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MONITORING OF THE PERFORMANCE OF A SOLAR HEATED AND COOLED APARTMENT BUILDING

by

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DISCLAIMER

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EXECUTIVE SUMMARY REPORT

INTRODUCTION:

A contract was obtained by The University of Texas at Austin from the Department of Housing and Urban Development (H-2772) under the second cycle of the Solar Heating and Cooling Demonstration Program to retrofit an all-electric apartment building for solar heating and cooling and hot water. The resulting system consists of an array of 1280 square feet of Northrup concentrating tracking collectors, a 5000-gallon hot water storage vessel, a 500-gallon chilled water storage vessel, a 25-ton Arkla Industries absorption chiller, and a two-pipe hydronic air conditioning system. The solar air conditioning equipment is installed in parallel with the existing conventional electric heating and cooling system, and the solar domestic water heating serves as preheat to the existing electric water heaters.

With support from the State of Texas Energy Development Fund (EDF) [IAC(78-79)1337] and the Department of Energy (DOE) (EM 78-5-01-5235) the system was fully instrumented for monitoring. The DOE funding was primarily for instrumentation while the EDF funding was primarily for faculty and student time support. The instrumentation was installed after the solar retrofit of the building was completed because the necessary funds were not available during the retrofit.

INSTRUMENTATION:

The system in Figure 3 was instrumented for monitoring with temperature, flow rate, electrical power, and meteorological sensors as shown. The sensors used were resistance type temperature sensors (ARI Industries, Inc.), target strain gage-type flow sensors (Ramapo), watt transducers (Ohio Semetronics), pyranometer and pyrheliometer solar sensors (Eppley), and wind sensor (Weather Measure). Because of a delay in funding for the data acquisition system intended for the project, a data logger (Fluke Instrument Co.) available from the University was used in the interim. While this system did not have the desired capability and did not permit as extensive and frequent data collection as planned, it did permit acquiring useful data for the summer and fall months of 1979. In September of 1979 the Hewlett Packard automatic data acquisition system (Model 3052) was received, and it has been installed. It has been checked out and is currently available for data collection. However, the limited data presented and discussed herein are those obtained with the Fluke data logger.

MONITORING RESULTS:

The primary data obtained and analyzed are for approximately a 3-week period in July/August. Other data obtained since late August have not been processed because of computer difficulties. Due to a contractual problem with the installation and insulation of the domestic hot water portion of the system, solar domestic hot water use was not possible. Thus the solar energy delivery for this period involved only that for solar cooling.

The table below summarizes the data over this period in terms of the conventional (Conv), solar (Sol), and total (Tot) energy delivered.

Consumption Data

Cooling (MBtu)				DWH (MBtu)				Composite (MBtu)			
Conv	Sol	Tot	%	Conv	Sol	Tot	%	Conv	Sol	Tot	%
10.64	1.34	11.98	11.2	4.44	0	4.44	0	15.08	1.34	16.42	8.2

This indicates that 11.2% of the cooling load was met by solar and 8.2% of the total load (cooling plus hot water) was met by solar. The reasons for this disappointingly low values are several. The concentrating solar collectors did not perform as well as represented by the manufacturer. In general, the measured collector efficiencies were approximately 60% of the manufacturer's suggested performance curves. This is in part due to a bank of collectors not performing as well as an accurately-tracked single collector, which was the basis for the manufacturer's performance data. Also the collector performance is degraded for in-plane but off-normal radiation. It was also found from tests of a single collector in our laboratory that the measured performance of a single collector fell approximately 30% below the manufacturer's recommended performance curve. Another factor influencing the low solar cooling fraction was that the thermostat (sensor in hot tank) turned the chiller on at too low a temperature. This caused excessive cycling of the chiller, which resulted in a poor average chiller coefficient of performance (C.O.P.). Steady-state chiller operation exhibited a C.O.P. very close to the manufacturer's specified performance values, but the time averaged chiller C.O.P. is degraded due to cycling.

The low composite solar fraction (8.2%) is a result of the above deficiencies, as well as the fact that during this monitoring period there was no solar domestic hot water delivery. Had the solar domestic hot water system been operable, less solar cooling would have been delivered but this would have been off-set by considerably more solar energy used for domestic hot water, resulting in a greater composite load carried by solar.

During this monitoring period the daily average direct-normal radiation was 1166 Btu/ft^2-day and the daily average total horizontal radiation was 1657 Btu/ft^2-day. The direct-normal radiation is of primary importance since the collectors are concentrating-tracking. While the average direct-normal was 1166 Btu/ft^2-day, the maximums on "clear" days were approximately 2500 Btu/ft^2-day; in other words, the average direct-normal was a little less than 50% of that available on a "clear" day. In the late summer period of the year this is largely a result of partial (cumulus) cloud cover. The collector efficiency (based on the direct-normal) over this period was 32%, a somewhat lower average collector efficiency than expected.

Approximately six additional weeks of data were taken in the early fall 1979 after the solar domestic hot water was turned on and while solar cooling was still needed. To date, the data have not been reduced and evaluated because of problems with the mini-computer used for data processing. It is expected that this data will be processed and be made available in early 1980.

The Hewlett Packard 3052 data acquisition system was received in early September 1979 but was not installed because it would have interrupted data gathering during the remainder of the 1979 cooling season. Data collection was continued with the Fluke data logger through September of 1979 as discussed above. The Hewlett Packard system was subsequently installed and began data acquisition in late January 1980. This system has considerably more capability than the previous system. It has more channels and the computational capability permits frequently scanning and averaging of data, which will permit both more extensive and more accurate data collection.

CONCLUSIONS AND RECOMMENDATIONS:

The evaluation of system performance, which to date is for the cooling season, indicates a lower performance than expected. However, it is felt that system performance in the cooling mode can be improved by better adjustment of the thermostats and controls. The objective of this project was in fact to assess the system performance and to modify control strategy and improve performance. The remaining data obtained during last year's cooling season (including domestic hot water load) will be analyzed. Continued data collection and analysis will be performed, starting in the middle of this year's heating season, using the new Hewlett Packard system which is now operational. The objective will be to improve system operation, assess performance limits, and compare results with design projections.

1. INTRODUCTION

A significant portion of the energy demand in Texas is used in residential/commercial applications, somewhat in excess of 20% according to [1]. Of this demand, approximately 6.1 and 4.9% is demanded for space cooling and space heating respectively. This represents a considerably larger percentage for cooling demand than the national average (2.5%). Also, the cooling demand exceeds the heating demand annually, while nationally the heating demand is several times the cooling demand. Solar energy has the potential to meet an important portion of space heating and cooling and hot water demand; however, in the south-central region the ability of a system to meet the cooling load is crucial to system design as well as to the ultimate impact that solar energy utilization can have in energy displacement in the residential/commercial sector.

With the high potential for solar cooling in the south-central area, a study was initiated in 1975 of its feasibility in multiple family dwellings. The interest in apartment buildings was a result of the possible economy of scale, more people living in apartments, and a lack of information on solar energy application in multiple family dwellings, particularly for solar cooling. After considering both private and institutional apartments, one building in the Gateway Apartments, a University of Texas married student residential complex, was selected for a preliminary design of a solar retrofit demonstration project. Subsequently, a grant to proceed with the project was obtained in October 1976 from the Department of Housing and Urban Development

(H-2772) under its second cycle residential solar heating and cooling demonstration program. The project consisted of retrofitting one 12-unit apartment building for solar heating and cooling and domestic hot water. The equipment consists of 1280 square feet of Northrup concentrating collectors, a 5000-gallon hot water storage vessel, a 500-gallon cold water storage vessel, a 25-ton Arkla Industries absorption chiller and a 2-pipe hydronic air conditioning system. The solar air conditioning equipment is installed in parallel with the existing conventional electric heating and cooling system and the solar domestic water heating serves as preheat to the existing electric water heaters. It was projected that the solar equipment would supply most of the domestic hot water and approximately 85% of the heating and 50% of the air conditioning. The construction and system checkout were effectively completed in October 1978, though there have been some system modifications since then. Details of the project are available in [2, 3, 11].

When the project was proposed it was intended that the actual demonstration project and an evaluation of it were equally important; however, the grant excluded the latter. Subsequent to obtaining the grant and proceeding with the project, proposals were written to the State of Texas, Energy Development Fund (EDF), and the Department of Energy (DOE) to jointly support a monitoring and evaluation study. Support for this project was received from EDF in April 1978 under Contract IAC(78-79)1337 and from DOE in September 1978 under Contract EM78-5-01-5235. The EDF funds were primarily for student and faculty time support; the DOE funding was primarily for the instrumentation, its installation, and maintenance.

Because funds for the monitoring and evaluation of the project were not assured until the retrofit was largely completed, it was not possible to install the instrumentation during the retrofit construction. Even though the retrofit construction was effectively completed in October 1978, two subsequent problems with the system did not permit it to operate satisfactorily until they were finally resolved in June 1979. The instrumentation sensors were installed between January and March 1979. Meanwhile, the receipt of the data acquisition system intended for the project was delayed because of contractual problems, and an acquisition system available at the University was used in its stead. Meteorological and solar collector data were initiated in May 1979, cooling data collection started in July, and domestic hot water in early September. The new data acquisition system was received in late August and installed in early October 1979.

While there have been many solar water heating and space heating projects completed and reported on, performance evaluation on integrated energy systems supplying heating, cooling, and domestic hot water are less common. Reported work on several integrated systems [4, 5, 6] describes successes in a single family dwelling, a 2-story office building, and a complex of dormitories and athletic facilities. Of these systems, only one [5] does not use auxiliary heating when operating the absorption water chiller. All three systems use conventional boilers in series with the solar systems when supplying space heating and hot water. Four demonstration projects involving cooling have been compared by Bartlett and Wallace [7]. These involve application in a recreation center, 2 public schools, and an office building. The comparative results indicate that the system configuration and components, including how auxiliary energy and storage are used (if at all), are very important to the resulting system performance. These applications are markedly different from the present application to a multi-family residence.

This report describes the retrofit project itself, the instrumentation for the project, and the results of the monitoring to date. In addition to the limited but valuable data obtained to date, the monitoring has identified several important areas for improvement with respect to the instrumentation and acquisition system and the operation of the solar equipment itself.

2. APARTMENT BUILDING AND SOLAR SYSTEM

2.1 APARTMENT BUILDING PRIOR TO SOLAR RETROFIT

The apartment building consists of 12 one-bedroom apartments, each having 600 square feet of floor space. The building is 2 stories, with 6 first-floor and 6 second-floor apartments. Since the length of each apartment spans the width of the building, each apartment has a minimum of 2 exterior walls. The length of the building is aligned 15 degrees clockwise from east to west. A single-story laundry room is located at the west end of the building. This laundry serves the approximate equivalent of 2 additional similar apartment buildings, since there are 5 laundries in the 18-building, 200-apartment complex.

The buildings are all electric, each apartment having individual heating and air conditioning controls and individual heating and air conditioning equipment. The conventional fan unit, air conditioning evaporator coil, and resistance heater are located in a fir down above the kitchen ceiling of each apartment. The air conditioning compressor and condenser unit for each apartment are located on the building's roof. An electric water heater is located in each apartment and a larger electric water heater is located in the laundry room.

2.2 SOLAR COMPONENTS DESCRIPTION

A simplified schematic of the solar energy system is shown in Figure 1. The major components in the system are 1280 square feet of Northrup concentrating collectors, a 5000-gallon hot water storage tank, a 25-ton absorption chiller, a 500-gallon chilled water storage tank, a domestic water heat exchanger in the hot tank, and 12 liquid-to-air

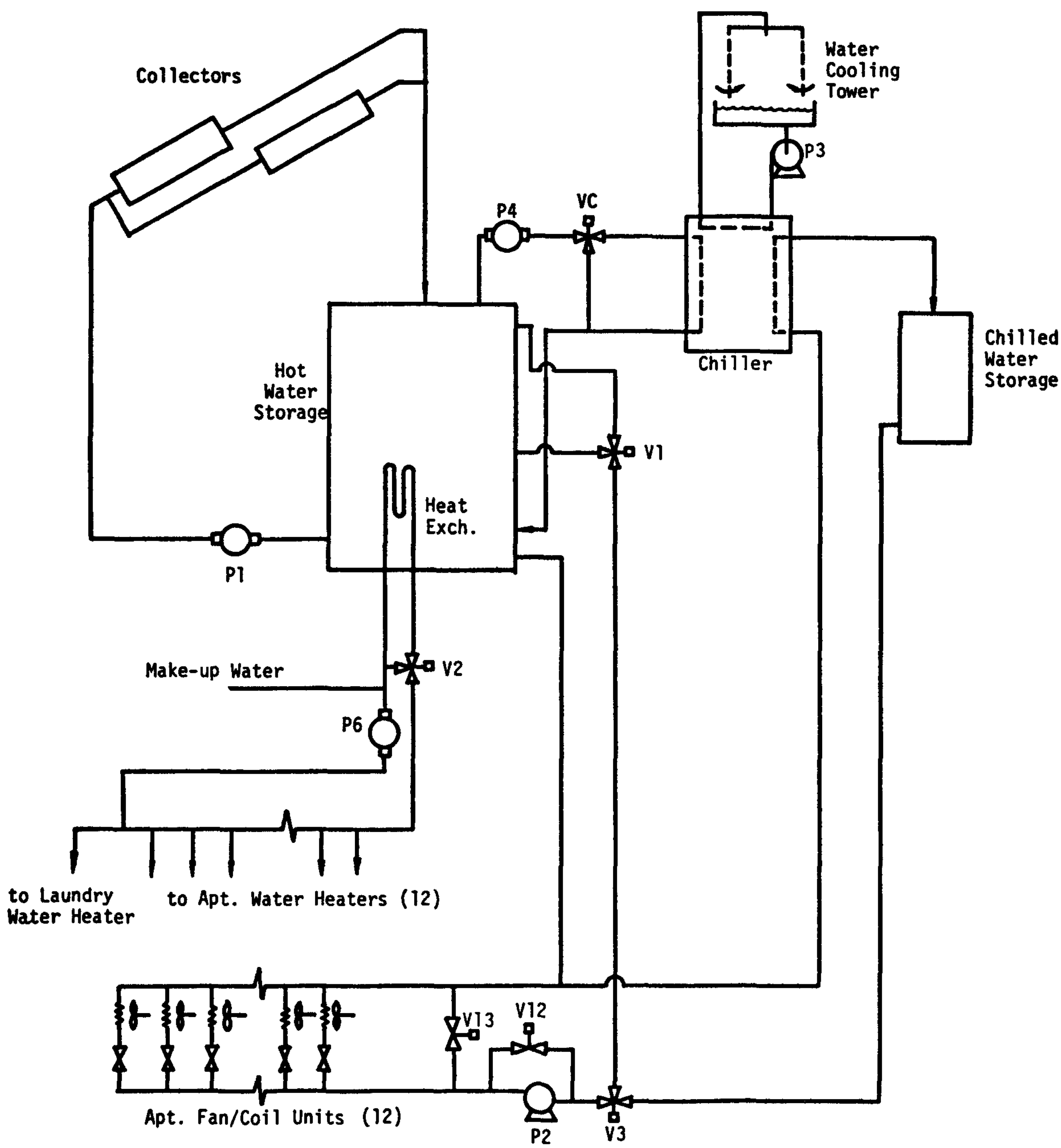


Figure 1. Solar Heating and Cooling Schematic

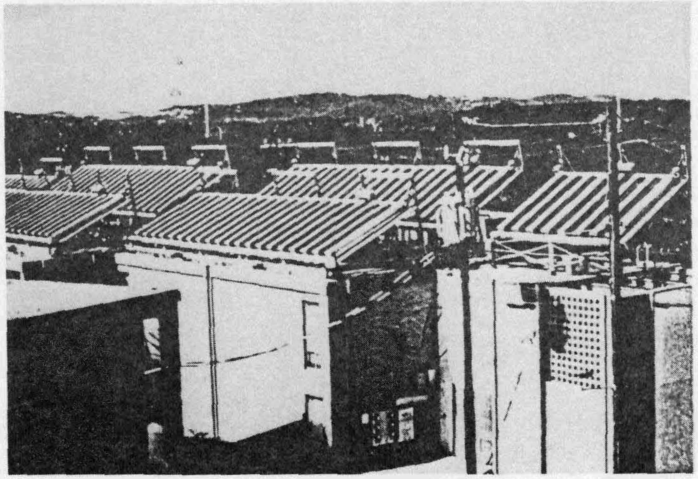
fan/coil units in the apartments. In addition, the system includes pumps, valves and plumbing, and an automatic control system to provide proper functioning of the system in its several modes of operation.

2.2.1 Solar Collectors

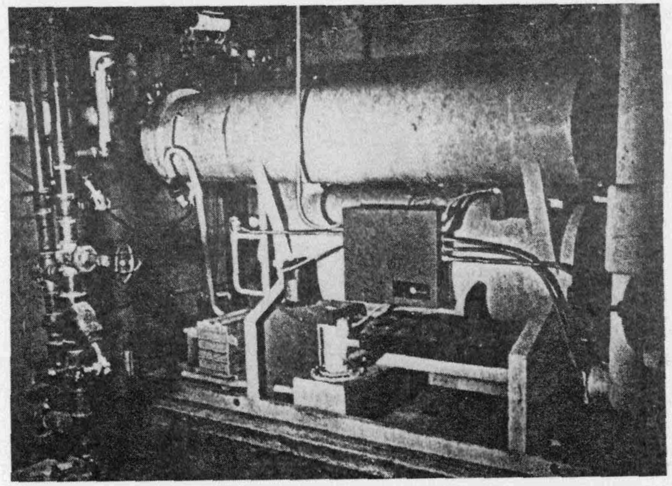
The array of solar collectors, shown in Figure 2A, consists of 128 concentrating, tracking collectors of the linear, Fresnel lens type, manufactured by Northrup Incorporated. Each collector has an aperture approximately 10 feet long and 1 foot wide, with an effective collecting area of 9.7 square feet resulting in a total net collection area of 1242 square feet. The collectors are arranged in 7 banks on the building roof: 3 banks of 20 each tilted at 25 degrees and 3 banks of 20 and 1 bank of 8 tilted at 30 degrees. The banks located in front are tilted at 25 degrees and the rear banks are elevated 2 feet higher to minimize shading on the rear banks. All collector banks face approximately 15 degrees west of south because of the orientation of the building and the lack of sufficient roof area to orient the collectors directly south. Each collector bank tracks independently from horizontally to the east (required for complete drainage for freeze prevention) to approximately 15 degrees from horizontal to the west.

