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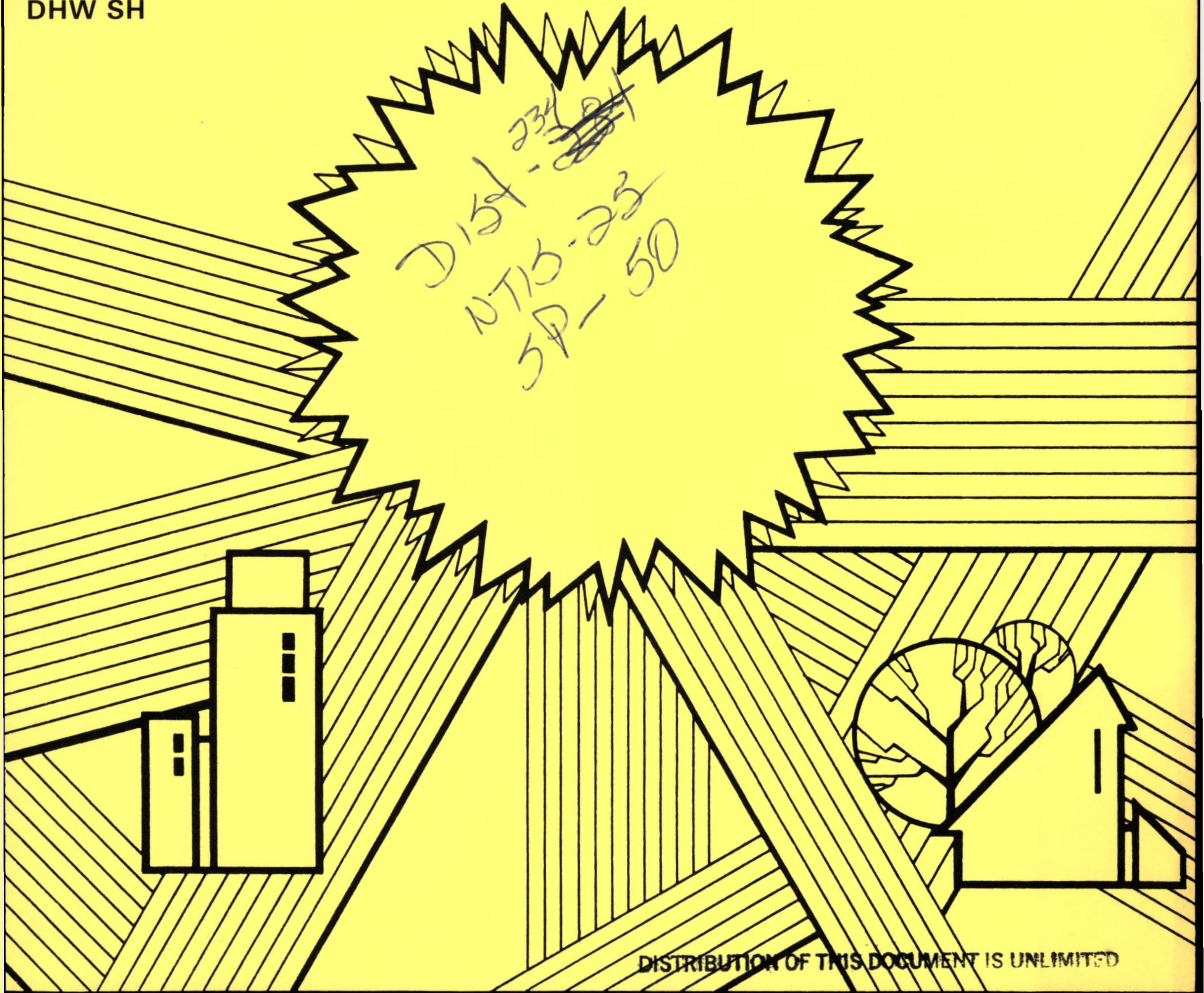
SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

SCATTERGOOD SCHOOL
West Branch, Iowa
June 1979 through April 1980
DHW SH



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SOLAR/2003-80/14

SCATTERGOOD SCHOOL

WEST BRANCH, IOWA

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

JUNE 1979 THROUGH APRIL 1980

Prepared by Eric M. Schatzberg

Approved:
for D. M. Roha
Program Manager

Vitro Laboratories Division
Automation Industries, Inc.

The National Solar Data Network
Department of Energy Contract Number DE-AC01-79CS30027
Contract Management by:
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

A. A. Longnecker, Project Manager

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FOREWORD

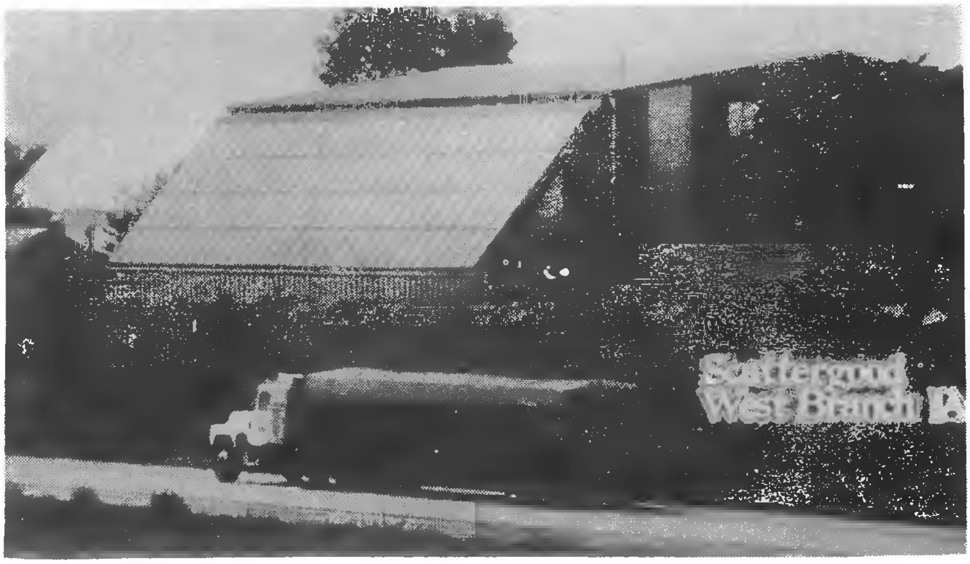
This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic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

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 reduce the use of nonrenewable fuels by encouraging the application of solar energy for heating, cooling, and domestic hot water. Vitro Laboratories Division operates the NSDN, under contract with the Department of Energy, to collect daily data 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, Hawaii and Puerto Rico. 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.

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 is highly automated.

In addition to these "Seasonal" Reports, NSDN information is disseminated for each operational site via Monthly Performance Reports, and special reports.



SCATTERGOOD SCHOOL

SCATTERGOOD SCHOOL

The Scattergood School site is a high school gymnasium in West Branch, Iowa. The active solar energy system is designed to supply the following:

Seasonal Design Factors
(Million BTU)

	Total Load	Solar Contribution	% Solar
Heating	406	305	75
Hot Water	N/A	N/A	75

It is equipped with:

Collector	2,496 sq. ft. of flat-plate air collectors
Storage	65 tons of 3/4-inch washed river gravel in an adjoining unconditioned space Two 120-gallon water preheating tanks
Auxiliary	Propane unit heaters for space heat Electric immersion heaters for DHW

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SECTION 1

SOLAR SYSTEM PERFORMANCE
SCATTERGOOD SCHOOL

JUNE 1979 THROUGH APRIL 1980[1]

Solar Fraction[2]	81%
Solar Savings Ratio[3]	0.74
Conventional Fuel Savings[4]	1,763 kwh; 1,343 gallons of propane
System Performance Factor[5]	1.09
Solar System COP[6]	11.29

Seasonal Energy Requirements
June 1979 through April 1980
(Million BTU)

	Total Load	Solar Contribution	% Solar
Heating	78.29	72.78	93
Hot Water	27.37	14.86	50

Environmental Data

	Measured Average	Long-Term Average
Outdoor temperature	50°F	52°F
Heating degree-days	4,829	4,292
Daily incident solar energy	1,438 BTU/ft^2	1,442 BTU/ft^2

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[1] Does not include months of November and December 1979.

[2] $$\text{Solar Fraction} = \frac{\text{Solar Energy Supplied to Loads}}{\text{Total Load}}$$

[3] $$\text{Solar Savings Ratio} = \frac{\text{Solar Energy Supplied to Load-Solar System Operating Energy}}{\text{Total Load}}$$

[4] Assumes an electric hot water heater and a propane space heater using 3,413 kwh/BTU and 90,330 BTU/gallon of propane, respectively.

[5] Ratio of system load to the total equivalent fossil energy expended or required to support the system load.

[6] $$\text{Solar System COP} = \frac{\text{Solar Energy Used}}{\text{Solar Unique Operating Energy}}$$

1.1 SUMMARY AND CONCLUSIONS

The Scattergood School solar energy system completed its third year of consistently fine performance. This site was turned off in the beginning of May 1980 to prevent overheating in the gymnasium. During the reporting period, the Scattergood School solar energy system supplied 93% of the space heating and 50% of the domestic hot water required for the school. The system operated from June 1979 to April 1980 with no mechanical failures.

The grain drying subsystem was used during the last two weeks of October. Operation of the grain drying subsystem considerably improved overall system performance. Had the October data been available, it probably would have reflected this improved performance, particularly with respect to fossil fuel savings, collector array efficiency, and ECSS conversion efficiency.

The quantity of fossil fuel and electrical energy saved by the operation of the solar energy system provides the primary criterion for the performance evaluation of a solar energy system. Fuel and electric savings can be readily translated into monetary terms. The high space heating solar fraction is in part enabled by allowing the building interior temperature to vary (see Space Heating). However, the solar savings remain impressive. The system saved a total of 1,343 gallons of propane (121.31 million BTU) and 1,763 kwh of electricity (6.02 million BTU). At the Scattergood School's utility rates of $0.56/gallon of propane and $0.06/kwh, the total savings are $858.00. These reported savings would have been significantly larger if the data from November and December had been available. (See Space Heating for savings estimate that includes the effect of losses.) Malfunctions with the Site Data Acquisition Subsystem (SDAS) resulted in loss of data from October 16 through January 3.

1.2 OVERALL SYSTEM PERFORMANCE

The flow of solar energy through the Scattergood School site for the 11-month period from June 1979 through April 1980 is presented in Figure 1. This Energy Flow Diagram shows the amount of energy collected, transported, stored, consumed or lost at each point in the system.

The overall thermal performance of the solar energy system is presented in Table 1 and shown graphically in Figure 2.

From June through September, the system operated in the summer mode. The collected solar energy was only used by the domestic hot water (DHW) subsystem. Losses from the collector subsystem caused some heating of the building (see Solar Energy Utilization). During September, the hot water usage increased due to the return of students for the school year. A large amount of the auxiliary energy was used by the system from June through August to satisfy standby losses from the domestic hot water tanks. In October, the space heating subsystem was turned on. The data presented in Figure 1 does not include the months of November and December due to an SDAS failure. During the heating season, the space heating subsystem performed extremely well with a solar fraction of 93%. The operating energy in Figure 2 is plotted as a negative value to represent a system expense.

