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SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

MASTER

TROY-MIAMI LIBRARY
Troy, Ohio
November 1979 through April 1980
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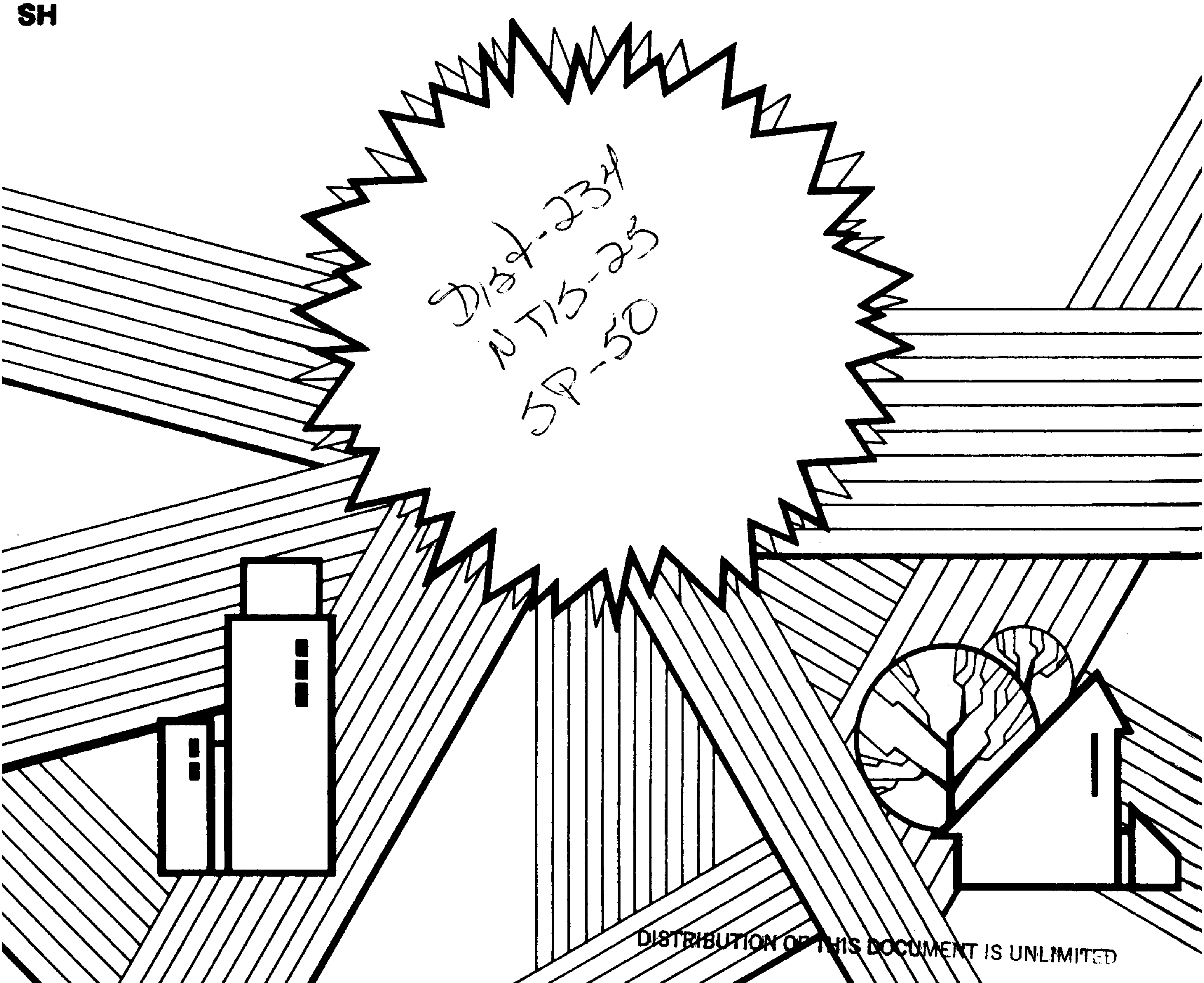

U.S. DEPARTMENT OF ENERGY

NATIONAL SOLAR DATA PROGRAM

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TROY-MIAMI LIBRARY

TROY, OHIO

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

NOVEMBER 1979 THROUGH APRIL 1980

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Vitro Laboratories Division
Automation Industries, Inc.

