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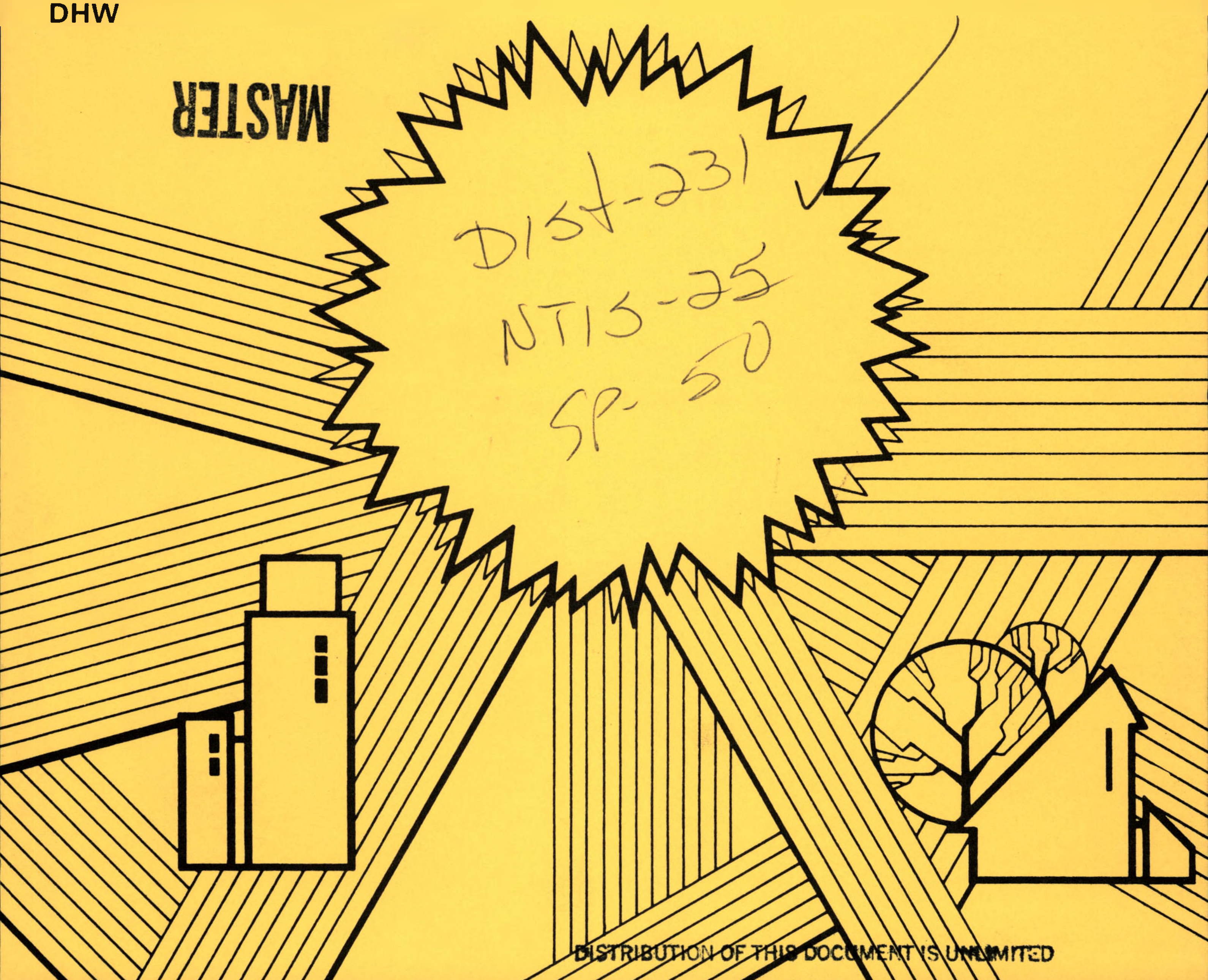
SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

LOUDOUN COUNTY SCHOOL

Leesburg, Virginia
July 1979 through June 1980
DHW



U.S. DEPARTMENT OF ENERGY
NATIONAL SOLAR DATA PROGRAM

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LOUDOUN COUNTY SCHOOL

LEESBURG, VIRGINIA

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

JULY 1979 THROUGH JUNE 1980

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Program Manager

Vitro Laboratories Division
Automation Industries, Inc.

The National Solar Data Network
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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.

LOUDOUN COUNTY SCHOOL

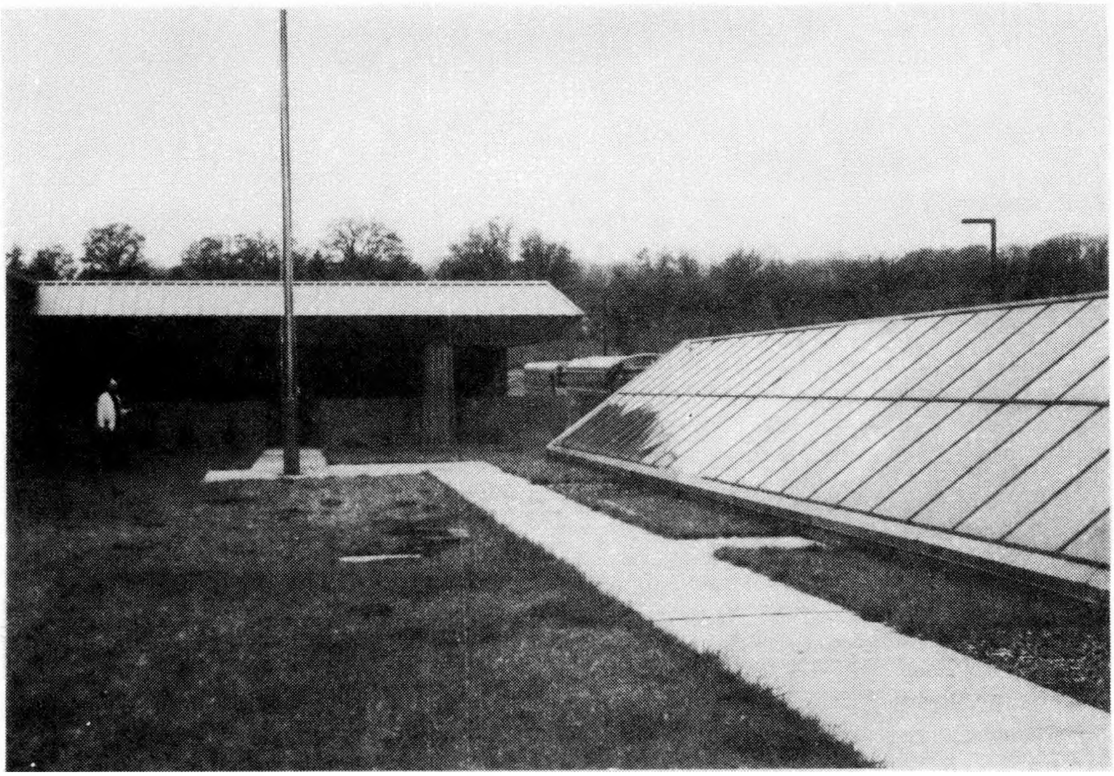
The Loudoun County site is the Charles S. Monroe Vocational Technical School in Leesburg, Virginia. The active solar energy system is designed to supply the following:

Annual Design Factors
(Million BTU)

	Total Load	Solar Contribution	% Solar
Hot Water	161.85	42.08	26%

It is equipped with:

Collector	1,225 square feet of double glazed flat-plate collectors manufactured by Southwest Enertech
Storage	2,056 gallon liquid storage located in the schools mechanical room
Auxiliary	Electric immersion heater, 2 stage, 20 kw per stage



LOUDOUN COUNTY SCHOOL

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Seasonal Energy Requirements
July 1979 through June 1980
(million BTU)

	Total Load	Solar Contribution	% Solar
Hot Water	64.94	73.37	60

Environmental Data

	Measured Average	Long-Term Average
Outdoor temperature	55°F	54°F
Heating degree-days	4,805	5,010
Cooling degree-days	936	940
Daily incident solar energy	1,243 BTU/ft^2	1,329 BTU/ft^2

1. $$\text{Solar Fraction} = \frac{\text{Solar Energy in DHW Tank}}{\text{Total Energy in DHW Tank}}$$

2. $$\text{Solar Savings Ratio} = \frac{\text{Solar Energy Used by the Load Subsystem} - \text{Solar System Operating Energy}}{\text{Total Load}}$$

3. $$\text{Conventional Fuel Savings} = \frac{\text{Solar Energy Used} - \text{Solar Operating Energy}}{3{,}412 \text{ (BTU per kwh)}}$$

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

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

1.1 SUMMARY AND CONCLUSIONS

The Loudoun County solar energy system operated very well during the period from July 1979 through June 1980. During this period, the solar energy system supplied 60% of the energy required for domestic hot water. The thermal performance is summarized in Table 1.

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

LOUDOUN COUNTY SCHOOL
JULY 1979 THROUGH JUNE 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* (PERCENT)	
			PREDICTED	MEASURED	ELECTRICAL		ELECTRICAL	PREDICTED	MEASURED
JUL	12.14	0.91	4.62	5.48	0.03	0.43	5.13	84	100
AUG	10.29	0.91	5.08	5.69	0.04	0.42	5.35	89	99
SEPT	7.58	3.32	6.23	5.66	2.08	0.30	5.43	80	80
OCT	7.85	4.51	4.78	4.56	5.19	0.54	4.10	49	51
NOV	9.24	6.40	3.92	4.65	6.45	0.51	4.21	35	47
DEC	11.47	5.85	3.11	4.32	5.84	0.44	3.95	31	51
JAN	5.05	6.95	3.06	3.25	8.27	0.32	3.00	27	30
FEB	10.00	8.96	7.49	6.63	6.12	0.53	6.15	59	55
MAR	8.60	9.23	8.82	7.06	6.13	0.58	6.54	67	57
APR	11.55	8.80	9.66	8.95	3.63	0.72	8.30	77	71
MAY	12.99	7.49	9.62	9.48	2.05	0.87	8.68	84	82
JUN	11.80	1.61	7.16	7.65	0.00	0.90	6.82	94	91
TOTAL	118.56	64.94	73.55	73.37	45.81	6.56	67.65	-	-
AVERAGE	9.88	5.41	6.13	6.11	3.82	0.55	5.64	62	60

* Predicted performance was determined from a modified f-Chart computer simulation using measured weather, measured subsystem loads, and computed losses as input.

A modified f-Chart computer simulation using measured weather, measured subsystem loads and computed losses was compared to the actual performance of the solar energy system at the school. The predicted collector array efficiency was equal to the actual efficiency of 21%. This value was calculated based on total insolation on the collector array. The Loudoun County solar energy system collected nearly three percent more energy than predicted (118.56 million BTU actual versus 115.55 million BTU predicted) and the amount of solar energy used was approximately the same as predicted. The overall system solar fraction was 60% compared to a predicted value of 62%.

The annual hot water load at the school, 64.94 million BTU, was far below the design value of 161.85 million BTU; consumption was 305 gallons per day compared to the design consumption of 1,800 gallons per day. Even with the summer months excluded due to the school not being in full session, and basing usage on a five day school week, the average consumption was 530 gallons per day.

The design solar contribution was 26% of the design load of 161.85 million BTU, or 42.08 million BTU. The actual solar contribution of 38.96 million BTU was 60% of the actual load of 64.94 million BTU. The design contribution was eight percent more than the actual solar contribution. This should be expected because the annual insolation for the reporting period was six percent less than the long-term average. Although the design solar fraction of 26% was much less than the actual solar fraction of 60%, the design and actual solar contribution were both about the same. This was due to the design load of 161.85 million BTU being much greater than the actual load of 64.94 million BTU. This caused the actual solar fraction to be much higher than the design solar fraction.

