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COO/2624-76/2

UNITED STATES SPECIAL FORMAT REPORT: NORTHVIEW
JUNIOR HIGH SOLAR ENERGY SCHOOL HEATING
AUGMENTATION EXPERIMENT

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June 1976

Work Performed Under Contract No. E(11-1)-2624

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ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Division of Solar Energy

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NATO Committee on the Challenges of Modern Society
CCMS SOLAR ENERGY PILOT STUDY
Solar Heating and Cooling Systems in Buildings

UNITED STATES SPECIAL FORMAT REPORT

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This report was prepared according to the Special Reporting Format developed by the CCMS Solar Energy Pilot Study. The text of the Special Reporting Format is found at the end of this document.

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NORTHVIEW JUNIOR HIGH SCHOOL

I. General Description of System Project and Environment

A. Objective of Project

The program described in this report demonstrates the ability of solar collectors to supplement the heating and hot water requirements of North View Junior High School in suburban Minneapolis. The program is obtaining engineering data which may be used to improve collector performance and system performance or design. In addition, data are being compiled which may be used to define investment requirements for similar installations. The program is also helping to determine community acceptance of solar heated school buildings. Construction was initiated during January 1974 and completed during May 1974.

The basic rationale for the program is the necessity of obtaining firm answers in three areas: 1) validation of system performance, 2) determination of overall system costs, and 3) acquisition of data to determine the benefits of such a system.

Only by actually constructing a solar heating system and full scale testing can good engineering data be obtained to compare with analytical predictions. Further, testing the system in conjunction with its actual use in a functioning building will provide real-time inputs not envisioned in simulation or other artificial test environments. The testing location provides a long, severe heating season with a wide variation of insolation and other environmental factors. The testing program was conducted from 16 May 1974 to the 16 May 1975.

B. Description of the Environment

1. Climate

Situated very close to the geographical center of the North American continent, the climate of Minneapolis is predominately the continental type with a general tendency to extremes in all climatic features. There are wide variations in temperature, ample summer rainfall, and scanty winter precipitation. U.S. Weather Bureau data for the 1935 - 1974 period show an average annual rain and snow fall of 674 mm and 1143 mm respectively. With very low cloudiness prevailing during the late fall and early spring, and with sunshine at its minimum during the winter months, the same records indicate an annual average of 58 percent of maximum possible sunshine hours.

2. Location

At $44^{\circ}53'$ N latitude and $93^{\circ}13'$ W longitude, the terrain varies little in elevation from the official 254 m above mean sea level. Averaged air pollution index values from stations in the metropolitan area and at the boundary indicate a relatively satisfactory air quality.

3. Solar Radiation

Hourly values of total radiation, based on data supplied by the U.S. Weather Bureau for the year 1956, were calculated to predict the monthly values of insolation on a south facing surface inclined at an angle of 55° from the horizontal. The year 1956 is considered to be a typical year and the ASHRAE procedures were used as the basis of our computations. Table (1) shows the mean monthly values of the insolation and the ambient conditions.

TABLE 1. MEAN MONTHLY VALUES

	Insolation*	Dry Bulb	Degree Days		Relative	Wind*	
	MJ/M ²	Temperature*	Base 18°C		Humidity*	Speed*	Direction*
		°C	Heating/Cooling*		%	m/sec	
January	342.82	-11.0	909	0	70	4.65	NW
February	452.93	- 8.6	754	0	69	4.74	NW
March	405.04	- 2.0	632	0	69	5.05	NW
April	474.94	7.3	332	0	64	5.54	NW
May	471.54	13.9	151	14	63	5.14	SE
June	504.19	19.4	36	68	65	4.69	SE
July	467.95	22.2	6	125	67	4.16	S
August	509.02	21.2	12	101	69	4.11	SE
September	485.71	15.6	96	13	73	4.43	S
October	483.49	10.0	262	4	71	4.69	SE
November	289.73	0.2	543	0	75	4.92	NW
December	240.13	- 7.4	799	0	76	4.65	NW

*Based on record for the 1941-1970 period

Figure 1 is a schematic of the complete solar system as installed. The collector array is composed of six parallel rows of flat-plate collectors. The system pump moves heated fluid from the collectors to the system load. The 11,400 liter storage tank can be used to store the excess energy. The swimming pool water heater and the domestic water heater are tube-and-shell heat exchangers. One air heater is used to temper outside ventilation to air, while the other reheats the mixed air. The system operates on a demand basis, with air heating having the first priority, pool water heating the second, and domestic water heating the third. All automatic control functions can also be operated manually.