2.2.2 Absorption Chiller

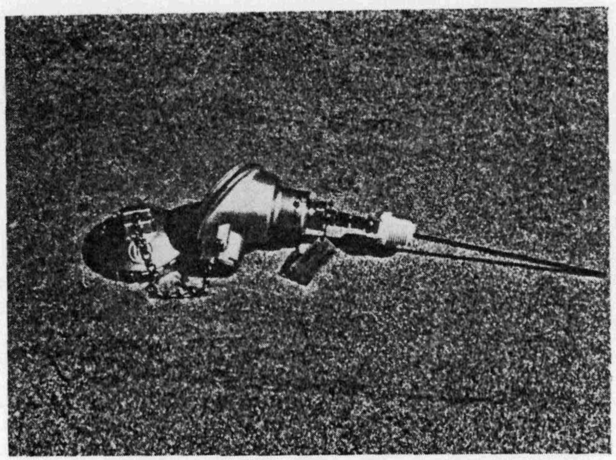
The absorption chiller, shown in Figure 2B, is an Arkla Industries model WFB 300, 25-ton unit which uses water-lithium bromide. The chiller has a rated capacity of 25 tons with 195°F inlet water. In the present application, because of the lower cooling load on the building (approximately 12 tons maximum), the unit is operated with reduced



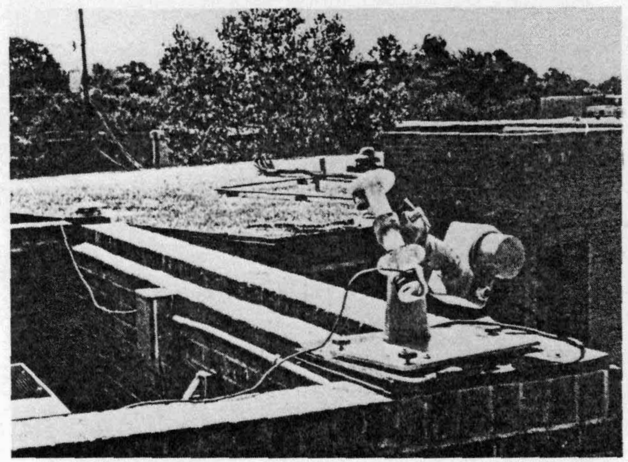
a. Solar Collector Array



b. Absorption Chiller



c. Water Temperature Sensor



d. Solar Instrument Installations

Figure 2. Views of Various Equipment

condensing, chilled, and hot water flow rates to give a rated capacity of 15 tons with 185°F hot water. The unit will deliver 19 tons of cooling with 200°F inlet hot water, and 6 tons of cooling with 165°F inlet hot water. All these capacities are with 45°F leaving chilled water and 85°F inlet condensing water, which are realistic operating conditions.

2.2.3 Solar Apartment Fan/Coil Units

A solar fan/coil unit is installed in parallel with the existing heating and air conditioning system in each apartment. Each unit consists of a liquid-to-air heat exchanger, and a fan for air circulation. A back-draft damper is installed on the inlet of this unit, and on the inlet to the conventional heating and air conditioning unit to prevent flow of conditioned air into the return air plenum. A normally closed electric solenoid valve is actuated to allow hot or chilled water to flow through the coil when demanded.

2.2.4 Domestic Hot Water Heat Exchanger

The water in the hot storage tank, collector circulation loop, chiller regeneration loop, and air conditioning water loop is treated to prevent corrosion and scaling. Thus the potable domestic hot water must be isolated from the treated water. In this system a horizontal tube bundle is mounted in the side of the hot water storage tank for domestic water heating. The bundle consists of 55 5/8-inch outside diameter by 42 inch-long tubes. Heat transfer on the outside (tank side) of the bundle is by natural circulation, augmented by any convection occurring in the tank by water circulation into and out of the tank.

2.2.5 Storage Tanks

Two storage tanks are used in the solar system, one for hot water storage, and a second smaller tank for chilled water. The hot storage tank is 8 feet in diameter by 14 feet high, and has a nominal capacity of 5000 gallons (4740 gallons actual). The tank itself is raised off the floor by a 3/8-inch thick steel skirt, which adds an additional foot to the total height of the tank. This skirt reduces the conduction heat loss that would result if the tank bottom rested on the floor. Since a chilled water storage tank is necessary only to reduce chiller cycling, a smaller, 500-gallon cold storage tank is used. The tank is cylindrical in shape; 42 inches in diameter and 7.5 feet tall. The tank is supported by three legs to prevent conduction losses as described above.

2.2.6 Insulation

All piping in the solar system is insulated with 1-inch thick molded urethane pipe insulation. Indoors, the pipe insulation is covered with a mastic sealing compound; outdoors, the insulation is covered with glass cloth imbedded in a coat of mastic, which is then covered with a second coat of mastic. Each of the two water storage tanks is covered with a nominal 2-inch thickness of sprayed-on urethane foam insulation. The chilled water storage tank insulation is covered with a vapor barrier to reduce moisture absorption.

2.2.7 Pumps, Control Valves

The pumps and control valves crucial to system operation are located as shown in Figure 1. Each pump and control valve and its operation is described in Table 1.

Table 1. Solar System Pumps and Control Valves

Designation	Description	Function
P1	centrifugal pump, 51.2 gpm, 3/4 hp	supplies flow to solar collectors from hot water storage tank
P2	centrifugal pump, 36 gpm, 1 1/2 hp	air conditioning water pump
P3	centrifugal pump, 54 gpm, 1 hp	chiller condensing water pump
P4	centrifugal pump, 54 gpm, 1/2 hp	chiller hot water pump
P6	centrifugal pump, 4 gpm, 1/4 hp	domestic hot water recirculating pump
V1	three-way valve	diverts space-heating water supply from middle of hot storage tank to top of hot storage tank
V2	three-way valve	modulates flow of domestic hot water through heat exchanger
V3	three-way valve	diverts air conditioning water flow from hot storage tank for heating mode to chiller and cold storage tank for air conditioning
VC	three-way valve	modulates flow rate of hot water through chiller
V12	two-way valve	modulates air conditioning water supply pressure in heating mode
V13	two-way valve	modulates air conditioning water supply pressure in cooling mode, allows recirculation through chiller

2.3 SYSTEM OPERATION

A comprehensive automatic control system is an integral part of the solar system. A description of the control logic adequate for a basic understanding of system operation is presented here. A more thorough description of the control logic and system operation can be found in [2, 11]. For operational and control purposes, the solar energy system can be divided into a solar collector system, domestic hot water system, and an air conditioning (cooling and heating) system, each operating independently.

2.3.1 Solar Collector System

The function of the solar collector system is to supply heat to the hot water storage tank. Two temperature sensors, one located in the outlet manifold of one collector bank, and the second located in the bottom of the hot water storage tank, provide the primary control for collector loop circulation. When the solar collector outlet temperature is 15°F or more higher than the tank temperature, pump P1 is turned on and water is circulated through the entire collector array. When this temperature difference drops below 3°F, a 3-minute timer is activated so that if the temperature differential rises above 3°F within the 3-minute interval, pump P1 remains on; otherwise, pump P1 is turned off. Other collector loop circulation controls include: (a) If the temperature in the collectors drops to near freezing, 38°F or lower, as indicated by a sensor on the lower manifold of one collector bank, all collector banks are automatically drained down to the level of the lower manifold through solenoid valves on each bank. (b) If the temperature in the outlet manifolds exceed 230°F, indicating overheating, the power to the tracker motor is temporarily interrupted, defocusing the collectors.

2.3.2 Domestic Hot Water System

The purpose of the domestic hot water control system is to modulate the temperature of the hot water supplied to the apartments and laundry room. Pump P6 is operated by a timer, which permits it to run only between 6 a.m. and 11 p.m. or as otherwise set. Also, a temperature sensor located downstream of valve V2 senses the hot water supply temperature, and limits it to 140°F by modulating valve V2 to divert more or less water through the heat exchanger.

2.3.3 Air Conditioning System

By far the most complex controls are required to operate the air conditioning system. The ambient temperature, as sensed by an outside thermostat, determines if the solar system is in the heating or cooling mode. If the system control switch is in the "COOL" or "AUTO" position and the outside temperature is above 60°F, the system is placed in the cooling mode. This positions valve V3 so pump P2 will circulate chilled water from the chiller and cold storage tank to the apartment fan/coil units. If the system control switch is in the "HEAT" or "AUTO" position and the ambient temperature is below 60°F, the system is placed in the heating mode. This positions valve V3 so pump P2 will circulate water from the hot water storage tank to the apartment fan/coil units.

a. Heating Mode

With the solar air conditioning system in the heating mode, pump P2 is turned on if the temperature at the top of the hot storage tank is above 100°F. In this configuration, V13 is closed completely and V12 allows recirculation around pump P2 to keep the supply pressure to the apartment fan/coil units at 20 pounds per square inch (psig). With all of the above conditions present (system switch on "HEAT" or "AUTO", ambient temperature below 60°F, and pump P2 on), the strip heater and conventional fan in each apartment are disabled; and when an apartment's thermostat demands heat, the solar fan/coil unit is activated and supplies space heating. A refinement in the system allows water from the middle of the hot storage tank to be circulated to the apartment fan/coil units when it is above 100°F at the middle of the tank, but in all cases water is withdrawn from the top of the tank when the ambient temperature is below 40°F. This feature preserves hot water in the top of the tank for cooling in those periods when both heating and cooling may be demanded during the same day.

b. Cooling Mode

When the solar air conditioning system is in the cooling mode, pumps P2, P3, and P4 are turned on if the temperature in the top of the hot storage tank is above 160°F (minimum temperature for chiller operation). In the cooling mode, V12 is closed completely and V13 modulates supply pressure to the apartment fan/coil units, but more importantly, allows water to recirculate through the chiller and cold water storage tank. When the chiller senses flow from pump P2, it opens valve VC allowing hot water to fire the chiller, and turns on the chiller solution pump. If air conditioning water to the chiller drops below 45°F, valve VC closes partially to decrease the cooling capacity. If air conditioning water to the chiller drops below 40°F, valve VC is closed completely and the chiller solution pump is turned off.

To prevent the condenser water supply temperature from dropping below 75°F, which could cause damage to the chiller, the cooling tower fan is thermostatically operated. This fan is turned on only when the condensing water supply temperature is above 85°F. Additional chiller controls operate devices within the chiller to prevent chiller damage should condenser inlet water temperature drop too low.

With the air conditioning system in the cooling mode, pump P2 on, and the cold water storage tank temperature below 60°F, each apartment's conventional air conditioning unit and fan unit are disabled and solar air conditioning may be supplied to the apartments. When an apartment's thermostat demands cooling, cold water is circulated through its solar fan/coil unit, thus supplying cooling to that apartment.

An additional step in the control logic allows pump P2 to run if the cold water storage tank temperature is below 60°F, even if the hot storage tank top temperature is not above 160°F. This allows cold storage to be depleted once the chiller has stopped operating.

In any of the system configurations described above each apartment has the option of either heating or cooling at any time. If the solar system is supplying neither heating nor cooling, the strip heater or conventional air conditioner operates when required by the apartment's thermostat. When the solar system is in the heating mode, the conventional air conditioner in each apartment will operate if required by the apartment's thermostat. Likewise, when the solar system is in the cooling mode, the strip heater in each apartment will operate as demanded by the apartment thermostat. With this control logic operational, the apartment resident should never be inconvenienced by a deficiency in the solar system.

3. PERFORMANCE MONITORING SYSTEM

The primary objective of the monitoring system is to acquire sufficient information to evaluate the performance of the overall solar heating, cooling, and domestic hot water systems. This involves determining the portions of each of these loads met by solar and the fraction of the building energy demand supplied by solar. To obtain these data the various energy flows of the solar equipment and the electrical demand of the conventional energy systems must be measured. An important part of this evaluation is determining the amount of electric (parasitic) power consumed by the solar energy system.

A second objective of the project is to provide performance evaluations on the individual solar energy system components. This information can be used to determine if equipment is operating as projected, to see if it is sized properly for optimum functioning in the system, and to identify any particular problems that might hamper proper system operation.

3.1 INSTRUMENTATION SCHEME

Extensive measurements are required to satisfy the above objectives. To measure energy flows in each fluid stream, the inlet and outlet temperatures to the load and the associated water flow rate must be measured. To measure conventional electric power consumption, several watt transducers are needed. Also, extensive meteorological data must be collected to properly evaluate the operation of the solar energy equipment. With these objectives in mind, a system of 25 temperature sensors, 8 water flow rate sensors, 33 electric watt transducers, and 4 weather instruments was devised. The weather measurements include direct-beam and total-hemispherical solar radiation, wind speed and dew point as well as the dry bulb temperature.

A schematic of the solar energy system and the location of the various sensors is shown in Figure 3. In this figure, a temperature sensor location is indicated by a circled "T", flow rate sensor by "F", electric power sensor by "E", and weather measuring sensor by "W". The symbol and number associated with each T, F, E, or W constitute the designations used for each sensor or instrument for bookkeeping purposes.

3.2 SENSOR DESCRIPTIONS

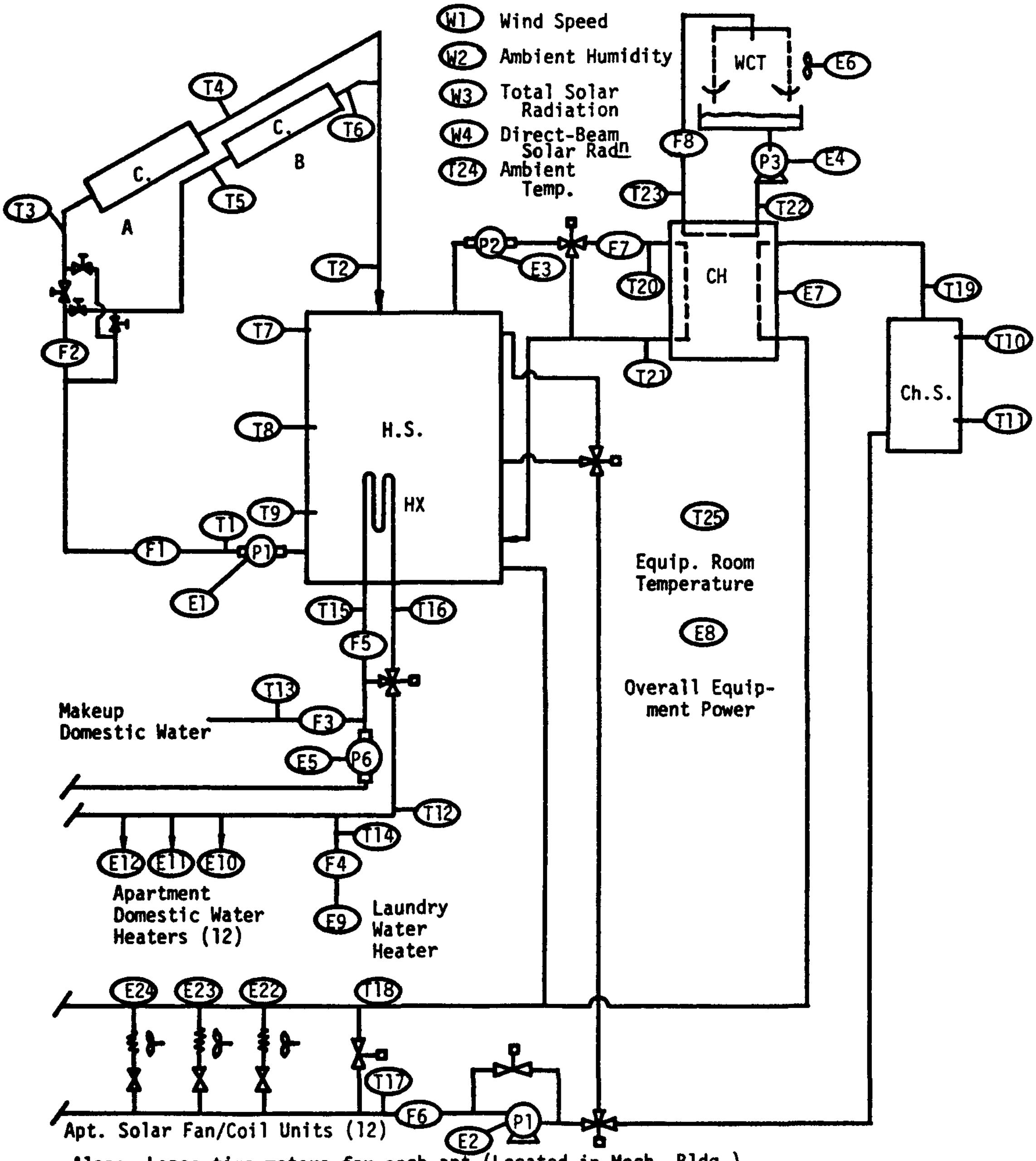
As shown in Figure 3, sensors are installed to measure 23 water temperatures, 2 air temperatures, 8 water flow rates, 33 electric consumption rates, total horizontal solar radiation, direct-beam solar radiation, wind speed, and ambient dew point.

3.2.1 Temperature Sensors

The temperature sensors are all resistance temperature detectors (RTD's) which utilize a platinum sensing element in a stainless steel sheath.

a. Water Temperature Sensors

Each water temperature sensor is an ARI Industries model R-96.4, which has a 4-lead wire connection arrangement, an 8-inch long, 1/8-inch diameter probe, and an industrial-type weatherproof head with internal screw connectors. The sensors have an ice point resistance of 100 ohms and a temperature coefficient of 0.392 ohms per degree centigrade. Additional specifications are given in Appendix Table A-1.



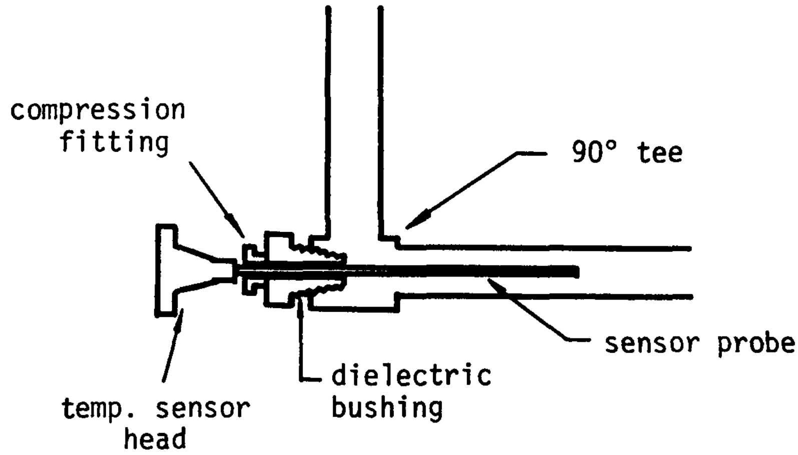
Also: Lapse time meters for each apt (Located in Mech. Bldg.),
Integrating flow meters on total DHW makeup and laundry DHW tank makeup.
Watt-hour meters for each apartment.