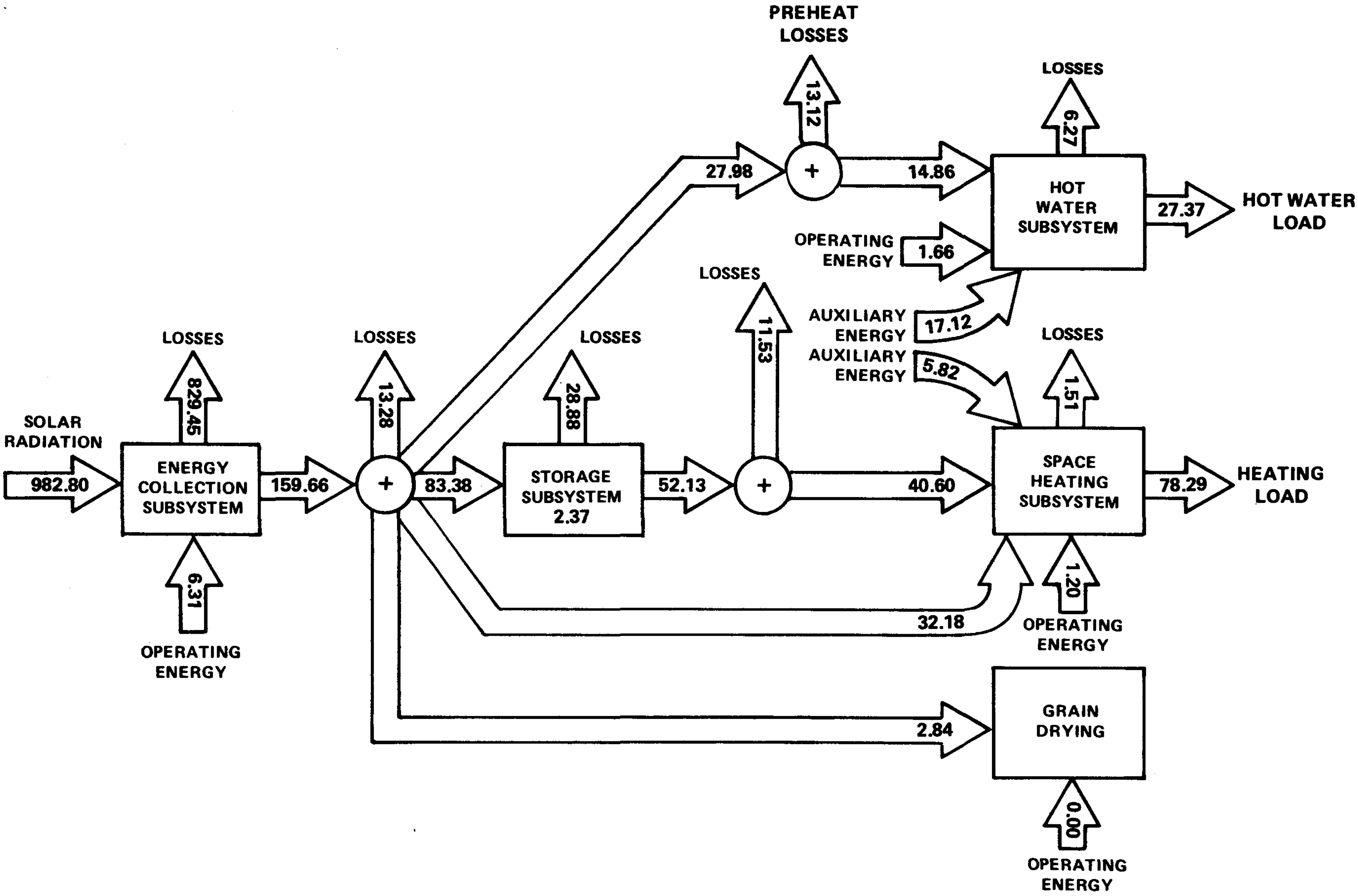


Figure 1. Energy Flow Diagram for Scattergood School
June 1979 through April 1980
(Figures in million BTU)

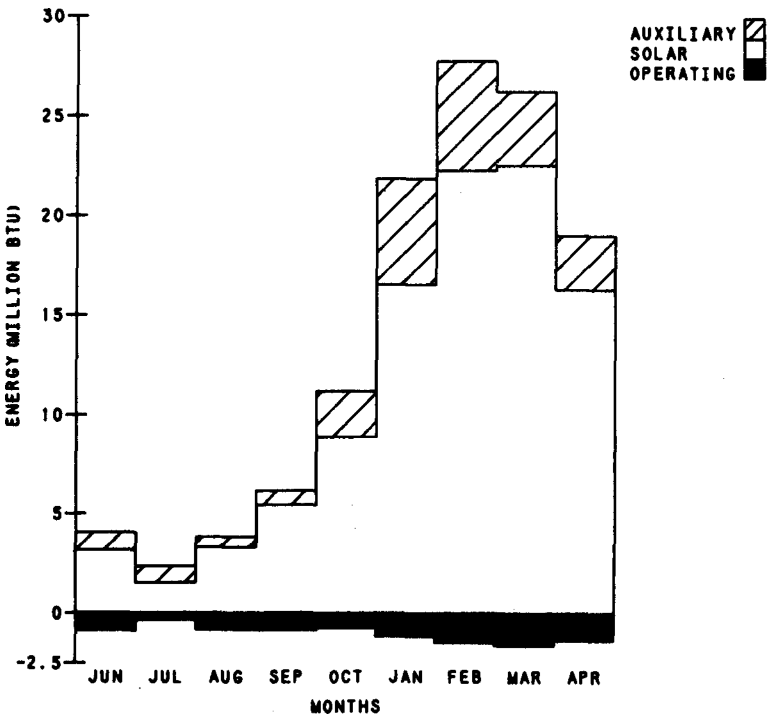
Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

SCATTERGOOD SCHOOL
JUNE 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	SOLAR ENERGY USED	AUXILIARY ENERGY		OPERATING ENERGY	ENERGY SAVINGS		SOLAR FRACTION (%)
			MEASURED	FOSSIL	ELECTRICAL		FOSSIL	ELECTRICAL	MEASURED
JUN	15.89	0.62	3.19	0.00	0.85	0.87	0.00	-0.33	52
JUL	2.53	0.46	1.49	0.00	0.84	0.33	0.00	-0.02	41
AUG	7.00	0.71	3.30	0.01	0.49	0.85	0.00	-0.15	90
SEP	9.52	3.49	5.41	0.00	0.71	0.85	0.00	2.37	83
OCT	17.30	9.80	9.79	0.16	2.18	0.74	11.02	1.58	78
NOV	*	*	*	*	*	*	*	*	*
DEC	*	*	*	*	*	*	*	*	*
JAN	20.20	21.95	16.54	5.21	2.72	1.15	24.53	0.16	75
FEB	29.14	26.52	22.26	2.45	4.03	1.46	32.37	0.73	82
MAR	31.35	24.43	22.51	1.89	2.59	1.60	32.97	-0.07	86
APR	26.75	17.68	16.27	0.00	2.71	1.32	20.42	1.75	86
TOTAL	159.66	105.66	100.76	9.72	17.12	9.17	121.31	6.02	-
AVERAGE	17.74	11.74	11.20	1.08	1.90	1.02	13.48	0.68	81

*Denotes unavailable data.



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
Scattergood School
June 1979 through April 1980

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 Scattergood School functioned at a weighted average COP value of 11.29 for the period June 1979 through April 1980.

The high COP for the heating subsystem (86.49) results from the distribution of solar energy to the gymnasium through natural convection and through a leak in damper MD2. (See the discussion under Space Heating.)

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

SCATTERGOOD SCHOOL
JUNE 1979 THROUGH APRIL 1980

MONTH	SOLAR ENERGY SYSTEM	COLLECTOR SUBSYSTEM	HOT WATER SUBSYSTEM	HEATING SUBSYSTEM
JUN	3.67	23.69	16.35	0.00
JUL	4.49	10.54	16.22	0.00
AUG	3.93	11.48	14.04	0.00
SEP	6.41	15.61	23.01	0.00
OCT	12.16	31.45	20.49	194.85
NOV	*	*	*	*
DEC	*	*	*	*
JAN	16.92	31.56	13.54	70.76
FEB	16.02	30.67	16.02	73.84
MAR	14.55	29.30	13.71	71.93
APR	12.33	27.58	17.93	95.73
AVERAGE	11.29	25.30	16.99	86.49

*Denotes unavailable data.

Natural convection space heating uses no operating energy. In addition, no fan energy is allocated to the space heating subsystem when the system is in collector-to-storage mode and space heating occurs through damper MD2. During the spring and fall, a greater portion of the space heating solar energy is delivered by the leak or by natural convection; this fact explains the high space heating subsystem COP during the spring and fall, including the October figure of 194.85.

A large improvement occurred in total system COP and collector subsystem COP between September and October. This roughly 100% improvement resulted from switching the system into winter operation from summer mode. No space heating occurs in the summer (or collector-to-water preheating) mode. The winter mode allows for greater utilization of the available solar energy at lower temperatures, hence at a much greater collector efficiency.

A 64% increase in DHW COP occurred between August and September. This increase resulted from the return of students and consequent increase in DHW load. The larger DHW load produced lower preheat tank temperatures, which reduced preheat tank losses. The DHW COP returned to the August level in January. This decrease was due to the lower temperatures at which solar energy is available during mid-winter.

In order to fully understand the data presented in Table 2, the analyst's methods used to allocate the energy consumed by fan B1 must be examined.

The system Schematic (Figure A-1) reveals that fan B1 serves multiple purposes. Fan B1 collects and stores solar energy, and distributes this energy to the gymnasium and the DHW preheat heat exchanger. Since fan B1 serves more than one subsystem, a pressure drop method is used to allocate the fan's energy to the various subsystems. This method allocates the fan energy to the subsystems based on the ratio of the pressure drop across subsystem components to the pressure rise across the fan. The pressure drops were measured on-site during August 1979 in each of five solar modes. For example, in storage-to-space heating mode, 56% of the fan energy is allocated to the ECSS subsystem, 14% to the DHW subsystem and 30% to the space heating system.

1.3 ENERGY SAVINGS

Energy savings for this site for the reporting period, June 1979 through April 1980, are presented in Table 3 and in Figure 3.

During the reporting period, energy savings for the space heating and DHW subsystems totaled 121.31 million BTU of fossil fuel and 12.29 million BTU of electrical energy. Operation of the energy collection and storage subsystem required 6.31 million BTU of electrical energy for a net electrical energy savings of 6.02 million BTU. These savings are equivalent to 1,343 gallons of propane and 1,763 kwh of electricity. At the Scattergood School's utility rates of $0.56/gallon of propane and $0.06/kwh, these savings total $858.00. See the discussion under Space Heating for an interpretation of the fossil fuel savings.

Energy savings calculations are based on a comparison of the actual energy requirements of the solar energy system to the predicted energy requirements of an assumed conventional system under the same environmental conditions. The conventional system is assumed to be a propane space heater with an efficiency of 60% and a standard DHW tank with electric immersion heaters.

Solar energy system 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.

Table 3. ENERGY SAVINGS

SCATTERGOOD SCHOOL
JUNE 1979 THROUGH APRIL 1980

(All values in million BTU)

		SOLAR ENERGY SAVINGS ATTRIBUTED TO					
		SPACE HEATING		DOMESTIC HOT WATER		NET ENERGY SAVINGS	
MONTH	SOLAR ENERGY USED	ELECTRICAL	FOSSIL FUEL	ELECTRICAL	ECSS OPERATING ENERGY	ELECTRICAL	FOSSIL FUEL
JUN	3.19	0.00	0.00	0.34	0.67	-0.33	0.00
JUL	1.49	0.00	0.00	0.22	0.24	-0.02	0.00
AUG	3.30	0.00	0.00	0.46	0.61	-0.15	0.00
SEP	5.41	0.00	0.00	2.98	0.61	2.37	0.00
OCT	9.79	-0.03	11.02	2.13	0.55	1.58	11.02
NOV	*	*	*	*	*	*	*
DEC	*	*	*	*	*	*	*
JAN	16.54	-0.21	24.53	1.01	0.64	0.16	24.53
FEB	22.26	-0.26	32.37	1.94	0.95	0.73	32.37
MAR	22.51	-0.28	32.97	1.27	1.07	-0.07	32.97
APR	16.27	-0.13	20.42	2.85	0.97	1.75	20.42
TOTAL	100.76	-0.91	121.31	13.20	6.31	6.02	121.31
AVERAGE	11.20	-0.10	13.48	1.47	0.70	0.68	13.48

*Denotes unavailable data.

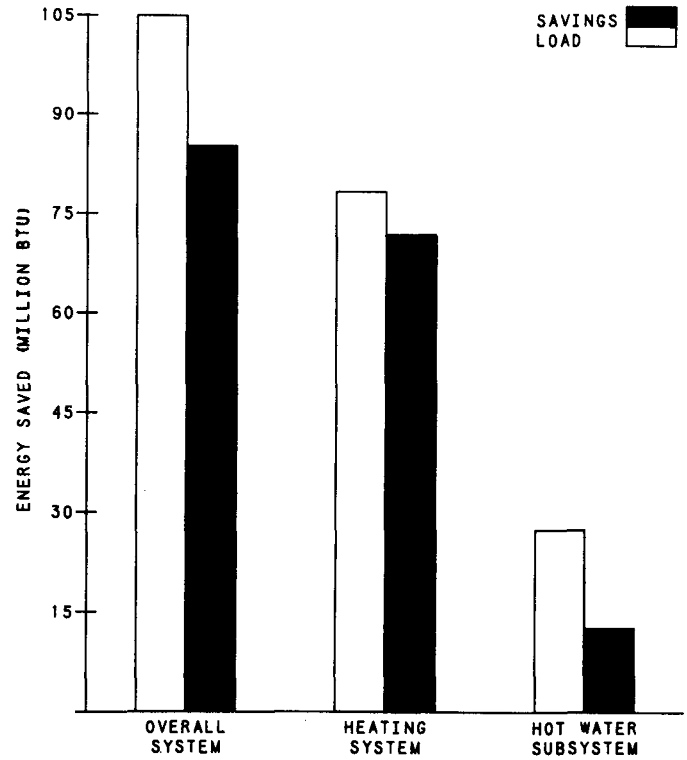


Figure 3. Combined Thermal Energy Savings Compared to Load
Scattergood School
June 1979 through April 1980

1.4 SOLAR ENERGY UTILIZATION

Figure 4 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 4.

The solar energy lost from the transport and storage subsystem lowers the heating energy needed by the gymnasium. Storage and transport losses occur in the equipment shed next to the gymnasium. The resulting temperature elevation from the shed reduces the gymnasium heat loss during the heating season. Losses occurring during the nonheating season are not large since the space heating system is turned off. The solar storage is only used for the space heating subsystem.

