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GENERAL ELECTRIC - MILWAUKEE
(OPERATIONAL TEST SITE)

MILWAUKEE, WISCONSIN

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

SEPTEMBER 1980 THROUGH MARCH 1981

Prepared by R. G. Howard

Approved: T T Bradshaw
T. T. Bradshaw
Program Manager

Vitro Laboratories Division
Automation Industries, Inc.
14000 Georgia Avenue
Silver Spring, Maryland 20910

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9700 South Cass Avenue
Argonne, Illinois 60439

G. A. McGinnis, Project Manager

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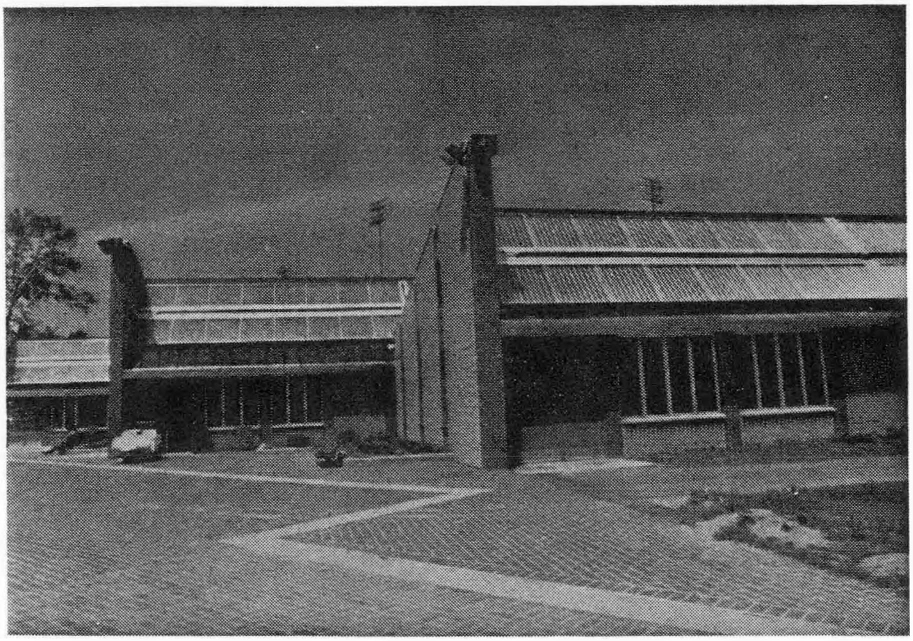
FOREWORD

This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic hot water and annual performance reports are issued for such sites.

The National Solar Data Network consists of instrumented solar energy systems in buildings selected from among the 5,000 installations built (since early 1977) as part of the National Solar Heating and Cooling Demonstration Program. The overall purpose of this program is to assist in the development of solar technologies for buildings by providing data and information on the effectiveness of specific systems, the effectiveness of particular solar technologies, and the areas of potential improvement. Vitro Laboratories Division responsibility in the NSDN, under contract with the Department of Energy, is to collect data daily from the sites, analyze the data, and disseminate information to interested users.

Buildings in the National Solar Data Network are comprised of residential, commercial and institutional structures which are geographically dispersed throughout the continental United States. The variety of solar systems installed employ "active" mechanical equipment systems or "passive" design features, or both, to supply solar energy to typical building thermal loads such as space heating, space cooling, and domestic hot water. Solar systems on some sites are used to supply commercial process heat. Some "Operational Test Sites" employ prototype Rankine cycle turbines to mechanically drive conventional vapor-compressor chillers for cooling.

The buildings in the NSDN program are instrumented to monitor thermal energy flows to the space conditioning, hot water, or process loads, from both the solar system and the auxiliary or backup system. Data collection from each site and transmission to a central computer for processing and analysis are highly automated.



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The General Electric - Milwaukee site is the Washington Park Community Center, a recreation hall for senior citizens in Milwaukee, Wisconsin. The active solar energy system is equipped with:

Collector	1,290 square feet of General Electric model TC100 Solartron, evacuated tubes
Storage	3,000 gallons of water in a General Electric tank located in basement
Auxiliary	Jernland brand natural-gas-fired furnace for space heating, heating air at 550,000 BTU/hr Jetglas model M5055LN1 natural-gas-fired domestic hot water heater, 50-gallon capacity, heating water at 42,000 BTU/hr.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION 1

SOLAR SYSTEM PERFORMANCE

GENERAL ELECTRIC - MILWAUKEE
SEPTEMBER 1980 THROUGH MARCH 1981

Solar Fraction[1]	10%
Solar Savings Ratio[2]	0.08
Conventional Fuel Savings[3]	57,109 cubic feet of natural gas
System Performance Factor[4]	0.27
Solar System COP[5]	5.00

Seasonal Energy Requirements
September 1980 through March 1981
(Million BTU)

	Total Load	Solar Contribution	% Solar
Heating	356.57	34.67	10
Hot Water	1.37	0.30	3

Environmental Data

	Measured Average	Long-Term Average
Outdoor temperature	38°F	35°F
Heating-degree days	5,846	6,346
Daily incident solar energy	1,117 BTU/ft^2	1,070 BTU/ft^2

1. $$\text{Solar Fraction} = \frac{\text{Solar Energy Supplied to Load}}{\text{Total Load}}$$

2. $$\text{Solar Savings Ratio} = \frac{\text{Solar Energy Supplied to Load} - \text{Solar Unique Operating Energy}}{\text{Total Load}}$$

3. $$\text{Conventional Fuel Savings} = \text{Savings in BTU's} \times 979.4 \times 10^{-6}\ \frac{\text{cubic feet of natural gas}}{\text{BTU}}$$

4. Ratio of system load to the total equivalent fossil energy expended or required to support the system load

5. $$\text{Solar System COP} = \frac{\text{Solar Energy Used}}{\text{Solar Unique Operating Energy}}$$

1.1 SUMMARY AND CONCLUSIONS

The General Electric - Milwaukee solar system operated below its potential during the period September 1980 through March 1981. However, the solar energy system still supplied 10% of the building energy demands. System performance was degraded by solar radiation being below the long-term average in September and December, by large energy losses from storage, by collector efficiency considerably lower than the value reported by the testing lab, and by low efficiency of the heating subsystem. The system thermal performance is summarized in Table 1.

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

GENERAL ELECTRIC - MILWAUKEE
SEPTEMBER 1980 THROUGH MARCH 1981

(All values in million BTU, unless otherwise indicated)

			SOLAR ENERGY USED*		AUXILIARY ENERGY		ENERGY SAVINGS		SOLAR FRACTION (PERCENT)	
MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	PREDICTED[(1)]	MEASURED	FOSSIL	OPERATING ENERGY	FOSSIL	ELECTRICAL	PREDICTED	MEASURED
SEP	10.29	1.74	1.86	1.62	1.70	10.04	2.70	-1.19	70	92
OCT	12.18	13.73	14.08	10.68	7.30	11.27	17.79	-1.47	94	78
NOV	8.74	38.78	25.01	6.60	55.12	10.11	11.01	-1.20	63	17
DEC	2.17	69.93	7.74	0.17	118.03	42.33	0.29	-0.33	11	0
JAN	2.43	85.93	19.14	0.03	145.01	46.32	0.05	-0.43	22	0
FEB	6.89	81.20	18.04	4.66	129.21	49.13	7.76	-0.82	22	6
MAR	13.90	66.63	26.37	11.21	94.03	64.66	18.69	-1.56	39	17
TOTAL	56.60	357.94	112.24	34.97	550.40	233.86	58.31	-7.00	-	-
AVERAGE	8.09	51.13	16.03	5.00	78.63	41.98	8.33	-1.00	31	10

(1) Predicted values obtained from f-Chart Version 4.0.

A meaningful method of evaluating the thermal performance of the system is to examine energy savings. Fossil fuel savings are based on assumed natural-gas-fired equipment operating with 60% efficiency. The overall fossil savings were 58.31 million BTU. The operation of the solar energy system required the use of electric energy for collector pumps, water pumps, and air fans. This electric energy, 6.70 million BTU, should be subtracted from overall fossil savings. This electric energy is called operating energy.

The overall energy transfers are shown in Figure 1. This Energy Flow Diagram shows the energy collected, stored, consumed, or lost in the subsystems. There were 358.35 million BTU of solar energy incident on the collector array.

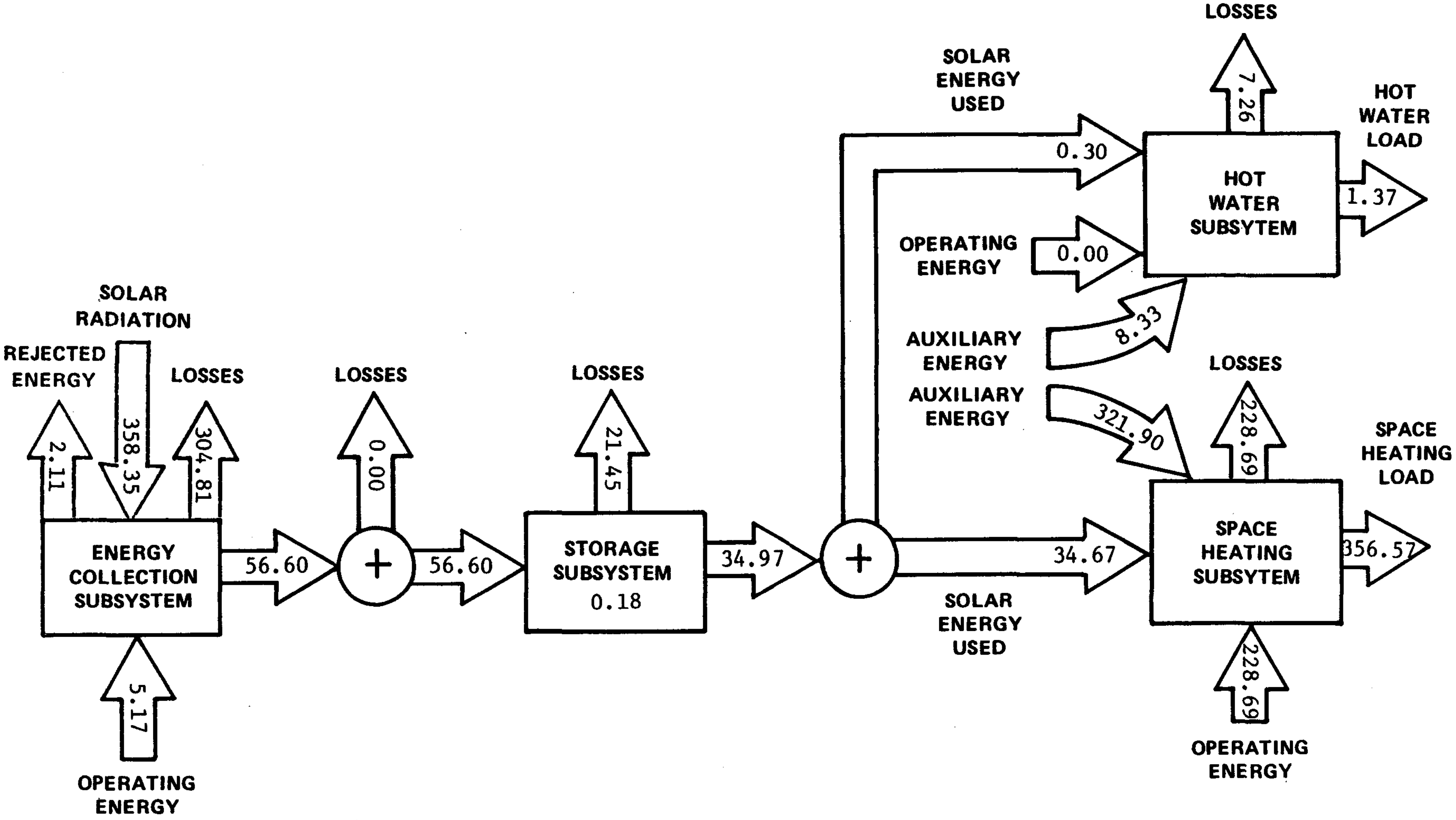
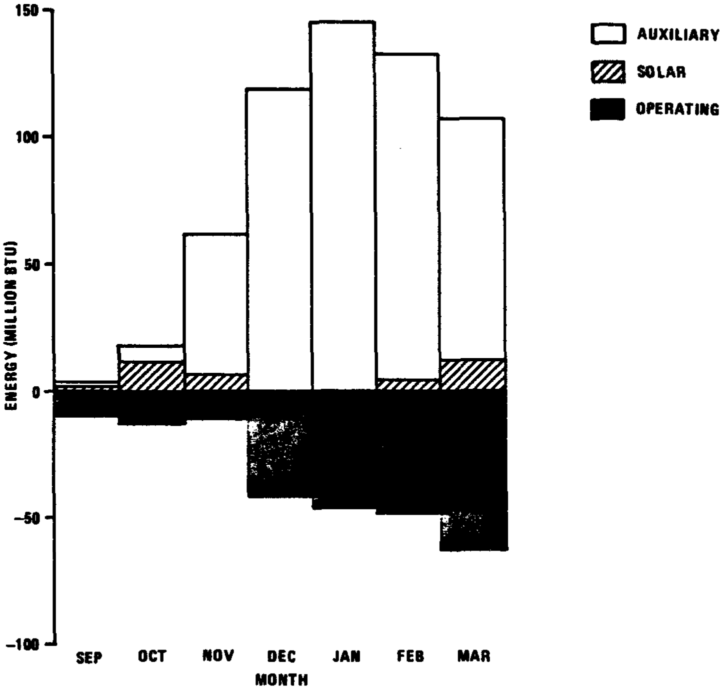


Figure 1. Energy Flow Diagram for General Electric - Milwaukee
September 1980 through March 1981
(Figures in million BTU)

Of this, 56.60 million BTU were transferred to the storage tank. The energy supplied to the hot water and space heating subsystems amounted to 34.67 million BTU from storage. The domestic hot water subsystem required auxiliary energy of 8.33 million BTU. The space heating subsystem required 321.90 million BTU of auxiliary energy.

The relative amounts of auxiliary and solar energies used each month are shown in Figure 2. Much less energy was consumed in the warmer months of September and October. Negligible solar energy was used in December and January because of the low level of sunlight and because of a collector subsystem malfunction. All these system performances are expanded in the rest of this report.



OPERATING ENERGY FOR THE SYSTEM IS CONSIDERED A SYSTEM PENALTY AND IS PLOTTED AS A NEGATIVE VALUE BELOW THE ORIGIN.

Figure 2. System Thermal Performance
General Electric - Milwaukee
September 1980 through March 1981

The solar energy coefficient of performance (COP) is indicated in Table 2. The COP simply provides a numerical value for the relationship of solar energy used or collected and the energy required to collect or deliver it. The greater the COP value, the more efficient the subsystem. The solar energy system at the General Electric - Milwaukee site functioned at a reporting period weighted average COP value of 5.00 for the period of September 1980 through March 1981.

The solar energy system COP is relatively low in December and January because relatively little solar radiation was available. Very little solar energy was collected, most of which was lost through the insulation of the 3,000-gallon storage tank. This also explains the zero space heating solar COP in January.

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

GENERAL ELECTRIC - MILWAUKEE
SEPTEMBER 1980 THROUGH MARCH 1981

MONTH	SOLAR ENERGY SYSTEM	COLLECTOR SUBSYSTEM	SPACE HEATING SOLAR
SEP	1.36	10.09	9.11
OCT	7.26	13.53	18.61
NOV	5.52	12.49	13.16
DEC	0.55	6.78	15.00
JAN	0.07	5.79	0.00
FEB	5.68	9.84	38.50
MAR	7.19	12.52	24.80
WEIGHTED AVERAGE	5.00	10.95	181.94

The COP for the domestic hot water subsystem has not been calculated because that subsystem uses no operating energy.

1.2 SYSTEM OPERATION

The solar energy system at the General Electric - Milwaukee site provides space heating and domestic hot water preheating. A description of the system, its operating modes, and a schematic are presented in Appendix A.

1.2.1 TYPICAL SYSTEM OPERATION

The typical clear, sunny day selected was October 5, 1980. There were requirements for space heating and DHW heating, and for operation of collectors and storage. Graphs of typical system operations during this day are presented in Figures 3a, 3b, and 3c.