Figure 3. Solar Heating and Cooling System Monitoring Instrumentation

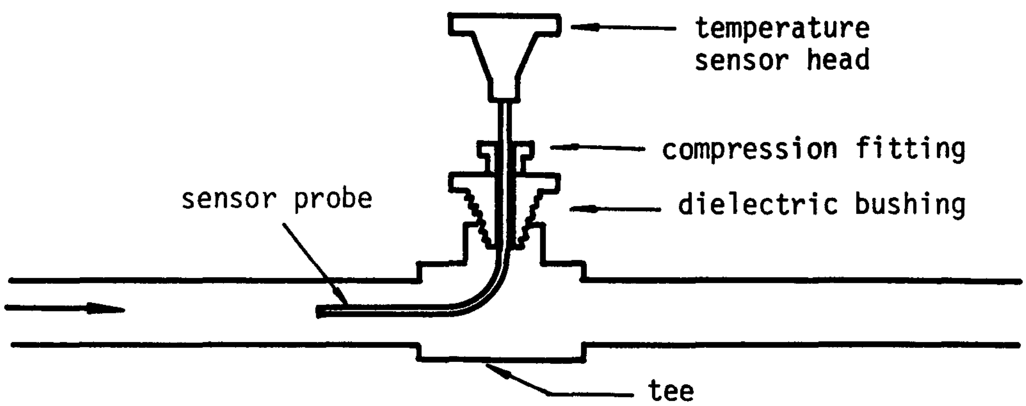
Each water temperature sensor is installed using a brass compression fitting. In Figure 2-C, a single sensor is shown with the compression fitting in place on the sensor probe. To install the sensors in the piping, 90-degree elbows were replaced with tee fittings. The temperature sensor was installed using whatever size pipe bushing necessary, with the probe immersed in the pipe to the maximum depth possible. A schematic of this installation is shown in Figure 4-A. In the event a temperature measurement was needed where a 90-degree bend in the pipe was not convenient, a tee was installed in a straight run of pipe. The temperature sensor was then installed in the tee with the probe bent 90 degrees to allow maximum immersion (Figure 4-B).

It was later discovered (as will be discussed in Section 5.0) that "ground loops" developed in the temperature sensor excitation circuit when the temperature sensors were excited in series and were not electrically isolated from one another. This ground loop situation was caused by the resistance between the sensor and sheath for some of the sensors being too low. This resulted in less excitation current being supplied to some sensors, and thus erroneous temperature measurements for some sensors. A dielectric bushing was installed with each temperature sensor to insulate the sensor case from the metal piping in which it was installed. This is shown in Figure 2-C. This was only partially successful and it was found that with series excitation it was necessary to use only sensors with high impedance to ground.

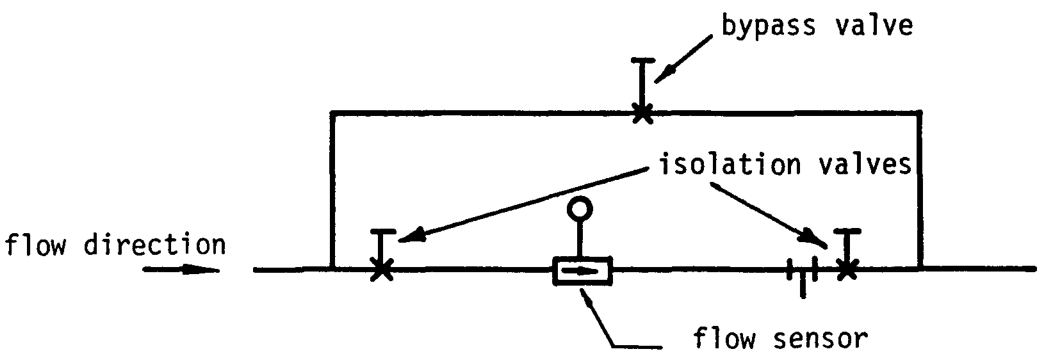
A summary of all temperature sensor locations is given in Appendix Table B-1.



4A Temperature Sensor Installation at Pipe Bend



4B Temperature Sensor Installation in Straight Pipe



4C Flow Sensor Installation

Figure 4. Water Temperature and Flow Sensor Installations

b. Air Temperature Sensors

The two air temperatures measured are the outside ambient dry bulb temperature and the equipment room temperature. The sensor used for equipment room temperature measurement is a water temperature sensor described previously. The ambient dry bulb temperature sensor is a platinum RTD with an ice point resistance of 100 ohms and temperature coefficient of 0.385 ohms per degree centigrade. The unit is a Hy-Cal Industries model RTS-55 with an 8-inch long stainless steel sheath and a radiation shield. Additional specifications of the sensor are given in Appendix Table A-2. The sensor is mounted on the shaded outside north wall of the equipment room.

3.2.2 Flow Rate Sensors

The 8 water flow rate sensors indicated in Figure 3 are Ramapo Instrument Co. Mark V target-type flow meters. This target-type flow meter senses flow rate by measuring the force exerted on an obstruction in the flow. These instruments are essentially strain gauge force measuring sensors, which are empirically calibrated to relate instrument output to fluid flow rate. The specifications of these instruments are listed in Appendix Table A-3, and the location and size of each instrument is given in Appendix Table B-2.

Each flow meter consists of a short section of pipe which houses the sensor. The flow meters, used for liquid flow rate measurements, are incorporated in the piping with a bypass as shown in Figure 4C. The flow meter is preceded by a length of straight pipe equivalent to 15 pipe diameters and is followed by 10 pipe diameters of straight pipe to ensure undisturbed flow. The bypass piping and valves allow the flow meter to be removed from the system without system shut-down. Also, the calibration of the flow meter can be checked with it in place by closing the valve downstream of the flow meter and connecting a flow meter of known accuracy to the pipe "T" downstream of the flow meter.

3.2.3 Electric Watt Transducers

The electric watt transducers utilize Hall Effect multipliers to provide an analog signal proportional to the electric power consumption rate of a piece of equipment. Each unit is an Ohio Semitronics, PC5 series watt transducer. Each instrument is installed in the electrical circuit supplying current to the piece of equipment to be monitored. In the smaller current circuits, connections are made so the total current to the equipment passes through the watt transducer itself. In the higher current applications, one or more external current transducers are used, eliminating the need to pass high electric currents through the watt transducer itself. In all cases, leads are connected from the instrument to each wire in the electric circuit to sense voltage. The specifications of the watt transducers used are given in Appendix Table A-4. The location, model number, and electric rating of each instrument are listed in Appendix Table B-3.

The power sensing instruments can be divided into two functional groups. One group measures solar energy system parasitic power consumption (i.e., power to pumps, the chiller, etc.). The other group measures power consumption by the conventional (backup or auxiliary) heating and air conditioning equipment and electric domestic water heaters in the apartments and/or laundry.

The amounts of parasitic power consumed by each pump in the solar equipment room, by the chiller, and by the chiller cooling tower fan are measured individually. The total power supplied to the solar system equipment room is monitored with a separate watt transducer. This instrument senses all of the power measured by the other watt transducers, as well as any other power (such as collector tracking motors, valve operators, controls, etc.) used by the solar equipment.

In each of the 12 apartments, one watt transducer measures power to the electric water heater and another measures the total power to the air conditioning and heating equipment. This latter instrument utilizes an external current sensor through which one wire of each circuit to be measured is passed. With this arrangement the sum of the power to the electric air conditioning unit, resistance strip heater, conventional fan, and solar fan is measured. One additional instrument is located in the building's laundry room to measure power consumption by the laundry electric water heater.

3.2.4 Meteorological Instruments

In order to properly evaluate solar system performance and to better understand changes in the building heating and air conditioning load, it is necessary to measure and record pertinent ambient weather data. The parameters monitored in this project are total solar radiation on a horizontal surface, direct-beam solar radiation, wind speed, and ambient humidity. As already described, ambient dry bulb temperature is also measured.

a. Solar Instruments

The solar radiation instruments used are an Eppley Model NIP normal incidence pyrheliometer and an Eppley Model PSP precision pyranometer. The pyrheliometer measures radiation incident at angles within 2.7 degrees of its optical axis. This type of measurement requires that the instrument track the sun continuously. This is done with an Eppley Model ST-1 solar tracker which has an equatorial mount similar to that used with many telescopes. The pyrheliometer and tracker are mounted atop the building in a location that allows no shading by adjacent structures. The pyranometer is mounted on a horizontal surface also atop the building. A view of the two solar instruments can be seen in Figure 2-D. Specifications for both instruments are included as Appendix Table A-5.

b. Dew Point Instrument

Ambient humidity is measured with an Atkins Technical, model 26432-09/21063-09 Dew Point Recording System. This instrument senses absolute humidity with an electrical impedance probe, which is a Dunmore-type hygrometer [8]. This sensor consists of two parallel electrodes in contact with a surface coated with lithium chloride, the electrical resistance of which is very sensitive to changes in humidity. The readout and signal conditioning instrument measures probe impedance which is a function of dew point temperature.

The sensor for this instrument is mounted in a sheet metal enclosure adjacent to the ambient temperature probe on the north (shaded) wall of the solar equipment room. The signal conditioning instrument is located inside the equipment room. Specifications for the humidity instrument and probe are included as Appendix Table A-6.

c. Wind Speed Sensor

The wind speed sensor is a Weather/Measure Corporation Model W2005 3-cup anemometer. The sensing device is a 2-pole alternating current generator which produces an output voltage proportional to wind speed. The sensor is mounted on a 10-foot strut attached to the framing of a rear collector bank. This arrangement places the sensor approximately 20 feet in the air above the roof of the 2-story building.

3.3 SENSOR EXCITATION AND SIGNAL CONDITIONING

Voltage excitation for the flow sensors and current excitation for the temperature sensors were achieved using a single DC power supply and the circuit shown in Figure 5.

Current excitation of approximately 2 milliamperes was needed for the resistance temperature detectors. The sensing elements of each RTD were connected in series so that only a single precision resistor for current measurement was required. With this arrangement, the common excitation current and the voltage drop across each RTD allowed calculation of each resistance using Ohm's Law.

A 5- to 10-volt DC potential was needed for flow meter excitation. This was achieved by exciting all flow meters in parallel from one voltage source and connecting an adjustable resistor in series with the flow meters for voltage trimming. In this way, only the common excitation voltage and signal from each flow meter need be measured.

An obvious concern with the flow meter voltage excitation is voltage drop in the lead wires to the instrument. The nominal resistance of the

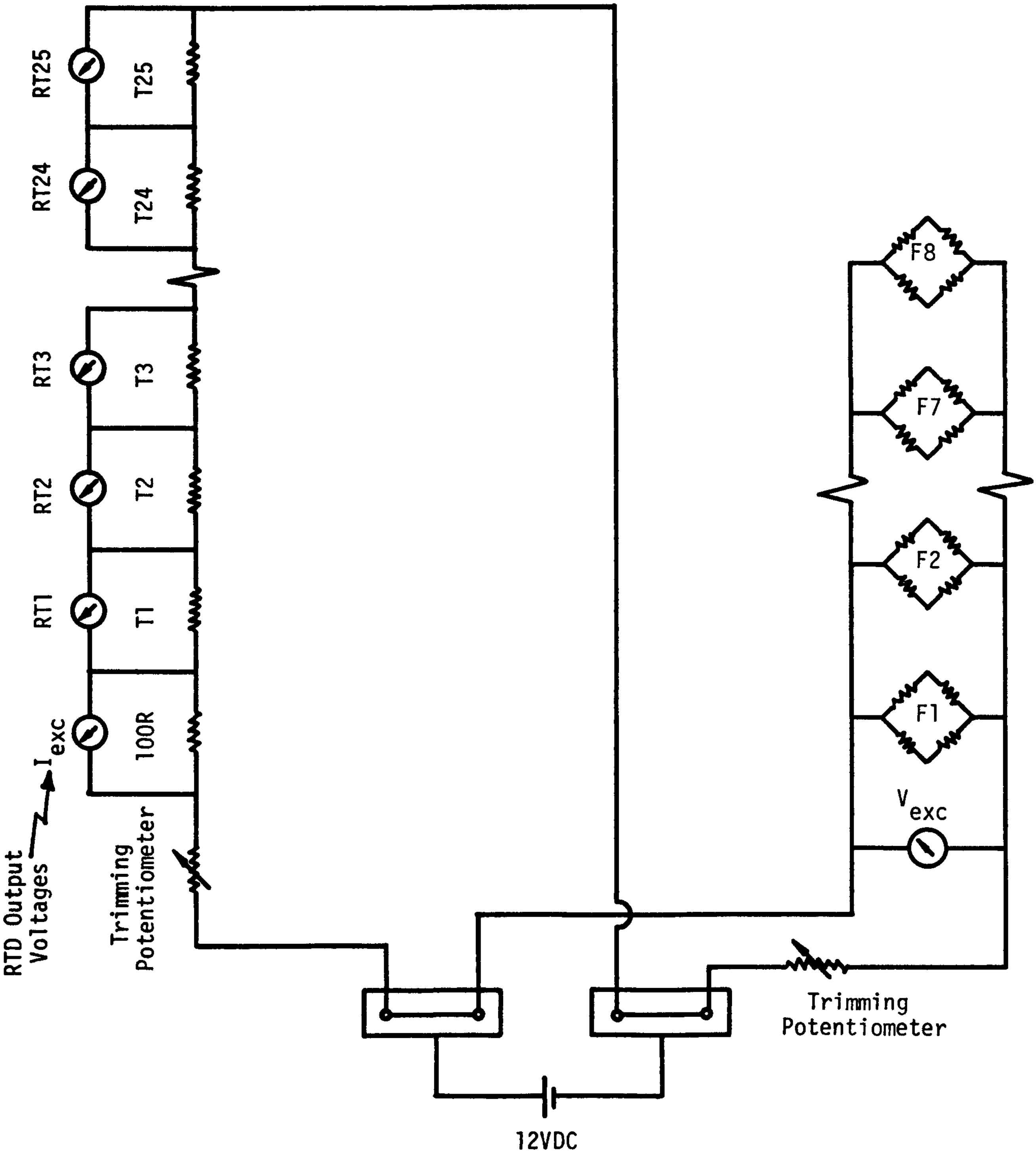


Figure 5. RTD and Flowmeter Excitation Circuits

20-gauge stranded copper conductor used is 9.4 ohms per 1000 feet. Considering the 350-ohm input impedance of each flow meter, an error of approximately 0.27% would result for a flow meter located 50 feet from the power supply. All flow meters in the equipment building are within this distance. However, 1 flow meter is located approximately 250 feet from the power supply in the building's laundry room. This length of 2 conductors would result in a 1.3% error, so an appropriate correction to the excitation voltage was made in the data analyses for that flow meter.

The wind speed sensor, as described above, produces an AC voltage proportional to wind speed. To make this signal compatible with the data acquisition system used, a full-wave rectifier circuit was fabricated. This circuit also included a voltage divider to give a 1mv/mph output.

3.4 DATA ACQUISITION SYSTEM

The data acquisition system used in this study consisted of a Fluke model 2240A Data Logger* and a Tektronix model 4923 Digital Cartridge Tape Recorder.

3.4.1 Data Logger

The Fluke data logger has the capability to monitor up to 60 channels of input data, and to output data on a digital display, internal adding machine type printer, any exterior RS 232 compatible recorder, or

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* It is to be noted that a Hewlett Packard 3052A Data Acquisition System was to be used in this project; however, extensive delays in its procurement resulted in using the Fluke instrument in the interim. The Hewlett Packard system was installed and became operational in January 1980.

any combination of these. The instrument includes a front-mounted control panel, a digital display, a digital printer, input locations for 6 input blocks of 10 analog signals each, and an output for use with digital recording equipment. The front panel controls are essentially push button switches divided into functional groups: one is the keyboard for command data entry, a second dictates what will be shown on the digital display, and another designates the scan format. Other control groups are used to set instrument ranges to be used and to determine what data is to be output to the digital printer or external recorder.

Measurement ranges available on the data logger vary from $\pm$40 mv (1 μv resolution) to $\pm$40 v (1 mv resolution). The input impedance of the data logger is greater than 200 mΩ, and total system accuracy is $\pm$(0.02% reading + 0.01% F.S. + 5 μv) or better for each range used.

3.4.2 Digital Tape Recorder

The Tektronix Model 4923 Digital Cartridge Tape Recorder provides the capability for local storage of the digital output of the data logger. Data are recorded on digital tape cassettes with a nominal capacity of 200,000 bytes, or characters. The recorder operates in an increment drive fashion similar to that of 7- and 9-track magnetic tape drives. When in the "write" mode, data received are stored in an internal buffer until a full record of 128 characters is received. At this point, the tape is advanced and the one record is written on it. When outputting data, the data are read in increments as when writing, and data output is at a constant speed.

3.4.3 Sensor Connections and Options

As used in this study, the data acquistion system has the capacity to record 60 instrument readings at 15-minute intervals. This interval length was chosen to allow changing recorder tapes no more frequently than every 3 days. A total of 70 instrument outputs, excitation voltage levels, and excitation current levels could be measured. Since some instruments are used only for component evaluations, 4 optional combinations were decided on. This monitoring scheme allows all energy collected and consumed, all weather data, and all excitation levels to be recorded using 53 of the 60 available channels. The remaining 7 channels can contain any of 4 combinations of instrument readings, as chosen by placing individual connector blocks of input channels into the data logger. The input block in use is indicated by a "fixed data" value in the outputted data, which is entered on the data logger front keyboard.

The 4 optional groups of instrument outputs are used to evaluate system losses, chiller performance, front collector bank (25° tilt) performance, and rear collector bank (30° tilt) performance. The instrument outputs connected to each of the 60 channels, the optional input groups, and the instrument ranges used for each instrument are given in Table 2.