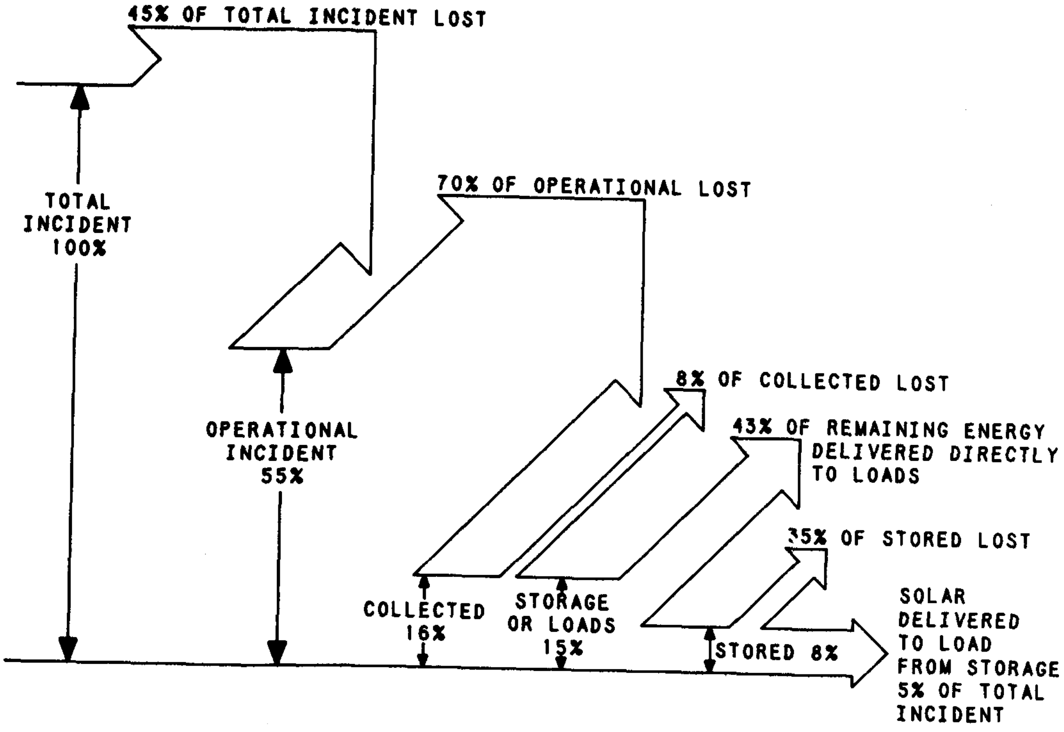


Figure 4. Solar Energy Use
Scattergood School
June 1979 through April 1980

Table 4. SOLAR ENERGY LOSSES

SCATTERGOOD SCHOOL
JUNE 1979 THROUGH APRIL 1980

	MONTH										
	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
1. SOLAR ENERGY (SE) COLLECTED MINUS SE DIRECTLY TO LOADS (million BTU)	12.68	1.04	3.70	4.11	11.41	*	*	7.66	16.29	21.34	18.43
2. SE TO STORAGE (million BTU)	9.19	0.00	0.00	0.00	10.98	*	*	8.19	15.85	20.89	18.28
3. LOSS - COLLECTOR TO STORAGE (%)	13	-	-	-	4	*	*	-26	3	2	1
4. CHANGE IN STORED ENERGY (million BTU)	-0.19	-0.56	0.00	0.03	1.42	*	*	0.08	0.39	1.33	-0.13
5. SOLAR ENERGY - STORAGE TO SPACE HEATING SUBSYSTEM (million BTU)	1.48	0.00	0.00	0.00	5.26	*	*	5.69	13.93	15.92	9.85
6. LOSS - FROM STORAGE (%)	86	-	-	-	39	*	*	29	10	17	47
7. HEATING SOLAR ENERGY FROM STORAGE (million BTU)	0.00	0.00	0.00	0.00	3.88	*	*	3.78	10.13	12.83	8.01

*Denotes unavailable data.

1.5 SOLAR SYSTEM AVAILABILITY

The solar system was operational with no serious problems during the entire period covered by this report.

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The Scattergood School collector array is composed of 128 Solaron Model 2000 collectors which use air as the heat transfer medium.

Collector subsystem performance for the Scattergood School site is presented in Table 5.

Table 5. COLLECTOR SUBSYSTEM PERFORMANCE

SCATTERGOOD SCHOOL
JUNE 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY	OPERATIONAL COLLECTOR EFFICIENCY (%)	ECSS OPERATING ENERGY	SOLAR ENERGY DIRECTLY TO LOAD SUBSYSTEMS	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE (°F)
JUN	112.33	15.87	14	60.24	26	0.67	3.19	9.19	76
JUL	114.70	2.53	2	24.47	10	0.24	1.49	0.00	80
AUG	122.31	7.00	6	54.33	13	0.61	3.30	0.00	78
SEP	148.39	9.52	6	70.24	14	0.61	5.41	0.00	75
OCT	114.18	17.30	15	52.35	33	0.55	5.89	10.98	*
NOV	*	*	*	*	*	*	*	*	*
DEC	*	*	*	*	*	*	*	*	*
JAN	75.58	20.20	27	53.32	38	0.64	12.54	8.19	25
FEB	92.45	29.14	32	71.96	41	0.95	12.85	15.85	24
MAR	101.29	31.35	31	76.84	41	1.07	10.01	20.89	38
APR	101.57	26.75	26	78.13	34	0.97	8.32	18.28	53
TOTAL	982.80	159.66	-	541.88	-	6.31	63.00	83.38	-
AVERAGE	109.20	17.74	16	60.21	29	0.70	7.00	9.48	56

*Denotes unavailable data.

The collector subsystem performed with an efficiency (29%) that is good for air systems. The subsystem was operational from June 1979 through April 1980. The data does not include the months of November and December. The incident solar energy was 982.80 million BTU with 541.88 million BTU incident with the collector pump active. The total energy collected was 159.66 million BTU corresponding to a 29% operational collector efficiency. The overall collector subsystem efficiency was 16%. The collected solar energy transferred to storage was 83.38 million BTU, of which 40.60 million BTU were transferred directly to the heating load. The ECSS operational energy was 6.31 million BTU.

2.2 STORAGE

Storage performance data for the site for the reporting period are shown in Table 6.

Table 6. STORAGE PERFORMANCE

SCATTERGOOD SCHOOL
JUNE 1979 THROUGH APRIL 1980

(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
JUN	9.19	1.48	-0.19	14	135	7.90
JUL	0.00	0.00	-0.56	0	98	0.56
AUG	0.00	0.00	0.00	0	92	0.00
SEP	0.00	0.00	0.03	0	91	-0.03
OCT	10.98	5.26	1.42	62	106	4.31
NOV	*	*	*	*	*	*
DEC	*	*	*	*	*	*
JAN	8.19	5.69	0.08	70	64	2.42
FEB	15.85	13.93	0.39	90	72	1.52
MAR	20.89	15.92	1.33	83	83	3.64
APR	18.28	9.85	-0.13	53	119	8.56
TOTAL	83.38	52.13	2.37	-	-	28.88
AVERAGE	9.26	5.79	0.26	65	96	3.21

* Denotes unavailable data.

During the reporting period, total solar energy delivered to storage was 83.38 million BTU. There were 52.13 million BTU delivered from storage to the space heating subsystem. Energy loss from storage was 28.88 million BTU. This loss represented 35% of the energy delivered to storage. The storage efficiency was 65%. (See Footnote 1.)

Storage losses of this magnitude have been observed for other air systems. These losses contribute to space heating by lowering the gymnasium building heat loss (see Solar Energy Utilization).

2.3 DOMESTIC HOT WATER (DHW)

The DHW subsystem performance for the Scattergood School site for the reporting period is shown in Table 7 and by graphic illustration in Figure 5.

Hot water consumption for the reporting period totaled 40,157 gallons for an average of 147 gallons daily. This consumption was delivered at an average temperature of 141°F. Heating this water from an average supply temperature of 60°F created a DHW load of 27.37 million BTU. To meet this load, the DHW subsystem used 27.98 million BTU of solar energy and 17.12 million BTU of auxiliary thermal energy, supplied by 5,016 kwh of electricity.

The solar fraction of the DHW load was 50%. This solar fraction is less than the ratio of solar energy to total energy consumed by the DHW subsystem due to the loss of some solar energy from the preheat tanks. The total losses from the subsystem were 19.39 million BTU, of which 13.12 million BTU were lost from the preheat tanks and 6.27 million BTU from the DHW tank. Large losses occur during the summer months when the hot water consumption is low. Transferring the solar energy to the DHW subsystem required 1.66 million BTU of operating energy.

The solar usage was low in July due to low water consumption. Most of the auxiliary energy used by the domestic hot water subsystem in the summer months (June through September) is used to satisfy standby losses. Consequently, the auxiliary used in the summer is an approximately constant value despite a varying water consumption.

---

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:

$$STEFF = (STECH + STEO)/STEI$$

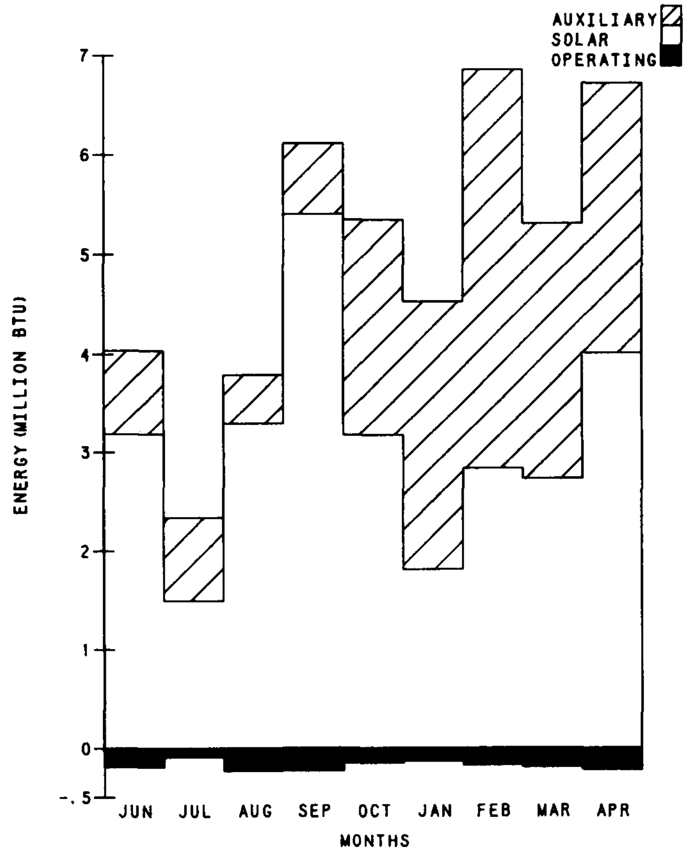
Where:
STEFF = Storage efficiency
STECH = Change in stored energy
STEO = Energy removed from storage
STEI = Energy added to storage

Table 7. DOMESTIC HOT WATER SUBSYSTEM PERFORMANCE

SCATTERGOOD SCHOOL
JUNE 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

		ENERGY CONSUMED				
MONTH	DHW LOAD	SOLAR	AUXILIARY ELECTRICAL	OPERATING EXPENSE	SOLAR FRACTION (%)	HOT WATER CONSUMPTION (GAL.)
JUN	0.62	3.19	0.85	0.20	52	1,075
JUL	0.46	1.49	0.84	0.09	41	760
AUG	0.71	3.30	0.49	0.24	90	1,155
SEP	3.49	5.41	0.71	0.24	83	5,126
OCT	4.03	3.18	2.18	0.16	54	6,029
NOV	*	*	*	*	*	*
DEC	*	*	*	*	*	*
JAN	3.39	1.82	2.72	0.13	33	4,869
FEB	5.69	2.84	4.03	0.18	37	8,701
MAR	3.57	2.73	2.59	0.20	38	5,102
APR	5.41	4.02	2.71	0.22	54	7,340
TOTAL	27.37	27.98	17.12	1.66	-	40,157
AVERAGE	3.04	3.11	1.90	0.18	50	4,462



Operating energy for the system is considered a system penalty and is plotted as a negative value below the origin

Figure 5. DHW Subsystem Performance
Scattergood School
June 1979 through April 1980

2.4 SPACE HEATING

The space heating performance for the Scattergood School site for the reporting period is shown in Table 8 and presented graphically in Figure 6.

The heating season for Scattergood extends from October through April. The average building temperature during the heating season was 62°F. Maintaining this temperature created a space heating load of 78.29 million BTU. This load was satisfied by 72.78 million BTU of solar energy and 5.82 million BTU of auxiliary thermal energy provided by propane-fired unit heaters. (The slight discrepancy between the sum of solar and auxiliary energy, 78.60 million BTU, and the heating load, 78.29 million BTU, is due to methods used to extrapolate for missing data.) The solar fraction of the load was 93%. The propane heaters consumed 9.72 million BTU (108 gallons) of propane.