The National Solar Data Network
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FOREWORD

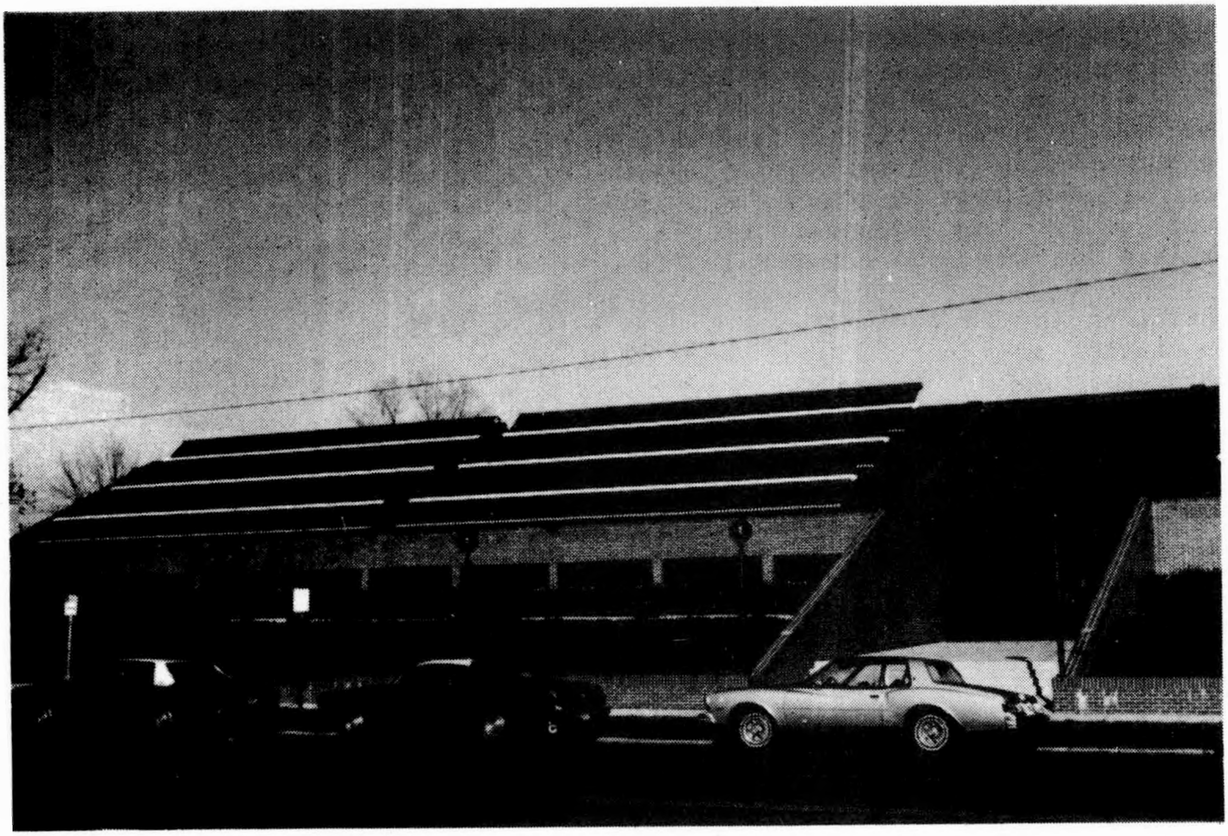
This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic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



TROY-MIAMI LIBRARY

TROY-MIAMI LIBRARY

The Troy-Miami Library is a county public library located in Troy, Ohio. The active solar energy system is designed to supply the following:

Seasonal Design Factors
(Million BTU)

	Total Load	Solar Contribution	% Solar
Heating	420.60	290.20	69

It is equipped with:

Collector 3,264 square feet of Owens-Illinois Sunpak Shaped Reflector evacuated glass tube collectors

Storage A 5,000-gallon, steel-lined, fiberglass water tank which is buried outside the building.