Since in a building of this size, the use of solar energy to supplement total building heating requirements would have been beyond the scope of the project funding, the swimming pool space was selected for supplemental heating as well as pool water heating and domestic hot water heating. Figure 2 is a drawing of the system as it is located around the building.

FIGURE 1
SCHEMATIC OF SOLAR HEATING SYSTEM
FOR NORTHVIEW JUNIOR HIGH

Figure 2. Solar Heating System - Northview Junior High School

C. Description of System

1. Qualitative Description

The solar energy system is located in Minnesota Independent School District No. 279 at Northview Junior High School, 5869 69th Avenue North, Brooklyn Center, Minnesota, a suburb of Minneapolis. The building is a modern educational facility of about 15,300 square meters with swimming facilities, a gymnasium, a cafeteria, and an array of various classrooms.

The statistics for the Northview Junior High School building are:

● Building area	15,383 square meters
● Building volume	65,869 cubic meters
● Prime and equipment contracts awarded	\$3,114,120.00
● Cost per square meter	\$202.44
● Site area	Approximately 121,400 square meters
● Construction period	1968-1969
● Architects	Matson and Wegleitner
● Student capacity	Approximately 1300

The solar system consists of 464 square meters of flat-plate, liquid-cooled collectors which supply energy through exchangers to heat:

- Ventilation air for the swimming pool
- Swimming pool water
- Domestic water

2. Quantitative Description

The collector system as installed is shown in Figure 3. The collector array is composed of 246 collectors arranged for parallel flow. The collectors are facing south at a 0° angle inclined at an angle of 35° between the horizontal and normal to the collector.

Figure 3. Installed Collector System

As previously described, the solar collectors are divided into six sections with parallel inputs and outputs. The common outputs go into the building to the air separator-filter combination then through the pump, flow control valve, and flow meter towards the storage tank. The flow can be directed into the top of the storage area and out the bottom, into the bottom and out the top, or bypassed around the tank by appropriately switching Valves 1, 2, and 3. After passing around or through the storage tank, the flow is directed to domestic water heating or to air

heating, depending upon the position of Valve 5. When directed towards air heating, Valve 4 determines if the return air heating coil will be bypassed. After passing Valve 5, the flow is directed to or around the collectors, depending upon the position of Valve 6. The domestic water is directed around or through the heat exchanger, depending upon the position of Valve 7. An additional line from the heat exchanger output to the pool or drain is provided for emergency extraction of heat from the collectors. During the one-year test program, the pool water heater was installed. Whenever space heating is satisfied, the system switches to heat pool water through Valves V5 and V8. If this load is satisfied, the system then switches to heat domestic water.

Figure 4 is a schematic of the control system as initially installed. The system incorporates Honeywell's pneumatic controllers and valves. The valves are actuated either manually from control switches on the control panel, or automatically when the valve switches are so set. Pneumatic temperature readouts are provided on the panel so temperatures may be seen. The control panel itself is a schematic layout of the plumbing system with valve switches locations corresponding to actual valve locations.

Instrumentation

Temperatures are measured with the use of stainless steel sheathed copper-constantan thermocouples located at important points in the liquid and air loops, as well as at selected points on the collectors. There are additional access points throughout the system for additional temperature measurements should they be needed. For example, each bank of collectors has an access port at the inlet and outlet. All thermocouple access ports incorporate a special Viton sealed plug which permits the insertion and removal of thermocouples by simply pulling the thermocouple out of the port. The plugs are self-sealing upon removal of the probe. Thermocouple locations are shown in Figure 5. Temperatures are recorded with the use of a 24-channel recorder with selectable channels. During operation of a particular mode only those thermocouples needed to evaluate that mode are selected.

Wind speed and direction are measured using a remote sensor and recorder, while solar radiation is monitored with a Kipp and Zonen pyranometer installed in the collector plane. The radiation is recorded instantaneously and automatically integrated.