One reason the solar fraction is greater than design is that the effect of the variable building temperature was not included in the design. Also, the effect of storage losses on building heat loss may not have been included in the design.

Table 8. SPACE HEATING SUBSYSTEM

SCATTERGOOD SCHOOL
JUNE 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

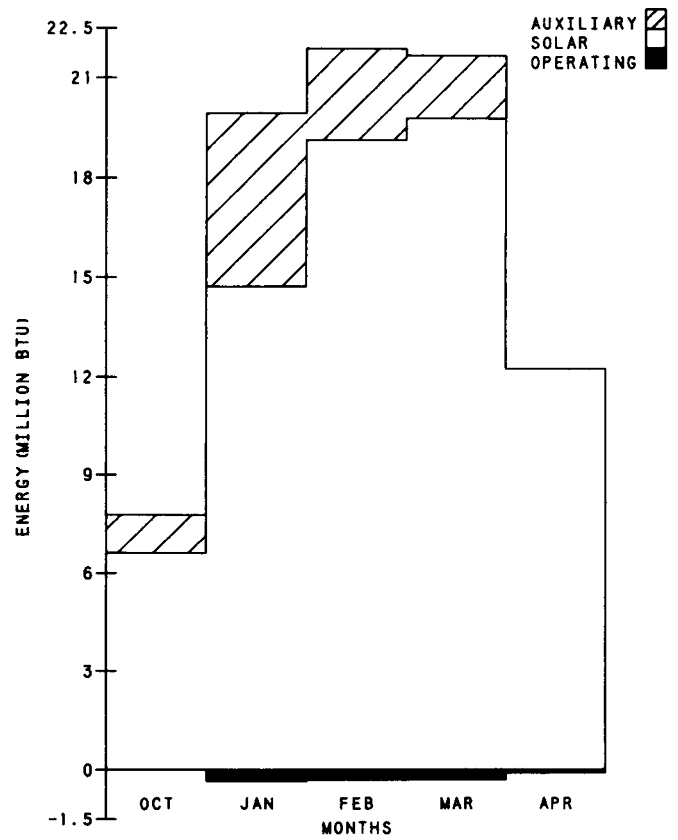
		ENERGY CONSUMED					
MONTH	SPACE HEATING LOAD	SOLAR	AUXILIARY THERMAL	AUXILIARY FOSSIL	OPERATING ENERGY	SOLAR FRACTION (%)	BUILDING TEMPERATURE (%)
JUN	0.00	0.00	0.00	0.00	0.00	NA	79
JUL	0.00	0.00	0.00	0.00	0.00	NA	80
AUG	0.00	0.00	0.00	0.01	0.00	NA	80
SEP	0.00	0.00	0.00	0.00	0.00	NA	79
OCT	5.77	6.61	0.10	0.16	0.03	98	70
NOV	*	*	*	*	*	*	*
DEC	*	*	*	*	*	*	*
JAN	18.56	14.72	3.12	5.21	0.38	83	54
FEB	20.83	19.42	1.47	2.45	0.33	93	57
MAR	20.86	19.78	1.13	1.89	0.33	95	61
APR	12.27	12.25	0.00	0.00	0.13	100	68
TOTAL	78.29	72.78	5.82	9.72	1.20	-	-
AVERAGE	8.70	8.09	0.65	1.08	0.13	93	70

There were 14.18 million BTU of solar energy used during the months June through September, when no demand for space heating existed. This "consumption" of solar energy results from a leak in damper MD2 during collector-to-storage mode or hot-water-preheating mode. These 14.18 million BTU of solar energy actually constitute a loss from the space heating subsystem. This wasted energy also increases the temperature in the gymnasium, which increases ventilation requirements and reduces comfort levels.

During the heating season, the energy supplied to the gymnasium by the leak in damper MD2 is included as part of the space heating load and space heating solar energy. The leak comprises 22% (17.16 million BTU) of the load reported during the heating season.

The use of solar energy for space heating saved an impressive 121.31 million BTU of propane (5,607 pounds or 1,343 gallons), and provided 93% of the thermal energy consumed for space heating. The excellent solar fraction results partly from manual control of the auxiliary heaters.

The control system is designed to turn on the auxiliary heaters when the second stage of the two-stage room thermostat is tripped or when the first stage is tripped and the temperature at the top of the rock storage bin is less than 90°F. The room thermostat is currently set at 60°F.



Operating energy for the system is considered a system penalty and is plotted as a negative value below the origin.

Figure 6. Space Heating Performance
Scattergood School
June 1979 through April 1980

Under actual operating conditions, the auxiliary heaters do not come on when solar energy is not available. Instead, the gymnasium temperature is allowed to fall, and the auxiliary heaters are actuated by site personnel to keep temperatures above approximately 40°F. In addition, students using the gymnasium sometimes turn on the auxiliary heat when daytime building temperatures become uncomfortable. On a number of occasions, the auxiliary heaters have remained on all night, maintaining the gymnasium at 60°F. Also, the gymnasium temperature often rises above 60°F during solar energy collection, due to the leaks in damper MD2. As a result of these operating conditions, building temperature swings of 20°F are not uncommon during cold, sunny periods.

The above discussion of operating conditions is needed for a correct interpretation of solar energy savings. Since the energy savings are derived from the amount of solar energy consumed, the energy saved is properly interpreted as the difference between the energy consumed by the actual heating system and the energy which would have been consumed by a conventional fossil system maintaining identical building temperatures. The calculated savings do not represent a comparison with a building under conventional operating conditions.

The space heating savings should include the effect of storage and delivery losses on the building heat load. In a previous seasonal report, it was estimated that 70% of these losses contribute to the space heating load. Assuming that this happened for the heating months in this report, 14.32 million BTU of the 20.45 million BTU storage loss and 8.07 million BTU of the 11.53 million BTU of the delivery loss would contribute to space heating. This would result in a solar fraction for space heating of 95% and a fossil fuel savings of 158.62 million BTU. At the Scattergood School's utility rate of $0.56/gallon of propane and a total electrical savings of $88.19, the total savings are $1,059.23. The savings would have been significantly larger if the data from November and December had been available.

SECTION 3

OPERATING ENERGY

Measured monthly values of the Scattergood School solar energy system and subsystem operating energy for the report period are presented in Table 9. A total 9.17 million BTU of operating energy was consumed by the entire system during the reporting period. A distribution of this operating energy among the subsystems is illustrated in Figure 7.

Table 9. OPERATING ENERGY

SCATTERGOOD SCHOOL
JUNE 1979 THROUGH APRIL 1980

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY (SOLAR UNIQUE)	DHW OPERATING ENERGY		SHS OPERATING ENERGY		TOTAL SOLAR UNIQUE OPERATING ENERGY	TOTAL SYSTEM OPERATING ENERGY
		TOTAL	SOLAR UNIQUE	TOTAL	SOLAR UNIQUE		
JUN	0.67	0.20	0.20	0.00	0.00	0.87	0.87
JUL	0.24	0.09	0.09	0.00	0.00	0.33	0.33
AUG	0.61	0.24	0.24	0.00	0.00	0.84	0.85
SEP	0.61	0.24	0.24	0.00	0.00	0.84	0.85
OCT	0.55	0.16	0.16	0.03	0.03	0.73	0.74
NOV	*	*	*	*	*	*	*
DEC	*	*	*	*	*	*	*
JAN	0.64	0.13	0.13	0.38	0.21	0.98	1.15
FEB	0.95	0.18	0.18	0.33	0.26	1.39	1.46
MAR	1.07	0.20	0.20	0.33	0.28	1.55	1.60
APR	0.97	0.22	0.22	0.13	0.13	1.32	1.32
TOTAL	6.31	1.66	1.66	1.20	0.91	8.85	9.17
AVERAGE	0.70	0.18	0.18	0.13	0.10	0.98	1.02

*Denotes unavailable data.

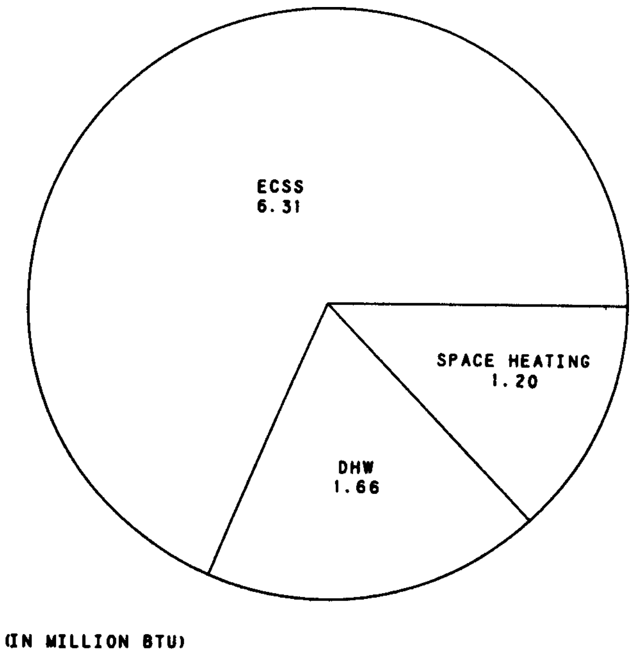


Figure 7. Total Operating Energy
Scattergood School
June 1979 through April 1980)

Operating energy is the power consumed by pumps, fans, and auxiliary equipment used to distribute thermal energy to meet system loads. See the discussion of coefficient of performance in the section on overall system performance for a description of the analysis methods used to calculate operating energies.

SECTION 4

WEATHER CONDITIONS

Scattergood School is located in West Branch, Iowa at 42 degrees N latitude and 91 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 10. 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 insolation values are total global horizontal radiation converted to collector angle and azimuth orientation.

Table 10. WEATHER CONDITIONS

SCATTERGOOD SCHOOL
JUNE 1979 THROUGH APRIL 1980

	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
JUN	1,500	1,579	70	71	20	21
JUL	1,482	1,604	73	75	5	0
AUG	1,581	1,608	72	73	17	11
SEP	1,982	1,561	65	65	73	82
OCT	1,476	1,487	50	54	465	345
NOV	*	*	*	*	*	*
DEC	*	*	*	*	*	*
JAN	977	1,017	19	21	1,426	1,362
FEB	1,277	1,274	20	25	1,305	1,109
MAR	1,309	1,391	32	35	1,023	920
APR	1,356	1,458	49	50	495	442
TOTAL	-	-	-	-	4,829	4,292
AVERAGE	1,438	1,442	50	52	537	477

*Denotes unavailable data.

During the period from June 1979 through April 1980, the average daily total incident solar radiation on the collector array was 1,438 BTU per square foot per day. This radiation was approximately equal to the estimated average daily solar radiation for this geographical area during the reporting period of 1,442 BTU per square foot per day for a south-facing plane with a tilt of 50 degrees to the horizontal. During the period, the highest monthly average insolation was 1,982 BTU per square foot per day during September. The average ambient temperature during the reporting period was 50°F as compared with the long-term average of 52°F. The highest monthly average ambient temperature was 73°F during July and the lowest monthly average ambient temperature was 19°F during January. The number of heating degree-days for the period (based on a 65°F reference) was 537 as compared with the long-term average of 477. The range of heating degree-days was from a high of 1,426 during January to a low of five during July.

Extraterrestrial radiation values are computed (see Footnote 1) and given in the table below for each month during the period. 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 61% during September to a low of 32% during January.

	MONTH										
	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
Extra-terrestrial Insolation	2,655	2,717	2,962	3,230	3,267	*	*	3,040	3,251	3,318	3,099
$\frac{\text{TTL INS}}{\text{EXT INS}}$ (%)	56	55	53	61	45	*	*	32	39	39	44

* Denotes unavailable data.

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

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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 5

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.

6. ASHRAE Standard 94-77, Methods of Testing Thermal Storage Devices Based on Thermal Performance, 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, July 1980, Parts 1, 2, and 3, SOLAR/0001-80/15, Vitro Laboratories, Silver Spring, Maryland.

*7. Monthly Performance Report, Scattergood School, June 1979, SOLAR/2003-79/06, IBM, Huntsville, Alabama.

*8. Monthly Performance Report, Scattergood School, July 1979, SOLAR/2003-79/07, IBM, Huntsville, Alabama.

*9. Monthly Performance Report, Scattergood School, August 1979, SOLAR/2003-79/08, IBM, Huntsville, Alabama.

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

**Note. Reference [6] only used if the heat transfer coefficient discussion in Section 5.3.1.2 applies.

*10. Monthly Performance Report, Scattergood School, September 1979, SOLAR/2003-79/09, IBM, Huntsville, Alabama.

*11. Monthly Performance Report, Scattergood School, October 1979, SOLAR/2003-79/10, IBM, Huntsville, Alabama.