The measured ambient temperature was 0.5°F above the long-term average. This resulted in 4,805 heating degree-days compared to the long-term average of 5,010 heating degree-days. The measured incident solar radiation of 1,243 BTU/ft^2-day was six percent less than the long-term average insolation of 1,329 BTU/ft^2-day.

The solar energy system was operational throughout the year except for the period from September 21 until October 3 when the collector pump was being replaced. In addition, there were 50 days during the year when the system did not operate throughout the day due to low insolation. (The control system functioned flawlessly throughout the year.) On 46 of the 50 days the system did not activate. The incident solar radiation was 375 BTU/ft^2-day or less. On three of the remaining four days the incident solar radiation was less than 475 BTU/ft^2-day. The highest insolation when the collectors did not operate was 629 BTU/ft^2-day. This was less than half of the value for the long-term daily insolation for the year of 1,329 BTU/ft^2-day.

The solar energy system at the Loudoun County School has functioned very well throughout the year. The actual system contribution has been about the same as the design contribution. This is exceptional considering the actual load was 40% of the design load. Storage efficiency for the year, at 85%, was also very good. The collector control system operated as designed throughout the year. The solar system performance and lack of malfunctions shows a well thought out design and high quality of construction.

1.2 OVERALL SYSTEM PERFORMANCE

The flow of solar energy through the Loudoun County site for the 12-month period from July 1979 through June 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. Figure 2 shows the amount of solar and auxiliary energy consumed by the system each month.

The solar energy system at Loudoun County School performed very well throughout the year. The system collected almost three percent more solar energy than the f-Chart computer simulation predicted. This was due to good collector efficiency (21% of total insolation) and a well designed control system.

The highest losses from the system were transport losses between the collectors and storage. Of the 118.56 million BTU the system collected during the year, 31.82 million BTU were lost between the collectors and storage. This was due to the collectors being located approximately 125 feet from the storage tank. Over one-third of this piping is buried outside between the collector array and the school building. Thus there was a large effect on transport losses. This is evidenced by the losses being influenced by the outside ambient temperature. Fifty-one percent of the seasonal transport losses were sustained from November to February when outside temperatures were low (average of 38°F for these months).

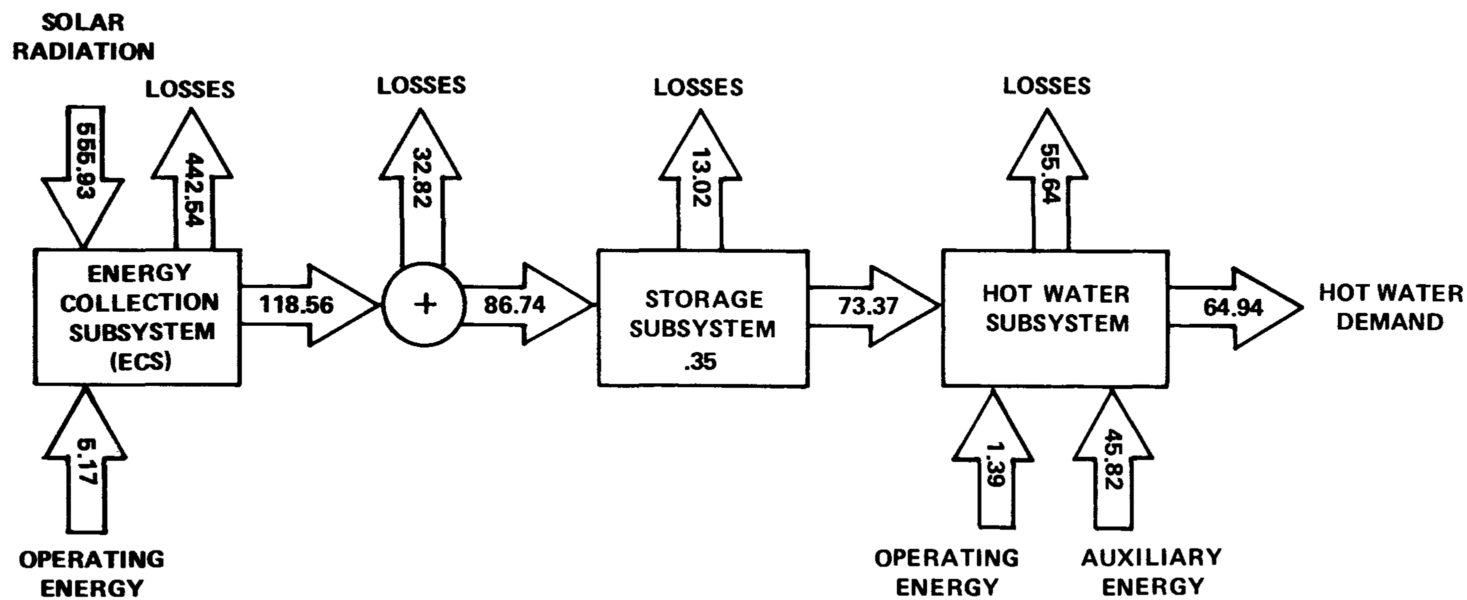
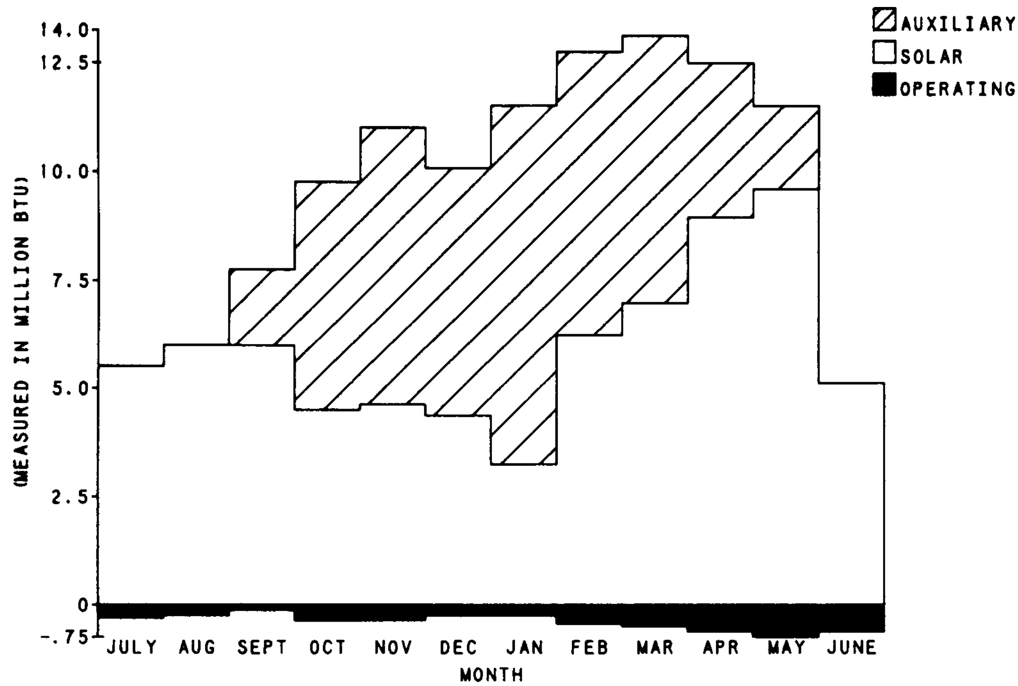


Figure 1. Energy Flow Diagram for Loudoun County School
July 1979 through June 1980
(Figures in million BTU)



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
Loudoun County School
July 1979 through June 1980

The annual efficiency of storage for the system was 85%. Six months during the year had an efficiency of over 90%. Of the 86.74 million BTU delivered to storage, 13.02 million BTU were lost into the mechanical room where the storage tank is located. The average temperature of the storage tank for the year was 112°F, resulting in an effective R-value of 9.1 for the storage tank. The estimated temperature of the mechanical room for the reporting period was 70°F. The storage tank had an increase of stored energy of 0.35 million BTU for the period. The remaining 73.37 million BTU delivered to storage was used by the domestic hot water system.

January had the lowest solar contribution during the reporting period. This was due to January having the lowest monthly average insolation for the year at 26.32 million BTU or 693 BTU/ft^2-day which is 210 BTU/ft^2-day below the long-term average. This resulted in comparatively little solar energy being collected, 5.05 million BTU. Energy delivered to storage was 2.70 million BTU during January due to the transport collector-to-storage losses.

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 delivered it. The greater the COP value, the more efficient the subsystem. The solar energy system at Loudoun County functioned at a reporting period weighted average COP value of 12.85 for the period July 1979 through June 1980. The collection subsystem had a weighted average COP of 22.90 for the season. This indicates the collectors and the control device for operating the collectors both worked very well during the reporting period.

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

LOUDOUN COUNTY SCHOOL
JULY 1979 THROUGH JUNE 1980

MONTH	SOLAR ENERGY SYSTEM	COLLECTOR SUBSYSTEM	DOMESTIC HOT WATER SOLAR
JUL	15.58	43.20	77.24
AUG	16.69	39.41	71.14
SEPT	24.39	41.89	110.96
OCT	9.92	18.01	198.04
NOV	10.51	22.21	178.73
DEC	11.58	31.95	307.43
JAN	12.94	20.35	1,083.00
FEB	13.82	21.32	603.00
MAR	13.67	17.10	542.77
APR	14.44	19.02	203.41
MAY	12.12	17.60	166.28
JUN	10.44	17.49	49.01
AVERAGE	12.85	22.91	133.63

Under normal conditions, the solar energy is delivered from storage to the domestic hot water subsystem via city water pressure. On occasion though, when the solar storage tank is warmer than the domestic hot water tank by at least 20°F, pump P2 activates and circulates water between storage and the domestic hot water tank. This is the only solar operating energy charged to the domestic hot water subsystem. Since this mode of operation occurs infrequently, very little power is ultimately charged to the subsystem. This results in very high COP values for the domestic hot water subsystem. There was good insolation during this period coupled with low DHW consumption, hence storage tank temperatures were usually high. This caused frequent operation of pump P2 resulting in lower COP values for these months. During the colder months when school was in session, the system had much higher DHW consumption contributing lower storage temperatures. The auxiliary electric heater maintained the hot water tank at approximately 126°F during the period December through February. These months had much higher COP values than the rest of the reporting period due to very little operation of pump P2. Note on Table 2 however the COP is much lower for June through August. This is due to the auxiliary power being shut down during most of the school's summer break, resulting in low hot water tank temperatures. As a result, standby losses were supplied by solar. Thus the pump P2 had to cycle on more frequently.

1.3 ENERGY SAVINGS

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.

Energy savings for this site for the reporting period, July 1979 through June 1980, are presented in Table 3 and shown graphically in Figure 3. For this 12-month period the total savings after subtracting solar unique operating energy were 67.65 million BTU, for a monthly average of 5.64 million BTU. This is approximately 19,808 kwh of electricity. The electrical energy expense incurred during the reporting period for the operation of solar energy components was 5.72 million BTU. The cost for electricity at the site for the reporting period was 3.78¢/kwh. This resulted in a net savings for the year of $748.74.