3.4.4 Recorded Data Format

Data as output by the data logger and recorded by the Tektronix recorder are stored in blocks as shown in Table 3. The data are preceded by a date code and time-of-day (hours, minutes, and seconds separated by colons). After a blank line, the "Fixed Data" value is written which

Table 2. Data Logger Connections and Ranges

CHANNEL	RANGE	DESIGNATION	INSTRUMENT DESCRIPTION/LOCATION
0	400 mv	E1	Collector pump (P1) power
1	"	E2	Air conditioning pump (P2) power
2	"	E5	Domestic hot water recirc. pump (P6) power
3	"	E8	Overall equipment power
4	"	E9	Laundry water heater power
5	"	E10	Apt. water heater power, Apt. A
6	"	E11	" Apt. B
7	"	E12	" Apt. C
8	"	E13	" Apt. D
9	"	E14	" Apt. E
10	"	E15	" Apt. F
11	"	E16	" Apt. J
12	"	E17	" Apt. K
13	"	E18	" Apt. L
14	"	E19	" Apt. M
15	"	E20	" Apt. N
16	"	E21	" Apt. P
17	"	E22	Apartment ACHV power, Apt. A
18	"	E23	" Apt. B
19	"	E24	" Apt. C
20	"	E25	" Apt. D
21	"	E26	" Apt. E
22	"	E27	" Apt. F
23	"	E28	" Apt. J
24	"	E29	" Apt. K
25	"	E30	" Apt. L
26	"	E31	" Apt. M
27	"	E32	" Apt. N
28	"	E33	" Apt. P
29	"	W1	Wind speed
30	"	W2	Ambient dew point
31	40 mv	W3	Pyranometer
32	"	W4	Pyrheliometer
33	40 v	Vexc	Flow meter excitation voltage
34	400 mv	Iexc	RTD excitation current
35	40 mv	F1	Collector loop flow rate
36	"	F3	Domestic hot water make-up flow rate
37	"	F4	Laundry water supply flow rate
38	"	F6	Air conditioning loop flow rate
39	400 mv	T1	Collector loop inlet temperature
40	"	T2	Collector loop outlet temperature
41	"	T7	Hot storage tank top temperature
42	"	T8	Hot storage tank middle temperature
43	"	T9	Hot storage tank bottom temperature
44	"	T10	Cold storage tank top temperature
45	"	T11	Cold storage tank bottom temperature
46	"	T12	Domestic hot water supply temperature
47	"	T13	Domestic hot water make-up temperature
48	"	T14	Laundry hot water supply temperature
49	"	T17	Air conditioning loop supply temperature
50	"	T18	Air conditioning loop return temperature
51	"	T19	Chiller cold exit temperature
52	"	T24	Ambient air temperature

Table 2 (cont'd) Data Logger Connections and Ranges

CHANNEL	RANGE	DESIGNATION	INSTRUMENT DESCRIPTION/LOCATION
Option 1--for measuring tank losses, system losses			
53	400 mv	T15	Domestic hot water heat exchanger inlet temp.
54	"	T16	Domestic hot water heat exchanger exit temp.
55	"	T20	Chiller hot water inlet temperature
56	"	T21	Chiller hot water outlet temperature
57	"	T25	Room air temperature
58	"	F5	Domestic hot water heat exchanger flow rate
59	"	F7	Chiller hot water flow rate
Option 2--for evaluating chiller efficiency			
53	400 mv	E3	Chiller hot water pump (P4) power
54	"	E4	Chiller condensing water pump (P3) power
55	"	E6	Cooling tower fan power
56	"	E7	Chiller power
57	"	T20	Chiller hot water inlet temperature
58	"	T21	Chiller hot water outlet temperature
59	"	F7	Chiller hot water flow rate
Option 3--for evaluating rear collector bank (30° tilt) efficiency			
53	400 mv	E3	Chiller hot water pump (P4) power
54	"	E4	Chiller condensing water pump (P3) power
55	"	E6	Cooling tower fan power
56	"	T7	Chiller power
57	"	T5	Rear collector bank inlet temperature
58	"	T6	Rear collector bank exit temperature
59	"	F2B	Rear collector bank flow rate
Option 4--for evaluating front collector bank (25° tilt) efficiency			
53	400 mv	E3	Chiller hot water pump (P4) power
54	"	E4	Chiller condensing water pump (P3) power
55	"	E6	Cooling tower fan power
56	"	E7	Chiller power
57	"	T3	Front collector bank inlet temperature
58	"	T4	Front collector bank exit temperature
59	"	F2A	Front collector bank flow rate

Table 3. Sample Data Acquisition System Output

000:00:06:34

000001

0 000000000

+ 0.04	+ 0.01	+ 28.27	+ 8.00	- 0.00
+ 0.05	+ 0.00	+ 0.06	- 0.11	- 0.00
+ 57.62	+ 0.07	+ 0.02	+ 0.11	- 0.06
+ 58.05	- 0.02	- 0.01	+ 0.08	+ 0.01
+ 0.02	- 0.01	+ 0.01	+ 0.00	- 0.00
+ 0.03	+ 0.00	+ 0.03	+ 0.04	+ 0.65
- 0.07	+ 2.84	+ 7.13	+ 8.592	+187.20
- 0.22	+ 0.00	+ 0.10	+ 0.20	+222.94
+231.12	+223.67	+223.35	+222.31	+194.80
+190.93	+208.53	+ 0.06	+202.82	+195.82
+195.02	+194.33	+204.30	+217.85	+209.95
+194.70	+196.26	+204.35	+ 0.03	- 0.01

000:00:07:04

000001

0 000000000

+ 0.03	+ 0.01	+ 28.46	+ 8.01	- 0.00
+ 0.05	+ 0.00	+ 0.06	- 0.11	- 0.00
+ 57.53	+ 0.06	+ 0.01	+ 0.06	+ 0.00
- 0.12	- 0.01	- 0.01	+ 0.08	+ 0.01
+ 0.02	- 0.01	+ 0.00	- 0.00	- 0.01
+ 0.03	+ 0.00	+ 0.04	+ 0.04	- 1.15
- 0.66	+ 2.80	- 3.97	+ 8.592	+187.19
- 0.23	- 0.00	+ 0.10	+ 0.20	+222.93
+231.12	+223.68	+223.34	+222.30	+194.80
+193.94	+208.51	+ 0.05	+202.74	+195.84
+194.99	+194.33	+204.84	+217.96	+209.98
+194.71	+196.26	+204.37	+ 0.03	- 0.01

identifies the optional group (option 1 in this case) allocated to the last 7 data channels. Then follows 1 line of meaningless zeroes and 12 lines each containing the outputs of 5 input channels. These 60 values are in the sequence given in Table 2.

4. DATA REDUCTION

As described in Section 3, collected data were stored initially as instrument output voltages on digital tape cartridges. The process to convert that information into temperatures, flow rates, and weather data, and finally to process that data into energy flows and daily summaries is described below.

4.1 COMPUTER SYSTEM

All data processing was done in the Department of Mechanical Engineering's Computer Application Laboratory (CAL), which has a number of microprocessor devices, several access lines to the University's CDC 6000 computers, and a Digital Equipment Corporation Model PDP 11/40 minicomputer system. It is the latter device that was used for all data processing.

The PDP 11/40 consists of a central processor with 32K bytes of core memory, one nonremovable 12.5-megabyte storage disc, and two disc drives that accept removable disc cartridges with a 12.5-megabyte capacity each. The system also utilizes a cassette tape drive, a 138-column line printer, and a CRT operator console. This computer has the capability to accept digital data from one additional external device. In this configuration, data stored on any device can be used as input for a computer program, and program output can be directed to any device (i.e., line printer, disc storage, CRT display, etc.).

4.2 DATA HANDLING

The first step in the reduction of raw data was to transfer information from the digital tape cartridges to disc storage. As the PDP system currently stands, there is not a device that is compatible with the 3M data cartridges used by the Tektronix recorder. Therefore, it was necessary to physically remove the recorder from the data acquisition system, transport it to the CAL location, and use it as a tape drive connected to the external input described above for the PDP 11/40. With this task done, the tape cartridges were played and the output transferred to disc storage.

This process was repeated after each two-to-three-week period. After the data transfer, the Tektronics recorder was moved back to the data acquisition system location, reconnected, and data acquisition was resumed. The process described resulted in a loss of approximately 8 to 10 hours of data each month.

4.3 DATA REDUCTION PROGRAMS

Reduction of data was done in 3 steps. First, raw data transferred from the tape cartridges to disc storage were converted from instrument output voltages to temperatures, flow rates, solar flux, wind speed, or electric power consumption using computer program "DACØNV." These data, in engineering units, were stored on disc to be used for further processing.

These engineering data were then processed to obtain system performance and ambient weather summaries, as well as component performance data. System performance and weather summaries were produced with program "DASUM." Solar collector array performance data were generated with the program "COLEFF," absorption chiller performance with "CHEFF," and hot and cold storage tank loss coefficients using "LOSS."

4.3.1 Raw Data Conversion

The first processing of the raw data, once on disc storage, was to convert the raw data into engineering units. Using program "DACØNV," raw data in the format shown in Table 3 were read from disc storage and converted to engineering units. The complete data set, with identifying date, time, and "fixed data" parameter, is output to permanent file disc storage in a compact format.

The computer program "DACØNV" contains all instrument calibration data, which are stored in the form of millivolt per kilowatt (kw) conversion factors for each watt transducer; millivolt per volt excitation to gallon per minute conversion factors for each flow meter; flow meter zero offset valves; temperature sensor ice point resistances and resistance to temperature conversion factors; pyranometer and pyrheliometer millivolt per unit solar flux factors; wind speed sensor calibration factor; and humidity instrument calibration factors. These calibration data in conjunction with the equations listed in Table 4, are used by "DACØNV" for the conversion to engineering units. These processed data use approximately 60% of the storage space required for the raw data.

4.3.2 Data Summaries

Further processing was required to change the instantaneous instrument readings into integrated energy flows and averaged ambient weather data. This step was done by program "DASUM," which uses the permanent file data from "DACØNV" to produce the following data summaries:

Table 4. Equations Used for Conversion of Instrument Output Signal to Engineering Units

Instrument	Calibration Data Used	Instrument Readings	Equation
Temperature Sensors	TZERO (ice point resistance, ohms) TCONV (resistance to temperature conversion factor, ohm/ohm °C)	RT (millivolt output) IEXC (excitation current)	$T(°F) = \left[\frac{\left(\frac{RT}{IEXC} - TZERO\right)}{TCONV \times TZERO} \times (9/5)\right] + 32$
Watt meters	ECONV (kilowatt per millivolt output)	RE (millivolt output)	$E(kw) = RE \times ECONV$
Flow meters	FZERO (instrument zero offset, millivolt/volt) FCONV $\left(\text{gallon per minute per } \sqrt{\frac{\text{millivolt output}}{\text{excitation voltage}}}\right)$	RF (millivolt output) VEXC (excitation voltage)	$F(gpm) = \left(\sqrt{\frac{RF}{VEXC}} - FZERO\right) \times FCONV$
Pyranometer, Pyrheliometer	WCONV ($Btu/Hr\text{-}Ft^2$ per millivolt signal)	RW (millivolt output)	$W\left[Btu/(Hr\text{-}Ft^2)\right] = RW \times WCONV$
Wind Speed Sensor	WCONV (miles per hour per millivolt signal)	RW (millivolt output)	$W(mph) = RW \times WCONV$
Humidity Instrument	Third order polynomial curve fit for converting millivolt output to dewpoint temperature, °C	RW (millivolt output)	$W(dewpoint, °F) = \left[\left(-10.23 + 1.43(RW) - 0.02(RW)^2 + 0.01(RW)^3 \times 9/5\right] + 32$

- Ambient weather
- Building energy consumption
- Solar energy system heat balance
- Parasitic power consumption

Each of these consists of a table of calculated, integrated, or averaged hourly data and day-long summaries for each day of data acquisition. Examples of each summary are shown in Tables 5, 6, 7, and 8.

In the ambient weather summary (Table 5), average ambient temperature, absolute humidity, wind speed, total solar flux incident on a horizontal surface, and direct-beam solar radiation values are listed for each hour of the day. These values are integrated averages of data taken within a one-hour period. At the bottom of the table integrated averages of ambient temperature, wind speed, and absolute humidity for the entire day are listed, as well as instantaneous maximum and minimum values measured for each of these 5 parameters. Also listed are the total radiation on a horizontal surface (Btu per ft^2) and the direct-beam radiation (Btu per ft^2) for the 24-hour period.

Energy consumed in the apartment building for heating, air conditioning, and domestic hot water is summarized in the building energy consumption summary (Table 6). Energy consumption is divided into that used for apartment heating and/or air conditioning, apartment domestic hot water, laundry room domestic hot water, and composites of these. Integrated totals for each category are given for each hour and also for each day. Instantaneous maximum and minimum values for each item are also listed in Btu's per hour. These energy consumption values are categorized in terms of the portion met by the conventional

Table 5. Example Ambient Weather Summary

AMBIENT WEATHER
DATE 8/ 6/79

TIME	AMBIENT TEMP, F	ABS HUM, GR/LB	WIND SP, MPH	SOLAR FLUX BTU/(HR-SQFT) TOTAL	DIRECT
0100	82 4	50 6	3 1	0 0	0 0
0200	81 4	51 1	2 9	0 0	0 0
0300	80 6	51 5	1 8	0 0	0 0
0400	79 0	51 4	1 5	0 0	0 0
0500	77 6	51 1	0 4	0 0	0 0
0600	76 6	51 2	0 0	0 0	0 0
0700	75 8	51 0	0 0	0 0	0 0
0800	78 0	50 8	0 0	14 1	44 6
0900	88 5	51 5	0 8	69 3	154 2
1000	93 3	51 1	1 4	135 1	207 5
1100	90 9	50 6	3 0	196 4	234 7
1200	93 4	49 5	3 9	251 0	248 1
1300	94 2	49 1	2 9	283 9	254 3
1400	95 4	49 2	4 6	304 2	257 6
1500	96 2	48 8	8 7	302 1	254 1
1600	96 3	48 4	5 1	250 0	205 8
1700	96 5	48 2	3 5	243 1	223 9
1800	95 8	48 5	5 9	180 3	209 2
1900	94 2	48 3	2 6	107 3	178 5
2000	92 3	48 2	3 7	39 8	120 1
2100	89 0	47 7	2 1	2 3	20 7
2200	85 5	49 5	0 5	0 0	0 0
2300	83 0	50 0	0 7	0 0	0 0
2400	81 7	50 4	1 3	0 0	0 0
MEAN	87 4	49 9	2 5	--	--
MAX	98 2	51 9	10 8	312 2	259 8
MIN	75 1	47 3	0 0	0 0	0 0
TOTAL	--	--	--	2344 1	2585 9

Table 6. Example Building Energy Consumption Summary

BUILDING ENERGY CONSUMPTION
DATE 8/ 6/79

TIME	APARTMENTS H/AC ENERGY CONSUMPTION, KBTU				DHW ENERGY CONSUMPTION, KBTU — APARTMENTS				DHW ENERGY CONSUMPTION, KBTU — LAUNDRY ROOM				DHW ENERGY CONSUMPTION, KBTU — COMPOSITE				COMPOSITE, KBTU			
	CONV	SOLAR	TOTAL	PCT	CONV	SOLAR	TOTAL	PCT	CONV	SOLAR	TOTAL	PCT	CONV	SOLAR	TOTAL	PCT	CONV	SOLAR	TOTAL	PCT
0100	76.3	0.0	76.3	0.0	3.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	3.0	0.0	79.3	0.0	79.3	0.0
0200	53.4	0.0	53.4	0.0	0.0	0.0	0.0	0.0	76.3	0.0	76.3	0.0	76.3	0.0	76.3	0.0	129.7	0.0	129.7	0.0
0300	54.9	0.0	54.7	0.0	3.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	3.0	0.0	57.9	0.0	57.9	0.0
0400	34.1	0.0	34.1	0.0	3.1	0.0	3.1	0.0	0.0	0.0	0.0	0.0	3.1	0.0	3.1	0.0	37.2	0.0	37.2	0.0
0500	34.9	0.0	34.9	0.0	3.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	3.0	0.0	37.9	0.0	37.9	0.0
0600	45.0	0.0	45.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	45.0	0.0	45.0	0.0
0700	35.2	0.0	35.2	0.0	6.9	0.0	6.9	0.0	0.0	0.0	0.0	0.0	6.9	0.0	6.9	0.0	42.2	0.0	42.2	0.0
0800	28.8	0.0	28.8	0.0	12.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0	12.0	0.0	40.7	0.0	40.7	0.0
0900	22.1	0.0	22.1	0.0	11.7	0.0	11.7	0.0	0.0	0.0	0.0	0.0	11.7	0.0	11.7	0.0	33.9	0.0	33.9	0.0
1000	21.0	0.0	21.0	0.0	19.5	0.0	19.5	0.0	0.0	0.0	0.0	0.0	19.5	0.0	19.5	0.0	40.5	0.0	40.5	0.0
1100	37.5	0.0	37.5	0.0	6.1	0.0	6.1	0.0	0.0	0.0	0.0	0.0	6.1	0.0	6.1	0.0	43.6	0.0	43.6	0.0
1200	28.5	0.0	28.5	0.0	13.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0	13.0	0.0	13.0	0.0	41.5	0.0	41.5	0.0
1300	37.8	2.2	40.0	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37.8	2.2	40.0	5.6
1400	2.1	23.3	25.4	91.8	8.7	0.0	8.7	0.0	74.1	0.0	74.1	0.0	82.7	0.0	82.7	0.0	84.8	23.3	108.1	21.5
1500	1.0	23.0	24.0	96.0	7.9	0.0	7.9	0.0	0.0	0.0	0.0	0.0	7.9	0.0	7.9	0.0	8.9	23.0	31.9	72.2
1600	1.4	31.2	32.5	95.7	9.8	0.0	9.8	0.0	0.0	0.0	0.0	0.0	9.8	0.0	9.8	0.0	11.2	31.2	42.3	73.6
1700	1.0	26.3	27.4	96.2	0.0	0.0	0.0	0.0	75.3	0.0	75.3	0.0	75.3	0.0	75.3	0.0	76.3	26.3	102.6	25.7
1800	1.8	35.8	33.5	95.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	36.8	38.5	95.4
1900	4.4	72.0	76.5	94.2	12.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0	12.0	0.0	16.4	72.0	88.4	81.5
2000	3.9	44.0	47.9	91.9	2.9	0.0	2.9	0.0	0.0	0.0	0.0	0.0	2.9	0.0	2.9	0.0	6.8	44.0	50.8	86.7
2100	28.3	19.8	48.1	41.2	2.9	0.0	2.9	0.0	0.0	0.0	0.0	0.0	2.9	0.0	2.9	0.0	31.2	19.8	51.0	38.9
2200	64.2	0.0	64.2	0.0	9.7	0.0	7.7	0.0	0.0	0.0	0.0	0.0	9.7	0.0	9.7	0.0	73.9	0.0	73.9	0.0
2300	68.9	0.0	68.9	0.0	11.9	0.0	11.9	0.0	0.0	0.0	0.0	0.0	11.9	0.0	11.9	0.0	80.8	0.0	80.8	0.0
2400	56.7	0.0	56.7	0.0	13.8	0.0	13.8	0.0	0.0	0.0	0.0	0.0	13.8	0.0	13.8	0.0	70.5	0.0	70.5	0.0
MAX	105.4	71.6	105.4	--	31.7	0.0	31.7	--	305.4	0.0	305.4	--	305.4	0.0	305.4	--	376.9	71.6	376.9	--
MIN	0.0	0.0	0.0	--	0.0	0.0	0.0	--	0.0	0.0	0.0	--	0.0	0.0	0.0	--	0.0	0.0	0.0	--
TOTAL	743.0	278.7	1021.7	27.3	160.9	0.0	160.9	0.0	225.7	0.0	225.7	0.0	386.6	0.0	386.6	0.0	1129.6	278.7	1408.3	19.8