*12. Monthly Performance Report, Scattergood School, January 1980, SOLAR/2003-80/01, Vitro Laboratories, Silver Spring, Maryland..

*13. Monthly Performance Report, Scattergood School, February 1980, SOLAR/2003-80/02, Vitro Laboratories, Silver Spring, Maryland.

*14. Monthly Performance Report, Scattergood School, March 1980, SOLAR/2003-80/03, Vitro Laboratories, Silver Spring, Maryland.

*15. Monthly Performance Report, Scattergood School, April 1980, SOLAR/2003-80/04, 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.

APPENDIX A

SYSTEM DESCRIPTION

APPENDIX A

SYSTEM DESCRIPTION

SYSTEM

Scattergood School is located near West Branch, Iowa, approximately 35 miles southeast of Cedar Rapids. Its solar energy system is designed to supply approximately 75% of the average annual energy requirements for space heating the gymnasium and for heating water for an adjacent locker room. Solar heating is also available for a grain-drying silo recently added to the site. The site has an array of flat-plate collectors with a gross area of 2,496 square feet that faces south at an angle of 50 degrees from the horizontal. Air is the medium used for transferring energy from the collector array to storage or directly to the gymnasium. Energy is stored in a bin containing 130,000 pounds of rocks and in two 120-gallon water preheating tanks. When solar energy is insufficient, propane gas heaters furnish auxiliary energy for space heating. Auxiliary heating for hot water is provided by standard electric immersion heaters in the 52-gallon domestic water heater. The system, shown schematically, has five modes of solar operation.

Mode 1 - Collector-to-Space Heating - This winter mode is initiated when there is a difference in temperature of 45 degrees between the outlet of the collector and a temperature representative of the gymnasium and the bottom of storage; and a demand for space heating exists as indicated by the manually preset, two-stage thermostat. Air from the collector is circulated through the air-handling unit to the gymnasium, through motorized dampers, and returned to the collector, bypassing the storage bin. Circulation continues in this mode until the difference in temperature between the outlet and inlet of the collector is less than 30 degrees or the demand for space heating is satisfied. Stage one of the thermostat requests solar energy, and stage two operates in conjunction with stage one to activate auxiliary heaters to supplement solar energy when the gymnasium temperature drops below a level determined by the thermostat setting.

Mode 2 - Storage-to-Space Heating - This winter mode is initiated when there is a demand for space heating, the collector loop is not active, and the temperature in the rock bed is 90°F or higher. Air is drawn through motorized dampers from storage, circulated through the air handling unit to the conditioned space, and returned to storage, bypassing the collector.

Mode 3 - Collector-to-Storage - This winter mode is initiated when the difference in temperature between the collector outlet and a temperature representative of the gymnasium and the bottom of the storage is 45 degrees or higher, and there is no demand for space heating. Air is drawn from the collector via the air-handling unit into the rock bin through motorized dampers and recirculated through the collector. Circulation continues in this mode until the difference in temperature between the outlet and inlet of the collector is less than 30 degrees. Mode 1 has priority over this mode.

Mode 4 - Collector-to-Water Preheating - the solar energy system is manually converted to the summer mode by opening slide gate damper D3 and closing D2, which isolates the rock bed from the solar energy system. Then the control system toggle switch is positioned to the summer mode. This summer operation mode is initiated when there is a demand for water heating and the difference between the collector outlet and a temperature representative of the gymnasium is 45 degrees or higher. Air is circulated from the collector through motorized dampers to an air-to-liquid heat exchanger, via the air-handling unit, and returned to the collector, bypassing the storage bin. This mode continues until the temperature in the preheat tank reaches 140°F or until the collector differential temperature drops below 30 degrees. This preheated water is stored in two 120-gallon tanks and delivered on demand to a commercial 52-gallon DHW tank with an auxiliary electric heating element. If a space heating demand exists, solar energy is directed to meet the demand. After the demand is satisfied, the system returns to the summer preheating mode. Water can also be preheated in modes 1 and 3 during the heating season when energy collection is present and a demand exists.

Mode 5 - Grain Drying - This manually-controlled winter mode is utilized to reduce the moisture of grain in a bin near the gymnasium. The mode is used in the fall and spring periods of the year to utilize excess solar energy. Manual dampers D8 and D5 are opened and manual dampers D4, D6, and D7 are closed. This action provides a path for outside air to pass through the collectors to the grain bin. The mode is initiated by raising the gymnasium thermostat to produce a false indication for space heating to the control system. The mode is terminated manually after the solar energy is exhausted or the grain reaches the desired humidity.

SUBSYSTEMS

Collector - The gross collector array area (gross panel area times number of panels) is 2,496 ft^2. The collectors face due South at an azimuth angle of zero degrees. The collectors are tilted to an altitude angle of 50 degrees from the horizontal. Orientation of the collectors is close to the optimum orientation for a system of this type, at a site latitude of 42 degrees North. Optimum collector orientation at this site is estimated to be zero degrees South at a tilt of 56 degrees.

The 128 Solaron 2000-series flat-plate collector panels have two glass covers and a non-selective absorber surface. The absorber surface has a solar absorptivity of 0.95 and an infrared emissivity of 0.95. Total solar transmissivity of the glazing is 80%. The absorber surface is composed of 28 gauge steel with baked on ceramic-enamel coating. The medium circulated through the collectors is air.

Storage - Solar energy storage is provided with a 65-ton concrete storage box located in a shed adjacent to the building. The storage has two inches of fiberglass at the bottom and two inches of fiberglass on the top and sides. Air is used as the medium to transfer solar energy to the DHW and space heating subsystems. Preheated city water is also stored in two 120-gallon DHW tanks.

Space Heating - The space heating subystem consists of two propane blower unit heaters designed to utilize solar energy through built-in blowers. The system has a 250-thousand BTU Peerless Heater and a 150-thousand BTU Bryant Heater designed to deliver a total of 0.40 million BTU/hour to satisfy the gymnasium heat load. The design solar fraction is 75%.

Hot Water - City water is preheated and stored in two 120-gallon storage tanks and supplied, on demand, to a conventional 52-gallon DHW tank. When solar energy is insufficient to satisfy the DHW load, an electrical immersion heater in the DHW tank provides auxiliary energy for heating the supply water. Solar energy is transferred from the collector loop to the DHW tank by an air-to-water heat exchanger.

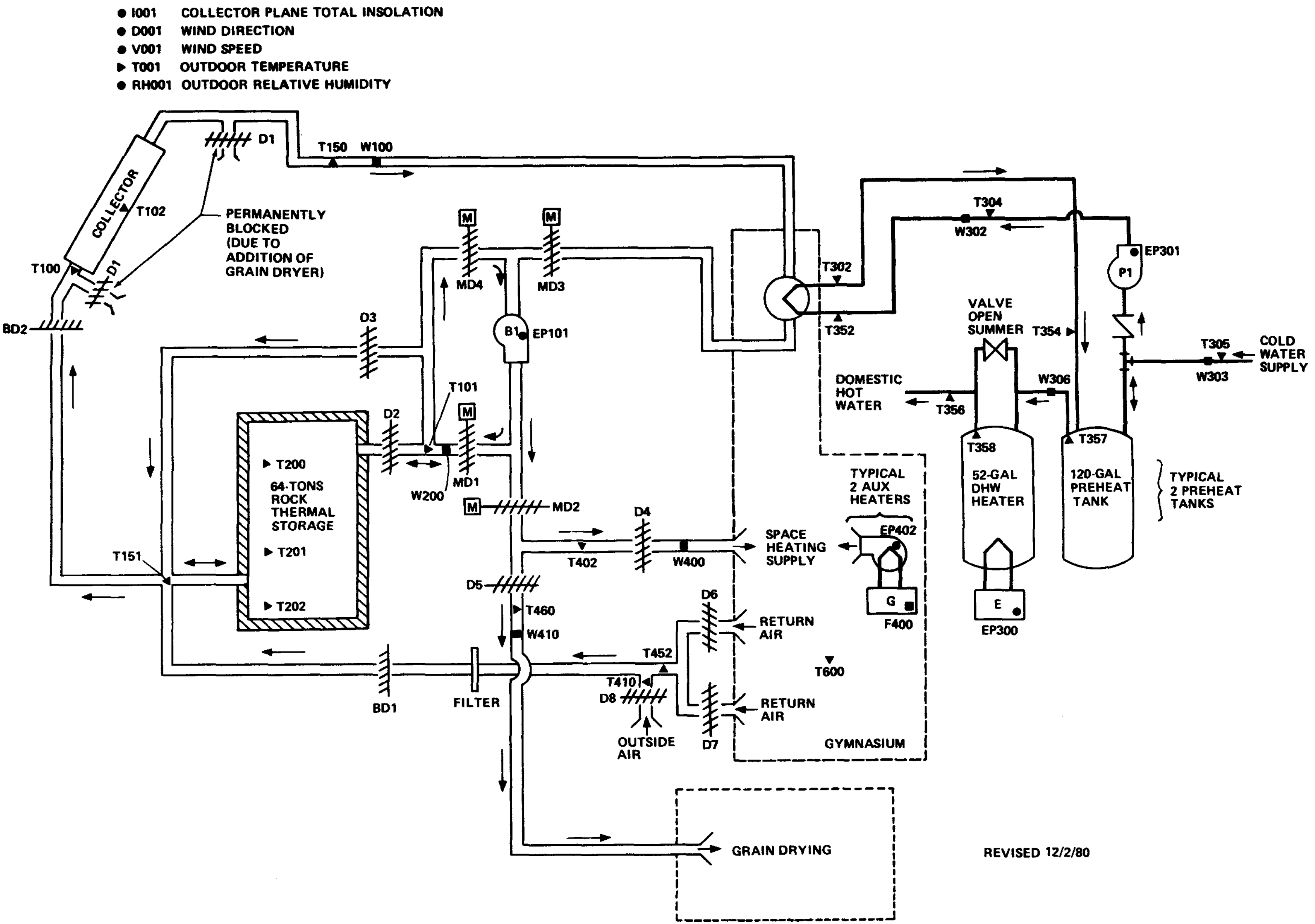

Figure A-1. Scattergood School Solar Energy System Schematic

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Scattergood School 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.

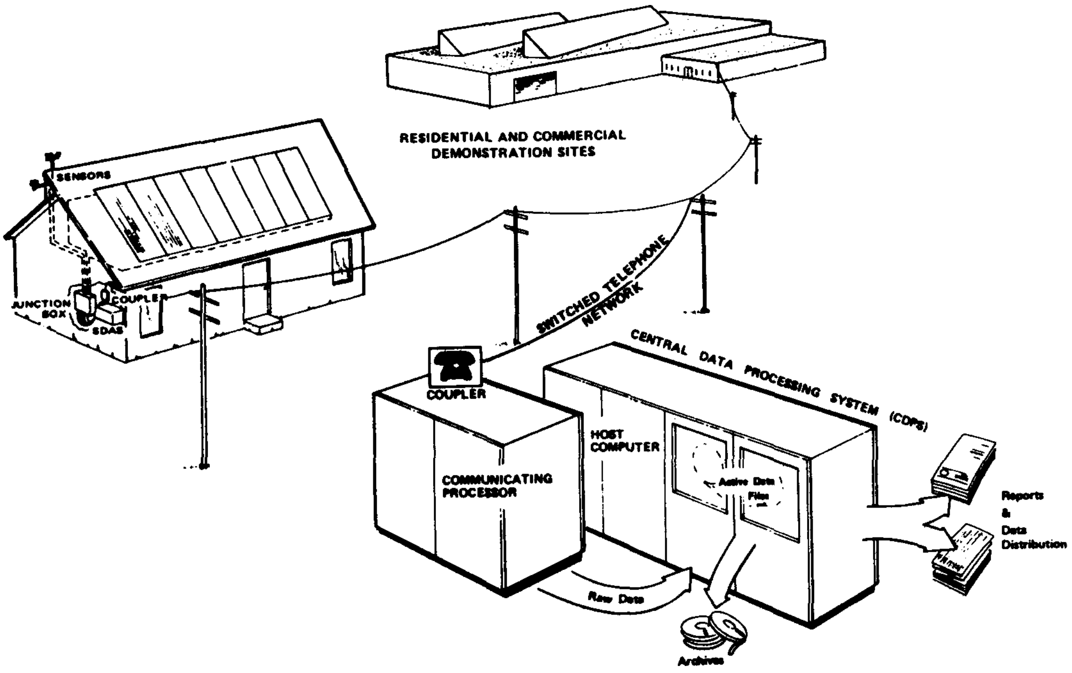

Figure B-1. The National Solar Data Network

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 micro-processor 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 five minutes (actually 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 five-minute period, 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 0-1023. 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, and these tabulations are also called "tab data." The CDPS is also capable of transforming this data into plots or graphs.

Solar system performance reports present system parameters as monthly values. If some of the data during the month is not collected due to solar system, instrumentation system, or data acquisition problems, or if some of the collected data is invalid, then the collected valid data is extrapolated to provide the monthly performance estimates. Researchers and other users who require unextrapolated, "raw" data may obtain such by contacting Vitro Laboratories.