Figure 3a shows the insolation and the collector flow. Fifteen minutes after the sun comes up, about 0700 hours, the collector flow starts as pump P1 activates. As the solar energy falls at about 1700 hours, the collector flow terminates. Figure 3b shows typical collector array temperatures and pump P1 electric power. The outlet temperature, monitored by T150, falls initially upon pumping because the cold collectors cool down the fluid. Note that collector pumping is initiated only after the solar radiation has averaged 70 BTU/hr-ft^2 for 15 minutes. Collector pumps are activated independently of storage temperature, collector absorber temperature, or collector-to-storage differential temperature.

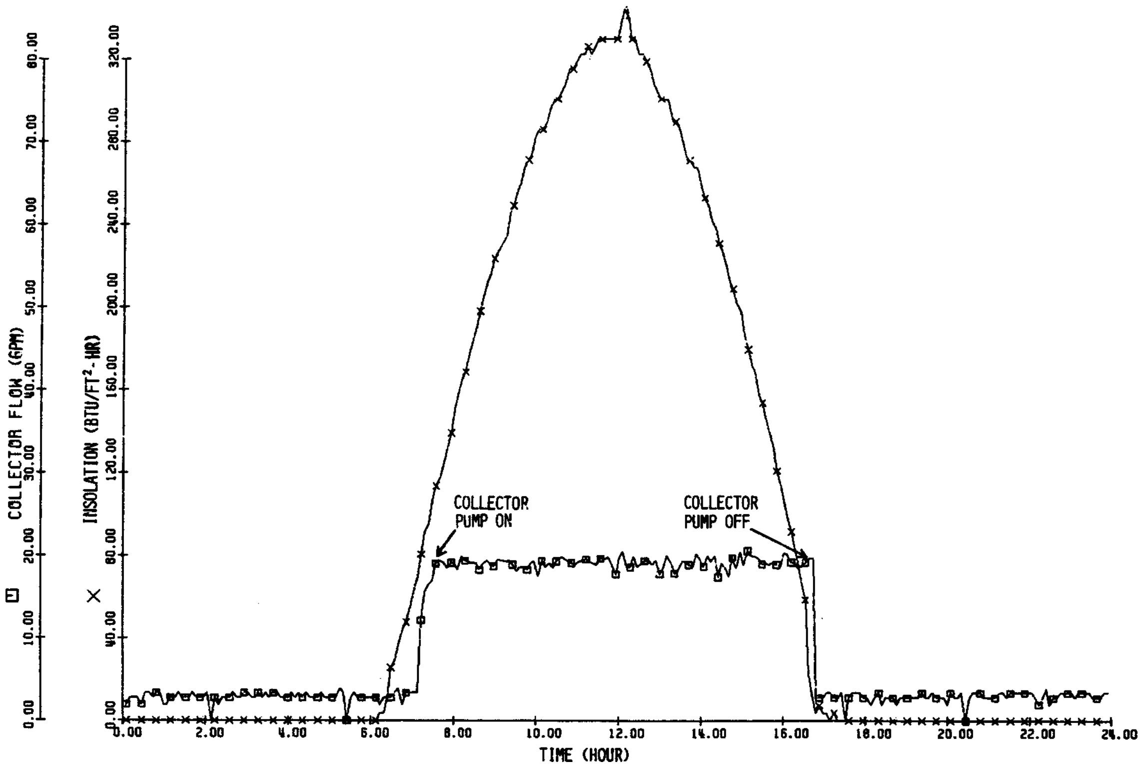


Figure 3a. Typical Insolation and Collector Flow Rates
General Electric - Milwaukee
October 5, 1980

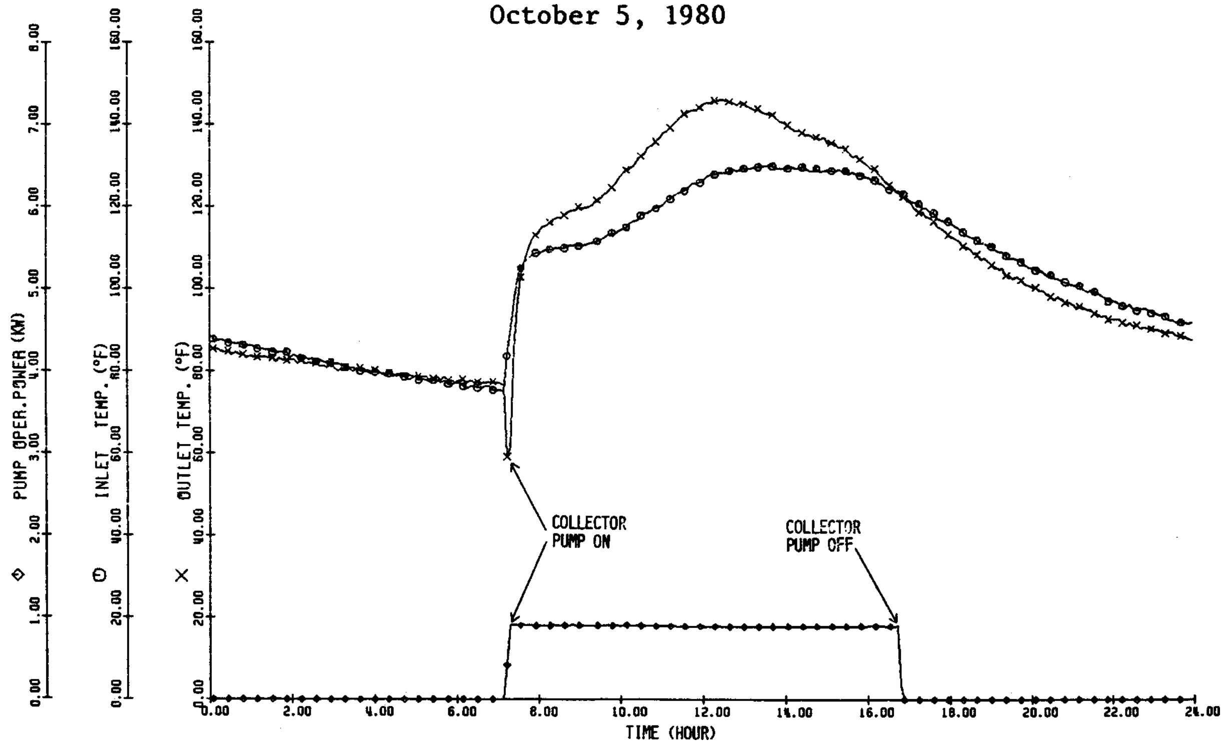


Figure 3b. Typical Collector Array Temperatures and Collector Pump Power
General Electric - Milwaukee
October 5, 1980

Solar energy supplied the entire space heating load on October 5, 1980. No auxiliary heating by natural gas was required to provide the 0.69 million BTU of demand. The solar heating subsystem pumps and fan required 0.33 million BTU to deliver the space heat. The building is generally used at night until 2100 or 2400 hours for recreation. The thermostat is set back after everyone leaves. The building is well enough insulated so that little or no space heating is required until the building is again occupied in the morning. Figure 3c shows the flow rate of solar heated water from the 3,000-gallon solar storage tank to the hydronic heat transfer coil in the air heating unit. The building temperature rises as the hydronic coil is activated; storage temperature drops. The storage temperature rises as the solar energy is collected.

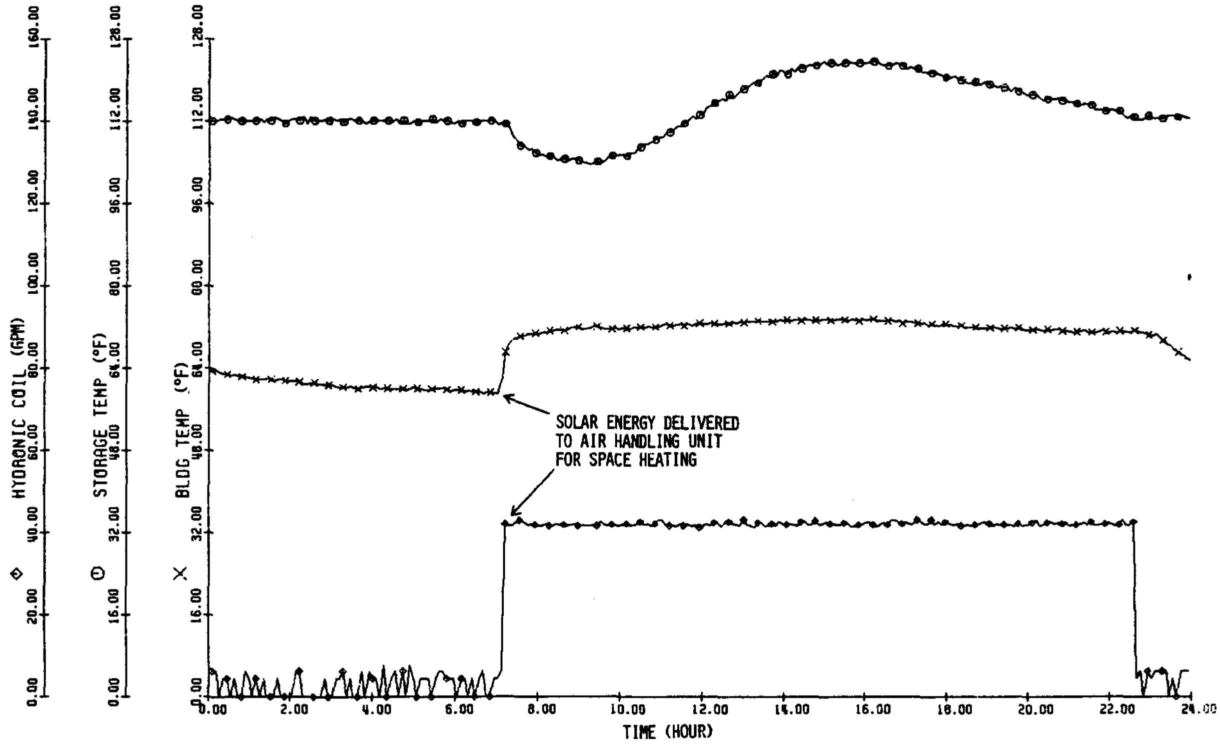


Figure 3c. Typical Hydronic Coil Flow Rate, Storage and Building Temperatuers
General Electric - Milwaukee
October 5, 1980

1.2.2 SYSTEM OPERATING SEQUENCE

Figure 4 presents a bar chart showing typical system operating sequences for October 5, 1980. This information correlates with the curves presented in Figures 3a, 3b, and 3c and provides some additional insight into those curves.

Solar energy supplied all the space heating requirement for the day. Whenever the collectors operated, the solar energy collected was always transferred to storage. Then the solar energy was transferred to the hydronic coil. The solar energy system maintained a building temperature high enough so that the

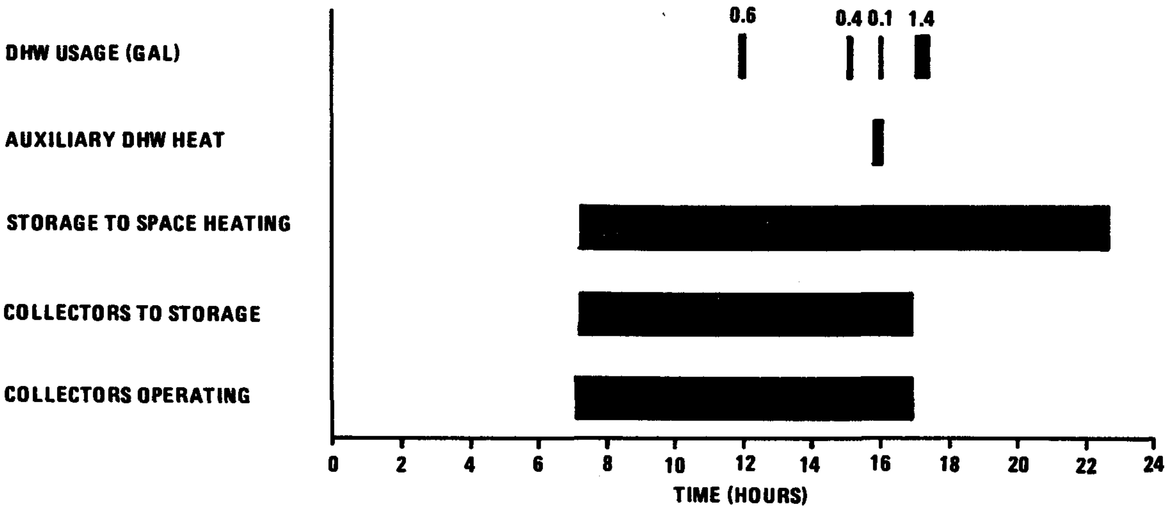


Figure 4. Typical System Operating Sequence
General Electric - Milwaukee
October 5, 1980

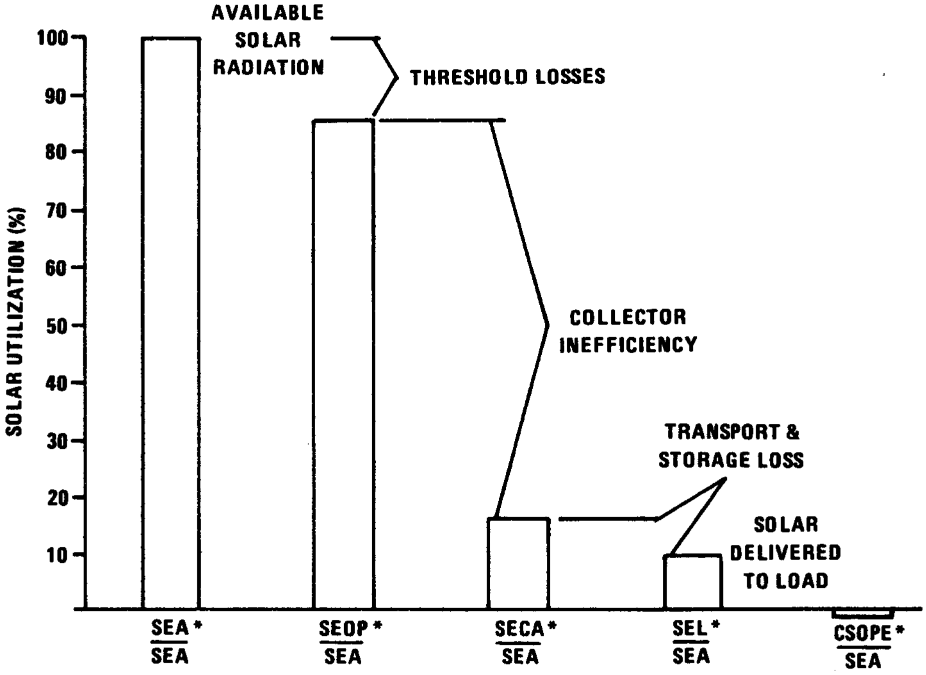
auxiliary space heating furnace never operated. The space heating strategy allowed the building temperature to fall in the middle of the night. Thus, solar energy was conserved by terminating operations before 2300 hours.

Notice that very little domestic hot water was used, 2.5 gallons. Thus the auxiliary DHW heat was supplied for only part of an hour in midafternoon.

1.3 SOLAR ENERGY UTILIZATION

Figure 5 shows the use of solar energy and the percentage of losses. The losses of solar energy at the different stages through the system, from incident radiation to the load, are also presented in Table 3. The energy transferred is shown in Figure 1.

The threshold losses are the result of low level solar radiation. The collector inefficiency was due to the weather conditions at the site. When the weather is cloudy or the sun is low on the horizon or the storage tank temperature is high, then the collectors are not operated. When the collectors are operating, more solar energy is collected when the collector fluid temperature is lower, when the ambient air temperature is higher, and when the sunlight is more intense. Transport losses occurred because heated collector fluid is



* SEE APPENDIX C FOR DEFINITIONS OF THESE ACRONYMS.

Figure 5. Solar Energy Use
General Electric - Milwaukee
September 1980 through March 1981

warmer than ambient air resulting in heat transfer through the piping insulation. This is shown on Figure 5 as zero percent but should be interpreted as less than one percent but finite. Heat transfer through the storage tank insulation resulted in the transport and storage losses of 32% of the energy in storage. These losses occur within the building and thus contribute to space heat anyway. Solar delivered to load is then 10% of the available solar radiation. If the loss from the storage tank is included in solar delivered to load, a respectable 16% of the available solar radiation was used. The electrical energy consumed by the collector and storage pumps was one percent of the available solar radiation.