Table 7. Example Solar Energy System Heat Balance

SOLAR ENERGY SYSTEM HEAT BALANCE
DATE 8/ 6/79

	ENERGY COLLECTION, KBTU			ENERGY DELIVERED, KBTU				STORAGE ADDED, KBTU		
TIME	AVLBL	COLL	PCT COLL	H/AC	DHW APTS	DHW LDRY	TOTAL	HOT	COLD	LOSSES
0100	0 0	0 0	0 0	0 0	0 0	0 0	0 0	-4 9	1 5	3 5
0200	0 0	0 0	0 0	0 0	0 0	0 0	0 0	-9 4	0 7	8 8
0300	0 0	0 0	0 0	0 0	0 0	0 0	0 0	-7 5	0 6	6 9
0400	0 0	0 0	0 0	0 0	0 0	0 0	0 0	-9 3	0 5	8 8
0500	0 0	0 0	0 0	0 0	0 0	0 0	0 0	-6 5	-0 3	6 7
0600	0 0	0 0	0 0	0 0	0 0	0 0	0 0	-8 0	1 0	7 0
0700	0 0	0 0	0 0	0 0	0 0	0 0	0 0	-8 0	0 3	7 7
0800	55 4	0 0	0 0	0 0	0 0	0 0	0 0	-20 6	-1 0	21 6
0900	191 5	0 0	0 0	0 0	0 0	0 0	0 0	-3 9	0 3	3 5
1000	244 0	20 2	8 3	0 0	0 0	0 0	0 0	-46 5	1 1	65 5
1100	271 4	113 8	39 0	0 0	0 0	0 0	0 0	113 4	1 0	-0 6
1200	308 1	130 1	42 2	0 0	0 0	0 0	0 0	146 2	0 8	-16 9
1300	315 8	137 9	43 7	2 2	0 0	0 0	2 2	91 3	5 3	39 1
1400	319 9	146 4	45 8	23 3	0 0	0 0	23 3	27 9	-39 9	135 1
1500	315 7	149 2	47 3	23 0	0 0	0 0	23 0	-2 9	-33 2	162 3
1600	255 6	134 1	52 5	31 2	0 0	0 0	31 2	-8 4	-21 0	132 4
1700	267 4	125 3	46 8	26 3	0 0	0 0	26 3	41 8	-0 8	57 9
1800	194 9	90 3	46 4	36 8	0 0	0 0	36 8	-28 0	3 2	78 3
1900	277 1	71 3	25 7	72 0	0 0	0 0	72 0	-57 6	18 4	38 5
2000	149 1	0 0	0 0	44 0	0 0	0 0	44 0	-125 7	15 8	65 8
2100	25 8	0 0	0 0	19 8	0 0	0 0	19 8	-54 9	30 2	4 9
2200	0 0	0 0	0 0	0 0	0 0	0 0	0 0	-3 5	5 6	-2 1
2300	0 0	0 0	0 0	0 0	0 0	0 0	0 0	-9 4	3 0	6 4
2400	0 0	0 0	0 0	0 0	0 0	0 0	0 0	-7 5	2 0	5 5
MAX	322 6	150 5	52 5	71 6	0 0	0 0	71 6	183 6	56 0	264 0
MIN	0 0	0 0	0 0	0 0	0 0	0 0	0 0	-185 1	-45 3	-68 7
TOTAL	3211 7	1118 6	34 8	278 7	0 0	0 0	278 7	-1 9	-4 8	846 6

Table 8. Example Parasitic Power Consumption Summary

PARASITIC POWER CONSUMPTION
DATE 8/ 6/79

TIME	COLLECTION SYSTEM KBTU COLLECTED	COLLECTION SYSTEM PAR PWR, KBTU EQ	COLLECTION SYSTEM PCT	H/AC SYSTEM KBTU DELIVERED	H/AC SYSTEM PAR PWR, KBTU EQ	H/AC SYSTEM PCT	DHW SYSTEM KBTU DELIVERED	DHW SYSTEM PAR PWR, KBTU EQ	DHW SYSTEM PCT	TOTAL SYSTEM KBTU DELIVERED	TOTAL SYSTEM PAR PWR, KBTU EQ	TOTAL SYSTEM PCT
0100	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 070	99 90
0200	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 092	99 90
0300	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 000	0 00	0 0	1 186	99 90
0400	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 000	0 00	0 0	2 133	99 90
0500	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 000	0 00	0 0	2 133	99 90
0600	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 000	0 00	0 0	1 068	99 90
0700	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 020	99 90
0800	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 000	0 00	0 0	1 988	99 90
0900	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 000	0 00	0 0	3 701	99 90
1000	20 2	0 580	2 87	0 0	0 000	0.00	0 0	0 000	0 00	0 0	5 704	99 90
1100	113 8	2 267	1 99	0 0	0 000	0 00	0 0	0 000	0 00	0 0	9 575	99 90
1200	130 1	2 253	1 73	0 0	0 000	0 00	0 0	0 000	0 00	0 0	7 556	99 90
1300	137 9	2 232	1 62	2 2	3 294	147 58	0 0	0 000	0 00	2 2	16 466	737 58
1400	146 4	2 235	1 53	23 3	12 869	55 24	0 0	0 000	0 00	23 3	36 727	157 65
1500	149 2	2 212	1 48	23 0	12 902	56 08	0 0	0 000	0 00	23 0	35 690	155 13
1600	134 1	2 232	1 66	31 2	12 946	41 56	0 0	0 000	0 00	31 2	36 808	118 41
1700	125 3	2 152	1 72	26 3	12 032	45 70	0 0	0 000	0 00	26 3	32 706	124 23
1800	90 3	1 671	1 85	36 8	9 743	26 51	0 0	0 000	0 00	36 8	26 286	71 51
1900	71 3	1 691	2 37	72 0	16 347	22 69	0 0	0 000	0 00	72 0	42 057	58 37
2000	0 0	0 000	0 00	44 0	13 035	29 61	0 0	0 000	0 00	44 0	27 661	62 83
2100	0 0	0 000	0 00	19 8	5 546	27 94	0 0	0 000	0 00	19 8	17 153	86 43
2200	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 000	0 00	0 0	1 356	99 90
2300	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 000	0 00	0 0	1 080	99 90
2400	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 000	0 00	0 0	2 800	99 90
MAX	150 5	2 320	2 87	71 6	13 178	147 58	0 0	0 000	0 00	71 6	39 268	737 58
MIN	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 000	0 00	0 0	0 000	58 37
TOTAL	1118 6	19 526	1 75	278 7	98 714	35 42	0 0	0 000	0 00	278 7	312 095	111 99

equipment, the portion met by solar, and the percentage of each energy flow category that was delivered by the solar energy system.

The solar heating and air conditioning energy flow is calculated using the air conditioning loop supply temperature (T17) and return temperature (T18), and air conditioning loop water flow rate (F6). Laundry room domestic hot water energy flow is calculated using the laundry room water supply temperature (T14), the water main supply temperature (T13), and the laundry room hot water supply flow rate (F4). The total energy supplied for domestic hot water is determined from the temperature difference between the recirculation loop supply temperature (T12) and the water main supply temperature (T13), and the domestic hot water system make-up flow (F3). The difference between the total energy supplied for domestic hot water and the laundry room domestic hot water is that delivered to the apartments.

Unlike the method used above to calculate the quantity of solar heating and air conditioning, several distinctions must be made to calculate the energy supplied by the conventional air conditioning (cooling and/or heating) equipment. In the conventional electrical resistance space heating mode the conversion of electrical energy to thermal energy is one-to-one. For air conditioning, the power to the conventional air conditioning equipment results in a cooling effect equivalent to the energy efficiency ratio (EER) for that equipment.

From actual measurements of power consumption by the heating and air conditioning equipment it was found that both the solar fan and the conventional fan in each apartment draw approximately 0.5 kw of electricity. The conventional air conditioner, consisting of both the fan unit and compressor unit, draw approximately 4 kw. The space heating resistance heater strips and fan draw 8 to 10 kw.

From these values, logic can be used in data processing to distinguish between conventional heating and conventional air conditioning. A distinction between the solar fan operating and conventional fan only operation is not possible with the instrumentation installed. If an additional 12 channels of data could be recorded, electrical signals from the solar fan elapsed time clocks installed in the solar equipment room could be used to make the distinction. Because of this limitation it has been assumed in the current data analysis that no operation of the air conditioning fan alone is done.

A final consideration is how to handle solar fan power in the energy accounting system used. Energy consumed by the fan is transferred to the air being circulated. This effect is taken into account in measuring the EER of a conventional air conditioner. In both conventional and solar space heating this can be considered as part of the heating effect delivered by conventional power. In solar air conditioning the fan power reduces the cooling effect and is also an expenditure of parasitic power.

In light of the above, conventional heating is distinguished by a power consumption rate above 6 kw and is assigned an EER of 3.412 (each watt of electricity is equivalent to 3.412 Btu). Conventional air conditioning is recognized by a power consumption rate between 1 and 6 kw and is assigned an EER of 6.0. This value is fairly low for new equipment, but is fairly representative of air conditioners produced in the early 1970's, which are the ones in place. Specification data on the existing units indicate an EER of approximately 6.4; however, since they have been installed for several years, an EER of 6.0 is used. Any power consumption rate below 1 kw represents either conventional fan only or the solar fan, but for reasons stated above is assumed to be the solar fan. The power measured is subtracted from the cooling effect and is treated as parasitic power consumption. The totals listed in the energy consumption summary table are the sums for the 12 apartments.

Conventional energy consumed for domestic hot water production is calculated from electric consumption by each water heater and is assigned an efficiency of unity. The values listed in the table for the apartments are the composites for the 12 apartments, which are calculated from E10 through E21. Laundry domestic hot water energy is the electric consumption measured by E9.

The maximum and minimum values listed are the extreme instantaneous values measured and the totals are for the 24-hour period.

The solar energy system heat balance summary shown in Table 7 indicates the energy available for collection, the energy actually collected, and the end to which the collected energy was used. Available energy is calculated as the direct beam solar radiation within the hour-long period multiplied by the collector array total aperture area. This scheme considers energy available as that which would be incident on the collectors if they were directed normal to the beam radiation.* Energy

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* Note that this method differs, intentionally, from that used when measuring "collector efficiency," which is based on radiation actually incident on a collector.

collected is calculated using the collector array inlet temperature (T1), return termperature (T2), and the collector loop water flow rate(F1). The energy delivered parameters are those described for the building energy consumption summary.

Energy added to storage is found by taking the difference in amounts of energy in storage between successive readings. This difference is converted to a rate using the time elapsed between the successive readings. The amount of energy in the hot storage tank is calculated as the tank temperature minus 60°F mutiplied by the tank volume and appropriate conversion factors. The hot tank temperature is a volume-weighted average calculated from the 3 hot tank temperatures measured (T7, T8, T9). The amount of storage in the cold water tank is defined as 60°F minus the tank temperature multiplied by the tank volume and conversion factors. Since the temperature sensors are mounted symmetrically on the tank, the cold storage tank temperature is calculated as the average of the 2 tank temperatures measured (T10, T11).

Losses are considered to be the difference between energy collected and the sum of energy delivered and storage added. This lumps the heat supplied to the chiller and rejected by the cooling tower in with thermal losses by the system. In a sense this value is a loss in that it is energy collected that is not delivered, but it is an intentional loss, unlike thermal losses from storage. With the instrumentation currently installed, the chiller heat flows are not monitored constantly; consequently, the thermal energy rejected from the chiller cannot be measured at all times.

As in the other summary tables, the maximum and minimum values of the energy flows and the 24 hour totals are listed.

The parasitic power consumption summary shown in Table 8 lists the energy collected, the heating and air conditioning energy delivered, the domestic hot water energy delivered; and the parasitic power associated with each energy flow. The total system parasitic power and the total energy delivered are also listed.

The parasitic power consumed by the heating and air conditioning equipment is comprised of power to the air conditioning pump (E2), chiller (E7), chiller condensor water pump (E4), chiller hot water supply pump (E3), cooling tower fan (E6), and the apartment solar fans (E22-33). The air conditioning pump power was monitored regardless of which optional input block was used in the data logger. The power consumption associated with the chiller, however, was not measured when block 1, used for measuring system losses, was in place. For this reason, it is not possible to debit some of these values to the heating and air conditioning system directly. The data reduction program substitutes average values for the chiller associated power when the air conditioning pump is operating and the ambient temperature is above 60°F, indicating that the chiller is in operation. As with the collector system, there are some control functions associated with the heating and air conditioning system that are accounted for only in the total system parasitic power. In comparison to the large power consumed by the chiller and associated pumps this other power consumption could be considered negligible.

The parasitic power consumption for the domestic hot water system consists of the power to the domestic hot water recirculating loop pump (E5). There are two control functions--a motor-operated valve (with temperature controller), and a timer for the recirculating pump--that are accounted for only in the total system parasitic power.

The total system parasitic power was calculated from the total power to the solar equipment room (E8). Electric power to the data acquisition system and the air conditioner for its enclosure were measured as part of E8. To compensate for this a constant value of 1.2 kw was subtracted. In addition to the parasitic power associated with the systems described above this power consumption value includes power to all controls and power to an exhaust fan for the equipment room.

4.3.3 Component Performance Programs

An important use of the information obtained in the performance monitoring process is to determine if individual pieces of equipment or individual subsystems within the solar energy system are performing as they were designed. Valuable system improvements could result from such information. Also, if a particular piece of equipment were to begin operating less than satisfactorily, performance measurements would indicate that a problem exists.

Three computer programs were written to calculate component performance data. These programs use the permanent file data generated by "DACØNV" to calculate collector array efficiency, chiller performance data, and storage tank loss coefficients.

Program "COLEFF" generates performance data for the entire solar collector array. It calculates pertinent energy flows and efficiency and its outputs are the data shown in Table 9. "COLEFF" reads data from the permanent file and checks several parameters before calculating collector efficiency data. Efficiency calculations are made only if the collector pump is running in both the set of data under inspection and at the time the previous set of datá was taken. This provides reasonable assurance that the collector pump had been running for 15 minutes. A flaw in this logic would occur if the collector pump cycled off then back on during the time between data acquisitions. This occurrence is very rare with the collector controls used.

Information calculated and output are the date, time-of-day, solar time, incidence angles for the front collector banks (25-degree tilt) and rear collector banks (30-degree tilt), composite incidence angle, incident energy, energy collected, efficiency, and parasitic power consumption. A useful parameter in collector efficiency correlations, $(T_{in} - T_{amb})/Q_{inc}$ designated as DT/QB, is also calculated and printed.

The angle of incidence of beam radiation is calculated using a relation for incidence to a cylindrical surface oriented along a north-south axis [10]. The tracking collectors used would have an angle of incidence identical to a long cylinder. To compensate for the 15-degree azimuth angle of the collector array, the incidence angle is calculated using an hour angle offset by 15 degrees.

The incident solar flux is calculated as the direct-beam radiation multiplied by the cosine of the angle of incidence and by the total collector area, 1242 square feet. The energy collected is calculated from the inlet (T1) and outlet (T2) temperatures and flow rate (F1). The efficiency is then calculated as the collected energy divided by the

Table 9. Example Output from "COLEFF"

COLLECTOR ARRAY EFFICIENCY CALCULATIONS

QINCIDENT QCOLLECTED, AND PARASITIC POWER ARE KBTU/HR
ALL TEMPERATURES ARE DEGREES F
QBEAM IS BTU/(HR-SQFT)

DATE	TIME	STIME	COS25	COS30	COSI	QBEAM	QINCIDENT	TAMB	TIN	TOUT	GPM	QCOLL	DT/QB	EFF	PAR PWR
7/17/79	11 59	10 27	0 991	0 978	0 984	155 2	189 54	99 1	148 8	153 9	47 69	122 42	0 325	0 65	2 35
7/17/79	12 14	10 42	0 979	0 978	0 978	261 2	317 13	97 7	151 9	157 4	47 25	131 22	0 212	0 41	2 35
7/17/79	12 29	10 57	0 961	0 978	0 970	205 6	247 52	99 7	152 4	158 6	47 72	148 29	0 264	0 60	2 28
7/17/79	12 44	11 12	0 957	0 978	0 968	265 2	318 60	97 7	153 5	159 7	47 49	147 10	0 217	0 46	2 34
7/17/79	12 59	11 27	0 973	0 978	0 975	264 8	320 57	97 9	154 5	160 6	46 80	143 79	0 219	0 45	2 29
7/17/79	13 14	11 42	0 988	0 978	0 983	263 7	321 61	97 7	155 6	161 3	47 52	134 59	0 224	0 42	2 33
7/17/79	13 29	11 57	0 992	0 978	0 985	190 2	232 35	100 0	156 0	162 5	47 43	154 51	0 299	0 66	2 33
7/17/79	13 44	12 12	0 985	0 978	0 981	264 1	321 64	98 3	157 1	163 3	47 32	148 23	0 227	0 46	2 31
7/17/79	13 59	12 27	0 960	0 978	0 973	172 5	208 36	99 8	158 1	164 3	47 11	147 81	0 347	0 71	2 32
7/17/79	14 14	12 42	0 956	0 978	0 967	167 4	200 95	100 0	159 1	165 4	47 53	149 13	0 365	0 74	2 33
7/17/79	14 29	12 57	0 965	0 978	0 972	232 1	279 72	100 3	160 0	166 4	46 87	150 81	0 265	0 54	2 27
7/17/79	14 44	13 12	0 933	0 978	0 930	255 3	310 56	98 6	161 0	166 2	47 33	123 05	0 249	0 40	2 32
7/17/79	14 59	13 27	0 992	0 978	0 984	191 6	234 11	99 9	162 0	168 4	47 17	151 30	0 329	0 65	2 31
7/17/79	15 14	13 42	0 990	0 978	0 983	257 5	314 20	99 0	162 9	169 3	47 05	150 92	0 252	0 48	2 25
7/17/79	15 29	13 57	0 976	0 978	0 977	253 4	307 22	99 5	163 9	170 0	47 38	142 96	0 260	0 47	2 30
7/17/79	15 44	14 12	0 959	0 978	0 969	249 0	299 39	100 0	164 8	170 9	47 26	144 02	0 269	0 48	2 31
7/17/79	15 59	14 27	0 959	0 978	0 969	87 2	104 83	88 9	165 4	169 5	47 38	97 68	0 905	0 93	2 37
7/17/79	16 14	14 42	0 976	0 978	0 977	105 9	128 47	87 7	166 2	171 7	47 29	129 44	0 758	1 01	2 34
7/17/79	16 29	14 57	0 990	0 978	0 983	117 0	142 75	88 4	167 0	172 3	47 38	126 37	0 683	0 89	2 32
7/17/79	16 44	15 12	0 992	0 978	0 984	131 3	160 41	87 1	167 9	172 0	47 55	97 32	0 626	0 61	2 32
7/17/79	16 59	15 27	0 903	0 978	0 980	124 7	151 66	87 7	168 7	170 5	47 17	42 49	0 662	0 28	2 32

energy incident. The correlation parameter DT/QB (Hr Ft^2 °F/Btu) in Table 9 is the difference between the collector inlet temperature (T1) and the ambient temperature (T24) divided by the beam radiation and the cosine of its angle of incidence. The parasitic power consumption rate is the power to the collector loop pump (E1).