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 five-minute period. 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 measuring 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 real time 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 Scattergood School solar energy system from June 1979 through April 1980 was analyzed during the heating and summer seasons, and Monthly Performance Reports were published 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. Also, much of the Monthly Performance data previously published has been corrected for minor problems. The most significant correction was the assignment of operating energy from fan B1 to the collector and space heating subsystems.

OTHER DATA REPORTS ON THIS SITE*

Monthly Performance Reports:

September 1977, SOLAR/2003-77/09
October 1977, SOLAR/2003-77/10
November 1977, SOLAR/2003-77/11
December 1977, SOLAR/2003-77/12
January 1978, SOLAR/2003-78/01
February 1978, SOLAR/2003-78/02
March 1978, SOLAR/2003-78/03
April 1978, SOLAR/2003-78/04
May 1978, SOLAR/2003-78/05
June 1978, SOLAR/2003-78/06
July 1978, SOLAR/2003-78/07
August 1978, SOLAR/2003-78/08
September 1978, SOLAR/2003-78/09
October 1978, SOLAR/2003-78/10
November 1978, SOLAR/2003-78/11
December 1978, SOLAR/2003-78/12
January 1979, SOLAR/2003-79/01
February 1979, SOLAR/2003-79/02
March 1979, SOLAR/2003-79/03
April 1979, SOLAR/2003-79/04
May 1979, SOLAR/2003-79/05
June 1979, SOLAR/2003-79/06
July 1979, SOLAR/2003-79/07
August 1979, SOLAR/2003-79/08
September 1979, SOLAR/2003-79/09
October 1979, SOLAR/2003-79/10
January 1980, SOLAR/2003-80/01
February 1980, SOLAR/2003-80/02
March 1980, SOLAR/2003-80/03
April 1980, SOLAR/2003-80/04

Solar Energy System Performance Evaluations:

SOLAR/2003-78/14.
SOLAR/2003-79/14

Solar Project Description, May 1978. SOLAR/2003-78/50.

Solar Project Cost Report, May 1978. SOLAR/2003-78/60.

Thermal Performance of Scattergood School Solar Energy System, July 1978. SOLAR/2003-78/23.

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* These reports can be obtained (free) by contacting: U.S. Department of Energy, Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830.

APPENDIX C

PERFORMANCE FACTORS AND SOLAR TERMS

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. Appendix C includes the symbol, 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 abbreviations used in this report.

Section 1. Performance Factor Definitions

Section 2. Solar Terminology

Section 3. Abbreviations

SECTION 1. PERFORMANCE FACTOR DEFINITIONS

SYMBOL	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.
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.
CSE	Solar Energy to SCS	Amount of solar energy delivered to the SCS.

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* Primary Performance Factors

SYMBOL	NAME	DEFINITION
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

	SYMBOL	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

SYMBOL	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

SYMBOL	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

SYMBOL	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

SYMBOL	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).
Figure of Merit, FMS	A calculated number showing the relative net fraction of the system load supplied from solar energy. $\text{FMS} = \text{Solar Energy Supplied to Load} - \text{Solar System Operating Energy}$
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.
Heating Degree Days	The sum over a specified period of time of the number of degrees the average daily temperature is <u>below</u> 65°F.
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.
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	The solar energy received by a surface.
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.

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: $\frac{\text{Ti-Ta}}{\text{I}} \quad \frac{^\circ\text{F x hr. x sq. ft.}}{\text{BTU}}$
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 that converts energy to useful thermal energy for heating without the use of collector circulating fluid.
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. ABBREVIATIONS

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

APPENDIX D

PERFORMANCE EQUATIONS

SCATTERGOOD SCHOOL

INTRODUCTION

Solar energy system performance is evaluated by performing energy balance calculations 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 typically by

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

where M100 is the mass flow rate of the heat transfer fluid in $\text{lb}_m\text{/min}$ 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 generally given by

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

where C_p is the average specific heat, in $\text{BTU/lb}_m\text{-°F})$, 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 an air system ΔH is generally given by

$$\Delta H = H_a(T_{out}) - H_a(T_{in})$$

where $H_a(T)$ is the enthalpy, in BTU/lb_m, of the transport air evaluated at the inlet and outlet temperatures of the heat exchanging component.

$H_a(T)$ can have various forms, depending on whether or not the humidity ratio of the transport air remains constant as it passes through the heat exchanging component.

For electrical power, a general example is

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

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

Letter Designations

C = Specific Heat

D = Direction or Position

EE = Electric Energy

EP = Electric Power

F = Fuel Flow Rate

I = Incident Solar Flux (Insolation)

N = Performance Parameter

P = Pressure

PD = Differential Pressure

Q = Thermal Energy

T = Temperature

TD = Differential Temperature

V = Velocity

W = Heat Transport Medium Mass Flow Rate

TI = Time

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)

$$\mathrm{TA} = (1/60) \times \Sigma\ \mathrm{T001} \times \Delta\tau$$

AVERAGE BUILDING TEMPERATURE (°F)

$$\mathrm{TB} = (1/60) \times \Sigma\ \mathrm{T600} \times \Delta\tau$$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

$$\mathrm{TDA} = (1/360) \times \Sigma\ \mathrm{T001} \times \Delta\tau$$

for ± three hours from solar noon

DHW SUPPLY WATER TEMPERATURE

$$\mathrm{TSW} = \Sigma\ (\mathrm{T305} \times \mathrm{M306}) \times \Delta\tau$$

DHW DELIVERED WATER TEMPERATURE

$$\mathrm{THW} = \Sigma\ (\mathrm{T306M1} \times \mathrm{M306}) \times \Delta\tau$$

INCIDENT SOLAR ENERGY PER SQUARE FOOT ($\mathrm{BTU/FT^2}$)

$$\mathrm{SE} = (\mathrm{T}/60) \times \Sigma\ \mathrm{I001} \times \Delta\tau$$

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

$$SEOP = (1/60) \times \Sigma\ [I001 \times CLAREA] \times \Delta\tau$$

when the collector loop is active

WIND SPEED

$$WIND = \Sigma\ (V001/60)\ \Delta\tau$$

HUMIDITY RATIO FUNCTION (BTU/lb_m-°F)

$$HRF = 0.24 = 0.444 \times HR$$

where 0.24 is the specific heat and HR is the humidity ratio of the transport air. This function is used whenever the humidity ratio will remain constant as the transport air flows through a heat exchanging device.

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \Sigma\ [M100 \times HRF \times (H100M - H100)] \times \Delta\tau$$

where H100M is the enthalpy of the collector outlet air and H100 is the enthalpy of the collector inlet air

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \Sigma\ [M200 \times (H101 - H101M)] \times \Delta\tau$$

where H101 is the enthalpy of the air flow to storage and H101M is the enthalpy of the air flow from storage

SOLAR ENERGY FROM STORAGE (BTU)

$$STEO = \Sigma\ [M200 \times (H101 - H101M)] \times \Delta\tau$$

where H101 is the enthalpy of the air flow to storage and H101M is the enthalpy of the air flow from storage. Calculated if $W100 < 400$ and $W400 > 0$

AVERAGE TEMPERATURE OF STORAGE (°F)

$$TST = (1/60 \times \Sigma\ [(T200 + T201 + T202)/3] \times \Delta\tau$$

ENERGY DELIVERED FROM ECSS TO SPACE HEATING SUBSYSTEM (BTU)

$$CSEO = \Sigma\ [M200 \times HRF \times (T400 - T450)] \times \Delta\tau$$

THE FOLLOWING CODE ALLOCATES THE POWER OF FAN B1 TO THE PROPER SUBSYSTEMS DEPENDING ON THE PRESSURE DROP ACROSS SYSTEM COMPONENTS. THE FOLLOWING TABLES GIVE THE PRESSURE DROPS COMPUTED FROM MEASUREMENTS TAKEN DURING A SITE VISIT (8/79).

PRESSURE DROP ACROSS COMPONENTS BY MODE

	MODE				
	1	2	3	4	5
FAN	0.72	1.13	0.86	0.68	0.73
COLLECTOR	0.40	0.00	0.27	0.49	0.40
DHW	0.10	0.00	0.19	0.19	0.20
STORAGE	0.00	0.70	0.40	0.00	0.00
HEATING	0.22	0.43	0.00	0.00	0.00
GRAIN DRY	0.00	0.00	0.00	0.00	0.13

FAN B1 POWER ALLOCATION BY MODE

	MODE				
	1	2	3	4	5
CSOPE	56%	62%	73%	72%	55%
HWOPE	14%	0%	22%	28%	27%
HOPE1	30%	38%	0%	0%	0%
GDOPE	0%	0%	0%	0%	18%

CSOPE, HWOPE, HOPE1 AND GDOPE

```
IF EP101 > FT & EP301 > FT THEN
IF EP101 > 0.0 THEN DO;
     IF MODE(1) = 1   MODE(7) = 1
          THEN DO;
               TV(#CSOPE) = 0.56 x EP101 x EPCONST;
               TV(#HWOPE) = (0.14 x EP101+ EP301) x EPCONST;
               TV(#HOPE1) = 0.30 x EP101 x EPCONST;
               TV(#GDOPE) = 0.0;
          END;
     IF MODE(2) = 1   MODE(8) = 1
          THEN DO;
               TV(#CSOPE) = 0.62 x EP101 x EPCONST;
               TV(#HWOPE) = 0.0;
               TV(#HOPE1) = 0.38 x EP101 x EPCONST;
               TV(#GDOPE) = 0.0;
          END;
```

```
IF MODE(3) = 1
    THEN DO;
        TV(#CSOPE) = 0.78 x EP101 x EPCONST;
        TV(#HWOPE) = (0.22 x EP101 + EP301) x EPCONST;
        TV(#HOPE1) = 0.0;
        TV(#GDOPE) = 0.0;
    END;
IF MODE(4) = 1
    THEN DO;
        TV(#CSOPE) = 0.72 x EP101 x EPCONST;
        TV(#HWOPE) = (0.28 x EP101 + EP301) x EPCONST;
        TV(#HOPE1) = 0.0;
        TV(#GDOPE) = 0.0;
    END;
IF MODE(5) = 1
    THEN DO;
        TV(#CSOPE) = 0.55 x EP101 x EPCONST;
        TV(#HWOPE) = (0.27 x EP101 + EP301) x EPCONST;
        TV(#HOPE1) = 0.0;
        TV(#GDOPE) = 0.18 x EP101 x EPCONST;
    END;
ELSE TV(#CSOPE), TV(#HWOPE), TV(#HOPE1), TV(#GDOPE) = 0.0;
```

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$$\mathrm{HOPE} = \mathrm{HOPE1} + \mathrm{EPCONST} \times \mathrm{EP402}$$

SOLAR ENERGY TO SPACE HEATING SUBSYSTEM (BTU)

$$\mathrm{HSE} = \Sigma\ [\mathrm{M400} \times \mathrm{HRF} \times (\mathrm{T402} - \mathrm{T452})] \times \Delta\tau$$

SPACE HEATING SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

HAT = AMOUNT OF PROPANE MEASURED THROUGH F400 x 0.6

SPACE HEATING SUBSYSTEM LOAD (BTU)

HL = HSE + PROPANE GAS AUXILIARY HEATING MEASURED BY F400 x 0.6

BUILDING TEMPERATURE (°F)

$$\mathrm{TOFF} = (1/60) \times \Sigma\ \mathrm{T600} \times \Delta\tau$$

HOT WATER SUBSYSTEM LOAD

$$\mathrm{HWL} = \Sigma\ [(\mathrm{T306M1} - \mathrm{T305}) \times \mathrm{W306} \times \mathrm{RhoT306M} \times \mathrm{CpT306M4}] \times \Delta\tau$$

SOLAR ENERGY TO DHW SUBSYSTEM

$$\mathrm{HWSE} = \Sigma\ [\mathrm{T352} \times \mathrm{W302} \times \mathrm{RhoT304M} \times \mathrm{CpT302M1}] \times \Delta\tau$$

AUXILIARY ELECTRICAL ENERGY TO DHW SUBSYSTEM

$$HWAE = 56.8833 \times EP300$$

AUXILIARY THERMAL ENERGY TO DHW SUBSYSTEM

$$HWAT = HWAE$$

DHW CONSUMPTION

$$HWCSM = \Sigma\ W306 \times \Delta\tau$$

SOLAR FRACTION OF HOT WATER LOAD

$$HWSFR = [HWSE1/(HWAT + HWSE1)] \times (1-TEMP) + (HWSFR\_P/100.0) \times TEMP$$

where $TEMP = EXP\ [-(HWAT + HWSE1)/TANK\ V]$ and $TANK\ V = HWCAP \times [RHO\ (THW) \times CP\ (THW) \times THW - RHO\ (TSW) \times CP\ (TSW) \times TSW)]$

DHW ELECTRICAL ENERGY SAVINGS

$$HWSVE = HWSE1 - HWOPE$$

GRAIN DRYING LOAD

$$GDSE = \Sigma\ [M410 \times (H460 - H410)] \times \Delta\tau$$

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$$SEA = (CLAREA \times I001)/60$$