Table 3. ENERGY SAVINGS

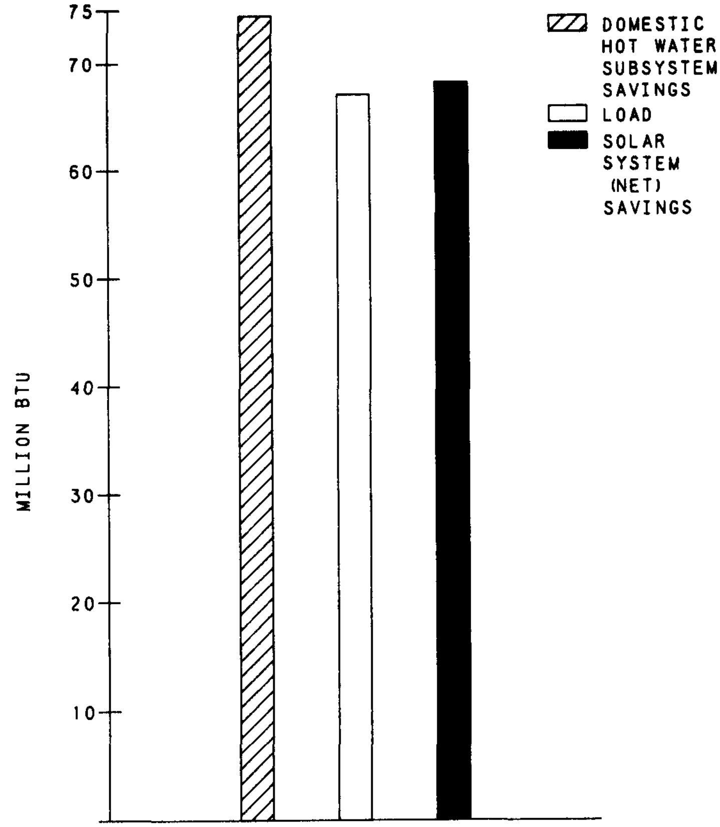
LOUDOUN COUNTY SCHOOL
JULY 1979 THROUGH JUNE 1980

(All values in million BTU)

MONTH	SOLAR ENERGY USED	DOMESTIC HOT WATER ELECTRICAL	ECSS OPERATING ENERGY	NET ENERGY SAVINGS ELECTRICAL
JUL	5.48	5.41	0.28	5.13
AUG	5.69	5.61	0.26	5.35
SEPT	5.66	5.61	0.18	5.43
OCT	4.56	4.53	0.46	4.10
NOV	4.65	4.62	0.42	4.21
DEC	4.32	4.30	0.36	3.95
JAN	3.25	3.25	0.25	3.00
FEB	6.63	6.62	0.47	6.15
MAR	7.06	7.04	0.50	6.54
APR	8.95	8.91	0.61	8.30
MAY	9.48	9.42	0.74	8.68
JUN	7.65	7.48	0.68	6.82
TOTAL	73.37	72.82	5.17	67.65
AVERAGE	6.11	6.07	0.43	5.64

The auxiliary source at Loudoun County site consists of an electric immersion heater. This unit is considered to be 100% efficient for computational purposes.

The monthly savings varied markedly throughout the year. This was due to several reasons. Obviously, the incident solar radiation available and the monthly load had a marked effect on savings. The outdoor ambient temperature was also a factor. Lower outdoor temperatures caused higher transport losses, resulting in less solar energy being delivered to storage. (Also see Solar Utilization.) April and May achieved the most savings due to load and insolation both being higher than average. There is no known reason for the load increases. The outdoor ambient temperature for April and May were 55°F and 66°F respectively.



THE DIFFERENCE OF 5.17 MILLION BTU BETWEEN THE SAVINGS FOR THE DOMESTIC HOT WATER SUBSYSTEM AND THE SOLAR SYSTEM IS DUE TO THE 1,514 KWR (5.17 MILLION BTU) USED BY THE COLLECTOR PUMP (P-1) FOR COLLECTION OF SOLAR ENERGY.

Figure 3. Combined Thermal Energy Savings Compared to Load
Loudoun County School
July 1979 through June 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 throughout the system, from incident radiation to the load, are also presented in Table 4.

Twenty-one percent of the total incident solar energy was lost due to periods when insolation was available but the collector pump was not running. This figure is low in comparison to other sites and indicates a well operating collector control system. The controls did not activate the collector pump when insolation was too low to collect solar energy. This occurred during the early morning after sunrise and in the late afternoon to evening when the sun was about to set. Additionally, it occurred on 50 days during the year when the total daily insolation was very low. On 92% of the days the system did not activate, the insolation for the day was 375 BTU/ft^2 or less. During these times, the collector was not able to heat the transport fluid to 20°F above the storage tank temperature which would cause the control to activate the collector pump.

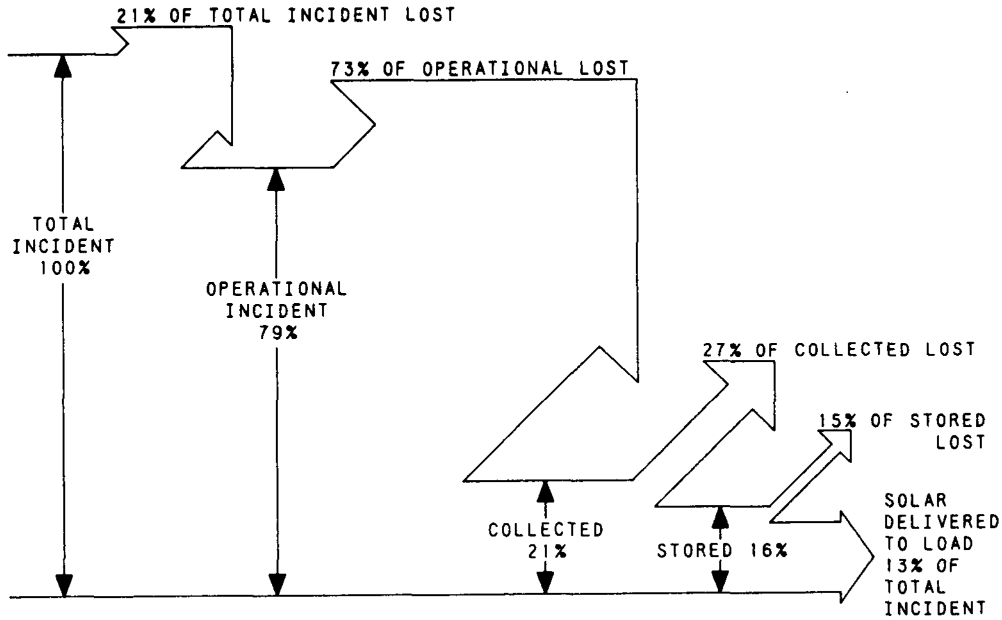


Figure 4. Solar Energy Use
Loudoun County School
July 1979 through June 1980

Table 4. SOLAR ENERGY LOSSES

LOUDOUN COUNTY SCHOOL
JULY 1979 THROUGH JUNE 1980

	JUL	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
1. SOLAR ENERGY (SE) COLLECTED - SE DIRECTLY TO LOADS (million BTU)	12.14	10.29	7.58	7.85	9.24	11.47	5.04	10.00	8.60	11.55	12.99	11.80
2. SE TO STORAGE (million BTU)	9.25	8.00	5.90	5.86	5.29	4.91	2.70	6.70	7.14	9.76	10.98	10.25
3. LOSS - COLLECTOR TO STORAGE (%)	24	22	22	25	43	57	46	33	17	15	15	13
4. CHANGE IN STORED ENERGY (million BTU)	0.01	0.12	-0.94	0.58	-0.14	0.35	-0.78	-0.01	0.00	0.02	0.79	0.36
5. SOLAR ENERGY - STORAGE TO DHW SUBSYSTEM (million BTU)	5.48	5.69	5.66	4.56	4.65	4.32	3.25	6.63	7.06	8.95	9.48	7.65
6. LOSS FROM STORAGE (%)	41	27	20	12	15	5	9	1	1	8	6	22
7. SOLAR ENERGY - STORAGE TO DHW SUBSYSTEM (million BTU)	5.48	5.69	5.66	4.56	4.65	4.32	3.25	6.63	7.06	8.95	9.48	7.65

The operational incident energy was 79% of the total incident energy, 21% of the incident energy was collected and 73% was lost. This results in a collector array efficiency of 21% for total insolation and 27% for operational incident energy. Seventy-three percent of the collected solar energy was delivered to storage. This was 16% of the total incident energy.

It is felt that most of the 32.18 million BTU collector-to-storage losses occurred in the 50 foot long pipe run between the collector array and the school building. This was inferred by the losses being proportional to the outside ambient temperature. The collector-to-storage losses averaged 45% of total collected energy for the period November through February when the average ambient temperature was 38°F. However, these losses averaged only 16% of total collected energy for the period March through May when the average ambient temperature was 54°F. The losses did not serve to heat the school, as the losses were underground between the school and the collector array. The remaining collector-to-storage losses were lost inside the school. Additionally 15% of the energy in the storage tank was lost in the mechanical room. During times when space heating was required, these losses helped reduce the space heating load. Conversely, during times when space cooling was required, these losses actually increased the cooling load of the school. (The mechanical room is in an air conditioned space.)

The remaining 13% of the incident solar energy was delivered to the hot water subsystem.

1.5 SOLAR SYSTEM AVAILABILITY

From September 21 until October 3, 1979 the system was shut down. The collector pump (P1) was being replaced during this time. Additionally, during the season the system did not operate on 50 days with low insolation. The threshold for system operation was about 0.5 million BTU of incident energy on the array. Only four of the fifty days were greater than 0.5 million BTU incident. For exact days and insolation on those days, see Table 5. All insolation figures are given in millions of BTU.

Table 5. INOPERATIVE SOLAR ENERGY SYSTEM/DAYS

LOUDOUN COUNTY SCHOOL
JULY 1979 THROUGH JUNE 1980

(All values in million BTU)

MONTH	DAY	INSOLATION	MONTH	DAY	INSOLATION
JUL 1979	4	0.24	JAN 1980	1	0.77
				4	0.11
AUG 1979	12	0.31		5	0.16
	18	0.41		7	0.15
				9	0.33
SEPT 1979	5	0.18		11	0.10
				14	0.03
OCT 1979	5	0.21		17	0.25
	10	0.58		18	0.03
	12	0.20		22	0.09
	24	0.36		25	0.12
	28	0.37		28	0.46
NOV 1979	2	0.14	FEB 1979	6	0.26
	10	0.17		9	0.44
	11	0.05		22	0.16
	12	0.31		28	0.23
	13	0.12			
	24	0.15	MAR 1980	1	0.54
				13	0.08
DEC	6	0.25		17	0.09
	13	0.01		24	0.23
	16	0.25		28	0.42
	18	0.53		31	0.18
	19	0.17			
	20	0.12	APR 1980	14	0.07
	21	0.42		26	0.24
	22	0.24		27	0.17
	24	0.08		28	0.29

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The Loudoun County collector array consists of 34 custom made, double-glazed, flat-plate collectors manufactured by Southwest Enertech. The total gross collector area of the array is 1,225 ft^2. The collectors use silicone oil as a transport medium. The collector array, which is mounted at ground level in one bank facing 15 degrees west of due south at an angle of 37 degrees to the horizontal.

Collector subsystem performance for the Loudoun County site is presented in Table 6.

