1 | 0.0 | 127.1 | 11.9 | 139.0 | 0.000 | .802 | .760 |
| 6 | 0.0 | 345.7 | 37.8 | 383.5 | 0.0 | 56.9 | 0.0 | 42.6 | 345.7 | 26.0 | 371.6 | 0.0 | 0.0 | 11.8 | 11.8 | 0.000 | 1.000 | .687 |
| 7 | 0.0 | 284.2 | 45.7 | 329.9 | 0.0 | 62.1 | 0.0 | 43.8 | 284.2 | 34.6 | 318.8 | 0.0 | 0.0 | 11.1 | 11.1 | 0.000 | 1.000 | .757 |
| 8 | 0.0 | 448.3 | 51.5 | 499.8 | 0.0 | 53.5 | 0.0 | 43.7 | 426.0 | 41.0 | 467.0 | 0.0 | 22.2 | 10.6 | 32.8 | 0.000 | .950 | .795 |
| 9 | 0.0 | 104.4 | 49.7 | 154.0 | 0.0 | 64.3 | 0.0 | 37.1 | 99.5 | 31.5 | 131.1 | 0.0 | 4.8 | 18.1 | 23.0 | 0.000 | .954 | .635 |
| 10 | 0.0 | 91.9 | 51.9 | 143.9 | 0.0 | 33.9 | 0.0 | 34.2 | 91.9 | 30.3 | 122.3 | 0.0 | 0.0 | 21.6 | 21.6 | 0.000 | 1.000 | .584 |
| 11 | 0.0 | 427.5 | 39.7 | 467.2 | 0.0 | 55.6 | 0.0 | 41.3 | 329.8 | 29.3 | 359.1 | 0.0 | 97.8 | 10.4 | 108.1 | 0.000 | .771 | .738 |
| 12 | 0.0 | 267.0 | 31.4 | 298.5 | 0.0 | 49.9 | 0.0 | 42.1 | 233.2 | 20.4 | 253.5 | 0.0 | 33.9 | 11.1 | 44.9 | 0.000 | .873 | .648 |
| 13 | 0.0 | 210.5 | 16.9 | 227.4 | 0.0 | 53.5 | 0.0 | 46.3 | 210.5 | 6.2 | 216.7 | 0.0 | 0.0 | 10.7 | 10.7 | 0.000 | 1.000 | .369 |
| 14 | 0.0 | 0.0 | 58.7 | 58.7 | 0.0 | 66.5 | 0.0 | 46.9 | 0.0 | 45.5 | 45.5 | 0.0 | 0.0 | 13.2 | 13.2 | 0.000 | 0.000 | .775 |
| 15 | 0.0 | 257.0 | 19.9 | 276.9 | 0.0 | 45.6 | 0.0 | 43.3 | 257.0 | 8.0 | 265.0 | 0.0 | 0.0 | 11.9 | 11.9 | 0.000 | 1.000 | .402 |
| 16 | 0.0 | 0.0 | 27.4 | 27.4 | 0.0 | 40.9 | 0.0 | 42.4 | 0.0 | 16.5 | 16.5 | 0.0 | 0.0 | 11.0 | 11.0 | 0.000 | 0.000 | .601 |
| 17 | 0.0 | 0.0 | 15.1 | 15.1 | 0.0 | 69.8 | 0.0 | 44.6 | 0.0 | 4.0 | 4.0 | 0.0 | 0.0 | 11.1 | 11.1 | 0.000 | 0.000 | .267 |
| TOTAL | 0. | 4318. | 676. | 4995. | 0. | 1006. | 0. | 731. | 3966. | 469. | 4436. | 0. | 352. | 207. | 559. | 0.000 | .918 | .694 |
| DAILY | 0.0 | 254.0 | 39.8 | 293.8 | 0.0 | 59.2 | 0.0 | 43.0 | 233.3 | 27.6 | 260.9 | 0.0 | 20.7 | 12.2 | 32.9 | 0.000 | .918 | .694 |
| MONTH | 0. | 4318. | 676. | 4995. | 0. | 1006. | 0. | 731. | 3966. | 469. | 4436. | 0. | 352. | 207. | 559. | 0.000 | .918 | .694 |

ALL DATA IN MEGAJOULES
* BASED ON 54.2 SQ.M COLLECTOR AREA

Table C-4C (continued)