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 = CSEO

ECSS SOLAR CONVERSION EFFICIENCY

CSCEF = SEL/SEA

SPACE HEATING SUBSYSTEM SOLAR FRACTION (PERCENT)

HSFR = 100 x HSE/HL

SPACE HEATING SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

HSVE = HSE - HOPE1

SYSTEM LOAD (BTU)

SYSL = HL + HWL

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

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

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

AXT = HAT + HWAT

AUXILIARY FOSSIL ENERGY TO LOADS (BTU)

AXF = AMOUNT OF PROPANE MEASURED THROUGH F400

AUXILIARY ELECTRICAL ENERGY TO LOADS (BTU)

AXE = HWAE

SYSTEM OPERATING ENERGY (BTU)

SYSOPE = HOPE + CSOPE + HWOPE

TOTAL ENERGY CONSUMED (BTU)

TECSM = SYSOPE + AXE + SECA + AXF

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

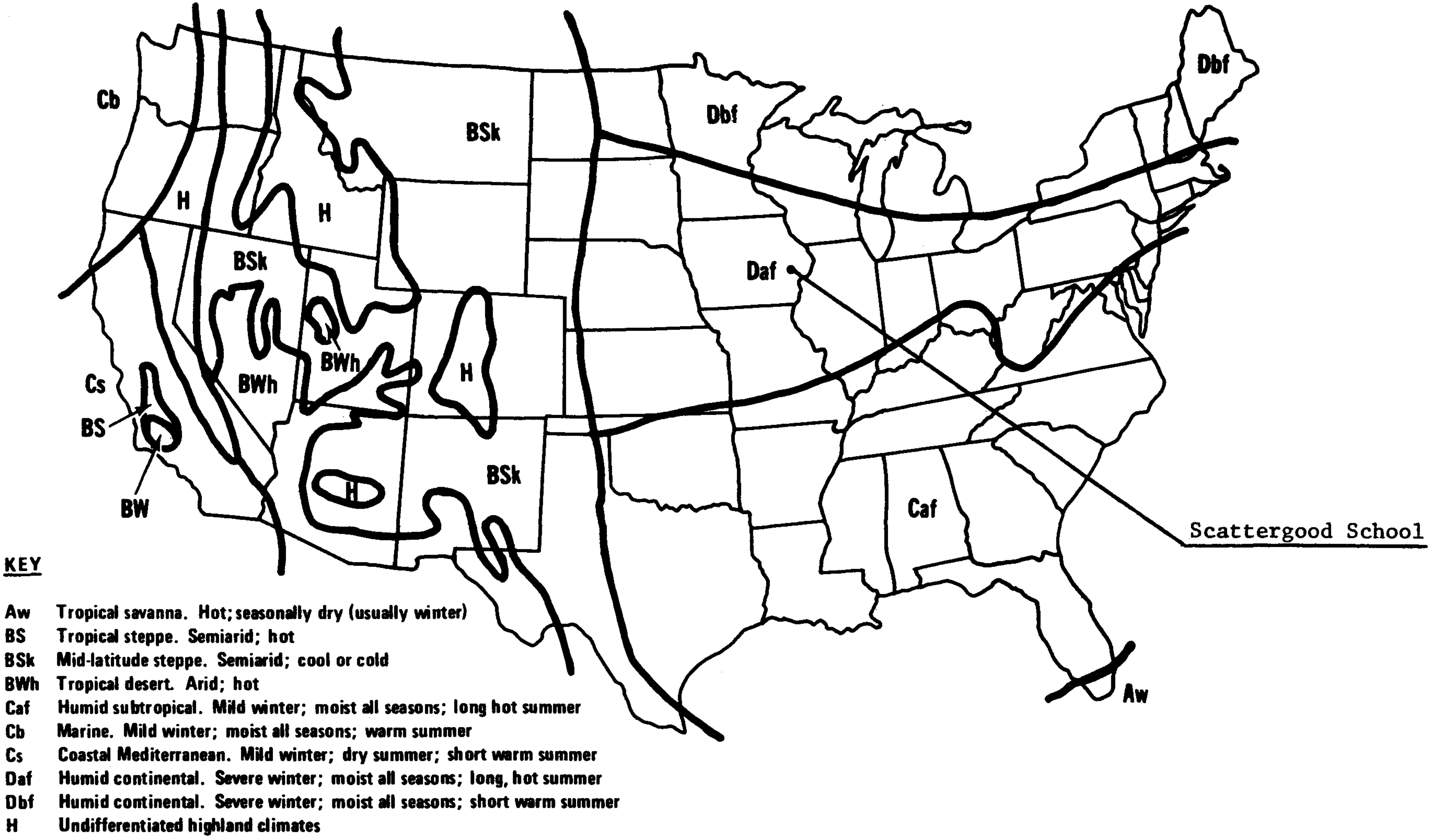
TSVE = HSVE - CSOPE + HWSVE

SYSTEM PERFORMANCE FACTOR

SYSPF = SYSL/[(AXE + SYSOPE) x 3.33]

APPENDIX E

METEOROLOGICAL CONDITIONS



KEY

Aw	Tropical savanna. Hot; seasonally dry (usually winter)
BS	Tropical steppe. Semiarid; hot
BSk	Mid-latitude steppe. Semiarid; cool or cold
BWh	Tropical desert. Arid; hot
Caf	Humid subtropical. Mild winter; moist all seasons; long hot summer
Cb	Marine. Mild winter; moist all seasons; warm summer
Cs	Coastal Mediterranean. Mild winter; dry summer; short warm summer
Daf	Humid continental. Severe winter; moist all seasons; long, hot summer
Dbf	Humid continental. Severe winter; moist all seasons; short warm summer
H	Undifferentiated highland climates

Trewartha, G.T. The Earth's Problem Climates. University Wisconsin Press, Madison, WI, 1961.

Figure E-1. Meteorological Map of the United States Showing Scattergood School Location

SCATTERGOOD SCHOOL LONG-TERM WEATHER DATA

COLLECTOR TILT: 50 DEGREES
LATITUDE: 42 DEGREES

LOCATION: WEST BRANCH, IOWA
COLLECTOR AZIMUTH: 0 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JUN	3,643	2,002	0.54954	0.789	1,579	21	193	71
JUL	3,541	1,973	0.55706	0.813	1,604	0	302	75
AUG	3,155	1,737	0.55048	0.926	1,608	11	258	73
SEP	2,554	1,372	0.53710	1.138	1,561	82	68	65
OCT	1,880	1,010	0.53738	1.472	1,487	345	16	54
NOV	1,339	608	0.45443	1.774	1,080	783	0	39
DEC	1,103	442	0.40120	1.908	844	1,200	0	26
JAN	1,230	546	0.44371	1.864	1,017	1,362	0	21
FEB	1,701	822	0.48344	1.549	1,274	1,109	0	25
MAR	2,320	1,132	0.48796	1.229	1,391	920	0	35
APR	2,976	1,478	0.49682	0.986	1,458	442	0	50

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: SCATTERGOOD SCHOOL
JUNE 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1785	63	71	*	I	I
2	2028	70	79	*	I	I
3	1886	72	82	*	I	I
4	1232	71	76	*	I	I
5	1764	70	*	*	I	I
6	1893	74	84	*	I	I
7	1092	73	*	*	I	I
8	537	68	72	*	I	I
9	771	70	73	*	I	I
10	1470	60	61	*	I	I
11	1736	69	77	*	I	I
12	1482	70	79	*	I	I
13	1467	67	71	*	I	I
14	1794	73	79	*	I	I
15	1931	78	84	*	I	I
16	1580	77	83	*	I	I
17	1236	68	72	*	I	I
18	701	62	64	*	I	I
19	1662	74	*	*	I	I
20	1810	73	80	*	I	I
21	1948	75	84	*	I	I
22	1849	72	80	*	I	I
23	548	57	*	*	I	I
24	1844	63	70	*	I	I
25	1940	67	75	*	I	I
26	1979	72	79	*	I	I
27	1033	72	75	*	I	I
28	1103	71	77	*	I	I
29	1070	69	70	*	I	I
30	1838	72	81	*	I	I
SUM	45006	-	-	-	-	-
AVG	1500	70	76	*	I	I

*DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SCATTERGOOD SCHOOL
JULY 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1742	76	85	*	I	I
2	1906	74	81	*	I	I
3	532	74	*	*	I	I
4	1279	68	70	*	I	I
5	1597	62	68	*	I	I
6	1307	63	72	*	I	I
7	1786	68	75	*	I	I
8	1748	71	80	*	I	I
9	1538	74	83	*	I	I
10	1760	77	86	*	I	I
11	1215	72	76	*	I	I
12	1718	78	86	*	I	I
13	749	73	*	*	I	I
14	1095	74	78	*	I	I
15	1666	75	82	*	I	I
16	1720	73	80	*	I	I
17	1719	68	76	*	I	I
18	1708	69	78	*	I	I
19	1793	71	79	*	I	I
20	1810	73	83	*	I	I
21	1709	75	85	*	I	I
22	1869	76	85	*	I	I
23	1583	76	83	*	I	I
24	947	73	77	*	I	I
25	676	73	77	*	I	I
26	1671	74	79	*	I	I
27	1651	77	87	*	I	I
28	1159	75	83	*	I	I
29	1158	74	81	*	I	I
30	1770	76	82	*	I	I
31	1372	73	82	*	I	I
SUM	45954	-	-	-	-	-
AVG	1482	73	80	*	I	I

*DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SCATTERGOOD SCHOOL
AUGUST 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	880	69	74	*	I	I
2	1672	72	79	*	I	I
3	1909	75	82	*	I	I
4	1755	78	81	*	I	I
5	1898	81	89	*	I	I
6	1667	79	86	*	I	I
7	1988	83	89	*	I	I
8	1387	78	84	*	I	I
9	1991	78	86	*	I	I
10	1196	69	72	*	I	I
11	1893	65	71	*	I	I
12	2049	63	70	*	I	I
13	869	65	73	*	I	I
14	1056	59	61	*	I	I
15	1822	58	66	*	I	I
16	1249	63	68	*	I	I
17	1502	75	83	*	I	I
18	1239	76	85	*	I	I
19	1118	74	77	*	98	6
20	*	*	*	*	*	*
21	*	91	*	*	68	3
22	*	*	*	*	*	*
23	1376	65	*	*	289	6
24	2050	66	74	*	279	4
25	1597	71	79	*	*	3
26	1687	69	76	*	145	7
27	1019	69	75	*	285	3
28	1782	71	77	*	169	7
29	1843	75	83	*	300	4
30	2056	76	85	*	159	5
31	1711	76	83	*	159	10
SUM	49004	-	-	-	-	-
AVG	1581	72	78	*	*	I

*DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SCATTERGOOD SCHOOL
SEPTEMBER 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1009	73	78	*	7	8
2	1821	75	85	*	111	5
3	1954	72	81	*	0	2
4	2082	71	79	*	306	5
5	2076	73	83	*	351	3
6	1923	69	80	*	146	5
7	2236	58	66	*	174	3
8	1831	59	65	*	308	5
9	2181	66	75	*	356	12
10	1954	74	84	*	29	10
11	2139	73	83	*	341	6
12	1688	72	82	*	32	5
13	1850	61	68	*	153	6
14	1284	53	61	*	147	6
15	2074	57	68	*	100	3
16	2370	62	73	*	12	5
17	2266	63	75	*	21	8
18	2129	64	75	*	137	5
19	2219	60	71	*	315	4
20	1783	65	78	*	10	7
21	2155	58	67	*	194	4
22	2044	56	67	*	254	4
23	2022	56	67	*	312	8
24	*	*	*	*	*	*
25	2115	68	80	*	0	1
26	2199	68	80	*	319	5
27	2196	68	80	*	340	11
28	*	*	*	*	*	*
29	*	*	*	*	*	*
30	1908	64	74	*	224	3
SUM	59450	-	-	-	-	-
AVG	1982	65	75	*	1	6

*DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SCATTERGOOD SCHOOL
OCTOBER 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	356	55	*	*	146	12
2	1830	55	63	*	149	5
3	1440	53	61	*	126	7
4	584	45	49	*	145	7
5	1661	51	56	*	37	7
6	1617	47	52	*	138	10
7	2025	54	65	*	65	3
8	1632	57	70	*	215	6
9	1964	46	50	*	147	9
10	*	*	*	*	*	*
11	*	*	*	*	*	*
12	1330	40	*	*	142	12
13	1924	39	47	*	139	6
14	1984	48	56	*	15	8
15	836	58	66	*	337	8
16	*	*	*	*	*	*
17	*	*	*	*	*	*
18	*	*	*	*	*	*
19	*	*	*	*	*	*
20	*	*	*	*	*	*
21	*	*	*	*	*	*
22	*	*	*	*	*	*
23	*	*	*	*	*	*
24	*	*	*	*	*	*
25	*	*	*	*	*	*
26	*	*	*	*	*	*
27	*	*	*	*	*	*
28	*	*	*	*	*	*
29	*	*	*	*	*	*
30	*	*	*	*	*	*
31	*	*	*	*	*	*
SUM	45744	-	-	-	-	-
AVG	1476	50	*	*	129	8

*DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SCATTERGOOD SCHOOL
NOVEMBER 1979
ENVIRONMENTAL SUMMARY

(No data available)

MONTHLY REPORT: SCATTERGOOD SCHOOL
DECEMBER 1979
ENVIRONMENTAL SUMMARY

(No data available)

MONTHLY REPORT: SCATTERGOOD SCHOOL
JANUARY 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	*	*	*	*	*	*
2	*	*	*	*	*	*
3	*	*	*	*	*	*
4	294	25	29	85	I	I
5	1488	26	30	77	I	I
6	37	25	31	92	I	I
7	1504	8	10	78	I	I
8	1145	8	11	68	I	I
9	1332	7	12	75	I	I
10	385	32	33	84	I	I
11	1701	23	18	62	I	I
12	971	17	19	53	I	I
13	851	32	34	57	I	I
14	1709	34	41	76	I	I
15	101	40	43	89	I	I
16	*	*	*	*	*	*
17	*	*	*	*	*	*
18	*	*	*	*	*	*
19	*	*	*	*	*	*
20	*	*	*	*	*	*
21	*	*	*	*	*	*
22	*	*	*	*	*	*
23	*	*	*	*	*	*
24	173	32	41	92	I	I
25	1035	27	26	76	I	I
26	1009	10	13	68	I	I
27	756	8	*	74	I	I
28	634	9	*	67	I	I
29	1927	7	*	66	I	I
30	370	9	13	85	I	I
31	2114	5	*	84	I	I
SUM	30280	-	-	-	-	-
AVG	977	19	25	75	I	I

* DENOTES UNAVAILABLE DATA.
I DENOTES INVALID DATA.