Table 6. COLLECTOR SUBSYSTEM PERFORMANCE

LOUDOUN COUNTY SCHOOL
JULY 1979 THROUGH JUNE 1980

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR SUBSYSTEM EFFICIENCY %	OPERATIONAL INCIDENT ENERGY	OPERATIONAL COLLECTOR EFFICIENCY %	ECSS OPERATING ENERGY	SOLAR ENERGY DIRECTLY TO LOADS	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE °F
JUL	50.79	12.14	24	42.64	28	0.28	0	9.25	81
AUG	52.53	10.29	20	44.04	23	0.26	0	8.00	81
SEPT	47.91	7.58	16	33.09	23	0.18	0	5.90	74
OCT	40.67	7.85	19	29.54	27	0.44	0	5.86	62
NOV	35.64	9.24	26	27.49	34	0.42	0	5.29	56
DEC	37.10	11.47	31	26.97	43	0.36	0	4.91	45
JAN	26.32	5.05	19	15.17	33	0.25	0	2.70	36
FEB	46.64	10.00	21	36.16	28	0.47	0	6.70	37
MAR	45.92	8.60	19	35.24	24	0.50	0	7.14	47
APR	52.38	11.55	22	43.60	26	0.61	0	9.76	62
MAY	57.22	12.99	23	48.53	27	0.74	0	10.98	74
JUN	62.79	11.80	19	53.46	22	0.68	0	10.25	79
TOTAL	555.93	118.56	-	435.94	-	5.17	0	86.74	-
AVERAGE	46.33	9.88	21	36.33	27	0.43	0	7.23	61

The total incident solar radiation on the collector array for the period July 1979 through June 1980 was 555.93 million BTU. During the time the collector loop was operating, the total solar radiation on the array was 435.94 million BTU. Hence the control activated the collection mode for over 78% of the available insolation, indicating excellent control operation. The total collected solar energy for this period was 118.56 million BTU, which 86.74 million BTU were delivered to storage. The remaining 31.82 million BTU (27%) were lost in transport between the collection and storage subsystems. This resulted in a collector array efficiency of 21% based on incident solar energy and 27% based on operational incident energy. Collection of solar energy used 1,513 kwh (5.17 million BTU) for operation of the collector pump (P1).

The collectors were operational throughout the year except for two weeks in the fall. During that time the collector pump was being replaced. (Also see Solar Energy Utilization, page 1-8, and Site History, Problems and Changes, G-1). The replacement pump (which was rated for higher flow rates) was installed to enhance system performance. Examination of the data after the replacement did not show a change in system performance. The new pump had virtually no effect on the collector flow rate. The flow rate during July averaged 31 gpm. During August, the flow rate dropped for no apparent reason to an average of 24 gpm. After the new pump was installed, the flow rate returned to an average 29.3 gpm.

2.2 STORAGE

Solar energy storage at Loudoun County is provided by a 2,056 gallon steel storage tank located in the school's mechanical room. Storage performance data for the site for the reporting period are shown in Table 7.

Table 7. STORAGE PERFORMANCE

LOUDOUN COUNTY SCHOOL
JULY 1979 THROUGH JUNE 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)	EFFECTIVE HEAT LOSS COEFFICIENT (BTUh/ft^2 °F)	LOSS FROM STORAGE
JUL	9.25	5.48	-0.01	59	131	0.31	3.78
AUG	8.00	5.69	0.12	73	133	0.17	2.19
SEPT	5.90	5.66	-0.94	80	118	0.13	1.18
OCT	5.86	4.56	0.58	88	112	0.09	0.72
NOV	5.29	4.65	-0.14	85	105	0.11	0.78
DEC	4.91	4.32	0.35	95	96	0.05	0.24
JAN	2.70	3.25	-0.78	91	81	0.11	0.24
FEB	6.70	6.63	-0.01	99	97	0.02	0.08
MAR	7.14	7.06	0.00	99	96	0.02	0.08
APR	9.76	8.95	0.02	92	114	0.09	0.78
MAY	10.98	9.48	0.79	94	119	0.07	0.71
JUN	10.25	7.65	0.36	78	143	0.16	2.25
TOTAL	86.74	73.37	0.35	-	-	-	13.02
AVERAGE	7.23	6.11	0.03	85	112	0.11	1.09

During the reporting period, total solar energy delivered to storage was 86.74 million BTU. There were 73.37 million BTU delivered from storage to the DHW subsystem. An increase in storage temperature of 21°F resulted in a gain in stored energy of 0.35 million BTU. Energy loss from storage was 13.02 million BTU. This loss represented 15% of the energy delivered to storage. The storage efficiency was 85%. Storage efficiency remained above 80% during the months when school was in full session. During summer break, however, the storage efficiency did drop below 80%, due mainly to low hot water consumption accompanied by high storage temperatures (average of 136°F for June, July and August). When June, July and August are excluded, the seasonal storage efficiency was 92%.

Evaluation of the system storage performance under actual solar energy system operation and weather conditions can be performed using the parameters listed in Footnote 1. The utility of these measured data in evaluation of the overall storage design is illustrated in Table 7.

This effective storage heat loss coefficient has been calculated for each month in this reporting period and included, along with storage average temperature, in Table 7. Effective storage heat coefficient is comparable to the heat loss rate defined in ASHRAE Standard 94-77. (See Reference 6.)

The average heat loss coefficient, 0.11, is equivalent to an insulation R-value of 9.1. The 2.056 gallon cylindrical steel tank in fact has 3 inch thick sprayed on insulation (urethane) with a one inch thick overcoat (also sprayed on) of asbestos. The insulating value of this covering should theoretically equal approximately 15.0 R-value. The tank actually having an effective R-value less than 15.0 is due, in part, to the tank being in a relatively high humidity environment (the school's boiler room). Additionally, the storage tank has various pipes and temperature sensor wells projecting from it that contribute to tank losses.

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

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

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

   Effective storage heat loss coefficient (c) for the storage subsystem can be defined as follows:

   $$c = (STEI-STEO-STECH)/ \quad (T_s - T_a) \times t \quad \frac{BTU}{Hr\ °F}$$

   Where: c = effective storage heat loss coefficient

   T_s = average storage temperature

   T_a = average ambient temperature in the vicinity of storage

   t = number of hours in the month

2.3 DOMESTIC HOT WATER (DHW)

The DHW subsystem performance for the Loudoun County site for the reporting period is shown in Table 8 and by graphic illustration in Figure 5.

Table 8. DOMESTIC HOT WATER SUBSYSTEM PERFORMANCE

LOUDOUN COUNTY SCHOOL
JULY 1979 THROUGH JUNE 1980

(All values in million BTU, unless otherwise indicated)

MONTH	DHW LOAD	ENERGY CONSUMED SOLAR	ENERGY CONSUMED AUXILIARY ELECTRICAL	ENERGY CONSUMED OPERATING EXPENSE	SOLAR FRACTION %	HOT WATER CONSUMPTION GAL.
JUL	0.91	5.48	0.03	0.15	100	1,880
AUG	0.91	5.69	0.04	0.16	99	1,990
SEPT	3.32	5.66	2.08	0.12	80	6,577
OCT	4.51	4.56	5.19	0.10	51	9,028
NOV	6.40	4.65	6.45	0.09	47	11,080
DEC	5.85	4.32	5.84	0.08	51	10,525
JAN	6.95	3.25	8.27	0.07	30	10,896
FEB	8.96	6.63	6.12	0.08	55	13,956
MAR	9.23	7.06	6.13	0.08	57	14,469
APR	8.80	8.95	3.62	0.11	71	14,611
MAY	7.49	9.48	2.05	0.13	82	13,378
JUN	1.61	7.65	0.00	0.22	91	2,848
TOTAL	64.94	73.37	45.82	1.38	-	111,238
AVERAGE	5.41	6.11	3.82	0.12	60	9,270

The DHW subsystem required 73.37 million BTU of solar energy and 45.81 million BTU of auxiliary electrical energy to satisfy a hot water load of 64.94 million BTU. The solar fraction of this load was 60%, with an operating energy of 1.38 million BTU. Losses from the DHW subsystem were 55.62 million BTU. A daily average of 305 gallons of DHW was consumed at an average temperature of 129°F.

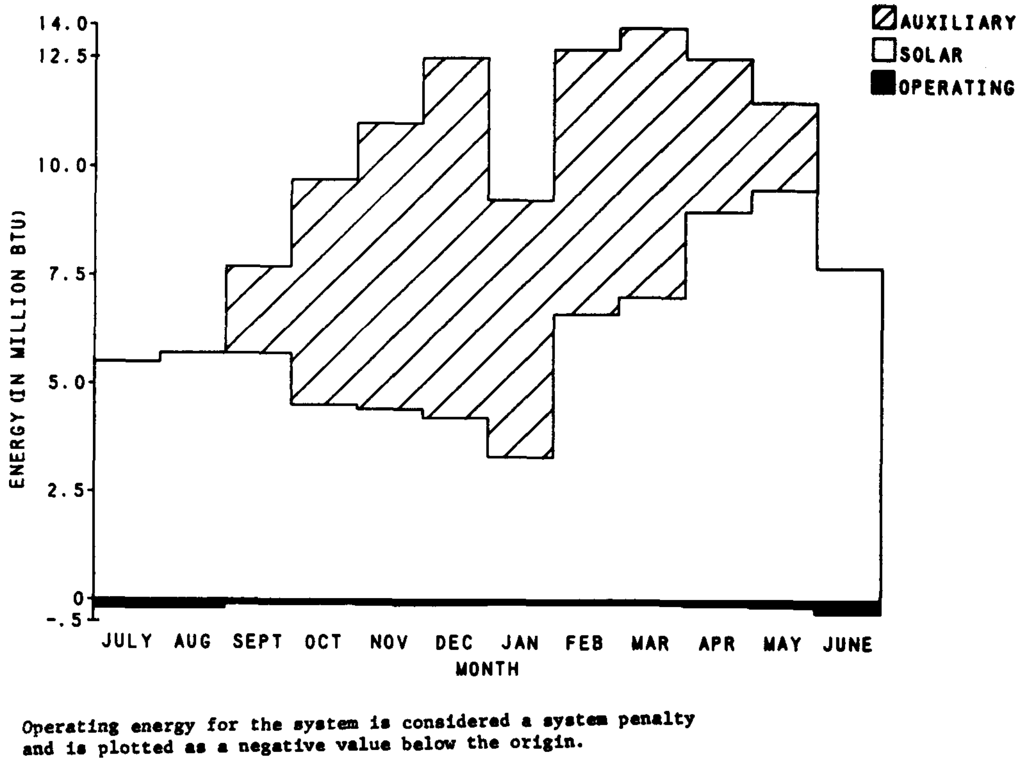

Figure 5. Domestic Hot Water
Loudoun County School
July 1979 through June 1980

When consumption is calculated during the September through May school year and based on a five-day school week, consumption averages 530 gallons per day. This was far below the design consumption of 1,800 gallons per day. The smaller load resulted in the actual solar fraction, 60%, being higher than the design solar fraction of 26%.

The electric auxiliary heater for the system was only on seven times between June 1 and September 20, 1979. During this time, 0.10 million BTU of auxiliary energy was used. This was due to a small amount of hot water consumption and high storage temperatures. Energy from the storage tank was used to replace the domestic hot water tank standby losses.

On September 21, 1979, the school used 1,213 gallons of hot water, which dropped the storage tank temperature 27°F. After September 21 the auxiliary heater had come on almost every day due to the increased consumption.

SECTION 3

OPERATING ENERGY

Measured monthly values of the Loudoun County solar energy system and subsystem operating energy for the report period are presented in Table 9. A total 6.56 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 6.