The instrumentation system was designed to evaluate the performance of the system as a whole instead of specific to detailed analysis of each component. However, individual components such as heat exchangers are instrumented in case any specific detailed information might be needed. The design and location of the sensors will enable data to be collected for evaluating the hourly values of:

- The amount of incident solar radiation on the collector plane
- The useful heat collected by the collector panels
- The efficiency variation of the collector panels
- The amount of heat stored in the storage mode
- The amount of heat extracted from the storage tank during any three discharge modes, namely:
 - Storage to fresh air
 - Storage to fresh air + reheat air
 - Storage to water heating
- Heat transferred in from the fresh air heating coil to the air stream
- Heat transferred from the reheat air coil to the air stream
- Heat used for heating domestic water both from collector and storage tank
- Total daily useful heat quantities for the above modes and system components
- The contribution of solar energy to the heating requirements of the school

FIGURE 5
SENSOR LOCATIONS

II. System Thermal Performance

A. Daily, Monthly and Annual Values

School Energy Consumption

Criteria for solar system evaluation and feasibility often require an assessment of its impact on the energy consumption and its potential for future energy savings. Several factors such as present fuel prices, and engineering costs for a prototype design would present some drawbacks and made such an analysis unrealistic. However, a look at the energy consumption pattern might yield some insights useful for future tradeoffs in system design and optimization.

Based on available records from January 1971 to June 1975, the energy consumed at the school is presented in Table 2. Energy conservation seems to account for the drop from 3.6×10^7 MJ in 1971-1972 to a more realistic 2.0×10^7 MJ for the 1975-1976 school year. Table 3 shows the accompanying increase in natural gas prices during the same period. The school energy consumption is increased over the more traditional school due to the availability of the school facilities to the public for various activities after school hours, on weekends and during summer vacation. Also, the presence of a swimming pool on a year-around basis adds an average of 1.6×10^3 MJ/day to the energy consumption.

An average of 2.1×10^6 MJ is required to maintain these recreational facilities during the summer months (Table 4). With boiler efficiencies known to drop rapidly at below 50 percent of input rating, the solar system is very attractive for the present application. In fact, with the boilers on a standby basis, the solar

system proved to be capable of supplying most of the heating demands of the school during the summer season. This is shown in Table 4 where one boiler was put on standby during the summer of 1975 and the solar system provided most of the energy. The savings over the summer alone amounted to an equivalent of \$1500 in natural gas costs.

Table 2. Fossil Fuel Energy Consumption at N. V. J. H.

Year (May-June)	Energy (M J.)
1971-72	3.57×10^7
1972-73	3.00×10^7
1973-74	1.98×10^7
1974-75	2.04×10^7

Table 3. Natural Gas Costs at N. V. J. H.

Year	Natural Gas Costs/M ³
1971-72	.020
1972-73	.023
1973-74	.032
1974-75	.036

Table 4. Energy Consumption over Summer Months at Northview Junior High (in M³ of Natural Gas)

	Average 1971-1974	1975
June	17,200	3,880
July	17,200	425
August	15,900	2,070

Solar Energy Incident and Collected

Continuous monitoring of system parameters and environmental factors was undertaken during the test period to accurately assess the solar system performance under several load demands when subjected to variable climatic conditions.

Solar flux measurements made in the plane of the collector were continuously recorded and integrated for daily performance figures. Temperature readouts from sensors located throughout the distribution system and the transfer fluid mass flow rate determined the state of the system on an hourly basis. Figure 6 shows the integrated values of incident and collected energy on a monthly basis.

E. Energy and Mass Balance

During the winter months, space heating provided the largest load and is a function of the ambient temperature and the amount of ventilation air used in space conditioning and would be the only load for some winter days. On warmer days, or those days when there was good solar collection, the space would be satisfied and the system would automatically switch from space heating to pool water heating. Figures 7 and 8 are the results of space heating only for 23 December 1974. Figure 7 shows the amount of solar and auxiliary heat supplied as well as the cumulative total for the day. Figure 8 illustrates the percentage of load supplied by solar as a function of time. Solar was supplying 100 percent of the load between 11:30 a.m. and 3:30 p.m. on this day. Figures 9 and 10 show collector inlet, outlet, and ambient temperatures, and the incident energy and the system's efficiency.