Table 3 breaks down the losses by month. Note that in September, February, and March, the solar energy to storage is greater than solar energy collected because of small measuring instrumentation inaccuracies. The quantities Loss-Storage to HWSE (hot water solar energy), and Loss-Storage to HSE (heating solar energy), were negligible because sufficient insulation on the piping prevented these losses. The Loss from Storage was high in September and February because the controls did not activate pump P3 even though the 3,000 gallon hot storage tank was warm enough. In December, the temperature of storage was too low to activate the pump. During these months, the stored energy was lost through the tank insulation.

Table 3. SOLAR ENERGY LOSSES

GENERAL ELECTRIC - MILWAUKEE
SEPTEMBER 1980 THROUGH MARCH 1981

	SEP	OCT	NOV	DEC	JAN	FEB	MAR
1. SOLAR ENERGY (SE) COLLECTED (million BTU)	10.29	12.18	8.74	2.17	2.43	6.89	13.90
2. SE TO STORAGE (million BTU)	10.60	11.86	8.72	1.72	1.44	7.43	14.84
3. LOSS - COLLECTOR TO STORAGE (%)	-3(1)	3	0	21	41	-8(1)	-7(1)
4. CHANGE IN STORED ENERGY (million BTU)	3.48	-1.81	-0.32	-0.08	0.68	-0.38	0.02
5. LOSS FROM STORAGE (%)	52	25	28	95	51	42	24
6. HOT WATER SOLAR ENERGY (HWSE) FROM STORAGE (million BTU)	0.07	0.07	0.02	0.02	0.03	0.04	0.05
7. LOSS - STORAGE TO HWSE (%)	0	0	0	0	0	0	0
8. HEATING SOLAR ENERGY (HSE) FROM STORAGE (million BTU)	1.55	10.61	6.58	0.15	0.00	4.62	11.16
5. LOSS - STORAGE TO HSE (%)	0	0	0	0	0	0	0

(1) Negative losses are the result of small inaccuracies in the measurements multiplied by long measurement times.

1.4 SOLAR SYSTEM AVAILABILITY

The solar system was operational except during the period from January 12 through January 26 when valve V4 malfunctioned. Solar radiation was at an extremely low level generally from November 30 through January 2, so that only 2.20 million BTU were collected. Although the system was available, there was essentially no solar energy collected. In general, the system worked as designed when there was sufficient solar radiation and when valve V4 and pump P3 controls were functioning.

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The General Electric - Milwaukee collector array is composed of 87 General Electric Solartron collectors, model TC100. The 1,514 gross square feet of collectors are mounted on the roof of the site at an angle of 53°F to the horizontal and facing due south. The net active area is 1,290 square feet including the reflectors. These collectors were designed to achieve relatively high efficiency as a result of the vacuum between the absorbing surface and the glazing, and because of the reflector. Two concentric glass cylinders are joined to form a vacuum chamber. The outer cylinder is the "window." The inner cylinder is coated on the outer surface with selective coating and is the absorber. A U-shaped copper tube carries the heat transfer fluid to and from the absorber, and is mechanically connected to it. The fluid is a 50% mixture of ethylene glycol in water. The vacuum chamber is nested in a cusp like reflector which improves performance by concentrating the solar radiation on the absorber. The level of concentration was selected to capture both diffuse and direct radiation.

These collectors operate in a "drainback" mode, the heat transfer fluid drains back into a tank when the collector pump shuts down. The collectors will not reactivate unless the previous shutdown has been followed by at least 15 minutes of darkness as detected by the solar integrator. If this condition is satisfied, fluid is again pumped into the collectors. The dark period is required to protect the collectors from thermal shock on the occasion of cold fluid entering collectors heated to several hundred degrees Fahrenheit by the sun. Drainback protects the collectors from possible freezing. A heat rejection system protects them from bursting due to the pressure of boiling water.

The collector subsystem performance is summarized in Table 4. Available solar energy dropped substantially in November and December. Low level solar radiation characterized November through February so that much less energy was collected than during other months. The low level solar radiation resulted in low heat transfer into the collectors and low efficiency. The efficiency in January was much less because a diverting valve malfunctioned and the hot collector fluid was diverted to the heat rejection system from January 12 - January 26. Solar energy to storage sometimes appeared to exceed collected solar energy because of accuracy limitations on the measuring instrumentation. The ECSS operating energy was utilized by the collector and storage heat exchanger pumps. The average ambient temperature was 41°F and collector efficiency was directly related to the change in temperature. More heat was transferred away from the collectors when the ambient air was colder.

Table 4. COLLECTOR SUBSYSTEM PERFORMANCE

GENERAL ELECTRIC - MILWAUKEE
SEPTEMBER 1980 THROUGH MARCH 1981

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR SUBSYSTEM EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY	COLLECTOR ARRAY OPERATIONAL EFFICIENCY (%)	ECSS OPERATING ENERGY	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE (°F)
SEP	61.55	10.29	17	57.31	18	1.02	10.60	69
OCT	59.34	12.18	21	55.14	22	0.90	11.86	53
NOV	43.65	8.74	20	40.23	22	0.70	8.72	42
DEC	22.31	2.17	10	17.78	12	0.32	1.72	28
JAN	51.76	2.43	5	26.24	9	0.42	1.44	25
FEB	48.99	6.89	14	44.69	15	0.70	7.43	30
MAR	70.75	13.90	20	66.41	21	1.11	14.84	42
TOTAL	358.35	56.60	-	307.80	-	5.17	56.61	-
AVERAGE	51.19	8.09	16(1)	43.97	18(1)	0.74	8.09	41

(1) Weighted Average.

Collector subsystem efficiency has been computed from two bases. The first assumes that the efficiency is based upon all available solar energy. This approach makes the operation of the control system part of array efficiency. For example, energy may be available at the collector, but the collector fluid temperature is below the control minimum; thus, the energy is not collected. In this approach, collector array performance is described by comparing the net amount of collected solar energy to the incident solar energy. Energy that is deliberately or inadvertently rejected or lost from the collector subsystem is subtracted from the collected energy in computing the net value. The ratio of these two energies represents the collector array efficiency which may be expressed as:

$$n_c = Q_s/Q_i$$

where: n_c = collector array efficiency

Q_s = collected solar energy

Q_i = incident solar energy

The monthly efficiency computed by this method is listed in the column entitled "Collector Subsystem Efficiency" in Table 4.

The second approach assumes the efficiency is based upon the incident solar energy only during the periods of collection.

Evaluation of collector efficiency using operational incident energy yields operational collector efficiency. Operational collector efficiency, n_{co}, is computed as follows:

$$n_{co} = Q_s/Q_{oi}$$

where: Q_s = collected solar energy

Q_{oi} = incident solar energy while the collector pumps operated

The monthly efficiency computed by this method is listed in the column entitled "Collector Array Operational Efficiency" in Table 4. This latter efficiency term is not the same collector efficiency as represented by the ASHRAE Standard 93-77. Both operational collector efficiency and the ASHRAE collector efficiency are defined as the ratio of actual useful energy collected to solar energy incident upon the collector, and both use the same definition of collector area. However, the ASHRAE efficiency is determined from instantaneous evaluation under tightly controlled, steady-state test conditions, while the operational collector efficiency is determined from the actual conditions of daily solar energy system operation. Measured monthly values of operational incident energy and computed values of operational collector efficiency are presented in Table 4.

The operational collector subsystem efficiency for the General Electric TC100 evacuated tube collectors is shown in Figure 6. The straight line is a first order curve fit to the data reported by Desert Sunshine Exposure Tests, Inc. The tests on a single module under ideal conditions were conducted according to ASHRAE 93-77 (Reference 5). The dots are actual hourly data from the General Electric - Milwaukee site based on the response of the entire collection and storage subsystem (ECSS) during March 1981. The difference between the ideal and actual data was the result of the different energy collection and storage subsystems and the variable weather under which the Milwaukee site operates. For example, when the storage tank is warmer, less efficiency, n_{co}, results. The actual collector subsystem pumps a variable temperature fluid to the collectors from the storage tank. Under ASHRAE 93-77, the fluid entering the collectors has a constant relatively low temperature, T_{IN}. The heat transfer rate to low temperature fluid is greater than to high temperature fluid. Thus ASHRAE 93-77 conditions will show a higher efficiency for this reason alone. A collector piped in series raises the temperature of the fluid before passing it to the next collector. Again, this will decrease the efficiency in the next collector. It may be possible that the collectors at this site have a range of different flow rates. This is the usual case with collector arrays because unequal pressure drops result from piping obstructions, pipe friction, and valve settings. Thus, some collectors have fluid flow rates below design level causing efficiencies below ideal. For these reasons and site specific reasons, most solar collector and storage subsystem efficiencies are below that for single panels tested under ASHRAE 93-77.

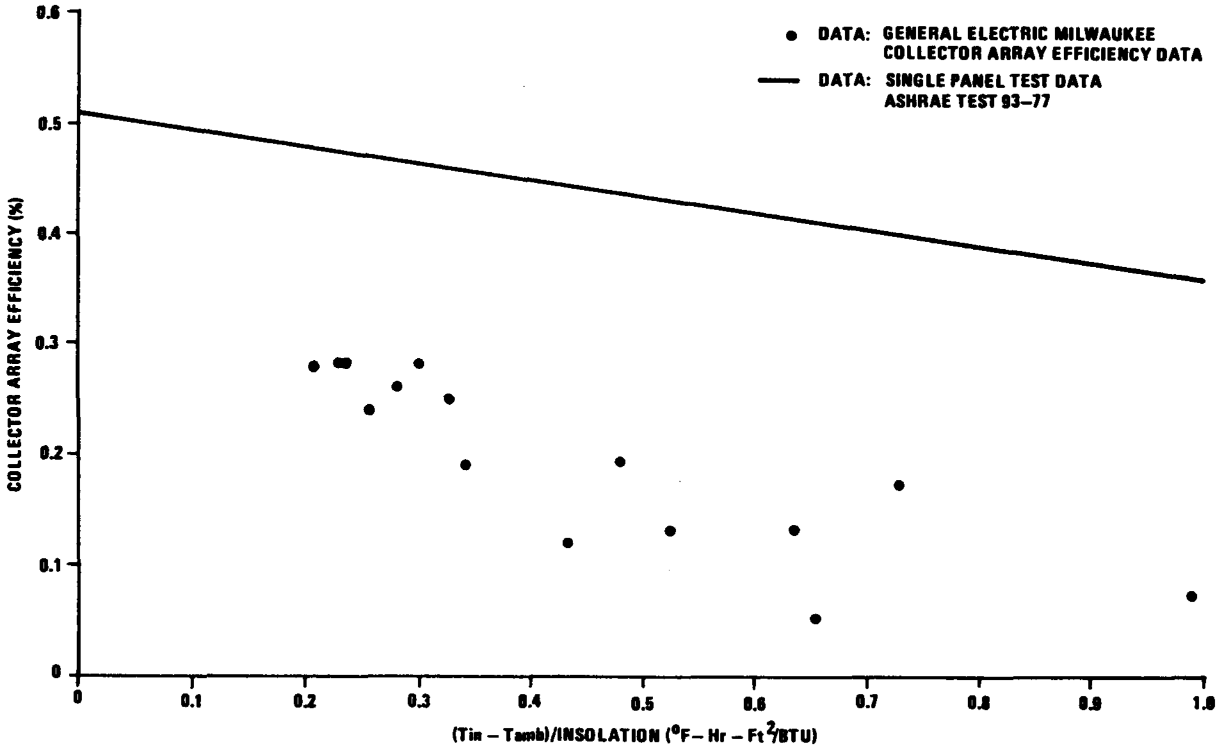


Figure 6. General Electric TC100 Collector Efficiency
General Electric - Milwaukee
March 1981

2.2 STORAGE

The storage tank is stone lined, has a 3,000-gallon capacity, and was supplied by General Electric. It is located in the basement of the building. Heat transferred through the six-inch-thick fiberglass insulated walls contributes to space heating.

Table 5 summarizes the storage performance. (See Footnote 1.) Total solar energy added to storage was 56.60 million BTU. Energy removed was 34.97 million BTU. The change in stored energy was 0.18 million BTU. Storage

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1. Storage subsystem performance is evaluated by comparison of energy to storage, energy from storage, and the change in stored energy. The ratio of the sum of energy from storage and the change in stored energy, to the energy to storage is defined as storage efficiency. This relationship is expressed in the following equation:

   STEFF = (STECH + STEO)/STEI

   Where: STEFF = Storage efficiency
   STECH = Change in stored energy
   STEO = Energy removed from storage
   STEI = Energy added to storage

Table 5. STORAGE PERFORMANCE

GENERAL ELECTRIC - MILWAUKEE
SEPTEMBER 1980 THROUGH MARCH 1981

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY TO STORAGE	ENERGY FROM STORAGE	CHANGE IN STORED ENERGY	STORAGE EFFICIENCY (%)	AVERAGE STORAGE TEMP. (°F)	LOSS FROM STORAGE
SEP	10.60	1.62	2.18	36	155	6.80
OCT	11.86	10.67	-1.95	74	108	3.14
NOV	8.72	6.61	-0.23	73	105	2.34
DEC	1.72	0.18	-0.18	0	92	1.72
JAN	1.44	0.03	0.73	53	82	0.68
FEB	7.42	4.65	-0.34	58	110	3.11
MAR	14.84	11.21	-0.03	75	110	3.66
TOTAL	56.60	34.97	0.18	-	-	21.45
AVERAGE	8.09	5.00	0.03	62(1)	109	3.06

(1) Weighted average.

efficiency was 62%. The efficiency was low because the storage temperature was frequently below 90°F, the temperature at which the controls were set to deliver solar energy from storage to the hydronic coil. Thus, the energy removed from storage was low and energy was transferred out through the insulation when the tank environment was at a lower temperature. Very little solar energy was added to storage in December and January. This was due to the combination of low level of available solar energy and a malfunctioning diverter valve. The diverter valve routed the collected solar energy to a heat rejection system from January 12 - January 26. All collected solar energy has to be transferred through storage before being transported to the loads. More solar energy would have been delivered to loads if a bypass had been installed around the storage tank between the collector loop heat exchanger and the inlet to pump P3. The bypass would operate when there was a load demand and when the collector loop outlet temperature was greater than a minimum specified value. The storage tank could be heated with the residual heat that was present in the hot water return flow after passing through the building air handler hydronic coil. When there was no load demand, available solar energy would be used to charge storage in the conventional manner. When the bypass operation could not supply the load directly, due to a low collector loop temperature, the load would be supplied directly from storage in the conventional manner.

2.3 DOMESTIC HOT WATER (DHW)

The DHW subsystem performance for the General Electric - Milwaukee site for the reporting period is shown in Table 6 and by graphic illustration in Figure 7. The DHW subsystem required 0.30 million BTU of solar energy and 13.88 million BTU of auxiliary natural gas to satisfy a hot water load of 1.37 million BTU, the energy content of the hot water consumed. The solar fraction of the total energy delivered to the DHW tank was three percent, with no operating energy required, a clear advantage. Losses from the DHW subsystem were 7.26 million BTU. A daily average of 10 gallons of DHW was consumed at an average temperature of 149°F. This small consumption is due to the pattern of use of the building. Recreation and meetings take place in the evening up until midnight. A third of the seven-month consumption occurred on three days. The average of the remaining days is then only seven gallons. Losses of energy through the tank and piping resulted in an excessive energy requirement of 6,300 BTU per gallon consumed.

Table 6. DOMESTIC HOT WATER SUBSYSTEM PERFORMANCE

GENERAL ELECTRIC - MILWAUKEE
SEPTEMBER 1980 THROUGH MARCH 1981

(All values in million BTU, unless otherwise indicated)

MONTH	HOT WATER LOAD	SOLAR FRACTION OF LOAD (%)	SOLAR ENERGY USED	AUXILIARY THERMAL USED	AUXILIARY FOSSIL USED	SUP. WATER TEMP (°F)	HOT WATER TEMP (°F)	HOT WATER CONSMP (GAL)
SEP	0.14	7	0.07	0.97	1.61	64	147	204
OCT	0.32	4	0.07	1.58	2.63	62	147	880
NOV	0.13	2	0.02	1.00	1.67	58	148	162
DEC	0.15	2	0.02	1.19	1.98	55	150	174
JAN	0.26	2	0.03	1.33	2.22	51	151	380
FEB	0.17	3	0.04	1.11	1.86	49	150	196
MAR	0.20	4	0.05	1.15	1.91	48	147	234
TOTAL	1.37	-	0.30	8.33	13.88	-	-	2,230
AVERAGE	0.20	3(1)	0.04	1.19	1.98	55	149	319

(1) Weighted Average.