Table 9. OPERATING ENERGY

LOUDOUN COUNTY SCHOOL
JULY 1979 THROUGH JUNE 1980

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY (SOLAR UNIQUE)	DHW OPERATING ENERGY TOTAL	DHW OPERATING ENERGY SOLAR UNIQUE	TOTAL SOLAR UNIQUE OPERATING ENERGY	TOTAL SYSTEM OPERATING ENERGY
JUL	0.28	0.15	0.07	0.35	0.43
AUG	0.26	0.16	0.08	0.34	0.42
SEPT	0.18	0.12	0.05	0.23	0.30
OCT	0.44	0.10	0.02	0.46	0.54
NOV	0.42	0.09	0.03	0.45	0.51
DEC	0.36	0.08	0.01	0.37	0.44
JAN	0.25	0.07	0.00	0.25	0.32
FEB	0.47	0.08	0.01	0.48	0.55
MAR	0.50	0.08	0.01	0.51	0.58
APR	0.61	0.11	0.04	0.65	0.72
MAY	0.74	0.13	0.06	0.80	0.87
JUN	0.68	0.22	0.16	0.84	0.90
TOTAL	5.17	1.38	0.54	5.71	6.55
AVERAGE	0.43	0.12	0.05	0.48	0.55

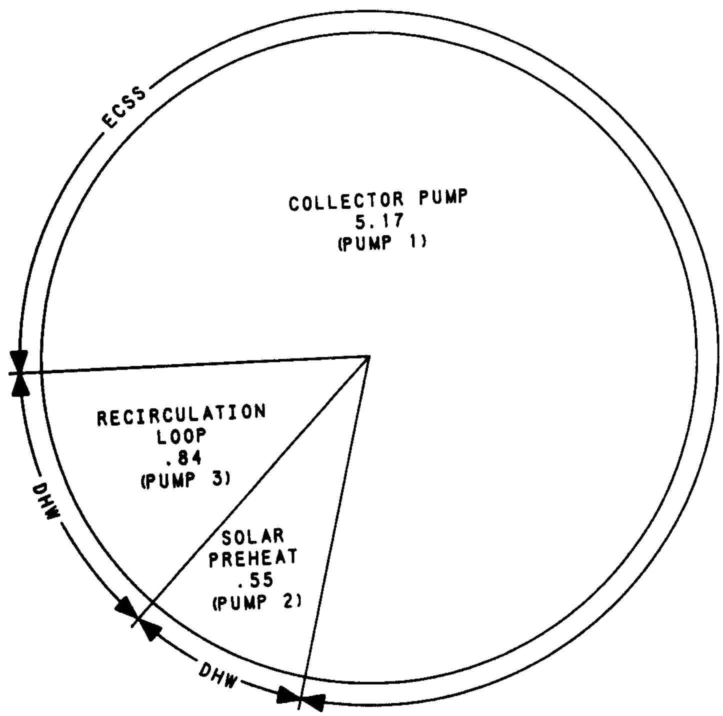

Figure 6. Total Operating Energy
Loudoun County School
July 1979 through June 1980

Total system operating energy for Loudoun County School is the electrical energy required to support the collection and domestic hot water without affecting their thermal states.

The overall electrical energy consumption of the solar system was small compared to the amount of solar energy collected. The electrical energy used to collect the solar energy was 1/23 of the collected solar energy. The domestic hot water subystem used a small amount of solar unique operating energy compared with the total solar energy used by the subsystem. The solar system has an overall COP for the year of 12.85.

The 1/2 hp collection pump (P1) was replaced with a 1 hp pump between September 21 and October 3, 1979. Although this pump had no effect on the collector fluid flow rate, it did have a pronounced effect on the collection subsystem electrical energy consumption. Average power consumption for the collector pump, P1, rose from 340 watts/hr to 840 watts/hr after the new 1 hp pump was installed. Higher energy use is shown for the collection subsystem starting in October in Table 9. If the pump has not been replaced, the collection subsystem would have achieved a higher COP for the reporting period.

The components which use operating energy in each subsystem are:

The energy collection and storage subsystem (ECSS)	Pump P1	Collector loop pump
DHW (for solar preheat)	Pump P2	Transfers energy from storage to the DHW storage tank
DHW (recirculation loop, not solar unique)	Pump P3	Recirculation loop pump

SECTION 4

WEATHER CONDITIONS

The Loudoun County site is located in Leesburg, Virginia at 33.12 degrees N latitude and 77.58 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

LOUDOUN COUNTY SCHOOL
JULY 1979 THROUGH JUNE 1980

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT^2-DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS		COOLING DEGREE-DAYS	
	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
JUL	1,339	1,625	74	75	5	0	286	319
AUG	1,385	1,582	74	74	11	0	272	267
SEPT	1,304	1,511	67	67	42	43	112	100
OCT	1,071	1,343	54	56	361	291	12	9
NOV	970	1,006	50	45	465	609	0	0
DEC	977	780	39	35	807	961	0	0
JAN	693	903	32	30	1,011	1,020	0	0
FEB	1,313	1,125	31	34	988	874	0	0
MAR	1,209	1,332	41	42	739	719	0	0
APR	1,425	1,494	55	53	295	357	0	0
MAY	1,507	1,579	66	63	60	131	99	57
JUN	1,709	1,664	70	71	21	5	155	188
TOTAL	-	-	-	-	4,805	5,010	936	940
AVERAGE	1,243	1,329	55	54	400	418	78	78

During the period from July 1979 through June 1980, the average daily total incident solar radiation on the collector array was 1,242 BTU per square foot per day. This radiation was below the estimated average daily solar radiation for this geographical area during the reporting period of 1,329 BTU per square foot per day for a south-facing plane with a tilt of 37 degrees to the horizontal. During the period, the highest monthly average insolation was 1,709 BTU per square foot per day during June. The average ambient temperature during the reporting period was 54°F, the same as the long-term average. The highest monthly average ambient temperature was 74 degree-days during July and August. The lowest monthly average ambient temperature was 31 degree-days during February. The number of heating degree-days for the period based on a 65°F reference was 4,805 as compared with the long-term average of 4,961. The range of heating degree-days was from a high of 1,011 degree-days during January to a low of five degree-days 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 78% during December to a low of 36% during September. The lowest monthly average insolation was 693 BTU/sq ft-day during January.

	JUL	AUG	SEPT	OCT	NOV	DEC
Extra-terrestrial Insolation	3,548	3,200	2,646	2,007	1,481	1,248
TTL INS (%) / EXT INS	38	43	36	53	65	78

	JAN	FEB	MAR	APR	MAY	JUN
Extra-terrestrial Insolation	1,375	1,836	2,428	3,040	3,467	3,640
TTL INS (%) / EXT INS	50	72	50	47	43	47

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

[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

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*9. Monthly Performance Report, Loudoun County School, September 1979, SOLAR/2016-79/09, 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.

*11. Monthly Performance Report, Loudoun County School, December 1979, SOLAR/2016-79/12, Vitro Laboratories, Silver Spring, Maryland.

*12. Monthly Performance Report, Loudoun County School, January 1980, SOLAR/2016-80/01, Vitro Laboratories, Silver Spring, Maryland.

*13. Monthly Performance Report, Loudoun County School, February 1980, SOLAR/2016-80/02, Vitro Laboratories, Silver Spring, Maryland.

*14. Monthly Performance Report, Loudoun County School, March 1980, SOLAR/2016-80/03, Vitro Laboratories, Silver Spring, Maryland.

*15. Monthly Performance Report, Loudoun County School, April 1980, SOLAR/2016-80/04, Vitro Laboratories, Silver Spring, Maryland.

*16. Monthly Performance Report, Loudoun County School, May 1980, SOLAR/2016-80/05, Vitro Laboratories, Silver Spring, Maryland.

*17. Monthly Performance Report, Loudoun County School, June 1980, SOLAR/2016-80/06, Vitro Laboratories, Silver Spring, Maryland.

* 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

The Loudoun County School site is the Charles S. Monroe Vocational Technical School located in Leesburg, Virginia. Solar energy is used for preheating domestic hot water (DHW). The solar energy system has an array of flat-plate collectors with a gross area of 1225 square feet. The array faces 15 degrees west of south at an angle of 37 degrees to the horizontal. A silicone oil solution is the transfer medium that delivers solar energy from the collector array to a heat exchanger. Solar energy is stored within the building in a 2056-gallon water tank.

Preheated water is supplied from the solar storage tank to a 1000-gallon DHW tank. Hot water from the DHW tank is circulated through the service hot water lines and back to the DHW tank to instantly provide hot water at the service taps. This circulation is controlled by a time clock so that circulation occurs only during hours of normal use. An electrical heating element immersed in the DHW tank provides auxiliary energy, as required, to maintain the desired 140°F service water temperature. The system, shown schematically, has four modes of operation, all of which operate independently of one another.

Mode 1 - Collector-to-Storage - This mode activates when there is a temperature difference of 20°F between a control sensor located at the collector and a control sensor located inside the storage tank (near the bottom). At this time the controller turns on pump P1 which circulates the transport fluid through the collectors and the heat exchanger located inside the storage tank. P1 continues to operate until the temperature difference between the control sensors is less than 5°F. At this point, P1 is turned off and the mode terminates. Mode 1 will also terminate when the storage tank temperature exceeds 200°F, as measured by another control sensor near the top of the storage tank.

Mode 2 - Solar Energy Preheat - This mode activates when there is a temperature difference of 20°F between a control sensor located near the top of the storage tank and a control sensor located near the bottom of the DHW tank. At this time the controller energizes pump P2, which delivers preheated water from the storage tank to the DHW tank and recirculates water from the DHW tank to the storage tank. When the temperature difference between the control sensors becomes less than 5°F, pump P2 turns off and the mode terminates. An electrical element in the DHW tank is energized to provide auxiliary water heating when the DHW tank temperature falls below a set point.

Mode 3 - Recirculate - This mode activates (under time-clock control) during hours of normal use, i.e., primarily during daylight and early evening hours every day of the week except Sunday. When activated, pump P3 is energized and hot water circulates from the hot water tank through the service hot water lines and returns to the hot water tank.

Mode 4 - DHW Load - This mode activates when hot water is drawn from any of the hot water taps in the building. The hot water demand is replenished by cold water supplied to the storage tank. The make-up water to the DHW tank from the storage tank goes through P2 (if mode 2 is active at this time) or bypasses P2 if mode 2 is inactive. Mode 3 need not be activated to supply the demand at the hot water taps.

SUBSYSTEMS

Collector - The gross collector array (consisting of 34 individual collector panels) is 1,225 ft^2. The collectors face 15 degrees west of south at tilt of 37 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 33.12 degrees North. Optimum collector orientation at this site is estimated to be 0 degrees west or east of South at a tilt of 40 degrees. Optimum orientation was predicted based on an f-chart simulation sensitivity analysis.

The collector panels have two low iron glass covers and a non-selective absorber surface (Nextel black velvet by 3M). The absorber surface has a solar absorptivity of 0.98 and an infrared emissivity of 0.89. Total solar transmissivity of the glazing is 0.72. The absorber surface is composed of two sheets of stainless steel (stainless 439) resistance roll welded. The fluid circulated through the collectors is silicone oil. The circulation pump (P1) is rated 1 hp (240 volt, 3 phase).

Storage - Solar energy storage is provided by a 2,056-gallon cylindrical steel storage tank located in the mechanical room of the building. The storage has three inches of urethane and one inch of asbestos applied around the entire storage tank. Water is used as the medium to transfer solar energy to the DHW system.

When the storage tank is 20°F warmer than the hot water tank, the control activates a 1/6 hp (120 Volt, 1 phase) pump (P2) to circulate water between storage and the hot water tank. This mode (mode 2, Solar Energy Preheat) ceases when the storage tank is less than 5°F warmer than the hot water tank.

Hot Water - City water is heated and stored in the 2,056-gallon storage tank and supplied, on demand, to the conventional 1,000-gallon 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 storage to the DHW tank by city water pressure upon demand. Water is the transfer medium. The system has a recirculation loop for maintaining hot water temperatures at all of the points of use. The recirculation loop pump (P3), which is activated by a timer during school hours, is a 1/6 hp (120 volt, a phase) pump.