Auxiliary Electric convection space heaters

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SECTION 1

SOLAR SYSTEM PERFORMANCE
TROY-MIAMI LIBRARY

NOVEMBER 1979 THROUGH APRIL 1980

The solar system performance can be briefly summarized: solar fraction[1], 31%; solar savings ratio[2], 0.20; conventional fuel savings[3], 11,421 kwh; system performance factor[4], 0.29; solar system COP[5], 2.96.

Solar energy was required only for space heating. The total heating load for the entire heating season was 190.35 million BTU of which 58.85 million BTU or 31% were supplied by solar energy.

Pertinent environmental data include the average outdoor temperature for the entire heating season, 36°F, compared with the long-term average of 37°F; the average daily incident solar energy for the season, 927 BTU/ft^2, against the long-term, 937 BTU/ft^2; the total heating degree-days for the whole season, 5,303, against the long-term total of 5,085.

1. $$\text{Solar Fraction} = \frac{\text{Solar Energy Supplied to Loads}}{\text{Total Load}} \times 100$$

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

3. Conventional Fuel 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.

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

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

1.1 SUMMARY AND CONCLUSIONS

The Troy-Miami Library solar energy system supplied 31% of the space heating required for this library during the heating season of November 1979 through April 1980. The overall performance of the solar system was below estimated design expectations during this season. The solar system was expected to supply 69% of the space heating load. Control problems in the storage-to-load loop and low solar use due to the electric heater/solar coil arrangement in three air handling units reduced the overall performance (see Space Heating). The thermal performance is summarized in Table 1.

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

TROY-MIAMI LIBRARY
NOVEMBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	SOLAR ENERGY USED	AUXILIARY SAVINGS	OPERATING ENERGY	ENERGY SAVINGS	SOLAR FRACTION (%)
			MEASURED	ELECTRICAL		ELECTRICAL	MEASURED
NOV	21.30	10.85	8.08	2.77	6.78	4.57	74
DEC	16.58	34.78	6.29	28.50	9.84	3.84	19
JAN	20.47	48.19	6.99	41.20	14.13	3.66	15
FEB	9.45	49.22	6.45	42.77	16.53	3.72	13
MAR	31.52	33.96	20.86	13.10	12.64	16.70	61
APR	28.16	13.35	10.18	3.16	8.59	6.49	76
TOTAL	127.48	190.35	58.85	131.50	68.51	38.98	-
AVERAGE	21.25	31.73	9.81	21.92	11.42	6.50	31

The collector array efficiency was 23%. (This efficiency is based on the total solar radiation incident on the array.) The collector array efficiencies for November 1979 through April 1980 (excluding March) were approximately 40% lower than the manufacturer's stated single-panel efficiency. Cloudy weather during February substantially reduced collector efficiency for that month. The collector array tilt probably reduces the overall efficiency. The array is tilted to an altitude angle of 40 degrees from the horizontal. The optimum tilt angle for a system at a latitude of 40 degrees is 55 degrees (latitude plus 15 degrees).

Control problems reduced the collector subsystem efficiencies for November through February.

No storage energy was used during the months of November and December, and very little was used during January and February. A differential controller in the storage loop was broken during these months (see Storage Performance).

The collector-to-space heating modes supplied the majority of the solar energy to the loads for every month but March, which had an equal contribution from storage. The solar system would have performed very poorly without the collector-to-space heating modes. Auxiliary electric energy satisfied most of the heating load during December, January, and February to compensate for the lack of solar energy used.

Anomalies, which occurred during the heating season of November 1979 through April 1980 and impacted upon system performance, include:

- The collector pump controls were set such that the collector pumps P2/P3 operated except when the storage-to-space heating pump P1 was on. This occurred from July 1979 through February 1980 and the month of April 1980. The two pumps, P2/P3 and P1, cannot pump water to the space heating subsystem simultaneously, so one pump has to switch off while the other is on. There was a pump running continually from September 1979 through February 1980. This problem caused the operating energy to increase. It also affected solar energy collection because the operation of pump P1 sometimes preempted the collector pump operation.