MONTHLY REPORT: SCATTERGOOD SCHOOL
FEBRUARY 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1954	7	17	73	I	I
2	1543	13	20	72	I	I
3	2003	15	22	70	I	I
4	1462	16	22	78	I	I
5	363	20	*	101	I	I
6	1570	21	26	87	I	I
7	1464	22	27	72	I	I
8	768	19	24	81	I	I
9	2118	14	21	79	I	I
10	1609	15	23	69	I	I
11	2143	15	17	80	I	I
12	2270	11	17	82	I	I
13	379	23	27	79	I	I
14	1304	25	30	80	I	I
15	369	20	24	89	I	I
16	164	25	9	76	I	I
17	253	77	14	83	I	I
18	1595	21	27	78	I	I
19	465	33	36	77	I	I
20	243	35	37	97	I	I
21	57	35	36	103	I	I
22	106	36	38	101	I	I
23	726	31	31	87	I	I
24	1618	30	35	81	I	I
25	1235	16	18	85	I	I
26	1186	14	16	83	I	I
27	1407	26	27	77	I	I
28	1801	22	28	79	I	I
29	1103	7	7	62	I	I
SUM	37040	-	-	-	-	-
AVG	1277	20	24	81	I	I

* DENOTES UNAVAILABLE DATA
I DENOTES INVALID DATA.

MONTHLY REPORT: SCATTERGOOD SCHOOL
MARCH 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	2058	12	18	62	*	*
2	2162	15	24	68	*	*
3	1969	27	34	*	*	*
4	795	31	37	*	*	*
5	2154	14	15	*	*	*
6	879	21	*	*	*	*
7	157	26	28	*	*	*
8	2179	29	34	*	*	*
9	12[illegible]5	31	37	*	*	*
10	2157	28	29	*	*	*
11	2157	24	30	*	*	*
12	474	27	28	*	*	*
13	770	27	29	*	*	*
14	2372	30	38	*	*	*
15	1999	44	53	*	*	*
16	278	46	53	*	*	*
17	1690	32	34	*	*	*
18	2294	42	51	*	*	*
19	1068	45	48	*	*	*
20	327	41	44	*	*	*
21	2385	35	39	*	*	*
22	946	33	36	*	*	*
23	418	40	47	*	*	*
24	271	32	33	*	*	*
25	1610	33	39	*	*	*
26	465	33	35	*	*	*
27	968	43	50	*	*	*
28	672	42	46	*	*	*
29	1332	41	45	*	*	*
30	192	37	40	*	*	*
31	2118	45	52	*	*	*
SUM	40581	-	-	-	-	-
AVG	1309	32	38	*	*	*

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SCATTERGOOD SCHOOL
APRIL 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	980	24	*	*	I	I
2	*	*	*	*	I	I
3	677	21	52	*	I	I
4	2190	23	43	*	I	I
5	2140	16	58	*	I	I
6	335	13	54	*	I	I
7	1333	9	*	*	I	I
8	162	21	*	*	I	I
9	376	32	34	97	I	I
10	988	30	38	82	I	I
11	270	33	33	95	I	I
12	2385	27	42	71	I	I
13	1415	28	42	63	I	I
14	532	33	33	98	I	I
15	2252	25	50	71	I	I
16	1998	17	*	62	I	I
17	916	14	54	62	I	I
18	2168	9	68	48	I	I
19	2119	3	72	50	I	I
20	2035	0	79	40	I	I
21	1987	0	*	46	I	I
22	1791	0	*	36	I	I
23	1658	8	62	36	I	I
24	2231	20	48	50	I	I
25	1341	16	57	57	I	I
26	1606	15	61	60	I	I
27	1492	8	64	53	I	I
28	1031	13	61	63	I	I
29	443	15	55	85	I	I
30	485	11	56	80	I	I
SUM	40692	-	-	-	-	-
AVG	1356	49	53	64	I	I

* DENOTES UNAVAILABLE DATA.
I DENOTES INVALID DATA.

APPENDIX F

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

APPENDIX F

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

Scattergood School was utilized for all of the reporting period. The solar system operated for the entire period. This system has been in operation since May 1978. Since being put into operation, there have not been any major operational problems.

APPENDIX G

CONVERSION FACTORS

APPENDIX G

CONVERSION FACTORS

Energy Conversion Factors[1]

Fuel Type	Energy Content	Fuel Source Conversion Factor
Distillate fuel oil[2]	138,690 BTU/gallon	7.21×10^{-6} gallon/BTU
Residual fuel oil[3]	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	979.43×10^{-6} cubic feet/ BTU
Electricity	3,413 BTU/kilowatt-hour	293.08×10^{-6} kwh/BTU

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[1] Source information is from the Dept. of Energy "Monthly Energy Review" FEB 1980

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

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

APPENDIX H

SENSOR TECHNOLOGY

APPENDIX H

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. The probes are designed to have a normal resistance of 100 Ohms at 32°F.

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 ducts or 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.

The RTDs are connected in a Wheatstone bridge arrangement to yield an output signal of 0-100 millivolts, which is measured by the SDAS. Different resistance values are used in the bridge, depending on the temperature range the sensor must measure. A third wire is brought out from the sensor and connected into the bridge to compensate for the resistance of the lead wires between the sensor and the SDAS.

The RTDs are individually calibrated by the manufacturer to National Bureau of Standards traceable standards. In addition, a five-point transmission system calibration check is done at the site to compensate for any deviation of the measurement system from nominal values.

The data-processing software takes these checks and calibrations into account, using a third-order polynomial curve fit to relate SDAS output to temperature.

Wind Sensor

Wind speed and direction are measured by a Model W101-P-DC/540 (or W102-P-DC/540) sensor made by the WeatherMeasure Corporation. This sensor is rugged, reliable and accurate and will withstand severe environments such as icing and hurricane winds.

Wind speed is measured by a four-bladed propeller vehicle coupled to a DC generator. The balanced propeller is fabricated from a special low-density, fiberglass-reinforced plastic to yield maximum sensitivity and strength. The DC generator has excellent linearity but somewhat higher threshold due to brush friction.

Dual-wiper, precious-metal slip rings are used to connect the wind speed generator signal (15 Volts DC at 100 miles per hour) to the data transmission lines. These generally provide trouble-free use for several years.

Wind direction is measured by means of a dual-wiper 1000-Ohm long-life conductive plastic potentiometer housed in the base of the sensor (0-540°). It is attached to the stainless steel shaft which supports and rotates with the upper body assembly.

The potentiometer is of high commercial grade and has sealed bearings. The conductive plastic resistance element has infinite resolution and a lifetime about 10 times that of wire-wound potentiometers. The base is of aluminum, and corrosion-resistant materials are used in the construction.

Humidity Sensors

Relative humidity is measured by a WeatherMeasure Corporation Model HM111-P/HM14-P sensor. This measurement is of particular importance in solar cooling systems.

This solid-state sensor measures relative humidity over the full range of 0-100%. Response of the sensing element is linear within approximately 1%, from 0-80% relative humidity, with small hysteresis and negligible temperature dependence.

The sensor is based upon the capacitance change of a 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. The thin polymer layer reacts very quickly and, therefore, the response time is very short (one second to 90% humidity change at 68°F).

The polymer material is resistant to most chemicals. Because the sensor response is based on "bulk" effect, under normal conditions dust and dirt do not easily influence its operation. For use outdoors, a sintered filter is used because sulphur dioxide absorbed on small particles can corrode the thin film electrodes of the sensor. The smaller the pore size of the filter, the greater the protection. The response time, however, is increased.

The sensor is mounted in a small probe which contains all the electronics necessary to provide a millivolt output. The output of the probe electronics is linear from 0-100% relative humidity. Because the capacitance change of the sensor is sensitive only to ambient water vapor, temperature compensation is not required in most situations.

Insolation Sensors

Eppley pyranometers and shadowband pyranometers are used to measure the amount of radiant energy incident on a surface. A standard pyranometer measures the total amount of solar energy available, including both the direct beam component and the diffuse component, while the shadow-band instrument is designed to measure the diffuse component only. The instruments are calibrated in the horizontal position, with an Eppley thermopile used as the signal generator of the sensor. The heating of the thermopile by the radiation of the sun generates the signal, with the response being linear over the operating range. Measurements are in BTU/ft^2-hr.

The addition of a shadow band to a pyranometer enables the instrument to record only the diffuse portion of the sunlight by shielding the sensor from the direct rays of the sun (the beam component). The amount of beam radiation available is readily calculated by subtracting the diffuse radiation measurement from the total radiation measured by the unshaded standard pyranometer. This beam radiation measurement is useful when working with focusing solar collectors. When using the shadowband pyranometer, the accuracy of its measurement depends on the correct adjustment of the shadow band to be certain that the sensor is shielded from the direct rays of the sun.

The pyranometer includes a circular multi-junction thermopile of the wire-wound type. The thermopile has the advantage of withstanding some mechanical vibration and shock. The receiver is circular, and coated with Parsons black lacquer. The instrument has a pair of removable precision ground and polished hemispheres of Schott optical glass. It also has a spirit level and a desiccator that can be readily inspected. The clear glass is transparent from a wave/length of about 285 to 2,800 nanometers. The temperature dependence is ±1% over the range of -4°F to 104°F. It has a response time of one second and a linearity of ±5% over the range of the instrument.

Flow Sensors

The Ramapo flowmeter is an accurate and sensitive liquid flow rate measuring device. The dynamic force of fluid flow, or velocity head of the approaching stream, is sensed as a drag force on a target (disc) suspended in the flow stream. This force is transmitted via a lever rod and flexure tube to an externally bonded, four active arm strain gauge bridge. This strain gauge bridge circuit translates the mechanical stress due to the sensor (target) drag into a directly proportional electrical output. Translation is linear, with infinite resolution, and is hysteresis free. The drag force itself is usually proportional to the flow rate squared. The electrical output is unaffected by variations in fluid temperature or static pressure head, within the stated limitations of the unit.

Power Sensors

A major component of the wattmeter is a concentrating magnetic core (usually a toroid). The conductor carrying current to the load is passed through the window (eye) of the magnetic core one or more times. The magnetic field surrounding the conductor (load-carrying wire) is instantaneously proportional to the current flowing in the conductor. This field is intercepted by the magnetic core, producing a magnetic flux which is also instantaneously proportional to the current flowing in the conductor. A Hall effect transducer is cemented into a thin slot milled through the concentrating magnetic core.

In this position it intercepts nearly all of the magnetic flux present in the core. Two of the transducer's terminals provide a full scale output of 50MVDC. The remaining two terminals are referred to as a control input. The output of the Hall transducer is not only proportional to the magnetic flux passing through it but also to any EMF which appears across its control terminals. The load voltage is applied to the transducer's control terminals.

The resultant measurements of the wattmeter are summarized below:

1. Output is directly proportional to the flux in the magnetic core which in turn is directly proportional to the load current (I).
2. Output is directly proportional to the load voltage (E).
3. Final output is directly proportional to the vector product of E, I, and cos ϕ (power factor angle). This output is read into the SDAS as an electrical power in watts.

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