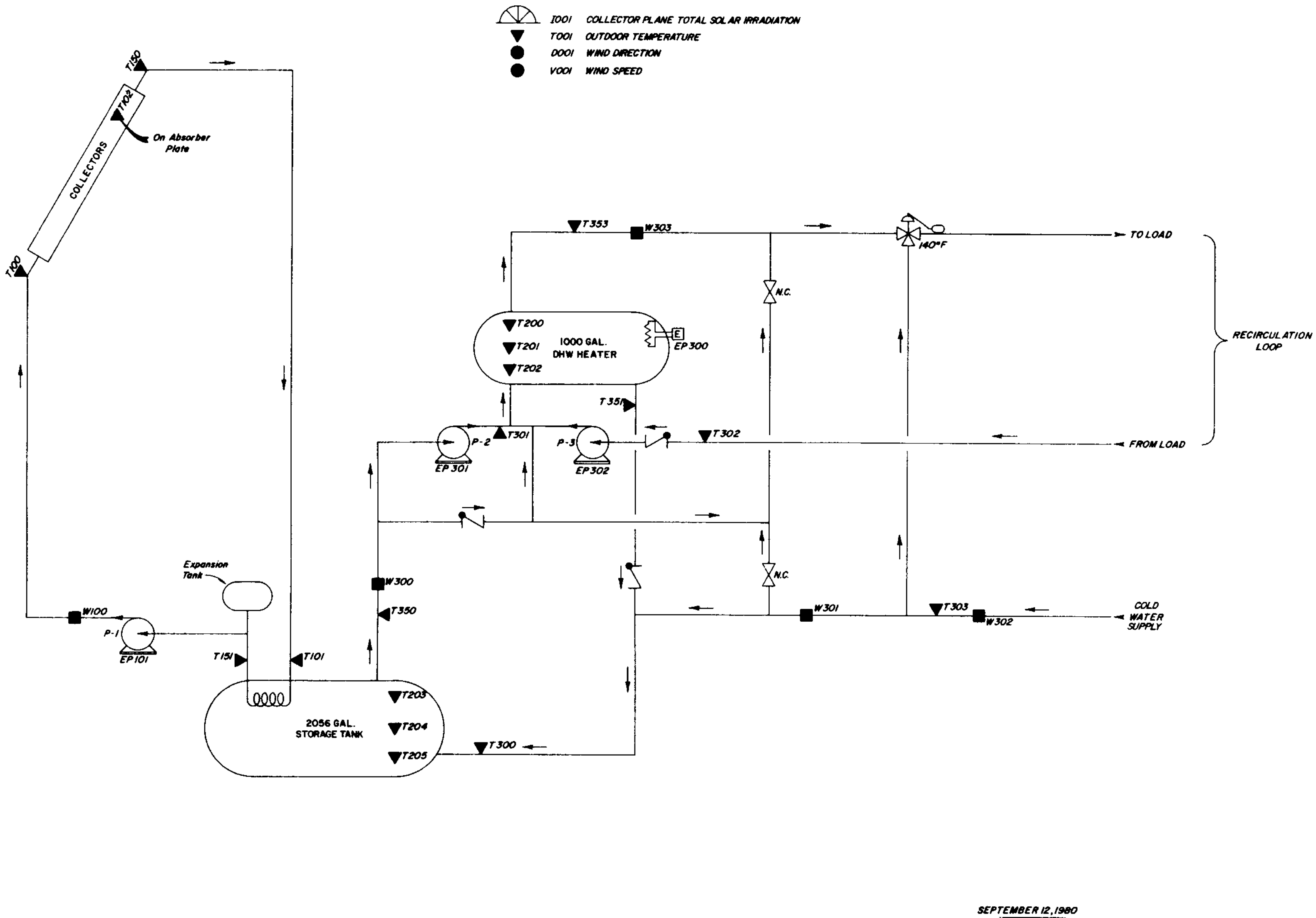


Figure A-1. Loudoun County School, Solar Energy System Schematic

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Loudoun County 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.

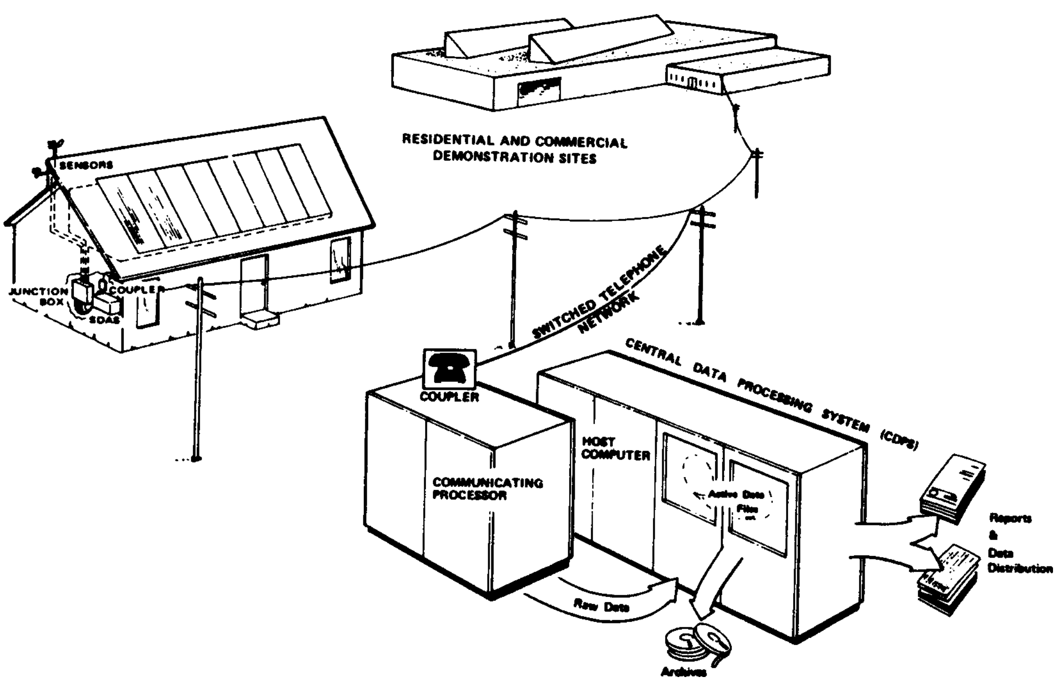


Figure B-1. The National Solar Data Network

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 Loudoun County School solar energy system from July 1979 through June 1980 was analyzed during the annual DHW season, 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.

OTHER DATA REPORTS ON THIS SITE*

Monthly Performance Reports:

February 1979, SOLAR/2016-79/02
March 1979, SOLAR/2016-79/03
April 1979, SOLAR/2016-79/04
May 1979, SOLAR/2016-79/05
June 1979, SOLAR/2016-79/06
July 1979, SOLAR/2016-79/07
August 1979, SOLAR/2016-79/08
September 1979, SOLAR/2016-79/09
November 1979, SOLAR/2016-79/11
December 1979, SOLAR/2016-79/12
January 1980, SOLAR/2016-80/01
February 1980, SOLAR/2016-80/02
March 1980, SOLAR/2016-80/03
April 1980, SOLAR/2016-80/04
June 1980, SOLAR/2016-80/06
July 1980, SOLAR/2016-80/07
August 1980, SOLAR/2016-80/08

* 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

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.

* 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.

* 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.

* 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.

* 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.

* 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.

* Primary Performance Factors

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

* 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.

$$FMS = \text{Solar Energy Supplied to Load} - \text{Solar System Operating Energy}$$

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.
Heat Exchanger	A device used to transfer energy from one heat transfer fluid to another while maintaining physical segregation of the fluids. Normally used in systems to provide an interface between two different heat transfer fluids.
Heat Transfer Fluid	The fluid circulated through a heat source (solar collector) or heat exchanger that transports the thermal energy by virtue of its temperature.
Heating Degree Days	The sum over a specified period of time of the number of degrees the average daily temperature is below 65°F.
Instantaneous Efficiency	The efficiency of a solar collector at one operating point, $\frac{Ti-Ta}{I}$, under steady state conditions (see Operating Point).
Instantaneous Efficiency Curve	A plot of solar collector efficiency against operating point, $\frac{Ti-Ta}{I}$ (see Operating Point).
Incidence Angle	The angle between the line to a radiating source (the sun) and a line normal to the plane of the surface being irradiated.
Incident Solar Energy	The amount of solar energy irradiating a surface taking into account the angle of incidence. The effective area receiving energy is the product of the area of the surface times the cosine of the angle of incidence.
Insolation	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: $\frac{Ti-Ta}{I}$ $\frac{°F \times hr. \times sq. ft.}{BTU}$
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 param eter 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 x 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 3410.6412 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

LOUDOUN COUNTY 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 lb_m/min and ΔH is the enthalpy change, in BTU/lb_m, of the fluid as it passes through the heat exchanging component.

For a liquid system ΔH is generally given by

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

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

* 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

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

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

LOUDOUN COUNTY SCHOOL

EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

AVERAGE AMBIENT TEMPERATURE (°F)

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

AVERAGE BUILDING TEMPERATURE (°F)

$$TB = (1/60) \times \Sigma\ T600 \times 101295 + T601 \times 17400)/118695] \times \Delta\tau$$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

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

for ± 3 hours from solar noon

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

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

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

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

when the collector loop is active

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)

$$SECA = M100 \times CP51^1\ ((T100 + T150) \times 0.5) \times T150 - T100)$$

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = M100 \times CP51\ ((T101 + T151) \times 0.5) \times (T101 - T151)$$

CP51 is a function which calculates the enthalopy of the systems transport medium (silicone oil in this case)

SOLAR ENERGY FROM STORAGE (BTU)

when is Mode 2 (Solar Energy Preheat)

STEO = M300 x HWD (T350 - T300)

SOLAR ENERGY FROM STORAGE (BTU)

when hot water is used

STEO = M301 x HWD (T350 - T300)

AVERAGE TEMPERATURE OF STORAGE (°F)

$TST = (1/60) \times \Sigma\ [(T203 + T204 + T205)/3] \times \Delta\tau$

ENERGY DELIVERED FROM ECSS TO DOMESTIC HOT WATER SUBSYSTEM (BTU)

CSEO = STEO

ECSS OPERATING ENERGY (BTU)

$CSOPE = 56.8833 \times \Sigma\ EP101 \times \Delta\tau$

HOT WATER SUBSYSTEM OPERATING ENERGY (BTU)

$HWOPE = 56.8833 \times (EP301 + EP302) \times \Delta\tau$

SOLAR UNIQUE HOT WATER SUBSYSTEM OPERATING ENERGY

$HWOPE1 = 56.8833 \times EP301 \times \Delta\tau$

SOLAR ENERGY TO DOMESTIC HOT WATER SUBSYSTEM (BTU)

HWSE = STEO

DOMESTIC HOT WATER SUBSYSTEM AUXILIARY ELECTRICAL FUEL ENERGY (BTU)

$HWAE = 56.8833 \times EP300 \times \Delta\tau$

DOMESTIC HOT WATER SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

HWAT = HWAE

DOMESTIC HOT WATER SUBSYSTEM LOAD

$HWL = M301 \times HWD\ (T353 - T303) \times \Delta\tau$

SOLAR ENERGY IN STORAGE TANK

HWTKSE = (HWSFR P/100) x (TANKE - HWSE - HWAT) + HWSE

AUXILIARY ENERGY IN STORAGE TANK

HWTKAUX = (HWSFR - P/100) x (TANKE - HWSE - HWAT) + HWAT

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

SEA = CLAREA x SE

COLLECTED SOLAR ENERGY (BTU)

SEC = SECA/CLAREA

COLLECTOR ARRAY EFFICIENCY

CAREF = SECA/SEA

CHANGE IN STORED ENERGY (BTU)

$STECH = STECH1 - STECH1_p$

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

STORAGE EFFICIENCY

STEFF = (STECH + STEO)/STEI

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

SEL = CSEO

ESCC SOLAR CONVERSION EFFICIENCY

CSCEF = SEL/SEA

DOMESTIC HOT WATER SUBSYSTEM SOLAR FRACTION (PERCENT)