The usage of DHW at this site is so low that point-of-use DHW heaters could be cost-effective. Electric heaters at the point-of-use would save energy lost through the DHW tank insulation and piping insulation. Point-of-use heaters would have saved the cost of the DHW tank, solar DHW preheat coil, distribution piping, and valves. The cost of heating the DHW consumed was $20.00 but the cost of the energy delivered to the DHW subsystem was $54.00. Architects and engineers designing similar sites should consider using point-of-use heaters. The f-Chart design program, Version 4.0, from the University of Wisconsin was used to compare against measured values. It predicted a hot water load of 8.32 million BTU and a solar fraction of load of 16%.

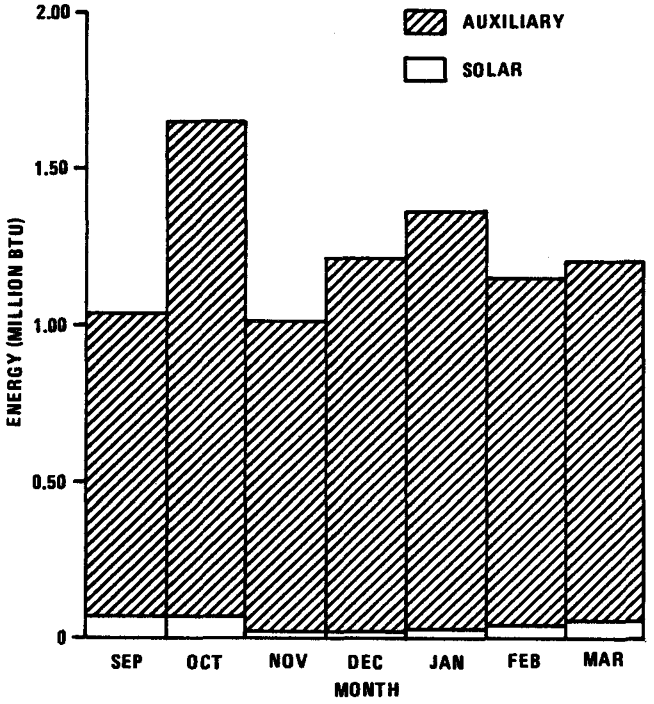


Figure 7. DHW Subsystem Performance
General Electric - Milwaukee
September 1980 through March 1981

2.4 SPACE HEATING

The space heating performance for the General Electric - Milwaukee site for the reporting period is shown in Tables 7 and 8 and presented graphically in Figure 8.

The space heating load of 356.57 million BTU was satisfied by 34.67 million BTU of solar energy and 321.90 million BTU of auxiliary energy. The solar fraction of this load was 10% with an operating energy expense of 1.83 million BTU for solar equipment alone. This solar energy system was retrofit on the existing building. Thus, the solar fraction was limited by the collector area that would fit on the roof. The solar heating is provided by circulating

Table 7. SPACE HEATING SUBSYSTEM I

GENERAL ELECTRIC - MILWAUKEE
SEPTEMBER 1980 THROUGH MARCH 1981

(All values in million BTU, unless otherwise indicated)

MONTH	SPACE HEATING LOAD	TOTAL SOLAR ENERGY USED	TOTAL AUXILIARY THERMAL USED	SOLAR FRACTION OF LOAD (%)	BLDG TEMP (°F)	AMB TEMP (°F)
SEP	1.60	1.55	0.05	96	76	64
OCT	13.41	10.61	2.80	79	68	48
NOV	38.65	6.58	32.07	17	66	39
DEC	69.78	0.15	69.63	0	63	26
JAN	85.67	0.00	85.67	0	66	22
FEB	81.03	4.62	76.41	6	69	27
MAR	66.43	11.16	55.27	17	72	38
TOTAL	356.57	34.67	321.90	-	-	-
AVERAGE	50.94	4.95	45.99	10(1)	69	38

(1)Weighted average.

Table 8. SPACE HEATING SUBSYSTEM II

GENERAL ELECTRIC - MILWAUKEE
SEPTEMBER 1980 THROUGH MARCH 1981

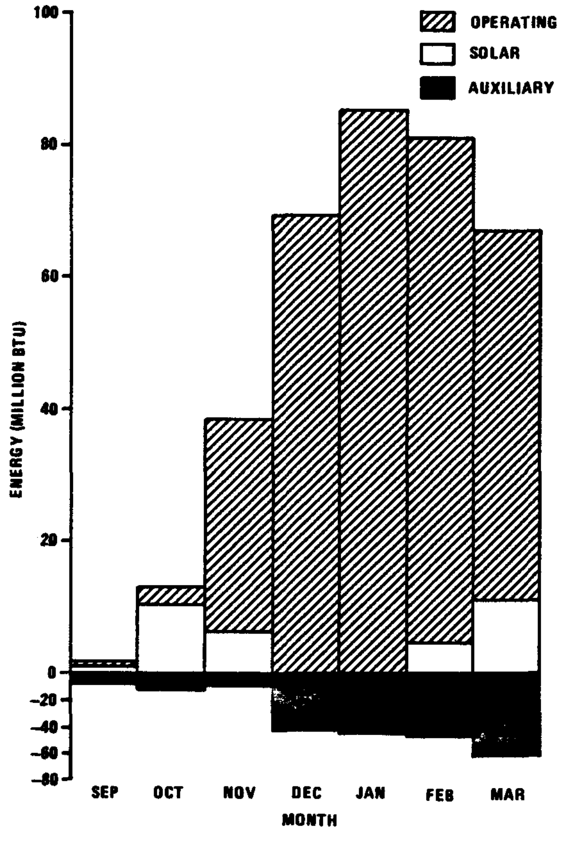
(All values in million BTU, unless otherwise indicated)

MONTH	SPACE HEATING LOAD	TOTAL OPERATING ENERGY	SOLAR SPECIFIC OPERATING ENERGY	AUILIARY FOSSIL FUEL	HEATING DEGREE-DAYS
SEP	1.60	9.02	0.17	0.09	83
OCT	13.41	10.37	0.57	4.67	530
NOV	38.65	9.41	0.50	53.45	781
DEC	69.78	42.01	0.01	116.05	1,213
JAN	85.67	45.90	0.01	142.79	1,339
FEB	80.03	48.43	0.12	127.35	1,060
MAR	66.43	63.55	0.45	92.12	840
TOTAL	356.57	228.69	1.83	536.52	5,846
AVERAGE	50.94	32.67	0.26	76.65	835

solar-heated water through a hydronic coil which transfers heat to the building air. The fossil fuel energy savings were 57.78 million BTU. The average building temperature for the season was 69°F, while the outside ambient temperature averaged only 38°F. The total operating energy of 228.69 million BTU was about 125 times the operating energy for the solar equipment, 1.83 million BTU. Clearly the heating season extended beyond the contractual monitoring period, so the seasonal totals are larger than reported. The f-Chart design program, Version 4.0, was used to compare against the measured values. It computed 355.89 million BTU for the space heating load and a solar fraction of load of 31% with a solar contribution of 110.93 million BTU.

Auxiliary heat is supplied by a natural-gas-fired furnace. The various zones of the building are controlled by individual thermostats and air duct dampers. Outside air is mixed with heated air in the ducts to deliver the air at a desirable temperature. There are also electric auxiliary heaters which contribute an extremely small fraction of the heating requirement and thus were not monitored.

Figure 8 shows the relative consumption of solar and auxiliary energies. The figure shows the operating energy for the air fans and water pumps.



OPERATING ENERGY FOR THE SYSTEM IS CONSIDERED A SYSTEM PENALTY AND IS PLOTTED AS A NEGATIVE VALUE BELOW THE ORIGIN.

Figure 8. Space Heating Performance
General Electric - Milwaukee
September 1980 through March 1981

SECTION 3

OPERATING ENERGY

Measured monthly values of the General Electric - Milwaukee solar energy system and subsystem operating energy for the report period are presented in Table 9. A total 7.00 million BTU of operating energy was consumed by the solar system during the reporting period.

Total system operating energy for General Electric - Milwaukee is the electrical energy required to support the collector, storage, and space heating subsystems without affecting their thermal states. There is no operating energy required by the DHW subsystem.

Table 9. SOLAR UNIQUE OPERATING ENERGY

GENERAL ELECTRIC - MILWAUKEE
SEPTEMBER 1980 THROUGH MARCH 1981

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY	SHS OPERATING ENERGY	TOTAL SOLAR UNIQUE OPERATING ENERGY
SEP	1.02	0.17	1.19
OCT	0.90	0.57	1.47
NOV	0.70	0.50	1.20
DEC	0.32	0.01	0.33
JAN	0.42	0.01	0.43
FEB	0.70	0.12	0.82
MAR	1.11	0.45	1.56
TOTAL	5.17	1.83	7.00
AVERAGE	0.74	0.26	1.00

SECTION 4

ENERGY SAVINGS

Energy savings for this site for the reporting period, September 1980 through March 1981, are presented in Table 10 For this seven-month period, the total savings of fossil fuel were 58.31 million BTU, for a monthly average of 8.33 million BTU. This is a total savings of approximately 57,109 cubic feet of natural gas. An electrical energy expense of 7.00 million BTU was incurred during the reporting period for the operation of solar energy components. The savings were $112.46 for the seven months based on an average cost for natural gas of $4.09 per 1,000 cubic feet and for electric energy of 5.68 cents per kwh.

Table 10. ENERGY SAVINGS

GENERAL ELECTRIC - MILWAUKEE
SEPTEMBER 1980 THROUGH MARCH 1981

(All values in million BTU)

		SPACE HEATING		DOMESTIC HOT WATER		NET ENERGY SAVINGS	
MONTH	SOLAR ENERGY USED	ELECTRICAL	FOSSIL FUEL	FOSSIL FUEL	ECSS OPERATING ENERGY	ELECTRICAL	FOSSIL FUEL
SEP	1.62	-0.17	2.58	0.12	-1.02	-1.19	2.70
OCT	10.68	-0.57	17.68	0.11	-0.90	-1.47	17.79
NOV	6.60	-0.50	10.97	0.04	-0.70	-1.20	11.01
DEC	0.17	-0.01	0.25	0.04	-0.32	-0.33	0.29
JAN	0.03	-0.01	0.00	0.05	-0.42	-0.43	0.05
FEB	4.66	-0.12	7.69	0.07	-0.70	-0.82	7.76
MAR	11.21	-0.45	18.61	0.08	-1.11	-1.56	18.69
TOTAL	34.97	-1.83	57.78	0.51	-5.17	-7.00	58.31
AVERAGE	5.00	-0.21	8.25	0.07	-0.74	-1.00	8.33

Solar energy savings are realized whenever energy provided by the solar energy system is used to meet system demands which would otherwise be met by auxiliary energy sources. The operating energy required to transport solar energy from the collector to storage is subtracted from the solar energy contribution to the loads to determine net savings.

The auxiliary system at General Electric - Milwaukee site consists of a natural-gas-fired furnace and a natural-gas-fired DHW heater. These units are considered to be 60% efficient for computational purposes.

At this site, the conventional heating and hot water system that was installed previous to the addition of a solar system is the auxiliary energy system. Energy savings are computed by comparing the actual fossil and electrical energy usage of the solar system to the projected fossil and electrical energy usage of the conventional system.

Energy savings were limited by the low level of solar radiation available. On many days there was no solar energy collected. Savings were also limited because of the need for solar energy to be transferred to storage before being delivered to the space heating subsystem. Energy was lost through the storage insulation. Hotter water could have been delivered for space heating from the collector loop heat exchanger than from the storage tank. Energy availability increases with the temperature of the solar heated water in the hydronic coil.

SECTION 5

WEATHER CONDITIONS

The General Electric - Milwaukee site is located in Milwaukee, Wisconsin at 43 degrees N latitude and 88 degrees W longitude.

Monthly values of the total solar energy incident in the plane of the collector array and the average outdoor temperature measured at the site during the reporting period are presented in Table 11. Also presented in the table are the corresponding long-term average monthly values of the measured weather parameters. These long-term average weather data were obtained from nearby representative National Weather Service and SOLMET meteorological stations. The long-term average insolation values are total global horizontal radiation converted to collector angle and azimuth orientation. Daily performance was irregular because it was driven by irregular weather conditions.

Table 11. WEATHER CONDITIONS

GENERAL ELECTRIC - MILWAUKEE
SEPTEMBER 1980 THROUGH MARCH 1981

	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT^2-DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS	
MONTH	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
SEP	1,355	1,451	64	61	83	140
OCT	1,264	1,283	48	51	530	440
NOV	961	866	39	37	781	855
DEC	475	654	26	24	1,213	1,265
JAN	1,103	837	22	19	1,339	1,414
FEB	1,156	1,093	27	23	1,060	1,190
MAR	1,507	1,306	38	31	840	1,042
TOTAL	7,821	7,490	-	-	5,846	6,346
AVERAGE	1,117	1,070	38	35	835	907

During the period from September 1980 through March 1981, the average daily total incident solar radiation on the collector array was 1,117 BTU per square foot per day. This radiation was above the estimated average daily solar radiation for this geographical area during the reporting period of 1,070 BTU per square foot per day for a south-facing plane with a tilt of 53 degrees to the horizontal. During the period, the highest monthly average insolation was 1,507 BTU per square foot per day during March. The average ambient temperature during the reporting period was 38°F as compared with the long-term average of 35°F. The highest monthly average ambient temperature was 64°F during September and the lowest monthly average ambient temperature was 22°F during January. The number of heating degree-days for the period (based on a 65°F reference) was 5,846 as compared with the long-term average of 6,346. The range of heating degree-days was from a high of 1,339 during January to a low of 83 during September.

Extraterrestrial radiation values are computed (see Footnote 1) and given in the table below for each month. The ratio of total insolation on a tilted surface to extraterrestrial radiation on a parallel surface is called the clearness index.

This parameter quantifies the effects of cloudiness and atmospheric transmission on the insolation received at the earth's surface. The clearness index ranged from a high of 51% during September to a low of 33% during December.

	MONTH						
	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Extraterrestrial Insolation (BTU/day)	2,853	2,701	2,263	1,963	2,196	2,552	2,807
$\frac{\text{TTL INS}}{\text{EXT INS}}$ (%)	51	47	38	33	38	43	47

For a more complete set of meteorological data see Appendix F, which contains daily average values for the months of the reporting period.

Insolation is quite variable at this site. November incident solar energy was 11% more than the long-term average while the December solar energy was 27% less and January solar energy was 32% more. Although the January total was high, the typical intensity of solar energy in January was generally very low so that the collectors were seldom activated. The long-term average for November, December, and January is roughly half that for April through September.

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1. Computation method given in "TRNSYS, a Transient Simulation Program," Engineering Experiment Station Report #38, Solar Energy Laboratory, University of Wisconsin, Madison.

SECTION 6

REFERENCES

*1. National Solar Data Network, Department of Energy, prepared under Contract Number DE-AC01-79CS30027, Vitro Laboratories, Silver Spring, Maryland, January 1980.

2. J. T. Smok, V. S. Sohoni, J. M. Nash, "Processing of Instrumented Data for the National Solar Heating and Cooling Demonstration Program," Conference on Performance Monitoring Techniques for Evaluation of Solar Heating and Cooling Systems, Washington, D.C., April 1978.

3. E. Streed, et al, Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program, NBSIR-76-1137, National Bureau of Standards, Washington, D.C., 1976.

*4. Mears, J. C., Reference Monthly Environmental Data for Systems in the National Solar Data Network. Department of Energy report SOLAR/0019-79/36. Washington, D.C., 1979.

5. ASHRAE Standard 93-77, Methods of Testing to Determine the Thermal Performance of Solar Collectors, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, N.Y., 1977.

*6A. User's Guide to Monthly Performance Reports, June 1980, SOLAR/0004-80/18, Vitro Laboratories, Silver Spring, Maryland.

*6B. Instrumentation Installation Guidelines March 1981, Parts 1, 2, and 3, SOLAR/0001-81/15, Vitro Laboratories, Silver Spring, Maryland.