Performance data for the absorption chiller is calculated by "CHEFF," as shown in Table 10. "CHEFF" reads input data from the permanent file and calculates performance parameters from each data set if the fixed data parameter is 2 (which indicates the data logger optional input block for chiller efficiency calculations was in place), the chiller hot water supply pump (P7) was running, and the air conditioning pump (P2) was running. For each data point the values shown in Table 10 are calculated and output.

Hot water inlet (T20) and outlet (T21) temperatures and the hot water flow rate (F7) are used to calculate the hot water input energy rate. The chilled water inlet (T18) and outlet (T19) temperatures and the chilled water flow rate are used to determine the cooling effect. The heat rejected was not actually measured because of the limited number of measurements that could be recorded by the data logger. The heat rejected shown in Table 10 is calculated from the hot and cold water energy flows using an overall energy balance on the chiller.

The chiller C.O.P. is then calculated as the chiller cooling effect divided by the hot water heat input. The parasitic power consumption shown is the sum of the chiller power (E7), cooling tower fan power (E6), condensing water pump power (E4), chiller hot water pump power (E3), and air conditioning pump power (E2).

Table 10. Example Output from "CHEFF"

CHILLER C O P. CALCULATIONS

QHOT, QCOLD, AND QREJECTED ARE IN BTU/HR
QREJECTED IS CALCULATED AS QHOT+QCOLD
ALL TEMPERATURES ARE DEGREES F

DATE	TIME	HOT TIN	HOT TOUT	HOT GPM	QHOT	COLD TIN	COLD TOUT	COLD GPM	QCOLD	QREJ	COP	PAR. PWR
8/ 3/79	13 21	159 49	151. 02	30. 00	0. 127E 06	69. 07	65 33	48 93	0. 916E 05	0. 22E 06	0. 720	0. 131E 05
8/ 3/79	13 36	159 50	151 24	30 32	0 125E 06	65. 12	62 07	48. 29	0 737E 05	0. 20E 06	0. 588	0 131E 05
8/ 3/79	13 51	157 35	150 25	30 30	0 108E 06	62. 80	60 10	49 05	0. 663E 05	0. 17E 06	0. 615	0. 129E 05
8/ 3/79	14 6	157 18	150. 08	30. 30	0 108E 06	61. 14	58 53	48 66	0. 636E 05	0. 17E 06	0. 590	0. 130E 05
8/ 3/79	14 21	157 38	149. 80	30 28	0 115E 06	59. 77	57 87	48 95	0. 465E 05	0. 16E 06	0. 405	0. 130E 05
8/ 3/79	14 36	155 76	148 84	30 49	0 105E 06	58. 77	56. 28	49 21	0. 613E 05	0. 17E 06	0. 581	0. 129E 05
8/ 3/79	16 21	160 51	152 73	30 07	0 117E 06	62. 11	58 62	48. 42	0. 846E 05	0 20E 06	0. 722	0. 130E 05
8/ 3/79	16 36	160 38	152 19	30 24	0 124E 06	59. 10	56 17	48. 98	0. 718E 05	0. 20E 06	0. 579	0. 130E 05
8/ 3/79	17 6	158 83	151 41	30 07	0 112E 06	54 85	51 92	48 82	0. 716E 05	0. 18E 06	0. 641	0. 130E 05
8/ 3/79	17 21	158 75	150 88	30 34	0. 119E 06	53. 42	50 65	49. 05	0. 680E 05	0. 19E 06	0. 569	0 130E 05
8/ 3/79	17 36	158 04	150 65	30 15	0 112E 06	52 12	49 40	48. 39	0. 659E 05	0. 18E 06	0. 590	0 130E 05
8/ 3/79	17 51	157 68	150 52	30 26	0 109E 06	52 08	49. 45	48 99	0. 645E 05	0. 17E 06	0. 594	0. 130E 05
8/ 3/79	18 6	158 49	150 64	30 30	0 119E 06	53. 00	50 62	48 45	0. 577E 05	0. 18E 06	0. 484	0. 130E 05
8/ 3/79	18 21	156 81	149 76	30 24	0 107E 06	53 66	51. 35	48 84	0 565E 05	0 16E 06	0. 529	0 130E 05
8/ 3/79	18 36	155 86	149 18	30 38	0 102E 06	54. 02	51. 55	48 71	0 602E 05	0. 16E 06	0 593	0 130E 05
8/ 4/79	14 4	161. 22	152 49	30 32	0 132E 06	66 51	63 02	48 90	0. 854E 05	0. 22E 06	0. 645	0. 130E 05
8/ 4/79	14 19	160 58	152 29	30 32	0 126E 06	63 68	60 56	48 46	0. 757E 05	0. 20E 06	0. 601	0 129E 05
8/ 4/79	14 34	160 52	152 39	30 17	0 123E 06	60 83	57. 76	48 37	0. 743E 05	0. 20E 06	0. 606	0 128E 05
8/ 4/79	14 49	160 27	152 42	30 22	0 119E 06	57 03	55. 98	48 34	0. 738E 05	0. 19E 06	0. 622	0 129E 05
8/ 4/79	15 4	159. 82	152 34	30 42	0. 114E 06	59. 47	56. 90	49 00	0. 630E 05	0. 18E 06	0 553	0. 129E 05
8/ 4/79	15 19	159. 34	151. 93	30 34	0. 113E 06	58. 86	56. 00	49. 19	0. 704E 05	0. 18E 06	0. 626	0. 129E 05
8/ 4/79	15 34	158. 36	151. 06	30. 47	0 111E 06	58 68	55 93	48 58	0 669E 05	0 18E 06	0 601	0. 129E 05
8/ 4/79	15 36	158. 31	151 04	30. 00	0 109E 06	58 33	55. 54	49 39	0. 690E 05	0. 18E 06	0 632	0 128E 05
8/ 4/79	15 51	157 75	150 87	30 36	0 105E 06	58. 06	55. 47	48 96	0. 635E 05	0. 17E 06	0 607	0. 130E 05
8/ 4/79	16. 6	156 82	149 87	30. 22	0 105E 06	57. 36	54. 72	48 99	0 647E 05	0 17E 06	0. 616	0. 129E 05
8/ 4/79	16 21	155 96	149. 43	30 65	0 100E 06	57. 08	54. 93	48. 94	0 527E 05	0. 15E 06	0. 525	0. 130E 05
8/ 4/79	16. 36	156 46	149 68	30. 36	0. 103E 06	55. 95	53. 37	49. 24	0. 636E 05	0. 17E 06	0. 617	0. 129E 05
8/ 4/79	16 51	156 54	149 92	30 17	0 100E 06	55. 19	52 95	49. 14	0 551E 05	0. 16E 06	0. 551	0. 129E 05
8/ 4/79	17 6	156 60	149 84	30 26	0. 102E 06	54 30	51. 64	49. 32	0. 656E 05	0. 17E 06	0 641	0. 129E 05
8/ 4/79	17 21	156 35	149 69	30 53	0 102E 06	52 50	49. 98	48 14	0. 607E 05	0 16E 06	0. 596	0. 129E 05
8/ 4/79	17 36	156 32	149 36	30 43	0. 106E 06	50 82	48. 19	48. 30	0 636E 05	0. 17E 06	0. 600	0 129E 05
8/ 4/79	17 51	156 25	149 47	30. 40	0 103E 06	49. 65	47. 20	48. 47	0. 594E 05	0. 16E 06	0. 576	0 129E 05
8/ 4/79	18 6	155. 99	149 26	30 36	0 102E 06	48. 55	45. 85	48. 49	0. 655E 05	0 17E 06	0. 641	0 129E 05
8/ 4/79	18 21	155. 61	148. 91	30. 42	0 102E 06	47. 40	45. 02	48. 57	0. 578E 05	0. 16E 06	0 567	0. 129E 05
8/ 4/79	18 36	155. 22	148. 54	30 24	0 101E 06	46. 61	43 87	48 63	0. 667E 05	0. 17E 06	0. 660	0. 130E 05
8/ 4/79	18 51	154. 69	148 18	30. 26	0. 987E 05	45. 60	43. 36	48 18	0. 540E 05	0. 15E 06	0. 547	0. 129E 05

Loss coefficients for the hot water storage tank and cold water storage tank were calculated using program "LOSS" and an example output is shown as Table 11. "LOSS" reads data from the permanent file created by "DACØNV." Each set of data is checked to see that the fixed data parameter is 1, which indicates the data logger input block for calculating system losses is in use. In determining tank loss coefficients only data were used for which during the time interval of interest there were no in or out flows from the tanks. Calculations consist of determining the hot storage tank temperature and energy storage, and cold storage tank temperature and energy storage. This is done using the same method described for "DASUM." The change in energy stored in each tank, the time elapsed between initial and final data points, and the temperature differential between each storage tank and the equipment room temperature (T25) were calculated. The loss coefficients (UA), defined as change in storage energy per unit time per unit temperature difference, are then calculated for each tank and output in the format shown in Table 11.

Table 11. Example Output from "LOSS"

TANK LOSS COEFFICIENTS

UA VALUES ARE BTU/(HR DEG-F)

			HOT TANK		COLD TANK	
DATE	TIME	EQPT RM TEMP, F	TEMP, F	UA	TEMP, F	UA
8/ 8/79	2 13	77 6	152 4	92 3112	63 7	-32 1455
8/ 8/79	4 13	76 0	151 9	124 5684	63 8	-16 5246
8/ 8/79	6 13	75 5	151 6	97 7811	64 0	-20 4959
8/ 8/79	8 3	76 4	151 4	74 5234	64 3	-32 2516
8/ 8/79	10 3	82 7	151 0	108 6471	64 6	-27 0391
8/ 8/79	12 3	90 8	150 9	36 9198	65 2	-60 1148
8/ 8/79	14 3	91 4	150 6	90 5451	65 8	-47 6461
8/ 8/79	16 3	90 6	150 3	104 0661	66 3	-43 1907
8/ 8/79	18 3	85 8	149 8	168 7220	66 5	-22 8840
8/ 8/79	20 3	82 9	149 2	206 6216	66 7	-12 9298
8/ 8/79	22 3	79 2	148 7	135 0800	66 9	-19 8392
8/ 9/79	0 3	76 7	148 1	190 3385	66 9	-1 7064
8/ 9/79	2 3	74 8	147 7	129 5998	67 0	-17 3548
8/ 9/79	4 3	74 2	147 3	127 2793	67 1	-8 9746
8/ 9/79	6 3	73 4	146 8	143 0396	67 2	-9. 5130
8/ 9/79	8 3	74 4	146 4	147 3933	67 3	-12 4227
8/ 9/79	10 3	79 9	146 0	107 9916	67 4	-22 3019
8/ 9/79	12 3	92 3	145 8	72 1910	67 9	-51 0076
8/ 9/79	14 3	94 1	145 5	88 3016	68 4	-50 8588
8/ 9/79	16 3	93 8	145 2	106 0539	68 9	-51 1920

5. RESULTS

The results of this project to date include experience gained in installing and operating the instrumentation and data acquisition system, development of the data reduction programs, experience in getting the solar heating and cooling system operational, and acquisition of system performance data.

5.1 INSTRUMENTATION EXPERIENCE

Several instrumentation related problems occurred from which valuable experience was gained. At the time the solar energy system plumbing was modified for installation of the flow meters and temperature sensors the water temperature sensors had not yet been received from the vendor. Pipe plugs were temporarily installed at the temperature sensor locations. While installing the flow meters, one was irreparably damaged by the plumbers while it was attached to a piece of pipe during a pipe threading operation. This occurred despite clearly emphasizing to the plumbers the delicacy of the instruments prior to beginning the installation. Considering this experience, it would have been prudent to have substituted dummy pipe sections during the plumbing changes and installed the flow meters later. It was probably fortuitous that the temperature sensors were late in arriving.

With the loss of 1 flow meter, the remaining 7 flow meters were installed in those locations which would optimize the data collection and evaluation. The flow meter deleted would have measured the chiller condensing water flow, F7. For this reason, the chiller heat rejection cannot presently be measured directly.

Initially, the water temperature sensors were installed with steel pipe bushings rather than the dielectric bushings as shown in Figure 4A. The current excitation loop is as shown in Figure 5. The initial checkout of each sensor, using mercury thermometers where possible, indicated reliable readings. Later, during system data collection and analysis it was determined that some sensor measurements were erroneous, with those nearest the middle of the series network exhibiting the greatest errors. This was traced to partial grounding between the sensor leads and the sheaths of some of the sensors, resulting in reduced current excitation below that measured through the precision resistor. To rectify this, the sensor probes were remounted in dielectric bushings to improve isolation; however, the water is sufficiently conductive that erroneous readings were still present. Finally, it was necessary to eliminate those sensors with poor impedance between lead wires and sheath and use the remainder in those locations which would optimize the data collection.

Temperature sensors T3, T4, T5, T6, T22 and T23 were removed from the excitation circuit. This prevented measurement of individual collector bank data and the condenser water energy flow, which meant measurement of individual collector bank efficiencies and a complete chiller energy balance were not possible. However, the condenser water energy flow could not be measured because of the damage to the one flow meter and the limited capability of the Fluke data logger. Even though the condenser water inlet temperature was not monitored, it is controlled to 85°F or above by turning the cooling tower fan off and on automatically. From observations of system operation, the cycling of the chilling tower fan occurs frequently during chiller operation under most circumstances, indicating that the condenser water supply temperature is held fairly constant.

Even with these temperature measurements and one flow rate measurement deleted, the data that were collected were sufficient to determine those parameters which are most important in evaluating the performance of the solar energy system. All energy flows, including available, collected and delivered as well as the associated conventional energy consumption and parasitic power consumption, were measured. Following the changes described, acquisition of valid data began on July 17, 1979. Unfortunately, the nature of the problem which resulted in erroneous temperature measurements up to that time prevented accurately salvaging the previously collected data. However, most of the metereological data acquired prior to July 17, 1979, are valid.

On June 6, 1979, following several days of rainy weather, moisture condensed on the inner surface of the pyrheliometer lens. The pyrheliometer was partially disassembled, dried thoroughly, and reassembled. Particular care was taken to be certain the O-ring seals were installed properly and securely. Following rainfall on July 21, moisture was again discovered on the inside of the pyrheliometer lens. Undoubtedly this would result in erroneous measurement of beam radiation. At this point, another pyrheliometer was put into service to replace the faulty unit. The new unit has operated satisfactorily. This problem, however, did result in the loss of beam radiation data for July 21, 22, and 23, 1979.

5.2 SUMMARY OF COLLECTED DATA

Summaries of the processed data are given in Tables 12, 13, 14, and 15. Table 12 presents the ambient weather information, and the number of hours of each day for which data were collected. Data were lost for several reasons: tape drive inadvertently stopped recording, and noise was present on the data tape, among others. The reasons for gaps in the data recording are summarized in Table 16.

The summarized ambient weather information in Table 12 shows the daily averages of dry bulb temperature, absolute humidity, and wind speed for each day. The daily maximum and minimum dry bulb temperatures and the maximum wind speed measured each day are also listed. In all cases the minimum wind speed measured was zero. The total solar fluxes measured each day are also listed. All of these data were taken from the daily summaries generated by program "DASUM."

All of the data collected seem reasonable with the exception of the absolute humidity. Initial checks of the sensing element showed it to be operating properly and the output instrument itself is not normally prone to large shifts in calibration. The measured values are low for summer weather in this area and do not change markedly from day to day. This condition suggests a problem with the sensing element. Normally, recoating the element with a salt solution is required only every 90 days. From the data at hand, it appears that more frequent servicing is necessary.

The lack of direct-beam solar radiation data from July 21 to July 23 is the result of moisture condensed on the inside of the pyrheliometer lens. All data on days for which fewer than 24 hours of data were

Table 12. Summarized Ambient Weather Data

Date	Hours of Data	Temperature, °F Mean	Temperature, °F Max.	Temperature, °F Min.	Abs. Hum., Gr/Lb, Mean	Windspeed, mph Mean	Windspeed, mph Max.	Solar Flux, Btu/(hr-ft^2) Direct-Beam Total	Solar Flux, Btu/(hr-ft^2) Direct-Beam Max.	Solar Flux, Btu/(hr-ft^2) Total Total	Solar Flux, Btu/(hr-ft^2) Total Max.
7/17/79	13	87.2	100.3	77.2	48.8	4.3	16.7	1065.4	265.2	1585.1	312.9
7/18/79	14	82.1	91.3	75.7	49.8	4.8	17.3	331.2	171.0	1056.1	294.1
7/19/79	14	80.9	91.9	74.8	50.5	3.4	12.3	109.6	98.6	648.5	308.7
7/20/79	16	79.5	89.6	73.1	51.8	2.5	11.3	32.1	19.5	1092.7	251.6
7/21/79	24	81.1	92.2	70.9	51.3	2.4	12.1	nd(1)	nd	1933.7	315.6
7/22/79	24	84.5	94.7	73.0	51.2	2.9	12.4	nd	nd	1866.4	309.4
7/23/79	24	86.4	95.7	74.2	50.4	3.1	13.8	nd	nd	2198.2	320.7
7/24/79	24	86.0	95.3	75.3	51.4	3.8	14.1	1328.9	202.3	2075.4	378.3
7/25/79	19	85.5	94.5	76.5	51.4	7.0	24.5	544.8	166.3	1609.4	329.9
7/26/79	10	86.2	93.3	76.5	51.4	5.4	15.9	158.1	100.8	1158.4	373.4
7/27/79	12	74.4	77.8	70.5	51.4	6.3	25.8	0.5	0.4	42.1	33.8
7/28/79	0	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
7/29/79	10	89.8	96.7	79.4	50.9	8.6	14.3	736.6	270.6	1133.6	327.1
7/30/79	24	84.2	96.0	74.4	51.2	7.6	19.3	1672.6	273.1	2011.1	353.2
7/31/79	24	86.6	96.4	77.9	51.6	7.3	15.6	1717.8	262.7	1850.9	377.9
8/1/79	22	83.5	97.7	76.9	50.9	4.7	19.7	1247.7	262.7	1772.3	340.0
8/2/79	14	86.2	95.2	76.7	50.2	6.6	18.1	652.2	235.2	1345.5	370.6
8/3/79	24	85.0	95.3	74.6	49.7	6.7	17.3	1661.6	225.6	2240.7	352.2
8/4/79	24	84.7	96.5	71.4	49.4	4.0	11.9	2037.6	237.3	2269.7	347.3
8/5/79	24	86.4	96.3	73.2	49.8	2.6	9.1	2383.3	266.9	2215.8	361.2
8/6/79	24	87.4	98.2	75.1	49.9	2.5	10.8	2585.9	259.8	2344.1	312.2
8/7/79	24	86.0	96.9	74.6	49.4	2.8	12.4	1925.3	225.6	2226.1	316.3
8/8/79	24	82.3	92.8	75.3	49.1	3.4	12.9	866.2	199.3	1741.5	309.4
8/9/79	18	82.4	97.3	72.9	49.9	3.2	13.8	1128.2	248.5	1692.5	344.5

(1) The notation "nd" indicates no valid data was available.