HWSFR = HWTKSE x 100/(HWTKAUX + HWTKSE)

DOMESTIC HOT WATER SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

HWSVE = HWSE - HWOPE1

SYSTEM LOAD (BTU)

SYSL = HWL

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

SFR = HWSFR

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

AXT = HWAE

AUXILIARY ELECTRICAL ENERGY TO LOADS (BTU)

AXE = HWAE

SYSTEM OPERATING ENERGY (BTU)

SYSOPE = HWOPE + CSOPE

TOTAL ENERGY CONSUMED (BTU)

TECSM = SYSOPE + AXE + SECA

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

TSVE = HWSVE - CSOPE

SYSTEM PERFORMANCE FACTOR

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

APPENDIX E

CALCULATION OF PREDICTED VALUES

APPENDIX E

CALCULATION OF PREDICTED VALUES

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

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

Ref:

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

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

SYSTEM PERFORMANCE SUMMARY (f-CHART)*
LOUDOUN COUNTY
JULY 1979 THROUGH JUNE 1980

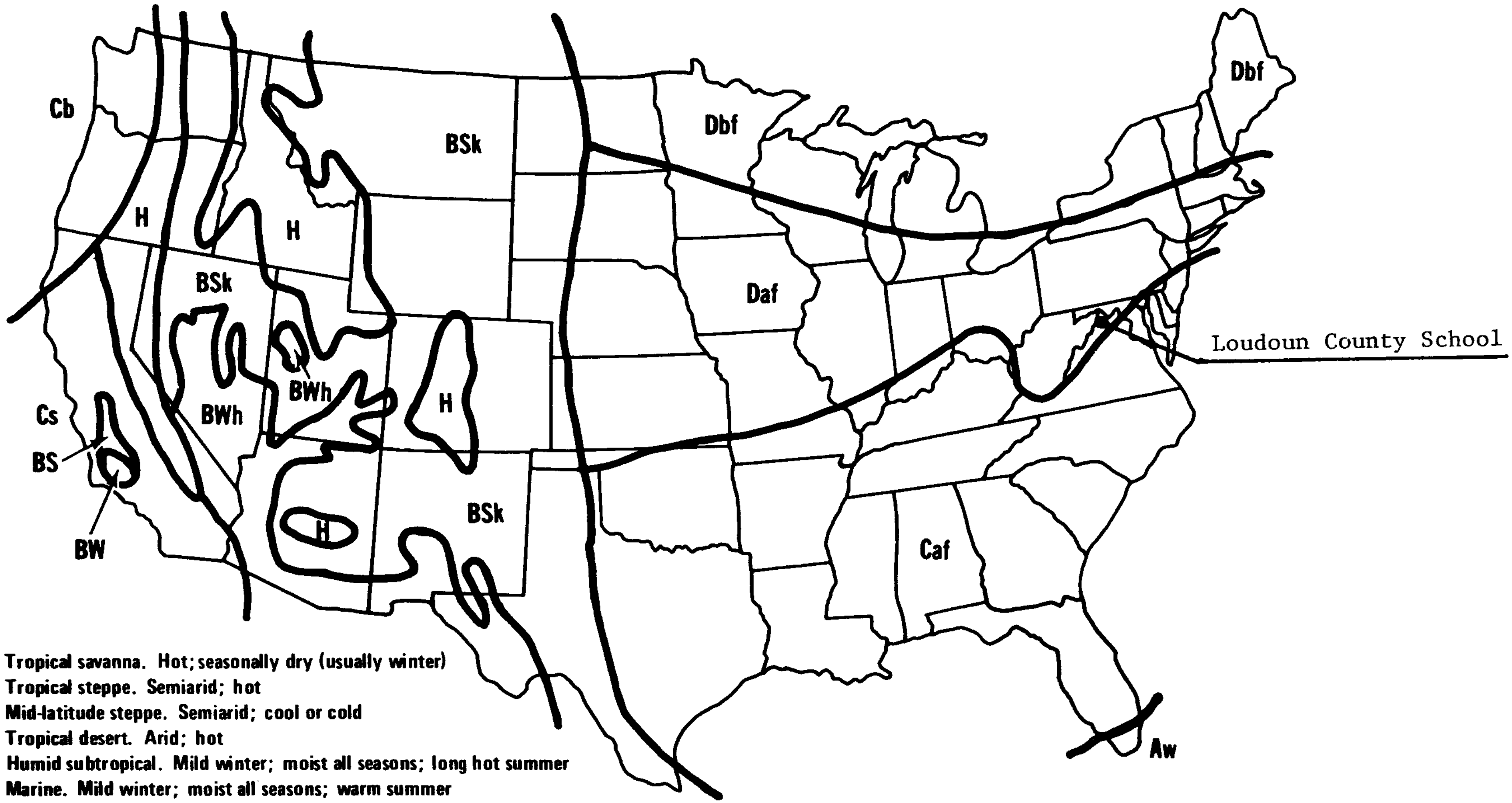
(All values in million BTU, unless otherwise indicated)

MONTH	ESFR (%)	ASFR (%)	LOAD	LOSS	STECH	ESECA	ASECA	ESEU	ASEU	LOSS (%)
JUL	84	100	5.512	6.670	-0.014	10.235	12.140	4.624	5.484	54.8
AUG	89	99	5.729	4.475	0.119	9.174	10.285	5.076	5.691	44.7
SEPT	80	80	7.737	2.860	-0.937	8.344	7.582	6.228	5.659	25.4
OCT	49	51	9.747	2.715	0.584	8.245	7.853	4.781	4.555	42.0
NOV	35	47	11.098	4.730	-0.137	7.795	9.240	3.920	4.647	49.7
DEC	31	51	10.153	6.800	0.352	8.261	11.470	3.110	4.318	62.4
JAN	27	30	11.519	2.581	-0.784	4.757	5.046	3.063	3.249	35.6
FEB	59	55	12.755	3.377	-0.010	11.285	10.000	7.485	6.633	33.7
MAR	67	57	13.183	1.543	0.002	10.753	8.602	8.821	7.056	18.0
APR	77	71	12.575	2.575	0.022	12.461	11.547	9.658	8.950	22.5
MAY	84	82	11.523	2.717	0.794	13.188	12.989	9.623	9.478	27.0
JUN	94	91	7.648	3.795	0.363	11.049	11.803	7.156	7.645	35.2
YR TOTAL AVERAGE	62	-	119.179	44.838	0.354	115.547	118.555	73.547	73.365	38.1

*See next page for Glossary for f-Chart terms.

APPENDIX F

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 F-1. Meteorological Map of the United States Showing Loudoun County School Location

MONTHLY REPORT: LOUDOUN COUNTY, JULY 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (0001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1295	67	79	127	0	1
2	1869	70	76	136	266	4
3	1927	74	79	139	274	3
4	198	62	63	136	0	1
5	1935	63	70	131	314	3
6	2116	67	77	136	0	1
7	2076	69	80	142	0	0
8	1850	71	83	148	0	0
9	1809	73	84	150	0	1
10	679	70	74	143	0	0
11	1611	74	83	133	0	0
12	1271	79	89	133	0	1
13	1555	78	92	133	0	0
14	813	74	78	132	0	0
15	1613	78	85	131	0	1
16	1240	79	85	137	0	0
17	1797	80	85	138	0	1
18	1122	77	81	135	0	1
19	1249	75	82	130	0	1
20	675	74	81	127	0	1
21	1130	74	80	124	0	0
22	1304	76	86	127	0	0
23	1309	78	86	132	0	0
24	1208	78	88	131	0	0
25	1017	77	87	131	0	0
26	978	78	82	129	0	1
27	1631	78	85	129	0	1
28	1051	76	84	131	0	0
29	783	73	76	127	0	1
30	635	73	76	126	0	0
31	1719	81	90	125	0	0
SUM	41465	-	-	-	-	-
AVG	1338	74	81	133	0	1

MONTHLY REPORT: LOUDOUN COUNTY, AUGUST 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (0001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1703	83	95	131	0	1
2	949	77	85	137	0	0
3	1020	76	80	131	0	1
4	1870	79	87	132	0	1
5	1792	80	89	143	288	2
6	1996	80	86	146	317	2
7	1967	77	84	148	0	2
8	1484	79	93	148	264	3
9	1722	79	86	147	*	2
10	1611	82	95	147	242	3
11	1002	71	84	144	0	2
12	255	59	59	136	350	6
13	2262	68	76	136	280	3
14	1866	72	83	143	248	3
15	1616	64	68	141	298	3
16	1973	62	70	142	309	3
17	1575	65	75	142	0	1
18	337	64	65	135	184	2
19	1093	72	85	129	0	1
20	1591	74	81	130	0	1
21	506	67	68	129	0	2
22	1587	69	78	125	0	1
23	346	71	75	127	0	1
24	1811	76	83	124	171	4
25	909	75	87	128	0	1
26	1364	77	82	130	0	1
27	1100	74	*	134	0	1
28	1374	75	80	133	0	1
29	759	74	79	132	173	3
30	1611	78	88	129	0	1
31	1837	77	88	135	0	1
SUM	42885	-	-	-	-	-
AVG	1383	74	81	136	0	2

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: LOUDOUN COUNTY, SEPTEMBER 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (0001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1026	74	82	135	0	1
2	1507	79	87	137	174	4
3	1326	78	87	139	0	2
4	1539	76	87	139	0	1
5	145	73	74	135	73	4
6	1462	77	*	130	231	6
7	1672	75	86	132	0	1
8	2073	66	72	139	323	3
9	2058	62	71	147	0	1
10	2086	64	77	153	190	2
11	1599	71	81	148	0	1
12	1393	69	76	140	0	2
13	846	69	75	132	0	2
14	825	74	79	121	182	8
15	1956	64	70	123	0	2
16	2040	62	72	137	0	1
17	2089	65	79	145	0	1
18	1938	67	80	147	0	2
19	1970	66	73	145	309	2
20	1815	58	67	141	163	2
21	59	63	64	130	0	1
22	302	63	64	114	348	3
23	2059	59	66	104	359	4
24	1272	57	65	99	0	2
25	776	59	64	93	0	1
26	1108	64	75	88	0	1
27	838	64	71	83	0	1
28	236	64	66	80	0	0
29	869	71	78	80	0	1
30	223	67	69	80	3	3
SUM	39111	-	-	-	-	-
AVG	1304	67	74	124	*	2

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: LOUDOUN COUNTY, OCTOBER 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (0001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	454	63	66	87	0	2
2	632	67	71	78	0	1
3	1727	64	70	79	255	5
4	1351	63	70	98	161	2
5	170	53	53	110	257	4
6	1904	54	62	105	181	4
7	1002	53	60	122	258	5
8	1839	55	64	129	228	4
9	378	53	59	131	*	5
10	470	37	*	120	0	1
11	1417	43	47	110	182	3
12	166	48	53	108	0	2
13	461	49	49	104	282	4
14	933	45	54	100	274	3
15	2032	49	61	112	201	3
16	586	55	63	125	0	1
17	1148	57	66	115	0	1
18	1676	61	73	123	0	1
19	1478	61	74	130	155	2
20	1512	65	75	133	167	2
21	1711	70	84	140	0	2
22	1743	70	84	147	165	2
23	463	60	70	142	214	7
24	290	46	48	125	267	6
25	856	46	51	113	269	6
26	592	40	46	108	292	2
27	1481	41	51	111	0	1
28	300	46	49	120	0	1
29	1701	55	66	122	300	3
30	1665	49	58	126	0	1
31	1064	48	55	120	0	1
SUM	33202	-	-	-	-	-
AVG	1071	54	62	116	255	3