7. Monthly Performance Report, General Electric - Milwaukee (Operational Test Site), September 1980, SOLAR/2097-80/09, Vitro Laboratories, Silver Spring, Maryland.

8. Monthly Performance Report, General Electric - Milwaukee (Operational Test Site), October 1980, SOLAR/2097-80/10, Vitro Laboratories, Silver Spring, Maryland.

9. Monthly Performance Report, General Electric - Milwaukee (Operational Test Site), November 1980, SOLAR/2097-80/11, Vitro Laboratories, Silver Spring, Maryland.

9. Monthly Performance Report, General Electric - Milwaukee (Operational Test Site), December 1980, SOLAR/2097-80/12, Vitro Laboratories, Silver Spring, Maryland.

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* Copies of these reports may be obtained from Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830.

11. *Monthly Performance Report, General Electric - Milwaukee (Operational Test Site), January 1981*, SOLAR/2097-81/01, Vitro Laboratories, Silver Spring, Maryland.

12. *Monthly Performance Report, General Electric - Milwaukee (Operational Test Site), February 1981*, SOLAR/2097-81/02, Vitro Laboratories, Silver Spring, Maryland.

13. *Monthly Performance Report, General Electric - Milwaukee (Operational Test Site), March 1981*, SOLAR/2097-81/03, Vitro Laboratories, Silver Spring, Maryland.

APPENDIX A

SYSTEM DESCRIPTION

The General Electric - Milwaukee site is the Washington Park Community Center, a recreation hall for senior citizens in Milwaukee, Wisconsin. It is a two-story building with 43,000 square feet of space to be heated and cooled. The 87 solar collectors, evacuated-tube type, are mounted 53 degrees from the horizontal and oriented due South with an active collection area of 1,290 square feet. The gross collector area is 1,514 square feet. The latitude is 43°. The medium for delivering solar energy from the collectors to the heat exchanger is a solution of 50% ethylene glycol in water. The medium for delivering solar energy from the heat exchanger to the 3,000-gallon storage tank is water. The heat exchanger isolates the glycol antifreeze from the water used inside the building. The solar energy storage tank provides heat to the occupied spaces and also functions as a preheater for the domestic hot water. When solar energy cannot supply all the heat to the spaces, a natural-gas-fired furnace also heats the air in the supply ducting. The system schematic is provided in Figure A-1.

The manufacturers of the major solar system equipment and components are listed below.

Equipment/Components	Manufacturer	Model No.
Collectors	General Electric	TC-100
Valves	Barber Coleman	
Heat Exchanger HX1	General Electric	
Pumps	TACO	
Solar Energy Tank	General Electric	
DHW Preheater	General Electric	
Hydronic Coil	McQuay	

The system has three modes of solar operation as shown in the system schematic.

Mode 1 - Collector-to-Storage - The energy collection and storage subsystem acts independently of the other subsystems. It has a primary loop including collectors, circulating pump P1, heat exchanger, expansion tank Number 1, and an excess energy rejection subsystem. The secondary loop includes a 3,000-gallon solar energy storage tank, a circulating pump P2, and an expansion tank Number 2. Also included is a coil for preheating the domestic hot water.

Operations are regulated by control sensors and control logic components to maximize the use of solar energy. The solar integrator S1, mounted on the collectors, measures solar energy and operates P1 at a predetermined threshold, 70 BTU/hr-ft^2 for 15 minutes. Valve V4 is a spring-return diverting valve which opens to the heat rejection subsystem when deenergized. Valve V5 is normally open. Pump P1 fills the collectors with fluid from the expansion tank Number 1 forcing the air from the collectors into expansion tank Number 1 and the heat rejector. After a fixed delay, two minutes, solar integrator S1 energizes V4 to allow flow from the collectors to P1 and also energizes V5 to close. Another solar integrator, S2, turns on P2. When solar energy falls below a threshold, S1 and S2 open V5 to drain fluid from the collectors, divert V4 to the heat rejector, and shut down P1 and P2.

Protection of the collectors and the solar energy storage tank are provided by thermal switch CT1 in the collector piping and CT4 in the solar energy storage tank. When CT1 senses 285°F, or CT4 senses 255°F, V4 diverts the collector fluid to the heat rejection system and P2 stops pumping.

Upon power loss, V5 opens and V4 diverts flow to the heat rejection system. High temperature fluid is cooled by heating city water to boiling. Upon restoration of power, S1 prevents operation of P1 until there are 15 minutes of darkness. A flash tank protects the subsystem from steam pressure by removing any vaporized collector fluid.

Mode 2 - Space Heating - The building is heated when the manual summer/winter switch is set to winter. Pump P3 operates continuously in this mode. Upstream of the furnace there is an air-mixing plenum where outside air is added to the return air from the building. An automatic damper helps to maintain a constant temperature in this plenum. Valve V1 is an automatic modulating valve which senses the temperature in the air-mixing plenum and also helps maintain building air at a preset constant by diverting flow of solar heated water to either the hydronic coil or the solar energy storage tank.

There are a natural-gas-fired furnace, air blowers, and ducting. The controls determine how much solar energy and how much the furnace will provide heat to the air coming from the plenum. If CT3 senses that the temperature of the storage tank is high enough, 90°F, solar heated water is pumped through the hydronic coil in the air stream. If necessary, the furnace transfers additional heat to the air. When the temperature of the storage tank is below a preset level, the furnace operates alone. The outdoor temperature reset control also determines whether the heat is supplied by the storage tank or the furnace. The determination is based on both outdoor and storage tank temperatures.

Mode 3 - Domestic Hot Water Preheating - City water is preheated before entering the domestic hot water heating tank. The DHW preheater is a coiled pipe immersed in the storage tank. A thermostatic mixing valve, V3, is used to combine cold city water with the preheated water coming from the storage tank to maintain the temperature at or below 140°F. This water is then delivered to the inlet of the DHW heating tank. The remainder of the heating is accomplished by a natural-gas-fired water heater which transfers heat into the DHW heating tank.

Collector

The gross area of the 87 collectors is 1,514 square feet. The collectors face south and are tilted to an angle of 53 degrees to the horizontal. Orientation of the collectors is close to the optimum orientation for winter operations at a site latitutde of 43 degrees north.

The General Electric TC100 Solartron collectors were designed to achieve relatively hiqh efficiency as a result of both a vacuum between the absorption surface and the outer glass tube window, and also a reflector behind the absorber. The vacuum minimizes thermal losses. The reflector concentrates energy on the absorber. The fluid transferring heat from the collectors is 50% ethylene glycol in water.

The collection and storage (ECSS) operation is controlled by the solar integrator. The solar integrator measures solar radiation and operates circulating pump P1 when the intensity reaches an average of 70 BTU/hr/ft^2 for a period of 15 minutes. When P1 begins to fill the collectors with fluid from the expansion tank Number 1, valve V4 diverts air to the heat rejection system and valve V5 diverts air back to the expansion tank Number 1. After a fixed time delay, when all the air is out of the collectors, the solar integrator switches valve V4 to divert fluid to the heat exchanger and switches valve V5 closed.

A second solar integrator controls pump P2. Pumps P1 and P2 operate simultaneously. The solar integrators control the system as though they were perfect differential temperature switches sensing collector and storage tank differences. This analogy is based on General Electric studies of annual savings.

Thermal switches protect the collectors and storage tank subsystems from operating at excessively high temperatures. One switch is set to open at 285°F and another at 255°F. Either switch sets valve V4 to divert fluid flow to the heat rejection system and stops pump P2. Upon electric power loss, valve V5 opens and valve V4 is set to divert fluid to the heat rejection system.

High collector stagnation temperature is decreased by rejecting steam through the flash tank and vent. Upon restoration of electric power, the solar integrator prevents operation of pump P1 until the solar integrator senses darkness for an unbroken 15-minute period. This prevents thermal shock to the collectors due to cold fluid entering collectors at stagnation temperature.

Storage

Solar energy storage is provided by a 3,000-gallon six-foot diameter, 14-foot-long tank built by General Electric. The tank, insulated with six inches of fiberglass, is located in the basement where any heat lost through the insulation can serve to heat the building. All collected solar energy passes through the tank before being delivered to the DHW subsystem or to the space heating subsystem.

Domestic Hot Water

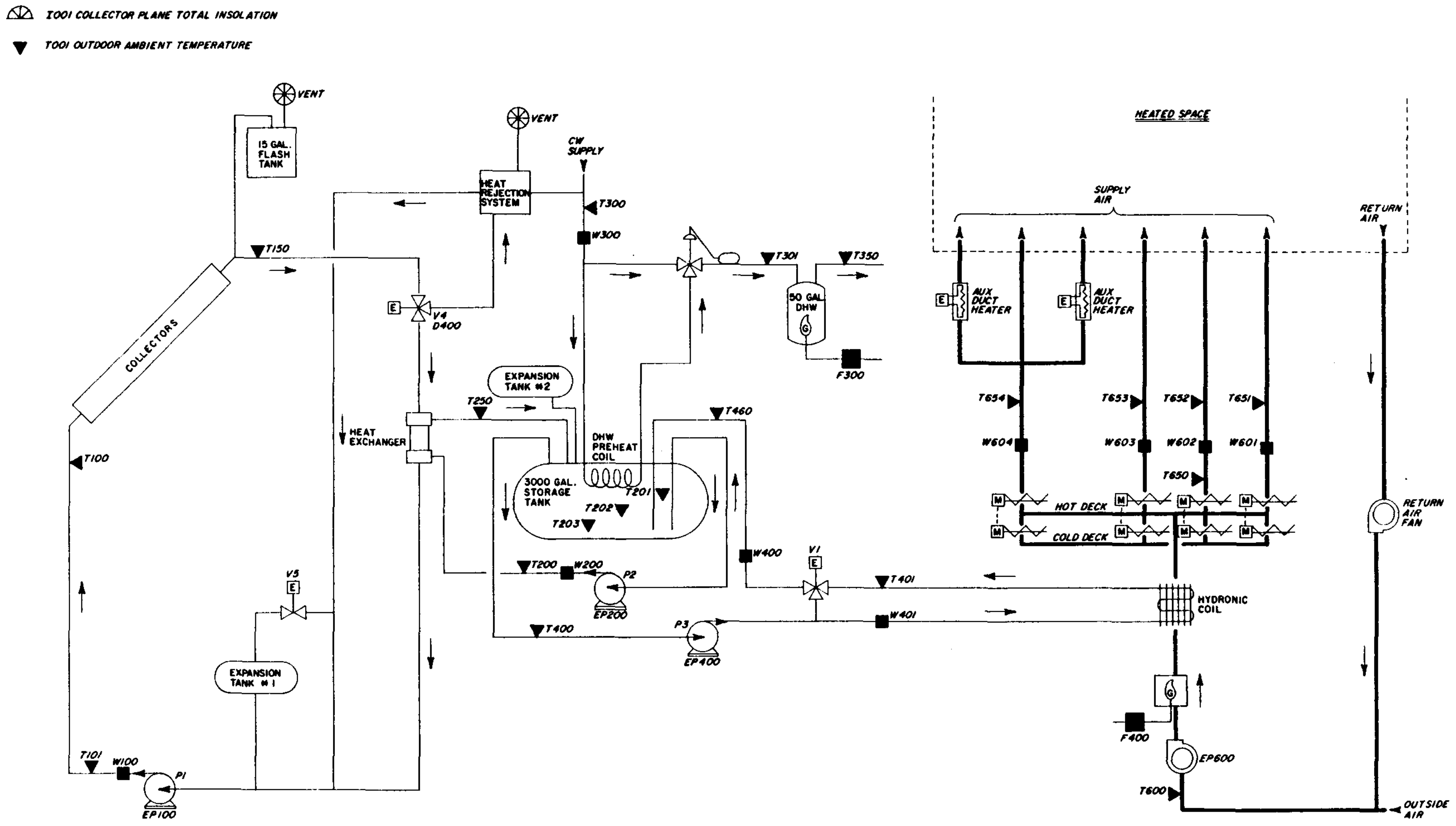
City water is preheated in a coiled pipe immersed in the solar energy storage tank. This preheated water is transferred to the domestic hot water tank to make up for water being used. The DHW tank is a Jetglas Model 5055LN1, 50-gallon capacity, which heats at 42,000 BTU/hr. No DHW pumping is required at the site because city water pressure is sufficient to force water through the piping and tanks.

Space Heating

The solar heating subsystem operates to provide solar heat, or fossil fuel heat from a natural-gas-fired furnace. The Jernland-brand furnace heats air at 550,000 BTU/hr. The operation of the solar energy portion of the system is regulated by a set of control sensors and a control package which forms the control subsystem to maximize the use of the solar system for fossil energy conservation. The hydronic coil is downstream of the furnace. There is a McQuay-brand water-to-air heat exchanger. The various zones in the building are separately heated through separate thermostats, ducting, and air dampers. Small electric auxiliary air duct heaters supply negligible additional heat at the point of use in three areas. These are not monitored due to small amounts of heat transfer.

The solar energy is supplied to the air handlers for satisfying the building space heating requirements. Pump P3 circulates solar heated water to the hydronic coil when the storage tank is at an adequate temperature. The thermal switch in the hot deck determines whether the hydronic coil will receive solar heated water or whether the gas furnace is used.

A thermal control switch in the storage tank determines when the solar energv will satisfy the space heating demand. When the solar storage tank temperature is above 90°F, pump P3 directs solar heated water to the hydronic coil. When the storage tank is below 90°F, P3 turns off and the controls will automatically call on the gas furnace to provide space heating.



DECEMBER 12, 1980

Figure A-1. General Electric - Milwaukee Solar Energy System Schematic

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the General Electric - Milwaukee solar energy system is evaluated by calculating a set of primary performance factors which are based on those in the intergovernmental agency report "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program" (NBSIR-76/1137).

An overview of the NSDN data collection and dissemination process is shown in Figure B-1.

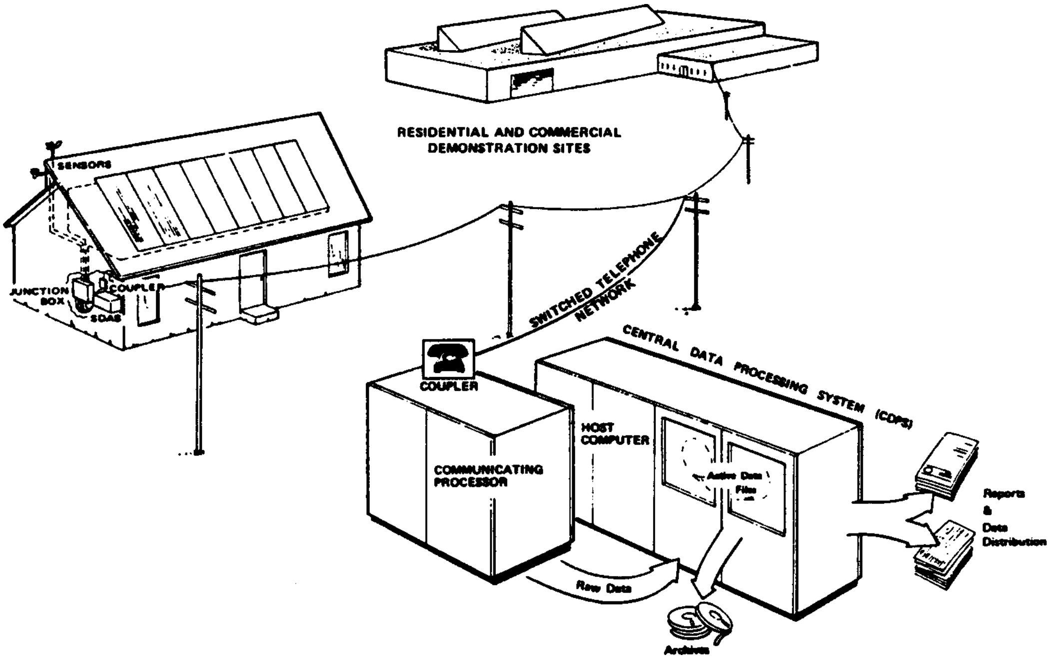


Figure B-1. The National Solar Data Network

DATA COLLECTION AND PROCESSING

Each site contains standard industrial instrumentation modified for the particular site. Sensors measure temperatures, flows, insolation, electric power, fossil fuel usage, and other parameters. These sensors are all wired into a junction box (J-box), which is in turn connected to a microprocessor data logger called the Site Data Acquisition Subsystem (SDAS). The SDAS can read up to 96 different channels, one channel for each sensor. The SDAS takes the analog voltage input to each channel and converts it to a 10-bit word. At intervals of every 320 seconds, the SDAS samples each channel and records the values on a cassette tape. Some of the channels can be sampled 10 times in each 320 second interval, and the average value is recorded in the tape.