The amount of ventilation air on this particular day was 92 percent. From 9:30 a.m. to 4:30 p.m., 5,081 MJ were needed to maintain the space at 27°C for an average outdoor temperature of -4°C . This is equivalent to 188,380 Watts and would have required an average of 413.82 W/m^2 of solar collection. Obviously, if the amount of ventilation air is reduced, the load would also be reduced. Analysis has shown that, for this space, 78 percent of the heat required is due to ventilation losses. The maximum collector outlet temperature required for the operation was 52°C , resulting in an efficient operation of the system and illustrating the large amount of energy which can be extracted from the solar system with the above ambient temperatures, such as shown in the figures. The increase in efficiency toward the end of operation is mainly due to the extraction of the heat stored in the thermal mass of the collectors.

The system pressure drops are as follows:

● Piping and fittings	55 Kpa
● Control valves	24 Kpa
● Heat exchangers	<u>69 Kpa</u>
Total	148 Kpa

FIGURE 6
MONTHLY TOTAL ENERGY INCIDENT AND COLLECTED

FIGURE 7
SPACE HEATING

FIGURE 8
PERCENT SPACE HEATING LOAD

Date: December 23, 1974

FIGURE 9
COLLECTOR INLET, OUTLET, AMBIENT TEMPERATURES FOR SPACE HEATING

FLOW RATE: 4 l/SEC.

December 23, 1974

FIGURE 10
ENERGY AND EFFICIENCY FOR SPACE HEATING

III. System Economic Analysis

A. Total Cost of Solar Portion of the System

The costs of the solar system assembly subtasks are tabulated below. These costs do not include engineering labor. All work outside of the collector assembly work was completed under fixed-price contracts with outside vendors. Some of these vendors were other Honeywell divisions. The costs reflected below include materials and labor which are difficult to separate on fixed price contracts to outside vendors.

Under the time constraints imposed by the initial design and build contract and the usually higher costs of a prototype system, the costs listed below would not reflect the costs of a similar system installed using the knowledge gained from the installation of the North View project and production techniques aimed at lowering system costs.

<u>Item</u>	<u>Cost</u>
Collectors (464 square meters)	\$98,600.00
Plumbing (includes manual valves, insulation pipe, fittings and labor)	63,782.00
Structure (materials and labor)	8,000.00
Components (heat exchangers, pump, expansion tanks, air control)	4,500.00
Storage tank and pad	6,330.00
Control system (panel, valves and controls)	12,000.00
Instrumentation	4,878.00
Electrical	1,300.00
Antifreeze	3,520.00
Fencing, painting and air filters	4,100.00
Collector installation	4,200.00
Total	\$211,210.00
Cost/m ²	\$455.00

B. Labor Costs for System Installation

Since the installation costs were under a fixed price contract, the number of man-hours for installation is not known. However, the rate at the time of installation was \$16.00/man-hour. It is estimated that the installation involved between 200 and 2500 man-hours.

C. Materials Costs - See Item A.

D. Operational Costs

During the one-year test period, the system pump operated a total of 1250 hours in about 210 days for an average of 5.95 or about 6 hours/day. Measured power consumed by the pump was 2.6 KW. At a cost of \$0.03/KWh the daily pump costs are \$0.468 or about 50¢/day. Energy collected/day averages 878 KWh at an equivalent cost of \$.014/KWh for an average savings of \$12.00/day. The cost of operating the pump is about 5 percent of the collected energy's worth. The assumed system lifetime is 20 years.

E. Local Economic Factors

The current inflation rate has been averaging about 7%/year. Interest rate has been averaging around 10%/year. Normal amortization period used in economic analysis has been 20 years.

F. Expected Selling Price or Costs

The expected selling price of the solar collectors assuming the system or components are mass produced would be on the order of \$215.00/m² for systems greater than 93m².

G. Maintenance Frequency and Costs

Glass breakage of the 4.76 mm tempered glass used on the collectors was not a major problem. A total of four sheets were replaced out of 256. Two were broken by vandals, while two were broken during operation of the system by Honeywell personnel. No breakage has occurred during the winter months. Replacing the glass takes about six man-hours, with all panels easily accessible from the ground.

Condensation in small amounts could be noticed on the underside of the glass surface during late fall and early spring. This did not present any problem as the condensation would be gone after about 10:00 a.m. In addition, no detectable decrease in performance could be determined either from condensation or from dusty or dirty glass. Periodic rainfall does an acceptable job of glass cleaning.