| DAY | ----- | ---COLLECTOR PERFORMANCE--- | | | | -CHILLER PERFORMANCE- | | | |
|---|---|---|---|---|---|---|---|---|---|
| | N601 TOTAL | S005 TOTAL SOLAR* | S007 SOLAR* WHEN COLLECTING | Q111 HEAT DELIVERED | N100 AVERAGE EFFICIENCY | Q502 TOTAL OUTPUT | Q541 SOLAR OUTPUT | N502 FRACTION BY SOLAR | E103 + E303 |
| 1 | .963 | 1443.5 | 1249.0 | 438.9 | .304 | 154.9 | 154.9 | 1.000 | 17.1 |
| 2 | .852 | 1114.4 | 923.2 | 302.2 | .271 | 245.2 | 212.9 | .868 | 17.0 |
| 3 | .953 | 1240.4 | 1126.2 | 409.2 | .330 | 90.0 | 90.0 | 1.000 | 16.8 |
| 4 | .972 | 1452.1 | 1235.2 | 427.3 | .294 | 137.2 | 137.2 | 1.000 | 17.5 |
| 5 | .799 | 1410.7 | 1198.0 | 481.6 | .341 | 321.5 | 261.8 | .814 | 16.9 |
| 6 | .969 | 1432.2 | 1243.4 | 476.1 | .332 | 169.0 | 169.0 | 1.000 | 19.2 |
| 7 | .966 | 1340.6 | 1153.2 | 426.9 | .318 | 138.6 | 138.6 | 1.000 | 16.8 |
| 8 | .934 | 1296.6 | 1135.0 | 399.7 | .308 | 225.9 | 213.9 | .947 | 17.1 |
| 9 | .851 | 252.6 | 7.3 | 0.0 | 0.000 | -.3 | -.2 | .606 | 4.7 |
| 10 | .850 | 1228.0 | 1043.6 | 414.5 | .338 | -.2 | -.2 | 1.000 | 17.2 |
| 11 | .769 | 1219.6 | 1022.2 | 384.7 | .315 | 228.0 | 177.7 | .779 | 17.1 |
| 12 | .849 | 1393.0 | 1231.0 | 471.9 | .339 | 143.5 | 126.9 | .884 | 18.0 |
| 13 | .953 | 1223.8 | 1042.4 | 381.6 | .312 | 108.3 | 108.3 | 1.000 | 15.5 |
| 14 | .775 | 491.4 | 254.3 | 49.4 | .101 | -.0 | -.0 | 1.000 | 8.7 |
| 15 | .957 | 906.7 | 649.2 | 194.8 | .215 | 141.8 | 141.8 | 1.000 | 14.7 |
| 16 | .601 | 893.6 | 631.7 | 162.9 | .182 | -.0 | -.0 | 1.000 | 12.5 |
| 17 | .267 | 497.6 | 162.1 | 23.4 | .047 | -.0 | -.0 | 1.000 | 5.5 |
| TOTAL | .888 | 18837. | 15307. | 5445. | .289 | 2103.3 | 1932.5 | .919 | 252.3 |
| DAILY | .888 | 1108.1 | 900.4 | 320.3 | .289 | 123.7 | 113.7 | .919 | 14.8 |
| MONTH | .888 | 18837. | 15307. | 5445. | .289 | 2103.3 | 1932.5 | .919 | 252.3 |

ALL DATA IN MEGAJOULES
*BASED ON 54.2 SQ. M COLLECTOR AREA

# APPENDIX D

# CALCULATION OF PRIMARY HEAT FLOW QUANTITIES

## CALCULATION OF PRIMARY HEAT FLOW QUANTITIES

(1) The useful heat delivered to the storage tank from the collectors is calculated by:

$$Q111 = IFX \times [ \int_{TTC}^{TFC} \rho(T)\, C_p(T)\, dT ]$$

where IFX is the integrated flow to the collector and TTC and TFC are the temperatures to and from the collector measured at the heat exchanger.

(2) The house heating or cooling load is given by:

$$Q402 = IFL \times [ \int_{TFL}^{TTL} \rho(T)\, C_p(T)\, dT ]$$

where IFL is the integrated load flow rate and TTL and TFL are the temperatures to and from the heating coil or Arkla chiller generator.

(3) The heat removed from the house by the Arkla chiller is given by:

$$Q \quad = IFCH \times [ \int_{TTCH}^{TFCH} \rho(T)\, C_p(T)\, dT ]$$

where IFCH is the integrated chilled water flow rate and TTCH and TFCH are the temperatures to and from the cooling coil.

(4) The cooling load type is determined by the value of the solar/auxiliary valve position indicator. The assignment is determined by:

QAIRCS = QLOAD if the valve is in the solar position
QAIRCG = QLOAD if the valve is in the auxiliary position

where QAIRC is the heat delivered to the Arkla chiller and the S or G indicates the source of heat, solar or electricity, respectively.

(5) The solar heat removed from the house by solar is given by:

Q = QCOOL if the valve is in the solar position

(6) The solar heat in storage above 20°C is given by:

$$Q205 = VST \times \left[ \int_{20°C}^{TSTOR} \rho(T)\, C_p(T)\, dT \right]$$

where VST is the volume of water in the storage tank and TSTOR is the average of the thermocouple temperature readings within the tank.

(7) The change in solar storage from time ($t_1$) to time ($t_2$) is given by:

$$\Delta Q205 = QSTOR(t_2) - QSTOR(t_1)$$

(8) The heat delivered to the preheat tank (when the tank is in the storage loop) is given by:

$$Q310 = IFL \times \left[ \int_{TTPHE}^{TTL} \rho(T)\, C_p(T)\, dT \right]$$

where IFL is the integrated flow to the load and TTPHE and TTL are the temperatures to and from the domestic hot water heat exchanger.

(9) The heat delivered by solar to the hot water tank is given by:

$$Q311 = HWLIT \left[ \int_{H_2OT}^{TP} \rho(T)\, C_p(T)\, dT \right]$$

where HWLIT is the integrated service hot water demand and TP and $H_2OT$ are the temperature of the top of the preheat tank and the water main temperature, respectively.

(10) The auxiliary heat delivered to the hot water tank is given by:

$$Q301 = HWLIT \times \left[ \int_{TP}^{TSHW} \rho(T)\, C_p(T)\, dT \right] + Q352 - Q308$$

where TSHW is the temperature of the top of the service hot water tank and all other quantities are as defined previously.

(11) The change in preheat tank energy from time ($t_1$) to time ($t_2$) is given by:

$$DELQPH = mC_p(T) \times [\ TPAVG(t_2) - TPAVG(t_1)\ ]$$

where $mC_p(T)$ is the mass-specific heat product of the tank and TPAVG is the average of the preheat thermocouple temperature readings.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1981-740-145/2252