Each SDAS is connected through a modem to voice-grade telephone lines which are used to transmit the data to a central computer facility. This facility is the Central Data Processing System (CDPS), located at Vitro Laboratories in Silver Spring, Maryland. The CDPS hardware consists of an IBM System 7, an IBM 370/145, and an IBM 3033. The System 7 periodically calls up each SDAS in the system and has the SDAS transmit the data on the cassette tape back to the System 7. Typically, the System 7 collects data from each SDAS six times a week, although the tape can hold three to five days of data, depending on the number of channels.

The data received by the System 7 are in the form of digital counts in the range of 0-1,023. These counts are then processed by software in the CDPS, where they are converted from counts to engineering units (EU) by applying appropriate calibration constants. The engineering unit data called "detailed measurements" in the software are then tabulated on a daily basis for the site analyst. The CDPS is also capable of transforming this data into plots, graphs, and processed reports.

DATA ANALYSIS

The analyst develops a unique set of "site equations" (given in Appendix D) for each site in the NSDN, following the guidelines presented herein.

The equations calculate the flow of energy through the system, including solar energy, auxiliary energy, and losses. These equations are programmed in PL/1 and become part of the Central Data Processing System. The PL/1 program for each site is termed the site software. The site software processes the detailed data, using as input a "measurement record" containing the data for each scan interval. The site software produces as output a set of performance factors, on an hourly, daily, and monthly basis.

These performance factors (Appendix C) quantify the thermal performance of the system by computing energy flows throughout the various subsystems. The system performance may then be evaluated based on the efficiency of the system in transferring these energies.

Performance factors which are considered to be of primary importance are those which are essential for system evaluation. Without these primary performance factors (which are denoted by an asterisk in Appendix C), comparative evaluation of the wide variety of solar energy systems would be impossible. An example of a primary performance factor is SECA - Solar Energy Collected by the Array. This is quite obviously a key parameter in system analysis.

Secondary performance factors are data deemed important and useful in comparison and evaluation of solar systems, particularly with respect to component interactions and simulation. In most cases these secondary performance factors are computed as functions of primary performance factors.

There are irregularly occurring cases of missing data as is normal for any realtime data collection from mechanical equipment. When data for individual scans or whole hours are missing, values of performance factors are assigned which are interpolated from measured data. If no valid measured data are available for interpolation, a zero value is assigned. If data are missing for a whole day, each hour is interpolated separately. Data are interpolated in order to provide solar system performance factors on a whole hour, whole day and whole month basis for use by architects and designers.

REPORTING

The performance of the General Electric - Milwaukee solar energy system from September 1980 through March 1981 was analyzed during the year, and Monthly Performance Reports were prepared for the months when sufficient valid data were available. See the following page for a list of these reports.

In addition, data are included in this report which are not in Monthly Performance Reports.

OTHER DATA REPORTS ON THIS SITE

Monthly Performance Reports:

September 1980, SOLAR/2097-80/09
October 1980, SOLAR/2097-80/10
November 1980, SOLAR/2097-80/11
December 1980, SOLAR/2097-80/12
January 1981, SOLAR/2097-81/01
February 1981, SOLAR/2097-81/02
March 1981, SOLAR/2097-81/03

APPENDIX C

PERFORMANCE FACTORS AND SOLAR TERMS

The performance factors identified in the site equations (Appendix D) by the use of acronyms or symbols are defined in this Appendix in Section 1. Section 1 includes the acronym, the actual name of the performance factor, and a short definition.

Section 2 contains a glossary of solar terminology, in alphabetical order. These terms are included for quick reference by the reader.

Section 3 describes general acronyms used in this report.

Section 1. Performance Factor Definitions and Acronyms

Section 2. Solar Terminology

Section 3. General Acronyms

SECTION 1. PERFORMANCE FACTOR DEFINITIONS AND ACRONYMS

ACRONYM	NAME	DEFINITION
AXE	Auxiliary Electric Fuel Energy to Load Subsystem	Amount of electrical energy required as a fuel source for all load subsystems.
AXF	Auxiliary Fossil Fuel Energy to Load Subsystem	Amount of fossil energy required as a fuel source for all load subsystems.
* AXT	Auxiliary Thermal Energy to Load Subsystems	Thermal energy delivered to all load subsystems to support a portion of the subsystem loads, from all auxiliary sources.
CAE	SCS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the SCS to be converted and applied to the SCS load.
CAF	SCS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the SCS to be converted and applied to the SCS load.
CAREF	Collector Array Efficiency	Ratio of the collected solar energy to the incident solar energy.
CAT	SCS Auxiliary Thermal Energy	Amount of energy provided to the SCS by a BTU heat transfer fluid from an auxiliary source.
* CL	Space Cooling Subsystem Load	Energy required to satisfy the temperature control demands of the space cooling subsystem.
CLAREA	Collector Array Area	The gross area of one collector panel multiplied by the number of panels in the array.
COPE	SCS Operating Energy	Amount of energy required to support the SCS operation which is not intended to be applied directly to the SCS load.
CSAUX	Auxiliary Energy to ECSS	Amount of auxiliary energy supplied to the ECSS.
* CSCEF	ECSS Solar Conversion Efficiency	Ratio of the solar energy supplied from the ECSS to the load subsystems to the incident solar energy on the collector array.

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* Primary Performance Factors

ACRONYM	NAME	DEFINITION
CSE	Solar Energy to SCS	Amount of solar energy delivered to the SCS.
CSEO	Energy Delivered from ECSS to Load Subsystems	Amount of energy supplied from the ECSS to the load subsystems (including any auxiliary energy supplied to the ECSS).
* CSFR	SCS Solar Fraction	Portion of the SCS load which is supported by solar energy.
CSOPE	ECSS Operating Energy	Amount of energy used to support the ECSS operation (which is not intended to be supplied to the ECSS thermal state).
CSRJE	ECSS Rejected Energy	Amount of energy intentionally rejected or dumped from the ECSS subsystem.
* CSVE	SCS Electrical Energy Savings	Difference in the electrical energy required to support an assumed similar conventional SCS and the actual electrical energy required to support the demonstration SCS, for identical SCS loads.
* CSVF	SCS Fossil Energy Savings	Difference in the fossil energy required to support an assumed similar conventional SCS and the actual fossil energy required to support the demonstration SCS, for identical loads.
HAE	SHS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the SHS to be converted and applied to the SHS load.
HAF	SHS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the SHS to be converted and applied to the SHS load.
HAT	SHS Auxiliary Thermal Energy	Amount of energy provided to the SHS by a heat transfer fluid from an auxiliary source.
* HL	Space Heating Subsystem Load	Energy required to satisfy the temperature control demands of the space heating subsystem.

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* Primary Performance Factors

ACRONYM	NAME	DEFINITION
HOPE	SHS Operating Energy	Amount of energy required to support the SHS operation (which is not intended to be applied directly to the SHS load).
HOURCT	Record Time	Count of hours elapsed from the start of 1977.
* HSFR	SHS Solar Fraction	Portion of the SHS load which is supported by solar energy.
HSE	Solar Energy to SHS	Amount of solar energy delivered to the SHS.
* HSVE	SHS Electrical Energy Savings	Difference in the electrical energy required to support an assumed similar conventional SHS and the actual electrical energy required to support the demonstration SHS, for identical SHS loads.
* HSVF	SHS Fossil Energy Savings	Difference in the fossil energy required to support an assumed similar conventional SHS and the actual fossil energy required to support the demonstration SHS, for identical SHS loads.
HWAE	HWS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the HWS to be converted and applied to the HWS load.
HWAF	HWS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the HWS to be converted and applied to the HWS load.
HWAT	HWS Auxiliary Thermal Energy	Amount of energy provided to the HWS by a heat transfer fluid from an auxiliary source.
HWCSM	Service Hot Water Consumption	Amount of heated water delivered to the load from the hot water subsystem.
* HWL	Hot Water Subsystem Load	Energy required to satisfy the temperature control demands of the building service hot water system.

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* Primary Performance Factors

ACRONYM	NAME	DEFINITION
HWOPE	HWS Operating Energy	Amount of energy required to support the HWS operation which is not intended to be applied directly to the HWS load.
HWSE	Solar Energy to HWS	Amount of solar energy delivered to the HWS.
* HWSFR	HWS Solar Fraction	Portion of the HWS load which is supported by solar energy.
* HWSVE	HWS Electrical Energy Savings	Difference in the electrical energy required to support an assumed similar conventional HWS and the actual electrical energy required to support the demonstration HWS, for identical HWS loads.
* HWSVF	HWS Fossil Energy Savings	Difference in the fossil energy required to support an assumed similar conventional HWS and the actual fossil energy required to support the demonstration HWS, for identical loads.
RELH	Relative Humidity	Average outdoor relative humidity at the site.
* SE	Incident Solar Energy	Amount of solar energy incident upon one square foot of the collector plane.
SEA	Incident Solar Energy on Array	Amount of solar energy incident upon the collector array.
* SEC	Collector Solar Energy	Amount of thermal energy added to the heat transfer fluid for each square foot of the collector area.
SECA	Collected Solar Energy by Array	Amount of thermal energy added to the heat transfer fluid by the collector array.
SEDF	Diffuse Insolation	Amount of diffuse solar energy incident upon one square foot of a collector plane.
SEOP	Operational Incident Solar Energy	Amount of incident solar energy upon the collector array whenever the collector loop is active.

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* Primary Performance Factors

ACRONYM	NAME	DEFINITION
* SEL	Solar Energy to Load Subsystems	Amount of solar energy supplied by the ECSS to all load subsystems.
* SFR	Solar Fraction of System Load	Portion of the system load which was supported by solar energy.
STECH	Change in ECSS Stored Energy	Change in ECSS stored energy during reference time period.
STEFF	ECSS Storage Efficiency	Ratio of the sum of energy supplied by ECSS storage and the change in ECSS stored energy to the energy delivered to the ECSS storage.
STEI	Energy Delivered to ECSS Storage	Amount of energy delivered to ECSS storage by the collector array and from auxiliary sources.
STEO	Energy Supplied by ECSS Storage	Amount of energy supplied by ECSS storage to the load subsystems.
* SYSL	System Load	Energy required to satisfy all desired temperature control demands at the output of all subsystems.
* SYSOPE	System Operating Energy	Amount of energy required to support the system operation, including all subsystems, which is not intended to be applied directly to the system load.
* SYSPF	System Performance Factor	Ratio of the system load to the total equivalent fossil energy expended or required to support the system load.
* TA	Ambient Temperature	Average temperature of the ambient air.
* TB	Building Temperature	Average temperature of the controlled space of the building.
TCECOP	TCE Coefficient of Performance	Coefficient of performance of the thermodynamic conversion equipment.
TCEI	TCE Thermal Input Energy	Equivalent thermal energy which is supplied as a fuel source to thermodynamic conversion equipment.

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* Primary Performance Factors

ACRONYM	NAME	DEFINITION
TCEL	Thermodynamic Conversion Equipment Load	Controlled energy output of thermodynamic conversion equipment.
TCEOPE	TCE Operating Energy	Amount of energy required to support the operation of thermodynamic conversion equipment which is not intended to appear directly in the load.
TCERJE	TCE Reject Energy	Amount of energy intentionally rejected or dumped from thermodynamic conversion equipment as a by-product or consequence of its principal operation.
TDA	Daytime Average Ambient Temperature	Average temperature of the ambient air during the daytime (during normal collector operation period).
* TECSM	Total Energy Consumed by System	Amount of energy demand of the system from external sources; sum of all fuels, operating energies, and collected solar energy.
THW	Service Hot Water Temperature	Average temperature of the service hot water supplied by the system.
TST	ECSS Storage Temperature	Average temperature of the ECSS storage medium.
* TSVE	Total Electrical Energy Savings	Difference in the estimated electrical energy required to support an assumed similar conventional system and the actual electrical energy required to support the system, for identical loads; sum of electrical energy savings for all subsystems.
* TSVF	Total Fossil Energy Savings	Difference in the estimated fossil energy required to support an assumed similar conventional system and the actual fossil energy required to support the system, for identical loads; sum of fossil energy savings of all subsystems.
TSW	Supply Water Temperature	Average temperature of the supply water to the hot water subsystem.

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* Primary Performance Factors

ACRONYM	NAME	DEFINITION
WDIR	Wind Direction	Average wind direction at the site.
WIND	Wind Velocity	Average wind velocity at the site.

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* Primary Performance Factors

SECTION 2. SOLAR TERMINOLOGY

Absorptivity	The ratio of absorbed radiation by a surface to the total incident radiated energy on that surface.
Active Solar System	A system in which a transfer fluid (liquid or air) is circulated through a solar collector where the collected energy is converted, or transferred, to energy in the medium.
Air Conditioning	Popularly defined as space cooling, more precisely, the process of treating indoor air by controlling the temperature, humidity and distribution to maintain specified comfort conditions.
Ambient Temperature	The surrounding air temperature.
Auxiliary Energy	In solar energy technology, the energy supplied to the heat or cooling load from other than the solar source, usually from a conventional heating or cooling system. Excluded are operating energy, and energy which may be supplemented in nature but does not have the auxiliary system as an origin, i.e., energy supplied to the space heating load from the external ambient environment by a heat pump. The electric energy input to a heat pump is defined as operating energy.
Auxiliary Energy Subsystem	In solar energy technology the Auxiliary Energy System is the conventional heating and/or cooling equipment used as supplemental or backup to the solar system.
Array	An assembly of a number of collector elements, or panels, into the solar collector for a solar energy system.
Backflow	Reverse flow.
Backflow Preventer	A valve or damper installed to prevent reverse flow.
Beam Radiation	Radiated energy received directly, not from scattering or reflecting sources.
Collected Solar Energy	The thermal energy added to the heat transfer fluid by the solar collector.

Collector Array Efficiency	Same as Collector Conversion Efficiency. Ratio of the collected solar energy to the incident solar energy. (See also Operational Collector Efficiency.)
Collector Subsystem	The assembly of components that absorbs incident solar energy and transfers the absorbed thermal energy to a heat transfer fluid.
Concentrating Solar Collector	A solar collector that concentrates the energy from a larger area onto an absorbing element of smaller area.
Conversion Efficiency	Ratio of thermal energy output to solar energy incident on the collector array.
Conditioned Space	The space in a building in which the air is heated or cooled to maintain a desired temperature range.
Control System or Subsystem	The assembly of electric, pneumatic, or hydraulic, sensing, and actuating devices used to control the operating equipment in a system.
Cooling Degree Days	The sum over a specified period of time of the number of degrees the average daily temperature is above 65°F.
Cooling Tower	A heat exchanger that transfers waste heat to outside ambient air.
Diffuse Radiation	Solar Radiation which is scattered by air molecules, dust, or water droplets and incapable of being focused.
Drain Down	An arrangement of sensors, valves and actuators to automatically drain the solar collectors and collector piping to prevent freezing in the event of cold weather.
Duct Heating Coil	A liquid-to-air heat exchanger in the duct distribution system.
Effective Heat Transfer Coefficient	The heat transfer coefficient, per unit plate area of a collector, which is a measure of the total heat losses per unit area from all sides, top, back, and edges.
Energy Gain	The thermal energy gained by the collector transfer fluid. The thermal energy output of the collector.

Energy Savings	The estimated difference between the fossil and/or electrical energy requirements of an assumed conventional system (carrying the full measured load) and the actual electrical and/or fossil energy requirements of the installed solar-assisted system.
Expansion Tank	A tank with a confined volume of air (or gas) whose inlet port is open to the system heat transfer fluid. The pressure and volume of the confined air varies as to the system heat transfer fluid expands and contracts to prevent excessive pressure from developing and causing damage.
F-Curve	The collector instantaneous efficiency curve. Used in the "F-curve" procedure for collector analysis (see Instantaneous Efficiency).
Fixed Collector	A solar collector that is fixed in position and cannot be rotated to follow the sun daily or seasonably.
Flat Plate Collector	A solar energy collecting device consisting of a relatively thin panel of absorbing material. A container with insulated bottom and sides and covered with one or more covers transparent to visible solar energy and relatively opaque to infrared energy. Visible energy from the sun enters through the transparent cover and raises the temperature of the absorbing panel. The infrared energy re-radiated from the panel is trapped within the collector because it cannot pass through the cover. Glass is an effective cover material (see Selective Surface).
Focusing Collector	A concentrating type collector using parabolic mirrors or optical lenses to focus the energy from a large area onto a small absorbing area.
Fossil Fuel	Petroleum, coal, and natural gas derived fuels.
Glazing	In solar/energy technology, the transparent covers used to reduce energy losses from a collector panel.