Snow build up on the collectors during the winter months presented a unique but major problem on a majority of the collectors. During the month of January 1975, the efficiency of collection showed a marked drop from the previous months (45% - 50% down to 34%). This was due to an accumulation of snow on the collector's surface. On January 10th and 11th, a major blizzard deposited a

large amount of snow on the collectors. A decision was made to leave the snow on the collectors to see if natural radiation would melt it, or, that failing, there were a possibility of melting the snow from the storage tank heat. Both techniques failed on the collector rows in which the lower edge of the collectors were less than 0.6 m to 0.9 m from the ground. On those collectors whose lower edges were higher than 0.9 m the natural radiation melted enough snow on the glass surface so that the remainder slid off the collectors. On the lower collectors, the snow would slide and form a bridge between the collectors and the ground. This would turn to ice and force further accumulations of snow. Figure 11 shows snow accumulation during the month of December and early January. Figure 12 is the snow accumulation from the blizzard of January 11, while Figure 13 shows the lowest row of collectors after the snow.

Periodic checks of the collector system's inlet pressure showed that, at the early morning start-up time, the inlet pressure was up to 107 Kpa at flow rates of 5.0 l/sec. The operating flow rate was lowered to 3.78 l/sec during the winter season, thus limiting the pressure build up. Available data for a 50% mixture of ethylene-glycol and water shows a viscosity increase from 4 to 22 Centipoise with a temperature drop from 21°C to -18°C. This viscosity change is more than enough to cause the increase in inlet pressure. The 3.78 l/sec flow rate was maintained during the cold winter months. Data evaluation has shown no detectable decrease in efficiency due to the lower flow rate.

One minor problem was encountered with the control system operation. This problem was caused by the parallel operation of the system's conventional HVAC system and the solar heating system. When solar heating of fresh air occurred under high solar insolation, the space was momentarily overheated because the conventional HVAC system thermostat would not respond fast enough to shut off the heating coil in the conventional system. Thus, both systems supplied heat simultaneously in cases when the solar heating system could have handled the entire load. Adjustment of thermostat set points helped to alleviate, but did not completely solve the problem. Subsequent checks of the thermostat showed that the device had corroded badly from pool-humidity. Replacing the thermostat solved the problem.

System maintenance has been very low since the Fall of 1974. One additional section of glass was replaced and no system leaks have been detected.

Figure 11. Snow Accumulations

Figure 12. Snow After Blizzard

Figure 13. Collectors After
Snow Removal

H. User Reactions and Comments

Several conclusions were reached after approximately two years of experience with the Solar Energy System at North-view Junior High School:

- Supplemental heating of large commercial buildings using solar energy is feasible. The system is capable of supplying up to 4,200 MJ per day, depending upon ambient conditions and building demand.
- Optimum system performance can only be realized if the building's heat demand matches the optimum operating conditions of the collector array. If demand is low, system efficiency decreases due to higher collector inlet temperatures.
- High operating temperatures in solar systems must be avoided if system pressurization is low. Boiling and inherent vapor locks and "steam hammering" are the results with this continuing until sundown.
- Condensation on the underside of the glass surfaces is most prominent in fall and spring in this climate. Condensation and leaks can deteriorate some absorber plate coatings and streak the glass.
- Snow covering collector surfaces in northern climates can be a serious problem. Collectors should be mounted to permit natural or mechanical snow removal.

- Community acceptance and interest is very good. Student organization, industry representatives and visiting dignitaries were continuously visiting the solar system.
- System operating costs of this single pump system are very low (5% of the value of the collected energy).
- The system was installed without any special problems which could not be solved with current construction practices.
- Ventilation air and domestic water preheating are particularly attractive loads for flat plate collector systems.
- System maintenance and operation can readily be performed with the custodial staff after a limited amount of familiarization with the system.
- Plate temperature sensing for system on-off control is adequate.

Recommendations

The following recommendations are submitted for future system design operations and evaluations:

- In northern climates, where there is little need for ventilated air, solar system should be used to preheat this air whenever possible.
- Solar system designs should incorporate provisions for directly using solar energy. Storage systems should be capable of being bypassed due to the greater efficiency of using energy directly, and due to storage heat losses.
- Storage sizing should be bound on energy availability and usage. Storage losses should be minimized through adequate insulation.
- Collector designs should incorporate as few interconnections as possible to minimize installation costs and leak points. For the high-temperature operation necessary for absorption-type air conditioners, the collectors should be designed under moderate pressures in a closed system. Design features should also include a high-temperature control in the event of low usage of incident energy or collector circulation failure.
- Solar control system designs should be fully automated and as consistent with present day HVAC control systems as possible.