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: LOUDOUN COUNTY, NOVEMBER 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (0001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1103	54	61	115	165	2
2	113	56	61	113	262	4
3	1187	47	52	111	305	5
4	1770	46	55	120	311	3
5	1884	44	54	131	0	1
6	1435	46	55	129	0	1
7	974	49	54	119	292	4
8	570	44	48	110	179	2
9	779	53	58	98	148	3
10	142	56	59	92	217	3
11	43	46	46	91	333	3
12	251	43	44	90	321	4
13	97	45	46	85	327	3
14	909	42	45	77	298	6
15	519	41	46	75	202	4
16	1546	44	50	84	290	4
17	1627	49	61	99	229	2
18	1612	57	71	123	245	3
19	1560	55	68	129	0	0
20	1403	56	70	128	0	1
21	1175	54	64	122	0	1
22	1304	54	62	123	0	1
23	810	56	64	123	177	2
24	119	63	65	122	174	3
25	952	65	72	119	136	4
26	346	59	67	119	166	7
27	1503	50	60	115	205	2
28	643	48	56	114	250	7
29	1162	33	37	106	274	7
30	1553	30	37	103	243	4
SUM	29093	-	-	-	-	-
AVG	970	50	56	109	254	3

MONTHLY REPORT: LOUDOUN COUNTY, DECEMBER 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (0001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1501	32	41	115	0	2
2	1077	32	37	118	292	7
3	1672	32	40	120	281	4
4	1308	38	49	117	272	3
5	1533	42	52	112	180	4
6	204	46	49	119	200	4
7	1513	46	52	102	234	5
8	1075	42	44	99	277	9
9	1515	35	42	108	211	3
10	1296	42	54	114	0	1
11	1502	49	63	113	179	2
12	927	56	64	111	186	2
13	11	45	43	101	353	4
14	1400	36	42	91	312	3
15	1484	32	40	95	0	2
16	207	42	46	106	0	2
17	1524	26	28	105	305	10
18	432	25	28	103	270	4
19	142	30	33	86	56	3
20	101	26	27	67	359	6
21	344	31	35	61	0	1
22	194	37	39	60	0	0
23	1111	45	54	61	0	0
24	62	49	50	71	0	1
25	712	49	52	84	256	6
26	757	40	43	85	296	9
27	536	37	42	88	292	6
28	1500	38	43	93	286	8
29	1605	45	51	114	280	5
30	1476	46	56	124	290	3
31	1568	37	44	127	0	2
SUM	30290	-	-	-	-	-
AVG	977	39	45	99	289	4

MONTHLY REPORT: LOUDOUN COUNTY, 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	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	625	33	40	0	1
2	857	33	36	306	6
3	576	34	39	0	2
4	89	28	28	28	5
5	127	26	28	317	6
6	1674	27	33	303	4
7	121	32	34	182	7
8	774	34	37	289	3
9	270	30	33	0	1
10	799	27	33	149	3
11	81	37	35	177	3
12	495	34	36	283	7
13	539	29	31	0	2
14	26	35	35	318	5
15	688	41	44	301	8
16	1389	43	52	312	2
17	204	38	41	0	2
18	20	40	41	0	1
19	1211	38	44	299	5
20	1399	37	44	278	3
21	1726	35	42	253	5
22	74	37	39	0	1
23	1062	34	38	282	7
24	771	23	28	254	5
25	94	29	29	0	1
26	1586	33	37	304	3
27	584	29	32	0	1
28	375	34	37	311	3
29	1225	30	35	304	4
30	673	22	25	282	4
31	1350	22	24	312	6
SUM	21482	-	-	-	-
AVG	693	32	36	298	4

MONTHLY REPORT: LOUDOUN COUNTY, 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	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1873	18	22	300	10
2	1889	20	25	293	9
3	1875	21	26	289	7
4	1725	25	30	293	7
5	1793	27	33	287	3
6	216	24	26	24	3
7	1784	28	33	301	8
8	1786	31	35	303	5
9	361	30	33	0	2
10	1705	27	30	312	4
11	1493	29	37	189	2
12	1964	28	32	281	6
13	1925	29	39	0	2
14	1385	37	51	265	3
15	624	37	*	0	2
16	860	33	39	295	5
17	1999	23	28	291	7
18	1838	27	37	213	3
19	1427	34	45	0	1
20	1696	42	52	0	2
21	1290	48	56	286	3
22	132	40	41	28	2
23	881	46	55	308	2
24	1297	47	53	292	3
25	858	41	43	9	2
26	*	*	*	*	*
27	240	31	*	240	7
28	187	25	28	0	1
29	1656	18	23	308	5
SUM	38072	-	-	-	-
AVG	1313	31	37	299	4

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: LOUDOUN COUNTY, MARCH 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (0001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	439	13	14	120	325	4
2	1503	17	*	91	345	7
3	2261	24	31	85	295	5
4	1300	35	42	97	0	1
5	697	44	46	97	196	6
6	1800	41	44	95	288	4
7	855	49	58	100	177	3
8	887	60	66	97	188	8
9	2104	47	50	107	290	6
10	1602	47	59	119	166	4
11	2248	38	38	115	277	11
12	1543	31	33	109	314	3
13	67	28	26	102	29	4
14	1309	35	39	98	269	7
15	2230	40	47	108	259	5
16	2048	44	55	129	142	2
17	74	51	52	131	173	4
18	2157	46	48	115	278	8
19	1708	45	55	113	158	3
20	758	53	59	108	163	3
21	277	51	57	98	247	10
22	1026	37	39	94	300	12
23	2220	43	51	105	294	4
24	184	44	48	117	165	3
25	874	46	51	103	303	6
26	1618	40	45	87	330	3
27	2249	45	54	96	327	2
28	345	43	49	108	140	3
29	372	48	52	102	0	1
30	586	50	54	98	62	3
31	144	41	42	91	19	4
SUM	37488	-	-	-	-	-
AVG	1209	41	47	104	275	5

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: LOUDOUN COUNTY, APRIL 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (0001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1666	46	53	103	0	2
2	1877	54	66	103	*	4
3	1772	56	65	109	116	4
4	1111	55	*	112	268	6
5	2289	50	55	125	282	8
6	2136	55	65	140	223	3
7	871	53	64	141	163	3
8	691	59	66	130	137	6
9	1527	60	63	113	162	4
10	761	56	64	108	258	2
11	2206	59	69	109	268	3
12	611	58	66	115	188	3
13	1523	55	60	118	336	5
14	60	55	51	122	*	8
15	696	50	54	102	248	5
16	2152	45	49	94	289	8
17	2292	45	53	111	293	2
18	2235	54	64	122	303	2
19	2189	60	72	130	307	2
20	2099	65	78	144	224	2
21	2251	63	67	151	347	4
22	2007	63	69	145	308	4
23	1867	61	69	134	0	2
24	1769	61	73	128	*	3
25	1735	59	66	121	306	4
26	195	48	49	117	0	2
27	142	49	50	109	28	3
28	235	51	52	105	314	3
29	1290	57	62	95	18	3
30	507	53	*	92	31	5
SUM	42763	-	-	-	-	-
AVG	1425	55	62	118	*	4

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: LOUDOUN COUNTY, MAY 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (0001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1108	59	64	96	316	6
2	1817	65	71	97	323	3
3	2089	67	75	120	280	3
4	2180	71	78	143	296	4
5	1990	73	86	149	255	4
6	1821	72	85	139	252	4
7	1576	67	80	130	*	4
8	1040	54	58	115	270	4
9	1783	51	59	105	294	4
10	2147	60	72	119	173	3
11	842	62	60	131	179	3
12	1369	72	87	129	0	1
13	1617	75	85	125	220	5
14	1329	65	72	121	319	4
15	2227	58	65	119	321	3
16	2177	62	72	129	0	1
17	887	61	69	131	147	3
18	1104	64	67	125	153	3
19	939	69	80	123	0	1
20	334	63	64	112	18	3
21	479	61	62	101	358	3
22	2042	70	81	105	0	2
23	1300	72	83	120	0	2
24	561	69	*	119	0	1
25	1154	71	76	121	328	4
26	2195	66	71	131	334	5
27	1902	65	71	136	304	3
28	2035	71	81	135	252	2
29	1933	74	83	137	0	2
30	1563	72	80	135	134	2
31	1172	73	79	130	190	4
SUM	46711	-	-	-	-	-
AVG	1507	66	74	123	295	3

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: LOUDOUN COUNTY, JUNE 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (0001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1808	75	90	135	209	2
2	859	75	81	139	204	3.
3	947	75	85	127	233	3
4	2122	68	73	128	304	5
5	2044	66	75	138	309	3
6	931	63	70	137	169	3
7	1687	76	90	136	222	3
8	2064	70	80	145	294	6
9	1721	63	73	149	233	6
10	1621	60	64	146	266	3
11	2110	61	70	145	323	2
12	2017	61	71	148	0	2
13	2136	66	79	150	0	1
14	2102	72	82	154	0	1
15	1337	73	88	158	214	3
16	499	63	61	148	322	3
17	2216	64	70	139	312	3
18	1790	64	75	143	158	2
19	1903	69	79	143	158	3
20	2055	67	72	146	267	6
21	1613	70	80	147	265	3
22	2082	73	87	152	0	1
23	2005	75	86	160	0	1
24	1323	75	84	155	188	2
25	1627	74	87	148	0	2
26	1560	73	82	145	0	2
27	1791	81	92	145	262	4
28	1873	82	89	148	192	4
29	*	*	*	*	*	*
30	*	*	*	*	*	*
SUM	51261	-	-	-	-	-
AVG	1709	70	79	145	261	3

* DENOTES UNAVAILABLE DATA.

LOUDOUN COUNTY SCHOOL LONG-TERM WEATHER DATA

COLLECTOR TILT: 37.00 DEGREES
LATITUDE: 39.10 DEGREES

LOCATION: LEESBURG, VIRGINIA
COLLECTOR AZIMUTH: 15.00 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JUL	3,548	1,818	0.51232	0.894	1,625	0	319	75
AUG	3,200	1,619	0.50575	0.978	1,582	0	267	74
SEPT	2,646	1,342	0.50728	1.126	1,511	43	100	67
OCT	2,007	1,003	0.49976	1.339	1,343	292	9	56
NOV	1,481	653	0.44061	1.542	1,006	609	0	45
DEC	1,248	483	0.38693	1.615	780	961	0	34
JAN	1,375	571	0.41571	1.580	903	1,020	0	32
FEB	1,836	815	0.44388	1.380	1,125	874	0	34
MAR	2,428	1,125	0.46308	1.184	1,332	719	0	42
APR	3,040	1,460	0.48023	1.023	1,494	357	0	53
MAY	3,467	1,718	0.49551	0.919	1,579	131	57	63
JUN	3,640	1,902	0.52273	0.875	1,664	5	188	71

LEGEND:

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

HBAR - Monthly average daily radiation (modeled from SOLMET) 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.

APPENDIX G

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

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SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

Loudoun County School was in use from July 1979 through June 1980. During this time the solar system operated the entire year minus two week in the fall. This system has been in operation since May of 1977. Since being put into operation, there has been only one major operational problem.

Date	Event
9/79	System down for almost two weeks during a collector pump (P1) replacement. (See Solar Utilization, Page 1-8.)

APPENDIX H

CONVERSION FACTORS

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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		
Natural gas	1021 BTU/cubic feet	979.43×10^{-6} cubic feet/ BTU
Electricity	3412 BTU/kilowatt-hour	293.08×10^{-6} kwh/BTU

[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 I

SENSOR TECHNOLOGY

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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 Weather Measure 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 gage bridge. This strain gage 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 watt meter 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 watt meter 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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