Heat Exchanger	A device used to transfer energy from one heat transfer fluid to another while maintaining physical segregation of the fluids. Normally used in systems to provide an interface between two different heat transfer fluids.
Heat Transfer Fluid	The fluid circulated through a heat source (solar collector) or heat exchanger that transports the thermal energy by virtue of its temperature.
Heating Degree Days	The sum over a specified period of time of the number of degrees the average daily temperature is below 65°F.
Instantaneous Efficiency	The efficiency of a solar collector at one operating point, $\frac{Ti-Ta}{I}$, under steady state conditions (see Operating Point).
Instantaneous Efficiency Curve	A plot of solar collector efficiency against operating point, $\frac{Ti-Ta}{I}$ (see Operating Point).
Incidence Angle	The angle between the line to a radiating source (the sun) and a line normal to the plane of the surface being irradiated.
Incident Solar Energy	The amount of solar energy irradiating a surface taking into account the angle of incidence. The effective area receiving energy is the product of the area of the surface times the cosine of the angle of incidence.
Insolation	Incoming solar radiation.
Load	That to which energy is supplied, such as space heating load or cooling load. The system load is the total solar and auxiliary energy required to satisfy the required heating or cooling.
Manifold	The piping that distributes the transport fluid to and from the individual panels of a collector array.
Microclimate	Highly localized weather features which may differ from long term regional values due to the interaction of the local surface with the atmosphere.

Nocturnal Radiation	The loss of thermal energy by the solar collector to the night sky.
Operating Energy	The amount of energy (usually electrical energy) required to operate the solar and auxiliary equipments and to transport the thermal energy to the point of use, and which is not intended to directly affect the thermal state of the system.
Operating Point	A solar energy system has a dynamic operating range due to changes in level of insolation (I), fluid input temperature (T), and outside ambient temperature (Ta). The operating point is defined as: $\frac{Ti-Ta}{I} \quad \frac{^\circ F \text{ x hr. x sq. ft.}}{\text{BTU}}$
Operational Collector Efficiency	Ratio of collected solar energy to incident solar energy only during the time the collector fluid is being circulated with the intention of delivering solar-source energy to the system.
Outgassing	The emission of gas by materials and components, usually during exposure to elevated temperature, or reduced pressure.
Passive Solar System	A system which uses architectural components of the building to collect, distribute, and store energy.
Pebble Bed (Rock Bed)	A space filled with uniform-sized pebbles to store solar-source energy by raising the temperature of the pebbles.
Reflected Radiation	Insolation reflected from a surface, such as the ground or a reflecting element onto the solar collector.
Rejected Energy	Energy intentionally rejected, dissipated, or dumped from the solar system.
Retrofit	The addition of a solar energy system to an existing structure.
Selective Surface	A surface that has the ability to readily absorb solar radiation, but re-radiates little of it as thermal radiation.

Sensor	A device used to monitor a physical parameter in a system, such as temperature or flow rate, for the purpose of measurement or control.
Solar Conditioned Space	The area in a building that depends on solar energy to provide a fraction of the heating and cooling needs.
Solar Fraction	The fraction of the total load supplied by solar energy. The ratio of solar energy supplied to loads divided by total load. Often expressed as a percentage.
Solar Savings Ratio	The ratio of the solar energy supplied to the load minus the solar system operating energy, divided by the system load.
Storage Efficiency, N_s	Measure of effectiveness of transfer of energy through the storage subsystem taking into account system losses.
Storage Subsystem	The assembly of components used to store solar-source energy for use during periods of low insolation.
Stratification	A phenomenon that causes a distinct thermal gradient in a heat transfer fluid, in contrast to a thermally homogeneous fluid. Results in the layering of the heat transfer fluid, with each layer at a different temperature. In solar energy systems, stratification can occur in liquid storage tanks or rock beds, and may even occur in pipes and ducts. The temperature gradient or layering may occur in a horizontal, vertical or radial direction.
System Performance Factor	Ratio of system load to the total equivalent fossil energy expended or required to support the system load.
Ton of Refrigeration	The heat equivalent to the melting of one ton (2,000 pounds) of ice at 32°F in 24 hours. A ton of refrigeration will absorb 12,000 BTU/hr, or 288,000 BTU/day.
Tracking Collector	A solar collector that moves to point in the direction of the sun.
Zone	A portion of a conditioned space that is controlled to meet heating or cooling requirements separately from the other space or other zones.

SECTION 3. GENERAL ACRONYMS

ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineering.
BTU	British Thermal Unit, a measure of heat energy. The quantity of heat required to raise the temperature of one pound of pure water one Fahrenheit degree. One BTU is equivalent to 2.932×10^{-4} kwh of electrical energy.
COP	Coefficient of Performance. The ratio of total load to solar-source energy.
DHW	Domestic Hot Water.
ECSS	Energy Collection and Storage System.
HWS	Domestic or Service Hot Water Subsystem.
KWH	Kilowatt Hours, a measure of electrical energy. The product of kilowatts of electrical power applied to a load times the hours it is applied. One kwh is equivalent to 3,413 BTU of heat energy.
NSDN	National Solar Data Network.
SCS	Space Cooling Subsystem.
SHS	Space Heating Subsystem.
SOLMET	Solar Radiation/Meteorology Data.

APPENDIX D

PERFORMANCE EQUATIONS

GENERAL ELECTRIC - MILWAUKEE

INTRODUCTION

Solar energy system performance is evaluated by performing energy balance computations on the system and its major subsystems. These calculations are based on physical measurement data taken from each sensor every 320 seconds.* This data is then mathematically combined to determine the hourly, daily, and monthly performance of the system. This appendix describes the general computational methods and the specific energy balance equations used for this site.

Data samples from the system measurements are integrated to provide discrete approximations of the continuous functions which characterize the system's dynamic behavior. This integration is performed by summation of the product of the measured rate of the appropriate performance parameters and the sampling interval over the total time period of interest.

There are several general forms of integration equations which are applied to each site. These general forms are exemplified as follows: the total solar energy available to the collector array is given by

$$\text{SOLAR ENERGY AVAILABLE} = (1/60)\ \Sigma\ [\text{I001} \times \text{AREA}] \times \Delta\tau$$

where I001 is the solar radiation measurement provided by the pyranometer in BTU per square foot per hour, AREA is the area of the collector array in square feet, $\Delta\tau$ is the sampling interval in minutes, and the factor (1/60) is included to correct the solar radiation "rate" to the proper units of time.

Similarly, the energy flow within a system is given by

$$\text{COLLECTED SOLAR ENERGY} = \Sigma\ [\text{M100} \times \Delta\text{H}] \times \Delta\tau$$

where M100 is the mass flow rate of the heat transfer fluid in lb_m/min and ΔH is the enthalpy change, in BTU/lb_m, of the fluid as it passes through the heat exchanging component.

For a liquid system ΔH is given by

$$\Delta\text{H} = \bar{\text{C}}_p\ \Delta\text{T}$$

where C_p is the average specific heat, in BTU/lb_m-°F, of the heat transfer fluid and ΔT, in °F, is the temperature differential across the heat exchanging component.

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* See Appendix B.

For electrical power, a general example is

$$\text{COLLECTOR PUMP ENERGY} = (3413/60)\ \Sigma\ [\text{EP100}] \times \Delta\tau$$

where EP100 is the power required by the pump in kilowatts and the two factors (1/60) and 3413 correct the data to BTU/min.

Letter Designations

C or CP = Specific Heat

D = Direction or Position

EE = Electric Energy

EP = Electric Power

F = Fuel Flow Rate

HWD = Functional procedure to calculate the specific heat of water at the average of the inlet and outlet temperatures

H = Enthalpy

HR = Humidity Ratio

I = Incident Solar Flux (Insolation)

M = Mass Flow Rate

N = Performance Parameter

P = Pressure

PD = Differential Pressure

Q = Thermal Energy

RHO = Density

T = Temperature

TD = Differential Temperature

V = Velocity

W = Heat Transport Medium Volume Flow Rate

TI = Time

_P = Appended to a function designator to signify the value of the function during the previous iteration

Subsystem Designations Number Sequence	Subsystem/Data Group
001 to 099	Climatological
100 to 199	Collector and Heat Transport
200 to 299	Thermal Storage
300 to 399	Hot Water
400 to 499	Space Heating
500 to 599	Space Cooling
600 to 699	Building/Load

EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

AVERAGE AMBIENT TEMPERATURE (°F)

$$TA = (1/60) \times \Sigma \; T001 \times \Delta\tau$$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

$$TDA = (1/360) \times \Sigma \; T001 \times \Delta\tau$$

for ± three hours from solar noon

INCIDENT SOLAR ENERGY PER SQUARE FOOT (BTU/FT^2)

$$SE = (1/60) \times \Sigma \; I001 \times \Delta\tau$$

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

$$SEOP = (1/60) \times \Sigma \; [I001 \times 1{,}514 \text{ square feet}] \times \Delta\tau$$

when the collector loop is active

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \Sigma \; [M100 \times CP \times (T150 - T100)] \times \Delta\tau$$

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \Sigma \; [M200 \times CP \times (T250 - T200)] \times \Delta\tau$$

SOLAR ENERGY FROM STORAGE (BTU)

$$STEO = \Sigma \; [M400 \times CP \times (T400 - T450)] + [M300 \times CP \times (T301 - T300)] \times \Delta\tau$$

AVERAGE COLD WATER SUPPLY TEMPERATURE (°F)

$TSW = 1/60 \times \Sigma\ T300 \times \Delta\tau$

when there is flow

AVERAGE HOT WATER TEMPERATURE (°F)

$THW = 1/60 \times \Sigma\ T350 \times \Delta\tau$

when there is hot water use

AVERAGE TEMPERATURE OF STORAGE (°F)

$TST = (1/60) \times \Sigma\ [(T203 + T201 + T202)/3] \times \Delta\tau$

ENERGY DELIVERED FROM ECSS TO HOT WATER SUBSYSTEM (BTU)

$CSEO = STEO$

ECSS OPERATING ENERGY (BTU)

$CSOPE = 56.8833 \times \Sigma\ EP100 \times \Delta\tau$

when system is in the collector-to-storage mode

SOLAR ENERGY TO HOT WATER SUBSYSTEM (BTU)

$HWSE = \Sigma\ M300 \times CP \times (T301 - T300) \times \Delta\tau$

HOT WATER SUBSYSTEM AUXILIARY FOSSIL FUEL ENERGY (BTU)

$HWAF = \Sigma\ 1021 \times F300 \times \Delta\tau$

HOT WATER SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$HWAT = HWAF \times 0.60$ efficiency

HOT WATER SUBSYSTEM LOAD (BTU)

$HWL = \Sigma\ M300 \times CP \times (T350 - T300)$

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$SEA = CLAREA \times SE$

COLLECTED SOLAR ENERGY (BTU)

$SEC = SECA/CLAREA$

COLLECTOR ARRAY EFFICIENCY

$CAREF = SECA/SEA$

CHANGE IN STORED ENERGY (BTU)

$STECH = STECH1 - STECH1_p$

where the subscript $_p$ refers to a prior reference value

STORAGE EFFICIENCY

STEFF = (STECH + STEO)/STEI

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

SEL = HSE + HWSE

ECSS SOLAR CONVERSION EFFICIENCY

CSCEF = SEL/SEA

HOT WATER SUBSYSTEM SOLAR FRACTION (PERCENT)

HWSFR = 100 x HWSE/(HWSE + HWAT)

SYSTEM LOAD (BTU)

SYSL = HWL + HL

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

SFR = (HWSFR x HWL + HSFR x HL)/SYSL

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

AXT = HWAT + HAT

AUXILIARY FOSSIL ENERGY TO LOADS (BTU)

AXF = HAF + HWAF

SYSTEM OPERATING ENERGY (BTU)

SYSOPE = CSOPE + HOPE

TOTAL ENERGY CONSUMED (BTU)

TECSM = SYSOPE + SECA + AXF

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

TSVE = HSVE - CSOPE

SYSTEM PERFORMANCE FACTOR

$$\mathrm{SYSPF} = \mathrm{SYSL}/(\mathrm{AXF} + 3.33 \times \mathrm{SYSOPE})$$

SPACE HEATING SUBSYSTEM AUXILIARY FOSSIL FUEL ENERGY (BTU)

$$\mathrm{HAF} = \Sigma\ 1000 \times \mathrm{F400} \times \Delta\tau$$

SOLAR ENERGY TO SPACE HEATING SUBSYSTEM (BTU)

$$\mathrm{HSE} = \Sigma\ \mathrm{M400} \times \mathrm{CP} \times (\mathrm{T400} - \mathrm{T450}) \times \Delta\tau$$

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$$\mathrm{HOPE} = 56.8833 \times \Sigma\ (\mathrm{EP400} + \mathrm{EP600}) \times \Delta\tau$$
$$\mathrm{HOPE1} = 56.8833 \times \Sigma\ \mathrm{EP400} \times \Delta\tau$$

SPACE HEATING SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$$\mathrm{HAT} = \mathrm{HAF} \times 0.60\ \text{efficiency}$$

SPACE HEATING SUBSYSTEM LOAD (BTU)

$$\mathrm{HL} = \mathrm{HSE} + \mathrm{HAT}$$

SPACE HEATING SUBSYSTEM SOLAR FRACTION (PERCENT)

$$\mathrm{HSFR} = (\mathrm{HSE}/\mathrm{HL}) \times 100$$

SPACE HEATING SUBSYSTEM SAVINGS OF FOSSIL FUEL (BTU)

$$\mathrm{HSVF} = \mathrm{HSE}/0.60\ \text{efficiency}$$

SPACE HEATING SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

$$\mathrm{HSVE} = -\mathrm{HOPE1}$$

APPENDIX E

CALCULATION OF PREDICTED VALUES

The modified f-Chart program is used by the NSDN to estimate performance of the solar system. The f-Chart program was developed by the Solar Energy Laboratory, University of Wisconsin-Madison, and was originally intended to be used as a design tool. This program has been modified to use measured weather data and measured subsystem loads and losses in place of average long-term weather data and ASHRAE building heat loss (UA) estimated loads. The results help to determine if the system is performing well.

In addition to the assumptions made for a normal f-Chart analysis, the modified f-Chart assumes that all subsystem loads and losses are reasonable and are the result of good design and insulation practice.

Ref:

(1) Solar Heating Design by the F-Chart Method. William A. Beckman, Sanford A. Klein, John A. Duffie, Wiley Interscience, N.Y. (1977)

(2) F-Chart User's Manual. EES Report 49-3, SERI, Department of Energy, (June 1978)

SYSTEM PERFORMANCE SUMMARY (f-CHART)*
GENERAL ELECTRIC - MILWAUKEE
SEPTEMBER 1980 THROUGH MARCH 1981

(All values in million BTU, unless otherwise indicated)

MONTH	ESFR (%)	ASFR (%)	LOAD	LOSS	STECH	ESECA	ASECA	ESEU	ASEU	LOSS (%)
SEP	70	92	1.74	6.80	2.18	16.67	10.29	1.86	1.62	84
OCT	94	78	13.73	3.14	-1.95	17.99	12.18	14.08	10.68	12
NOV	63	17	38.78	2.34	-0.23	26.91	8.74	25.01	6.60	24
DEC	11	0	69.93	1.72	-0.18	9.28	2.17	7.74	0.17	92
JAN	22	0	85.93	0.68	0.73	20.37	2.43	19.14	0.03	99
FEB	22	6	81.20	3.11	-0.34	18.97	6.89	18.04	4.66	32
MAR	39	17	66.63	3.66	-0.03	27.92	13.90	26.37	11.21	19
TOTAL	-	-	357.94	21.45	0.18	138.11	56.60	112.24	34.97	-
AVERAGE	31	10	51.13	3.06	0.03	19.73	8.09	16.03	5.00	38

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*See next page for glossary of f-Chart terms.