A. Solar Collectors

1. Description of Physical Configuration

The general design of the collectors consists of liquid-cooled steel plates coated with selective absorbing coatings and enclosed in an insulated steel housing which is covered by two transparent windows, one glass and one Tedlar. Figure 18 is a corner section of a typical collector. Shown are the glass cover, Tedlar sheet, absorber plate, insulation and the steel housing with the various structural assemblies.

The outer housing is composed of 1.21 mm, cold-rolled steel .91 meter wide, 2.4 meters long and .15 meter deep. The housing is formed from a single sheet of steel in a press brake and welded at the corners. Internal brackets are welded to the housing sides for support of the Tedlar sheet. Four access holes are provided for the plumbing and six additional holes are for maintenance and installation.

The absorber panel consists of two .533 mm, 1020 cold-rolled steel sheets .086 meter wide by 1.18 meter long with flow passages formed into the sheets. One sheet carries 6.35 mm x 1.27 mm deep grooves on 50.8 mm centers for basic heat transfer flow. The other sheet is formed to provide a 50.8 mm x 50.8 mm manifold at one end with a 12.7 mm x 12.7 mm manifold at the other end. The two sheets are assembled by spot and seam welding to form a parallel flow panel with large manifolds and small heat transfer channels. Formed steel tubulations on each corner permit connection by automotive type hose of a series of panels to form an array of parallel collectors with small vertical heat transfer passages. The design minimizes the effects on nonuniform flow through the panel assembly. The

Figure 18

final design of a complete collector used two absorber panels assembled within a unit for fabrication conveniences. The two panels are connected by small hoses between the smaller manifold tubulations and are attached to mounting brackets by insulating nylon washers. The completed assembly acts very much like a single panel.

Additional design features include a frame which is placed over the outside edges of the glass cover which is 4.76 mm x 88.6 cm x 2.4 meters tempered glass. A sealant tape is used on both sides of the cover near the edges. Insulation is 89 mm of fiberglass across the back of the collector and along the sides to reduce edge losses. Collector sizing of 464 square meters of absorber area dictated the fabrication of 246 individual assemblies which were then transported to and erected on the site.

2. Thermal Performance Characteristics

Figure 14 shows a performance curve experimentally determined during the test period. This is a curve for the collector array performance and includes all piping losses to and from the building, as well as collector and header connection heat losses. The curve shows that for air conditioning at a fluid inlet temperature of 93°C and ambient of 32°C with incident flux of 630.5 W/m^2 , the efficiency is about 20 percent. For fresh air heating when the difference between the fluid inlet at 38°C and a 10°C ambient, and the incident is 630 W/m^2 then the efficiency is around 48 percent. This is typical of many efficiencies obtained during the early morning hours of the winter months.

FIGURE 14
SYSTEM PERFORMANCE CURVE

The main heat losses in the system are the collector modules due to the condition of the insulation both on the back of the absorber panel and around the edges, particularly the top edges. This insulation has settled and compacted some on the backs and insufficient quantities were placed around the edges. The pressure drop through the collectors is .024 Kpa at .073 l/sec/m².

3. Lifetime Performance Characteristics

Corrosion

Exterior corrosion of the steel absorber panels is not evident. The units have a selective coating of black nickel over bright nickel. This coating shows good resistance to corrosion. Internal corrosion is inhibited by the heat transfer fluid.

The only significant leakage in the system was caused by the rubber hose connections originally used in the design. These hose connections have been replaced.

No degradation of the collector working fluid is apparent. The thermal characteristics of the collector panel are still the same as originally installed. This collector is no longer manufactured by Honeywell, but still serves as a testbed for lifetime testing of components, some of which are utilized in newer collector designs.

B. Heat Transfer Subsystem

1. Description of Physical Configuration

The system uses heat exchangers located in the pool air circulation loop and in the domestic water feedline and pool

water recirculating loop. These heat exchangers were sized on the basis of a 6°C rise across the collectors at a flow rate of 5.0 l/sec. The air circulation system has two heat exchangers -- one for heating outside air and the other for heating a combination of tempered outside air and pool return air. These heat exchangers are four rows, six fins per 2.54 cm glycol-water to air with a face area of 1.06 x 2.82 meters. A subsequent computer calculation assuming inlet glycol-water at 35°C and outside air at 4°C showed a mixed air temperature of 20°C and a glycol-water return temperature of 29°C with an air flow of $340\text{ m}^3/\text{min}$ and glycol-water flow rate at 5.0 l/sec. This corresponds to a heat extraction rate of 105,000 watts. The domestic water heater is a standard tube and shell heat exchanger and was sized on the basis of a water use which varies from .105 to .736 l/sec with a maximum outlet temperature of -60°C . Assuming an inlet water temperature of 4°C this exchanger is capable of transferring up to 293 KW. The pool water heat exchanger was sized on the basis of a heat transfer rate of 73.3 KW.