Table 13. Summarized Building Energy Consumption Data

Date	H/AC Energy, kBtu				DHW Energy, kBtu				Composite, kBtu			
	Conv.	Solar	Total	%	Conv.	Solar	Total	%	Conv.	Solar	Total	%
7/17/79	426.1	0.0	426.1	0.0	133.8	0.0	133.8	0.0	559.8	0.0	559.8	0.0
7/18/79	598.2	0.0	598.2	0.0	241.5	0.0	241.5	0.0	839.7	0.0	839.7	0.0
7/19/79	300.3	0.0	300.3	0.0	210.0	0.0	210.0	0.0	510.3	0.0	510.3	0.0
7/20/79	332.3	0.0	332.3	0.0	328.9	0.0	328.9	0.0	661.3	0.0	661.3	0.0
7/21/79(2)	620.3	0.0	620.3	0.0	272.0	0.0	272.0	0.0	892.3	0.0	892.3	0.0
7/22/79(2)	849.3	12.7	862.0	1.5	339.0	0.0	339.0	0.0	1188.3	12.7	1200.9	1.1
7/23/79(2)	688.8	132.6	821.3	16.1	430.3	0.0	430.3	0.0	1119.1	132.6	1251.6	10.6
7/24/79	1181.2	3.2	1184.4	0.3	555.4	0.0	555.4	0.0	1736.3	3.2	1739.7	0.2
7/25/79(3)	807.2	0.0	807.2	0.0	243.2	0.0	243.2	0.0	1050.4	0.0	1050.4	0.0
7/26/79	342.9	0.0	342.9	0.0	80.0	0.0	80.0	0.0	422.9	0.0	422.9	0.0
7/27/79	239.3	0.0	239.3	0.0	112.7	0.0	112.7	0.0	352.0	0.0	352.0	0.0
7/28/79	nd(1)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
7/29/79	723.4	0.0	723.4	0.0	180.7	0.0	180.7	0.0	904.1	0.0	904.1	0.0
7/30/79	575.9	268.8	844.7	31.8	310.9	0.0	310.9	0.0	886.8	268.8	1155.6	23.3
7/31/79	967.1	224.5	1191.6	18.8	317.3	0.0	317.3	0.0	1284.4	224.5	1508.9	14.9
8/1/79	1100.8	36.1	1137.0	3.2	350.5	0.0	350.5	0.0	1451.3	36.1	1487.5	2.4
8/2/79	959.5	0.0	959.5	0.0	325.8	0.0	325.8	0.0	1285.3	0.0	1285.3	0.0
8/3/79	838.3	122.6	961.4	12.7	370.7	0.0	370.7	0.0	1209.5	122.6	1332.0	9.2
8/4/79(3)	566.2	151.2	717.4	21.1	513.8	0.0	513.8	0.0	1079.7	151.2	1231.2	12.3
8/5/79	910.2	224.0	1134.2	19.8	253.2	0.0	253.2	0.0	1163.4	224.0	1387.4	16.1
8/6/79	557.4	260.7	818.2	31.9	386.6	0.0	386.6	0.0	944.0	260.7	1204.8	21.6
8/7/79	585.5	198.9	784.3	25.4	278.8	0.0	278.8	0.0	864.3	198.9	1063.2	18.7
8/8/79(4)	579.2	0.0	579.2	0.0	355.0	0.0	355.0	0.0	934.2	0.0	934.2	0.0
8/9/79(4)	301.7	0.0	301.7	0.0	120.3	0.0	120.3	0.0	422.0	0.0	422.0	0.0
Total	10638.4	1338.8	11977.2	11.2	4436.8	0.0	4436.8	0.0	15075.2	1338.8	16414.0	8.2

(1) The notation "nd" indicates no valid data was available.

(2) Valid solar insolation data was not available. This data was not used in energy collection totals.

(3) Collector pump was turned on manually and left running for collector efficiency test. Data was not used in energy collection totals or loss totals.

(4) Collector tracking was turned off while tank heat loss measurements were being made. Data was not used in energy collection totals.

Table 14. Summarized Solar Energy System Heat Balance Data

Date	Energy Collection, kBtu Available	Collected	%	Energy Delivered, kBtu H/AC	DHW	Total	Storage Added, kBtu Hot	Cold	Losses, kBtu
7/17/79	1323.3	614.3	46.4	0.0	0.0	0.0	579.7	10.7	188.3
7/18/79	411.3	0.0	0.0	0.0	0.0	0.0	-17.1	0.3	16.8
7/19/79	136.2	0.0	0.0	0.0	0.0	0.0	-70.7	2.6	68.1
7/20/79	39.9	10.5	26.4	0.0	0.0	0.0	-117.2	0.0	127.7
7/21/79(2)	nd(1)	318.1	--	0.0	0.0	0.0	193.5	4.3	120.4
7/22/79(2)	nd	449.9	--	12.7	0.0	12.7	-40.3	-72.3	549.9
7/23/79(2)	nd	785.4	--	132.6	0.0	132.6	-39.5	-4.1	696.4
7/24/79	1650.5	293.4	17.8	3.2	0.0	3.2	432.1	47.9	-44.7
7/25/79(3)	676.6	51.1	7.6	0.0	0.0	0.0	6.2	8.3	598.9
7/26/79	196.4	0.0	0.0	0.0	0.0	0.0	-56.6	4.8	51.8
7/27/79	0.6	0.0	0.0	0.0	0.0	0.0	-112.5	-2.3	114.8
7/28/79	nd	nd	nd	nd	nd	nd	nd	nd	nd
7/29/79	914.8	534.3	58.4	0.0	0.0	0.0	278.1	3.2	111.0
7/30/79	2077.4	358.1	17.2	268.8	0.0	268.8	-823.9	-84.0	1004.3
7/31/79	2133.5	758.3	35.5	224.5	0.0	224.5	-4.2	23.6	1006.8
8/1/79	1549.7	568.8	36.7	36.1	0.0	36.1	142.8	-44.5	434.4
8/2/79	810.1	178.6	22.1	0.0	0.0	0.0	188.2	13.4	60.9
8/3/79	2063.7	769.7	37.3	122.6	0.0	122.6	-98.6	-17.1	762.8
8/4/79(3)	2530.7	-896.2	0.0	151.2	0.0	151.2	-85.9	-2.8	2226.5
8/5/79	2960.1	990.6	33.5	224.0	0.0	224.0	99.1	2.6	665.0
8/6/79	3211.7	1118.6	34.8	260.7	0.0	260.7	-1.9	-4.8	864.6
8/7/79	2391.2	803.2	33.6	198.9	0.0	198.9	-14.3	1.2	617.4
8/8/79(4)	1075.8	0.0	0.0	0.0	0.0	0.0	-175.7	15.0	160.7
8/9/79(4)	1401.3	0.0	0.0	0.0	0.0	0.0	-128.5	9.7	118.7
Total	21870.4	6998.4	32.0	1338.8	0.0	1338.8	403.0	-42.4	6050.4

(1) The notation "nd" indicates no valid data was available.

(2) Valid solar insolation data was not available. This data was not used in energy collection totals.

(3) Collector pump was turned on manually and left running for collector efficiency test. Data was not used in energy collection totals or loss totals.

(4) Collector tracking was turned off while tank heat loss measurements were being made. Data was not used in energy collection totals.

Table 15. Summarized Parasitic Power Consumption Data

Date	Collector System Collected	Collector System Par Pwr	Collector System %	H/AC System Delivered	H/AC System Par Pwr	H/AC System %	DHW System Delivered	DHW System Par Pwr	DHW System %	Total System Delivered	Total System Par Pwr	Total System %
7/17/79	614.3	17.95	2.92	0.0	0.0	0.0	0.0	0.0	0.0	0.0	63.80	--
7/18/79	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.12	--
7/19/79	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.31	--
7/20/79	10.5	0.62	5.89	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40.06	--
7/21/79(2)	318.1	3.01	0.95	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.14	--
7/22/79(2)	449.9	4.18	0.93	12.7	33.78	266.45	0.0	0.0	0.0	12.7	69.38	547.23
7/23/79(2)	785.4	7.19	0.92	132.6	85.83	64.75	0.0	0.0	0.0	132.6	172.67	130.27
7/24/79	293.4	8.48	2.89	3.2	12.32	385.21	0.0	0.0	0.0	3.2	91.18	--
7/25/79(3)	51.1	23.34	45.63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	76.39	--
7/26/79	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.81	--
7/27/79	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.31	--
7/28/79	nd(1)	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
7/29/79	534.3	7.32	1.37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	44.20	--
7/30/79	358.1	7.90	2.20	268.8	96.39	35.86	0.0	0.0	0.0	268.8	245.82	91.46
7/31/79	758.3	12.10	1.60	224.5	75.42	33.60	0.0	0.0	0.0	224.5	213.98	95.32
8/1/79	568.8	8.33	1.46	36.1	31.36	86.75	0.0	0.0	0.0	36.1	113.17	326.9
8/2/79	178.6	2.89	1.62	0.0	0.0	0.0	0.0	0.0	0.0	0.0	49.57	--
8/3/79	769.7	6.79	0.88	122.6	67.20	54.83	0.0	0.0	0.0	122.6	209.48	170.93
8/4/79(3)	-896.3	27.03	--	151.2	85.82	56.75	0.0	0.0	0.0	151.2	272.26	180.04
8/5/79	990.6	12.93	1.31	224.0	98.35	43.90	0.0	0.0	0.0	224.0	249.45	111.35
8/6/79	1118.6	19.53	1.75	260.7	116.56	44.74	0.0	0.0	0.0	260.7	330.04	126.57
8/7/79	803.2	13.41	1.67	198.9	70.64	35.52	0.0	0.0	0.0	198.9	166.39	83.67
8/8/79(4)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.00	--
8/9/79(4)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.40	--
Total	8551.8	132.63	1.6	1484.1	687.85	46.3	0.0	0.0	0.0	1484.1	2132.88	143.7

(1) The notation "nd" indicates no valid data was available.

(2) Valid solar insolation data was not available. This data was not used in energy collection totals.

(3) Collector pump was turned on manually and left running for collector efficiency test. Data was not used in energy collection totals or loss totals.

(4) Collector tracking was turned off while tank heat loss measurements were being made. Data was not used in energy collection totals.

Table 16. Causes of Lost Data

Date(s)	Time	Reason
7/17/79	Before 1200	Final changes were being made on temperature sensor excitation circuit
7/18/79	0500 - 1200	Tape drive had stopped recording
7/19/79	0900 - 1300	Noise on data tape
7/19/79 7/20/79	1900 - 2400 0000 - 0800	Recorder was taken to C.A.L. to transfer data. When returned to data acquisition system, recorder was restarted, apparently stopped soon afterwards. The recorder was restarted the following morning.
7/25/79 7/26/79	1900 - 2400 0000 - 0900	After installing a fresh tape in the recorder, it worked satisfactorily. Apparently soon afterward it stopped recording. Recorder was restarted the following morning.
7/26/79	1900 - 2400	Recorder was taken to C.A.L. to transfer data.
7/27/79	1000 - 1100	Momentary power failure during a thunderstorm stopped the recorder. The recorder was manually restarted.
7/27/79 7/28/79 7/29/79	1500 - 2400 0000 - 2400 0000 - 1400	Recorder had stopped, possibly because of another power failure. The condition was not discovered until 7/29/79, when the recorder was manually restarted.
8/1/79	1800 - 1900	Noise on data tape
8/2/79	0400 - 1000	Recorder had stopped. It was manually restarted
8/9/79	1900 →	Recorder was taken to C.A.L. to transfer data

available are, of course, representative of the time of day when data were taken, and thus do not reflect conditions for the entire day.

The amount of energy consumed by the apartment building and the portion delivered by the solar energy system are shown in Table 13. As explained previously, at the time these data were taken the solar domestic hot water system was not yet operational. A cumulative total of 1339 thousand Btu's of air conditioning was delivered, which represented 11.2% of the air conditioning load for the building for the 3-week period. On individual days as much as 32% of the air conditioning load was supplied by the solar energy system.

The amount of air conditioning supplied, however, is less impressive when the parasitic power consumption, shown in Table 15, is considered. The electric power consumed that could be linked directly to the production of air conditioning was equal to 46.3% of the solar cooling energy delivered. When viewed in light of a C.O.P. of approximately 2 for the vapor compression air conditioners, the solar air conditioner is barely above the break even point. The amount of electric power (parasitic) consumed in producing solar air conditioning could have produced almost an equal amount of cooling using a conventional air conditioning system. If the total parasitic power used by the solar energy system is considered the system falls short of a break even point even on a one-to-one energy conversion comparison.

If the solar energy used to fire the absorption chiller had been used for producing domestic hot water a more favorable view of the solar energy system would be seen. Considering a chiller C.O.P. of approximately 0.6, the same solar energy used to generate the 1339 thousand Btu's of air conditioning would have resulted in 2231 thousand Btu's of domestic hot water energy. This would have represented approximately 50% of the energy expended producing domestic hot water and boosted the fraction of the total building energy consumption delivered by solar to 14%. An added bonus would have been maintaining the hot water storage tank at a lower temperature, which would have reduced thermal losses from storage and possibly have resulted in higher operating efficiency of the solar collectors.

The amount of solar energy available and the amount collected are shown in Table 14. These data show that 32% of the available energy was collected. The amount of energy collected is large compared to the parasitic electric power used to drive the collector pump; that is, the parasitic power was approximately 2.0% of the energy collected.

Some chiller C.O.P. data obtained under steady state operating conditions are shown in Table 17. The manufacturer's published performance data obtained for similar conditions (flow rates and temperatures) indicate the C.O.P. varies from approximately 0.47 to 0.63 over the input hot water temperature range of 155°F to 168°F for the present tests. The agreement with the manufacturer's data is much better than that described in reference 5 where results are reported for an identical chiller. In the report cited the chiller C.O.P. was found to be very sensitive to deviations from design operating conditions.

The parasitic power measured, when compared to chiller output, gives a more favorable ratio than a comparison to actual air conditioning delivered. The ratio measured, 22.1%, indicates that in operation

Table 17. Chiller C.O.P. Data

Date	Time	Hot Water Flow			Chilled Water Flow					
		T_{in}, °F	GPM	Q_{hot}, Btu/hr	T_{out}, °F	GPM	Q_{cold}, Btu/hr	Q_{cold}, Tons	C.O.P.	Par. Pwr, Btu/hr
7/23/79	18:19	157.68	27.83	9.23×10^4	45.76	48.63	5.45×10^4	4.54	0.590	1.32×10^4
7/30/79	19:47	168.32	30.52	14.8×10^4	45.71	47.97	8.78×10^4	7.31	0.594	1.31×10^4
7/30/79	20:17	165.31	30.36	13.5×10^4	44.14	47.77	8.03×10^4	6.70	0.595	1.31×10^4
7/30/79	20:32	164.05	30.17	12.9×10^4	45.05	47.79	7.65×10^4	6.38	0.594	1.31×10^4
7/30/79	20:47	162.92	30.32	12.4×10^4	44.63	48.13	7.10×10^4	5.90	0.572	1.32×10^4
7/30/79	21:32	159.69	30.30	11.2×10^4	44.75	48.23	5.79×10^4	4.83	0.516	1.29×10^4
8/04/79	18:06	155.99	30.36	10.2×10^4	45.85	48.49	6.55×10^4	5.46	0.641	1.29×10^4
8/04/79	18:21	155.61	30.42	10.2×10^4	45.02	48.57	5.78×10^4	4.82	0.567	1.29×10^4
8/06/79	15:02	162.09	30.32	13.8×10^4	45.24	48.41	7.10×10^4	5.90	0.513	1.29×10^4
8/06/79	18:15	160.72	30.41	12.7×10^4	45.40	48.84	6.67×10^5	5.56	0.526	1.31×10^4

a great deal of chiller output is not delivered to the load. Considering the 500 gallon volume of the cold water storage tank, it is conceivable that a significant fraction of chiller output is consumed initially in lowering the tank temperature to 60°F before air conditioning delivery is begun.

Efficiency evaluations of the entire collector array were made as described in Section 4. Data resulting from efficiency measurements are plotted in Figure 6. The narrow range of $\Delta T/QB$ values resulted primarily because the hot water storage tank temperature was kept near 160°F by the operation of the chiller. Also, direct-beam radiation did not vary markedly above the level required for collector operation. Very early and very late in the day (when direct-beam solar radiation is reduced), the collectors shade one another and no energy is collected.

Some efficiencies plotted in Figure 6 are much higher or much lower than the majority of the values. These values probably occur during periods of intermittent cloud cover when thermal time constant effects in the collector are important. Anomalous high efficiencies would also be measured soon after the collector pump is first started while collector heat storage has an effect. Those efficiency values which are much lower than the majority of the data could also result from collector tracking errors and from collector shading early and late in the day.