GLOSSARY OF f-CHART TERMS

ESFR - Expected (predicted) solar fraction

ASFR - Actual (measured) solar fraction

LOAD - Measured total system load

LOSS - Total system losses (transport and storage)

STECH - Change in stored energy

ESECA - Expected (predicted) solar energy collected

ASECA - Actual (measured) solar energy collected

ESEU - Expected (predicted) solar energy used

ASEU - Actual (measured) solar energy used

LOSS (%) - 100 x (ASECA - ASEU)/ASECA

APPENDIX F

METEOROLOGICAL CONDITIONS

GENERAL ELECTRIC - MILWAUKEE LONG-TERM WEATHER DATA

COLLECTOR TILT: 53 DEGREES
LATITUDE: 43 DEGREES

LOCATION: MILWAUKEE, WISCONSIN
COLLECTOR AZIMUTH: 0 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
SEP	2,570	1,309	0.50935	1.109	1,451	140	23	61
OCT	1,902	907	0.47691	1.415	1,283	440	6	51
NOV	1,363	524	0.38410	1.655	866	855	0	37
DEC	1,128	376	0.33353	1.740	654	1,265	0	24
JAN	1,255	479	0.38207	1.746	837	1,414	0	19
FEB	1,724	737	0.42774	1.482	1,093	1,190	0	23
MAR	2,339	1,088	0.46510	1.201	1,306	1,042	0	31

LEGEND:

HOBAR - Monthly average daily extraterrestrial radiation (ideal) in BTU/day-ft^2.

HBAR - Monthly average daily radiation (actual) in BTU/day-ft^2.

KBAR - Ratio of HBAR to HOBAR.

RBAR - Ratio of monthly average daily radiation on tilted surface to that on a horizontal surface for each month (i.e., multiplier obtained by tilting).

SBAR - Monthly average daily radiation on a tilted surface (i.e., RBAR x HBAR) in BTU/day-ft^2.

HDD - Number of heating degrees-days per month.

CDD - Number of cooling degrees-days per month.

TBAR - Average ambient temperature in degrees Fahrenheit.

MONTHLY REPORT: GENERAL ELECTRIC - MILWAUKEE
SEPTEMBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1058	73	77
2	3086	73	78
3	2576	76	81
4	1396	72	78
5	*	*	*
6	*	*	*
7	*	*	*
8	2034	74	80
9	1671	70	70
10	*	*	*
11	602	63	69
12	358	65	62
13	1837	73	81
14	258	61	60
15	312	59	61
16	114	57	61
17	*	*	*
18	2092	63	68
19	1604	65	69
20	707	68	74
21	817	69	69
22	570	62	66
23	1807	52	58
24	1672	57	66
25	1471	56	65
26	2079	50	56
27	1970	59	68
28	410	58	58
29	2086	65	74
30	1296	65	75
SUM	40657	-	-
AVG	1355	64	69

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: GENERAL ELECTRIC - MILWAUKEE
OCTOBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	603	62	70
2	1412	53	64
3	1419	43	47
4	1386	43	48
5	2231	44	51
6	1900	54	63
7	1852	62	70
8	2090	62	70
9	2186	51	56
10	1352	57	62
11	471	46	*
12	2055	43	49
13	1962	44	51
14	101	48	48
15	134	49	48
16	149	56	56
17	1385	62	69
18	458	48	50
19	1335	47	50
20	947	49	53
21	2070	47	52
22	1375	45	51
23	1402	52	54
24	249	49	55
25	244	37	38
26	761	35	37
27	245	35	39
28	2019	36	39
29	2064	36	44
30	1379	42	48
31	1959	48	54
SUM	39197	-	-
AVG	1264	48	53

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: GENERAL ELECTRIC - MILWAUKEE
NOVEMBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1452	38	44
2	791	42	46
3	627	53	59
4	1043	48	50
5	1592	40	43
6	1088	54	58
7	112	43	45
8	89	44	44
9	1758	51	54
10	1992	34	36
11	1423	33	37
12	368	43	43
13	83	47	54
14	305	35	37
15	574	34	35
16	598	36	40
17	620	33	37
18	1836	31	35
19	1536	36	43
20	1607	40	44
21	1534	37	39
22	1873	44	50
23	81	40	39
24	704	34	35
25	1679	32	37
26	1551	33	40
27	29	36	34
28	543	33	34
29	241	34	35
30	1104	41	46
SUM	28832	-	-
AVG	961	39	42

MONTHLY REPORT: GENERAL ELECTRIC - MILWAUKEE
DECEMBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	271	38	39
2	167	22	22
3	32	22	25
4	53	33	36
5	24	40	41
6	81	49	50
7	98	45	45
8	65	36	37
9	282	26	28
10	228	20	23
11	256	14	*
12	945	34	37
13	1736	25	25
14	687	24	*
15	456	25	28
16	213	28	28
17	237	32	31
18	104	27	28
19	1650	3	4
20	1730	6	9
21	1226	15	20
22	166	24	24
23	318	31	34
24	871	12	*
25	1316	6	9
26	425	18	19
27	84	25	27
28	278	29	31
29	592	32	34
30	77	29	31
31	71	32	32
SUM	14736	-	-
AVG	475	26	28

*DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: GENERAL ELECTRIC - MILWAUKEE
JANUARY 1981
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	178	28	30
2	548	14	13
3	1906	2	3
4	1791	0	4
5	1089	11	13
6	222	23	27
7	1239	5	7
8	1671	11	18
9	911	13	16
10	1804	6	9
11	1905	7	10
12	316	17	18
13	70	26	31
14	259	26	27
15	761	19	21
16	1721	18	20
17	1441	18	21
18	1980	33	36
19	1438	36	40
20	426	31	33
21	723	30	31
22	1896	34	38
23	1455	35	41
24	1854	39	50
25	344	41	42
26	119	36	36
27	179	30	33
28	916	21	24
29	1961	19	24
30	1967	21	27
31	1097	26	28
SUM	34188	-	-
AVG	1103	22	25

*DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: GENERAL ELECTRIC - MILWAUKEE
FEBRUARY 1981
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	219	29	31
2	2053	5	7
3	1676	2	6
4	2081	5	8
5	1080	13	16
6	1171	24	*
7	573	26	30
8	1679	14	17
9	1822	16	22
10	111	21	28
11	2487	-1	-2
12	793	5	9
13	1069	20	27
14	1955	33	38
15	1690	39	43
16	2062	45	50
17	1940	47	53
18	441	49	51
19	1421	47	57
20	181	34	36
21	263	35	34
22	58	39	38
23	136	36	36
24	1450	39	44
25	2178	34	41
26	229	30	30
27	95	36	33
28	330	38	38
SUM	32359	-	-
AVG	1156	27	30

*DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: GENERAL ELECTRIC - MILWAUKEE
MARCH 1981
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	216	34	32
2	947	27	28
3	1905	29	32
4	1653	36	41
5	2277	30	33
6	1013	26	26
7	921	27	30
8	2256	35	44
9	961	38	44
10	806	37	39
11	1622	35	39
12	2210	45	54
13	1168	35	36
14	2359	38	44
15	2135	45	56
16	1887	32	35
17	2319	30	31
18	821	26	30
19	494	27	28
20	1189	35	39
21	509	34	38
22	1978	37	45
23	2188	43	57
24	2237	37	44
25	1849	41	46
26	2131	47	52
27	2065	40	43
28	1492	59	66
29	296	59	58
30	945	54	58
31	1885	57	58
SUM	46731	-	-
AVG	1507	38	42

APPENDIX H

CONVERSION FACTORS

Energy Conversion Factors

Fuel Type	Energy Content	Fuel Source Conversion Factor
Distillate fuel oil[1]	138,690 BTU/gallon	7.21×10^{-6} gallon/BTU
Residual fuel oil[2]	149,690 BTU/gallon	6.68×10^{-6} gallon/BTU
Kerosene	135,000 BTU/gallon	7.41×10^{-6} gallon/BTU
Propane	91,500 BTU/gallon	10.93×10^{-6} gallon/BTU
Natural gas	1,021 BTU/cubic feet	979.4×10^{-6} cubic feet/BTU
Electricity	3,413 BTU/kilowatt-hour	292.8×10^{-6} kwh/BTU

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[1] No. 1 and No. 2 heating oils, diesel fuel, No. 4 fuel oils

[2] No. 5 and No. 6 fuel oils

APPENDIX I

SENSOR TECHNOLOGY

Temperature Sensors

Temperatures are measured by a Minco Products S53P platinum Resistance Temperature Detector (RTD). Because the resistance of platinum wire varies as a function of temperature, measurement of the resistance of a calibrated length of platinum wire can be used to accurately determine the temperature of the wire. This is the principle of the platinum RTD which utilizes a tiny coil of platinum wire encased in a copper-tipped probe to measure temperature.

Ambient temperature sensors are housed in a WeatherMeasure Radiation Shield in order to protect the probe from solar radiation. Care is taken to locate the sensor away from extraneous heat sources which could produce erroneous temperature readings. Temperature probes mounted in pipes are installed in stainless steel thermowells for physical protection of the sensor and to allow easy removal and replacement of the sensors. A thermally-conductive grease is used between the probe and the thermowell to assure faster temperature response.

All temperature sensors are individually calibrated at the factory. In addition, the bridge circuit is calibrated in the field using a five-point check.

Nominal Resistance @ 25°C:	100 ohms
No. of Leads:	3
Electrical Connection:	Wheatstone Bridge
Time Constant	1.5 seconds max. in water at 3 fps
Self Heating:	27 mw/°F

WIND SENSOR

Wind speed and direction are measured by a WeatherMeasure W102-P-DC/540 or W101-P-DC/540 wind sensor. Wind speed is measured by means of a four-bladed propeller coupled to a DC generator.

Wind direction is sensed by means of a dual-wiper 1,000-ohm long-life conductive plastic potentiometer. It is attached to the stainless steel shaft which supports and rotates with the upper body assembly.

Size:	29-3/4"L X 30"H
Starting Speed:	1 mph
Complete Tracking:	3 mph
Maximum Speed:	200 mph
Distance Constant (30 mph):	6.2'
Accuracy:	± 1% below 25 mph ± 3% above 25 mph
Time Constant:	0.145 second

HUMIDITY SENSORS

The WeatherMeasure HMP-14U Solid State Relative Humidity Probe is used for the measurement of relative humidity. The operation of the sensor is based upon the capacitance of the polymer thin film capacitor. A one-micron-thick dielectric polymer layer absorbs water molecules through a thin metal electrode and causes capacitance change proportional to relative humidity.

Range:	0-100% R.H.
Response Time:	1 second to 90% humidity change at 20°C
Temperature Coefficient:	0.05% R.H./°C
Accuracy:	± 3% from 0-80% R.H. ± 5-6% 80-100% R.H.
Sensitivity:	0.2% R.H.

INSOLATION SENSORS

The Eppley Model PSP pyranometer is used for the measurement of insolation. The pyranometer consists of a circular multijunction thermopile of the plated, (copper-constantan) wirewound type which is temperature compensated to render the response essentially independent of ambient temperature. The receiver is coated with Parsons' black lacquer (non-wavelength-selective absorption). The instrument is supplied with a pair of precision-ground polished concentric hemispheres of Schott optical glass transparent to light between 285 and 2800 nm of wavelength. The instrument is provided with a dessicator which may be readily inspected. Pyranometers designated as shadowband pyranometers are equipped with a shadowband which may be adjusted to block out any direct solar radiation. These instruments are used for the measurement of diffuse insolation.

Sensitivity:	9 μ V/W/m^2
Temperature Dependence:	± 1% over ambient temperature range -20°C to 40°C
Linearity:	0.5% from 0 to 2,800 W/M^2
Response Time:	1 second
Cosine Error:	± 1% 0-70° zenith angle ± 3% 70-80° zenith angle

LIQUID FLOW SENSORS (NON-TOTALIZING)

The Ramapo Mark V strain gauge flow meters are used for the measurement of liquid flow. The flow meters sense the flow of the liquids by measuring the force exerted by the flow on a target suspended in the flow stream. This force is transmitted to a four active arm strain gauge bridge to provide a signal proportional to flow rate squared. The flow meters are available in a screwed end configuration, a flanged configuration, and a wafer configuration. Each flow meter is calibrated for the particular fluid being used in the application.

Materials:	Target - 17-PH stainless steel Body - Brass or stainless steel Seals - Buna-N
Fluid Temperature:	-40°F to 250°F
Calibration Accuracy:	± 1% (½" to 3½" line size) ± 2% (4" and greater line size)
Repeatability and Hysteresis:	0.25% of reading

LIQUID FLOW SENSORS (TOTALIZING)

Hersey Series 400 flow meters are used to measure totalized liquid flow. The meter is a nutating disk, positive displacement type meter. An R-15 register with an SPDT reed switch is used to provide an output to the data acquisition subsystem.

The output of the reed switch is input to a Martin DR-1 Digital Ramp which counts the number of pulses and produces a zero to five volt analog signal corresponding to the pulse count.

Materials:	Meter body	- bronze
	Measuring chamber	- plastic
Accuracy:	± 1.5%	

AIR FLOW SENSORS

The Kurz 430 Series of thermal anemometers is used for the measurement of air flow. The basic sensing element is a probe which consists of a velocity sensor and a temperature sensor. The velocity sensor is heated and operated as a constant temperature thermal anemometer which responds to a "standard" velocity (referenced to 25°C and 760 mm Hg) or mass flow by sensing the cooling effect of the air as it passes over the heated sensor. The temperature sensor compensates for variations in ambient temperature.

Since the probe measures air velocity at only one point in the cross section of the duct, it is necessary to perform a careful duct mapping to relate the probe reading to the amount of air flowing through the entire duct. This is done by dividing the duct into small areas and taking a reading at the center of each area using a portable probe. The readings are then averaged to determine the overall duct velocity. The reading at the permanently installed probe is then ratioed to this reading. This duct mapping is done for each mode.

Accuracy:	± 2% of full scale over temperature range -20°C to 60°C ± 5% of full scale over temperature range -60°C to 250°C
Response Time:	0.025 second
Repeatability:	0.25% full scale

FUEL OIL FLOW SENSOR

The Kent Mini-Major is used as a flow oil flow meter. The meter utilizes an oscillating piston as a positive displacement element. The oscillating piston is connected to a pulser which sends pulses to the Site Data Acquisition Subsystem for totalization.

Operating Temperature: 100°C (max)
Flow Range: 0.6 to 48 gph
Accuracy: ± 1% of full scale

FUEL GAS FLOW SENSOR

The American AC-175 gas meter is used for the measurement of totalized fuel gas flow. The drop in pressure between the inlet and outlet of the meter is responsible for the action of the meter. The principle of measurement is positive displacement. Four chambers in the meter fill and empty in sequence. The exact volume of compartments is known, so by counting the number of displacements the volume is measured. Sliding control valves control the entrance and exit of the gas to the compartments. The meter is temperature compensated to reference all volumetric readings to 60°F.

Rated Capacity: 175 cubic ft/hr
Max Working Pressure: 5 psi

ELECTRIC POWER SENSORS

Ohio Semitronics Series PC5 wattmeters are used as electric power sensors. They utilize Hall effect devices as multipliers taking the product of the instantaneous voltage and current readings to determine the electrical power. This technique automatically takes power factor into consideration and produces a true power reading.

Power Factor Range: 1 to 0 (lead or lag)
Response Time: 250 ms
Temperature Effect: 1% of reading
Accuracy: 0.5% of full scale

HEAT FLUX SENSORS

The Hy-Cal Engineering Model BI-7X heat flow sensor is used for the measurement of heat flux. The sensor consists basically of an insulating wafer, with a series of thermocouples arranged such that consecutive thermoelectric junctions fall on opposite sides of the wafer. This assembly is bonded to a heat sink to assure heat flow through the sensor. Heat is received on the exposed surface of the wafer and conducted through the heat sink. A temperature drop across the wafer is thus developed and is measured directly by each junction combination embodied along the wafer. Since the differential thermocouples are connected electrically in series, the voltages produced by each set of junctions is additive, thereby amplifying the signal directly proportional to the number of junctions. The temperature drop across the wafer, and thus the output signal, is directly proportional to the heating rate.

Operation Temperature:	-50° to 200°F
Response Time:	6 seconds
Linearity:	2%
Repeatability:	0.5%
Sensitivity:	2 mv/BTU/ft^2-hr
Size:	2" X 2"

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