To minimize pressure losses in the system a pipe size of 76.2 mm was chosen. Total pipe footage from the collectors through the air heat exchangers back to the collectors is about 305 m. Assuming a flow rate of 5.0 l/sec, the pressure drop per 30.5 m of 7.6 cm schedule 40 steel pipe is 4.74 Kpa, or 47.4 Kpa, for the 305 m. Each 90-degree elbow in the system is equivalent to the pressure drop in .91 m of pipe. For approximately 60 elbows this is equivalent to 54.9 m of pipe or about 8.62 Kpa. Five control valves at 4.8 Kpa/valve contributes a 24.1 Kpa loss. The two air heat exchangers in series amount to 68.9 Kpa loss

at 5.0 l/sec. The flow meter contributes 6.89 Kpa while the collectors nominally contribute about 3.35 Kpa. The total calculated loss is about 159 Kpa. Assuming 5.0 l/sec flow of 50-50 glycol-water mixture with a specific gravity of about 1.1 would require an ideal pump size of about 895 watts. A 3730 watt pump was selected which would give a flow rate of 5.0 l/sec at 221 Kpa head. This is a centrifugal pump with the capability of machining the impeller to match the system flow and pressure drops. Subsequent operation of the system shows a nominal pressure drop of 145 Kpa in the loop.

To allow for system fluid expansion (estimated at 878 liters for a 50-50 glycol/water mixture from 4°C to 93°C) four 454 liter expansion tanks were connected in parallel and installed at the high point in the system. These expansion tanks are connected on the suction side of the pump at the collector common outlet. The system fluid capacities are broken down into 11,400 liters in storage, 1,180 liters in the collectors, 1,514 liters in the piping and 605 liters in the expansion tanks.

An air separator was installed on the suction side of the pump. This is a vertical air separator and filter combination with the air leaving at the top center of the unit to an air holding tank located about 3.05 meters above the separator. Periodic bleeding of air from this holding tank is required. Additional filters are installed at each collector row inlet and are of the commercial "Y" strainer type. Balancing valves are installed at each collector row inlet as well as shutoff valves at each outlet. Pressure relief valves are installed at each collector row inlet as well as shutoff valves at each outlet. Pressure relief valves are installed immediately after each collector outlet and are set at a nominal 103 to 140 Kpa range.

System insulation other than in the collectors is 5.1 cm, semi-rigid fiberglass on all interior and above ground exterior pipe. The above ground exterior pipe is also covered by an aluminum protective cover. All underground piping insulation is 5.1 cm of urethane covered with a waterproof coating.

C. Thermal Energy Storage Subsystems

1. Description of Physical Configuration

The storage tank size was based on storing approximately one day's collection of heat. This was due to the limited amount of space available for storage. Final design size was 11,400 liters and the tank was erected within the building from separate 6.35 mm thick steel sections. The tank is 2.1 meters in diameter and 43 meters long. Design working pressure is 241 Kpa, with the burst pressure being 620 Kpa. The tank is supported on a separate concrete slab which was poured to accommodate the additional concentrated load. The tank is insulated with 5.1 cm of rigid fiberglass. (Figure 15 shows the storage tank installed in the system).

2. Thermal Performance Characteristics

Storage tank charging was normally done in conjunction with some operating mode. During the winter, the load was usually large enough so that all collected energy could be used, therefore, very little storage charging was done in series with any of the operating modes. Figures 16 and 17 illustrate simple storage charging. Figure 16 shows the inlet, outlet and ambient temperatures. The

average storage tank temperature closely follows the inlet temperature at the beginning of the operation, but remains closer to the average between the inlet and outlet temperature for the remaining of the operation. This is due to the small volume of the tank relative to the collector area. The 11,400 liter tank was raised from 56°C to 98°C during the collection period adding 1,874 MJ to the capacity of the tank.