The majority of the data points calculated indicate an average efficiency somewhere between 46% and 50%. The solid line drawn in Figure 6 is the efficiency published in the manufacturer's brochure. The other efficiency line in Figure 6 is the result of a student project

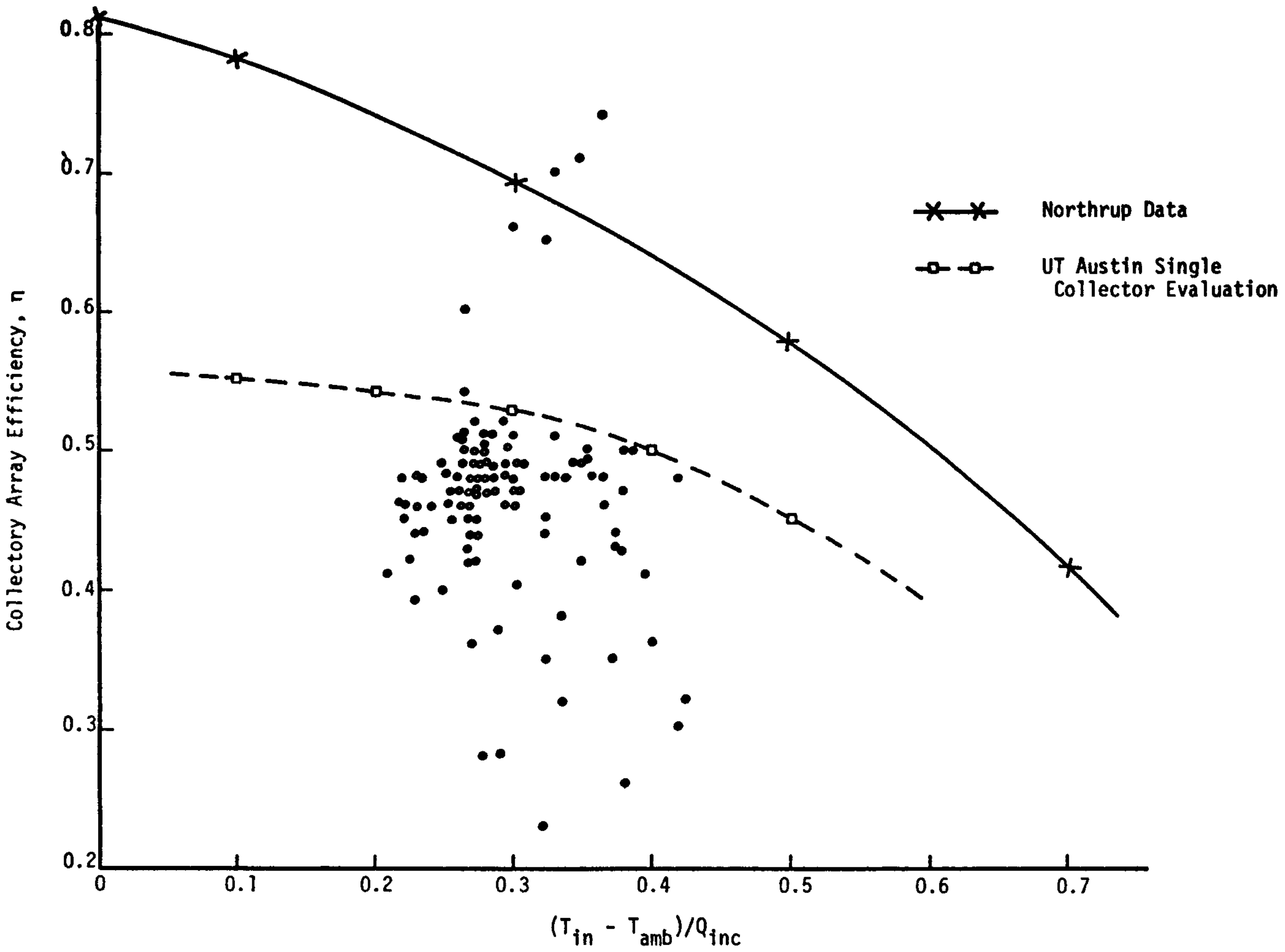

Figure 6. Collector Array Efficiency Data

done at The University of Texas at Austin using a prototype of the collectors studied [9].

The efficiency measured is somewhat less than the results of either of the earlier studies cited. The difference is probably accounted for by misalignment of individual collectors within the array, and by the variation of concentrating efficiency between individual collectors. A third reason could be that the collector lenses are somewhat soiled from normal use. In controlled tests like those cited any of the above conditions would probably have been corrected before testing. A final cause for lowered efficiency could be unbalanced water flow through each collector, which would result in some collectors operating at higher absorber temperatures than others.

Storage tank heat loss coefficents were computed from data taken during short periods of system inactivity between energy collection or air conditioning delivery. Some of these results are shown as the example "LOSS" computer program output in Table 11. The hot storage tank heat loss coefficient shows a great deal of variability and has an average value of approximately 117.64 Btu/Hr-°F. This value agrees fairly closely with a value of 93.06 measured in early January, 1979. This latter value was measured over a period of several days during which, after the hot tank was solar heated to a moderate temperature, all flows to and from the tank were interrupted for that period. If the nominal 2-inch thickness of polyurethane foam insulation is assumed to have a thermal conductivity of 0.02 Btu/Hr-Ft-°F, and the inside and outside heat transfer coefficients are assumed to be 5 and 1 Btu/Hr ft^2°F respectively, a somewhat lower loss coefficient is obtained, indicating possibly lower average insulation thickness and/or other heat loss paths such as pipes and supports.

The average cold storage tank loss coefficient was -28.02 Btu/Hr-°F. The negative sign is an indication that heat was being added to the cold storage tank. Similarly, this loss coefficient is greater than that predicted based on a 2-inch insulation thickness.

6. CONCLUSIONS AND RECOMMENDATIONS

Several conclusions can be drawn from the data acquired from this project and some areas for improvement in solar energy system operation have been identified. Areas for improvement in the instrumentation and data acquisition system were also found.

The most basic lesson to be learned from the data generated is that better utilization of energy, both energy collected and parasitic power, would have resulted by maximizing the delivery of domestic hot water rather than providing only solar air conditioning. The energy necessarily rejected in the absorption air conditioning process is a sizeable loss, resulting in productive utilization of only a fraction of the energy collected. Also, because of the relatively good EER of conventional vapor compression type air conditioners, the solar energy can be better utilized for domestic water heating. Domestic hot water delivery would result in a nearly 100% utilization of the energy collected.

If excess solar energy above that for domestic hot water is available, solar air conditioning should be delivered. This operational scheme is what would have occurred had the domestic hot water system been operational. The unfortunate construction problems resulted in the less efficient operation observed.

A modification in the solar air conditioning controls could result in better utilization of parasitic power. On several occasions the chiller operated for a period of time inadequate to reduce the cold water storage temperature to 60°F. This resulted in no energy actually delivered, but an expenditure of parasitic power. The temperature differential on the hot storage tank top temperature thermostat, which determines if adequate energy storage exists for chiller operation, should be increased, and the minimum temperature for the beginning of chiller operation should be increased. This would result in the chiller operating less frequently but for longer time periods, thus minimizing the impact of initially cooling the cold water storage.

Two shortcomings of the instrumentation become obvious. The series excitation circuit used for temperature sensors is prone to ground loops. Also, energy flows that change rapidly, particularly domestic hot water consumption and to a lesser degree the air condition loop energy flow and collector loop energy flow after pump start-up, need to be monitored at more frequent time intervals. The method used in this investigation (taking instantaneous readings every 15 minutes) could seriously err in measuring such transients.

The solution to both problems is found in the data acquisition system initially specified for this project. That system, a Hewlett Packard 3052A Data Acquisition System, has sufficient capability to monitor all of the four lead wire resistance devices individually. Thus, individual excitiation of each RTD would be permitted, eliminating any of the previous problems associated with ground loops. The Hewlett Packard system also has computational capabilities and more flexible scanning programming, which would allow integrating energy flows almost continuously.

The process required for the university to lease the Hewlett Packard instrument was begun in November, 1978. Due to delays in insuring funding for the system, to the lengthy purchasing process required by the State of Texas, and to the long delivery time from Hewlett Packard, the instrument was not received until mid-August 1979. The system was not installed immediately after delivery because monitoring was being continued with the Fluke data logger through September 1979 to obtain data for most of the 1979 cooling season. Subsequently, the 3052A system has been installed and became operational in January 1980.

Complete performance data on the system were not obtained as a result of some serious problems with the system and some significant instrumentation problems. However, the monitoring done with the Fluke instrument allowed collection of a considerable amount of data which permitted initial assessments of system and component performances and identified several areas for improvement in the instrumentation and the system that would not have been realized otherwise.

Appendix A

INSTRUMENT SPECIFICATIONS

Table A-1. Water Temperature Sensor Specifications

Manufacturer	ARI Industries, Inc.
Model	R96.4 - (8) D100
Accuracy	± 0.1% at 32°F
Lead configuration	4 wire
Stability	± 0.05% maximum ice point shift
Temperature range	-320°F to 1000°F
Excitation current	10 milliamperes DC maximum
Self-heating error	20 milliwatt power dissipation results in 70°F water
Response-time constant	3.0 seconds required for 63.2% response to step change from 70°F air to 212°F water at 3fps velocity
Platinum purity	99.999%+
Temperature coefficient	0.003916 Ω/°C
Ice point resistance	100Ω
Sheath O.D.	0.1125 inches
Probe length	8.0 inches
Sheath material	Stainless steel
Connection head	Industrial weatherproof head with internal screw terminals, 1/2" NPT exit thread for hard wiring

Table A-2. Air Temperature Sensor Specifications

Manufacturer	Hy-Cal Engineering
Model	RTS-55
Lead configuration	4 wire
Accuracy	± 0.1% at 32°F
Stability	0.1% maximum shift after 1 yr.
Temperature range	-200°C to +200°C
Excitation current	10 milliamperes maximum
Self-heating error	>5 mw/°C in air at 10 ft./sec.
Response-time constant	One minute nominal in air at 10 ft./sec.
Platinum purity	99.99%
Temperature coefficient	0.00385 Ω/Ω°C
Ice point resistance	100Ω
Sheath O.D.	0.11 inches
Shield	0.25 inches O.D., perforated
Probe length	8 inches
Sheath material	300 stainless steel
Connection head	Miniature weathertight connection head with internal screw terminals, 1/4" NPT connection

Table A-3. Flow Sensor Specifications

Manufacturer	Ramapo Instrument Company, Inc.
Model	Mark V, Series 5500
Accuracy	± 1% F.S. water flow calibration
Repeatability and hysteresis	0.25% of reading
Temperature rating	-40°F to 250°F
Pressure rating:	
Primary sensing element	1,000 psi max.
Line housing	Equivalent to schedule 40 pipe
Materials:	
Primary sensing element	17-4 PH S.S.
Line housing	304 S.S.
Seals	Buna N
Line connections	Male NPT
Pressure Drop at F.S.	
1" pipe size, 1-10 gpm	2 psi
1 1/4" pipe size, 2.5-25 gpm	3 psi
1 1/2" pipe size, 7-70 gpm	2 psi
2" pipe size, 5-50 gpm	1.5 psi
2" pipe size, 7-70 gpm	1 psi
Output	2.0 mV/V full scale
Input	5-15 volts AC or DC
Bridge resistance	350 ohms
Temperature effects:	
Bridge zero	± 2% F.S./100°F
Bridge span	∓ 2% reading/100°F
Electrical connections	Terminal strip in junction box

Table A-4. Watt Transducer Specifications

Manufacturer	Ohio Semitronics, Incorporated
Model	PC5 Series, models specified in Table B-3
Input:	
Voltage	0 to 110% F.S.
Current	0 to F.S.
Overload (continuous):	
Voltage	1.25 x rating
Current	2 x rating
Burden (full-scale input):	
Voltage	1.25 VA
Current	1.25 VA
Power factor range	Unity to lead, lag 0
Frequency range	50 to 70 Hz
Dielectric test (input/output/ease)	1,500 VAC
Response (transient - 90%)	100 microseconds
Output:	
F.S. output	50 or 100 mv, specified in Table B-3
Output loading	>1 meg ohms
Span adjustment range	0-100% F.S. output
Response time	250 milliseconds
Temperature effect (-10° to +60°C)	± 1% reading, ± 0.1% F.S.
AC component at unity P.F.	<1% F.S.
Accuracy:	
Models PC5-1F through PC5-29F	± 0.5% F.S.
Models PC5-52F, PC5-71F	± 0.75% F.S.

Table A-5. Pyrheliometer and Pyranometer Specifications

	Pyranometer	Pyrheliometer
Manufacturer	Eppley Laboratory, Inc.	Same
Model	PSP	NIP
Sensitivity	9.09 μv/watt m^{-2}	8.60 μv/watt m^{-2}
Impedance	700 ohms at 23°C	187 ohms at 23°C
Temperature dependence	$\pm$ 1% for -20°C to +40°C	Same
Linearity	$\pm$ 0.5% from 0 to 2800 watts m^{-2}	Same
Response time (1/e signal)	1 second	Same
Cosine	$\pm$ 1% from normalization 0-70° zenith angle, $\pm$ 3% 70-80° zenith angle	--
Orientation	No effect on instrument performance	5° 43' 30" field of view
Mechanical vibration	Capable of withstanding up to 20 g's	Same
Calibration	Integrating hemisphere (approximately 1 cal cm^{-2} min^{-1}, +25°C ambient temperature)	Reference Eppley Primary standard Group of Pyrheliometer
Size	5 3/4" diameter, 3 3/4" long	11" long
Weight	7 pounds	5 pounds

Table A-6. Humidity Instrument Specifications

Manufacturer	Atkins Technical, Incorporated
Model	26432-09/21063-09
Accuracy	± 1% F.S.
Range	-10°C to +50°C dewpoint
Power supply	14.85 VDC output ± .5%
Analog output	0-60 mv dc
Size	6 3/4"W x 8 5/8"H x 10"D
Weight	22 lb
Sensor probe:	
Model	11712-09
Interchangeability	1%
Range	11% to 100% R.H.
Size	1/2" o.d. x 4 1/4" long shield
Cable length	20 ft.
Accuracy (not including instrument)	± 1°C

Appendix B

INSTRUMENT LOCATIONS

Table B-1. Temperature Sensor Locations

Designation	Description/Location
T1	Collector loop inlet
T2	Collector loop return
T3	Front collector bank (25° tilt) inlet
T4	Front collector bank exit
T5	Rear collector bank (30° tilt) inlet
T6	Rear collector bank exit
T7	Hot storage tank top
T8	Hot storage tank middle
T9	Hot storage tank bottom
T10	Cold storage tank top
T11	Cold storage tank bottom
T12	Domestic hot water supply
T13	Domestic hot water make-up
T14	Laundry hot water supply
T15	Domestic hot water heat exchanger inlet
T16	Domestic hot water heat exchanger exit
T17	Air conditioning loop supply
T18	Air conditioning loop return, chiller cold inlet
T19	Chiller cold exit
T20	Chiller hot water inlet
T21	Chiller hot water exit
T22	Chiller condensing water inlet
T23	Chiller condensing water exit
T24	Ambient air
T25	Equipment room temperature

Table B-2. Flow Sensor Locations and Sizes

Designation	Flow Meter Size	Description/Location
F1	2" pipe, 75 gpm F.S.	Collector loop
F2A	1" pipe, 10 gms F.S.	Front collector bank (25° tilt)
F2B	1" pipe, 10 gpm F.S.	Rear collector bank (30° tilt)
F3	1 1/2" pipe, 70 gpm F.S.	Domestic hot water make-up
F4	1 1/4" pipe, 25 gpm F.S.	Laundry water supply
F5	1 1/2" pipe, 70 gpm F.S.	Domestic hot water heat exchanger
F6	2" pipe, 50 gpm F.S.	Air conditioning loop, chiller cold water
F7	2" pipe, 50 gpm F.S.	Chiller hot supply
F8	2" pipe, 50 gpm F.S.	Chiller condensing water

Table B-3. Watt Transducer Locations and Sizes

Designation	Model	Output at F.S.	Description/Location
E1	PC5-2F	50 mvdc at 1 kw	Collector pump (P1) power
E2	PC5-11F	50 mvdc at 2 kw	Air conditioning pump (P2) power
E3	PC5-2F	50 mvdc at 1 kw	Chiller hot water pump (P4) power
E4	PC5-2F	50 mvdc at 1 kw	Chiller condensing water pump (P3) power
E5	PC5-1F	50 mvdc at 0.5 kw	Domestic hot water recirculation pump (P6) power
E6	PC5-1F	50 mvdc at 0.5 kw	Cooling tower fan power
E7	PC5-2F	50 mvdc at 1 kw	Chiller power
E8	PC5-52F	100 mvdc at 10 kw	Overall equipment power
E9	PC5-71F	100 mvdc at 80 kw	Laundry water heater power
E10	PC5-20F	50 mvdc at 3 kw	Apt. water heater power, apt. A
E11	PC5-20F	50 mvdc at 3 kw	Apt. water heater power, apt. B
E12	PC5-20F	50 mvdc at 3 kw	Apt. water heater power, apt. C
E13	PC5-20F	50 mvdc at 3 kw	Apt. water heater power, apt. D
E14	PC5-20F	50 mvdc at 3 kw	Apt. water heater power, apt. E
E15	PC5-20F	50 mvdc at 3 kw	Apt. water heater power, apt. F
E16	PC5-20F	50 mvdc at 3 kw	Apt. water heater power, apt. J
E17	PC5-20F	50 mvdc at 3 kw	Apt. water heater power, apt. K
E18	PC5-20F	50 mvdc at 3 kw	Apt. water heater power, apt. L
E19	PC5-20F	50 mvdc at 3 kw	Apt. water heater power, apt. M
E20	PC5-20F	50 mvdc at 3 kw	Apt. water heater power, apt. N
E21	PC5-20F	50 mvdc at 3 kw	Apt. water heater power, apt. P
E22	PC5-29F	50 mvdc at 10 kw	Apartment ACHV power, apt. A
E23	PC5-29F	50 mvdc at 10 kw	Apartment ACHV power, apt. B
E24	PC5-29F	50 mvdc at 10 kw	Apartment ACHV power, apt. C
E25	PC5-29F	50 mvdc at 10 kw	Apartment ACHV power, apt. D
E26	PC5-29F	50 mvdc at 10 kw	Apartment ACHV power, apt. E
E27	PC5-29F	50 mvdc at 10 kw	Apartment ACHV power, apt. F
E28	PC5-29F	50 mvdc at 10 kw	Apartment ACHV power, apt. J
E29	PC5-29F	50 mvdc at 10 kw	Apartment ACHV power, apt. K
E30	PC5-29F	50 mvdc at 10 kw	Apartment ACHV power, apt. L
E31	PC5-29F	50 mvdc at 10 kw	Apartment ACHV power, apt. M
E32	PC5-29F	50 mvdc at 10 kw	Apartment ACHV power, apt. N
E33	PC5-29F	50 mvdc at 10 kw	Apartment ACHV power, apt. P

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