The integrated amount of energy collected was calculated at 2,777 MJ, resulting in system losses of 924 MJ. Of the total losses, 340 MJ of the Btus can be accounted for in piping and transport fluid thermal capacity. The remaining losses are heat losses from the storage tank and system piping, all well insulated with 5.1 cm of fiberglass. The wisdom of bypassing the storage tank and using the energy directly is apparent when the losses from the tank are a significant amount of the energy available.

The disadvantages of the storage-charging operation are evident from the plot of the energy collected. Because of the small tank volume, a rapid drop in system efficiency occurs in the early afternoon due to high operational temperatures. This also forced the operation to cease by 4:00 p.m., while the incident radiation is still significant (630 W/m^2). Also a large irrecoverable amount of energy was left stored in the plates in addition to the uncollected incident energy on the collectors between 4:00 to 6:00 p.m.

Figure 15. Storage Tank

FIGURE 16

COLLECTOR INLET, OUTLET AND AMBIENT TEMPERATURES FOR STORAGE CHARGING

STORAGE TANK CHARGING

MAY 16, 1975

FIGURE 17

ENERGY AND EFFICIENCY FOR STORAGE CHARGING

MAY 16, 1975

RECOMMENDED

CCMS SOLAR ENERGY PILOT STUDY

REPORTING FORMAT FOR

HEATING AND COOLING SYSTEMS IN BUILDINGS

August 1975

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

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

FORMAT FOR REPORTING SYSTEM PERFORMANCE

I. General Description of System Project and Environment

A. Objective of Project

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

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

1. Climate

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

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

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

2. Location

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

3. Solar Radiation

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

4. Ambient Temperatures

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

5. Wind

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

C. Description of System

1. Qualitative Description

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

2. Quantitative Description

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

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

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

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

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

+ Angle between horizontal and normal to collector.

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

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

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

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

- B. Record of the Quality of Thermal Performance of the System
(e.g. departure from the design temperature over reporting period)
- C. Solar Contribution to Energy Requirements - daily, monthly and annual values* of percent solar contribution to the energy requirements.
- D. Monthly and Annual Energy or Fuel Savings - based on primary fuel (state type).
- E. Energy and Mass Balances

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

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

I. System Economic Analysis

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

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

- A. Total Cost of the Solar Portion of the System - with a specific definition made of the interface between the solar and non-solar portions of the system. If possible, separate design costs from component and installation costs.
- B. Labor Costs - in man-hours and in local currency, for the installation of the system.
- C. Materials Costs - in weight or volume as appropriate and in local currency.
- D. Operational Costs - including supplemental energy costs, in local currency.

Since operational costs depend on the assumed system lifetime, it is suggested that the assumed system lifetime be stated along with the depreciation rate.
- E. Local Economic Factors - such as inflation, interest rates and amortization periods.
- F. Expected Selling Price or Costs - assuming that the system or solar components are mass produced.
- G. Maintenance Frequency and Costs - in hours and material.
- H. User Reactions and Comments

FORMAT FOR REPORTING SUB-SYSTEM PERFORMANCE

A. Solar Collectors

1. Description of Physical Configuration

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

2. Thermal Performance Characteristics

- o Collector efficiency curves (efficiency as a function of average fluid temperature or inlet coolant temperature, ambient air temperature, solar radiation normal to the collector, and wind speed) or equivalent collector performance indication (such as heat production) for several days that typify the full range of operation of the system.
- o Pressure drop through collectors.
- o Optical efficiency vs. incident angle, daily, monthly, and annual optical efficiency.*
- o Thermal loss coefficient as a function of the difference between the ambient and the mean plate temperature, for known wind speeds.*

3. Lifetime Performance Characteristics

- o Corrosion
- o Leakage
- o Hot spots
- o Breakage
- o Stability of collector working fluid

B. Heat Transfer Sub-system

1. Description of Physical Configuration

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

* Optional information to be included if known.

2. Thermal Performance Characteristics*

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

C. Thermal Energy Storage Sub-systems

1. Description of Physical Configuration

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

2. Thermal Performance Characteristics*

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

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

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

D. Air-Conditioning Sub-system

1. Description of Physical Configuration

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

2. Thermal Performance Characteristics

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

* Condenser, absorber and evaporator temperatures should be stated.

⁺ Including the ratio of sensible to latent heat removal.

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

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

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