- The space heating pump operated continually when the collector pump was off. This problem occurred from September 1979 through February 1980 and caused an unnecessary expenditure of operating energy.

On April 22, 1980, the solar energy system was switched to the summer operating mode. After this date, the system operated in the collector-to-storage mode and no energy went to the heating load. The electric chiller operated during the summer months.

1.2 OVERALL SYSTEM PERFORMANCE

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

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

The Troy-Miami Library solar system has not performed up to the design expectations of a 69% solar fraction this past heating season. The months that reduced system performance were December, January, and February, when there was a large load and little solar deliverable because of control problems. One major reason for this mediocre performance was that auxiliary electrical energy was utilized for space heating before the available solar energy was used (see Space Heating).

A differential controller in the storage loop broke and little or no storage energy was used for the first three and a half months of the heating season (see Storage). Also, the collector and space heating pumps operated continually for a large part of the heating season. The controls were arranged such that either the collector pump or the space heating pump would be operating. When one pump turned off, the other pump would immediately activate.

However, some improvements took place when the differential controller was fixed in February and a control workaround was instituted in three of the air handling units. This workaround enabled the space heating requirement to give priority to the use of solar energy before use of the backup auxiliary system.

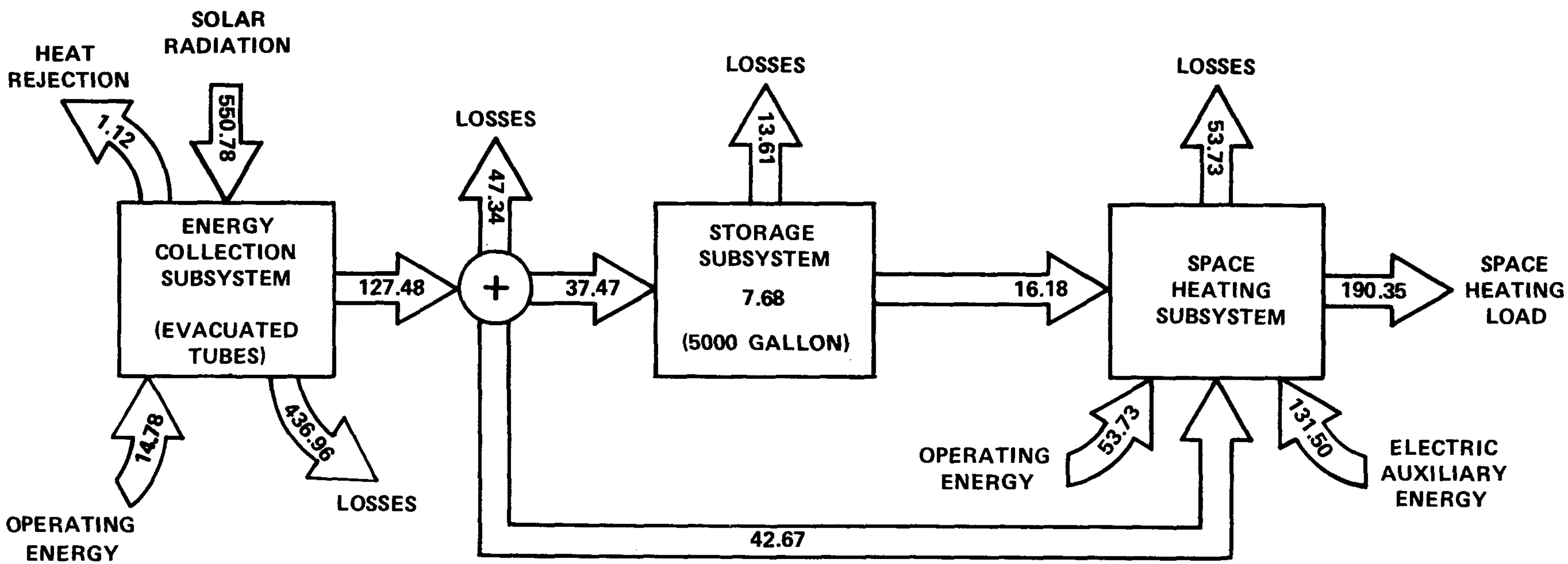
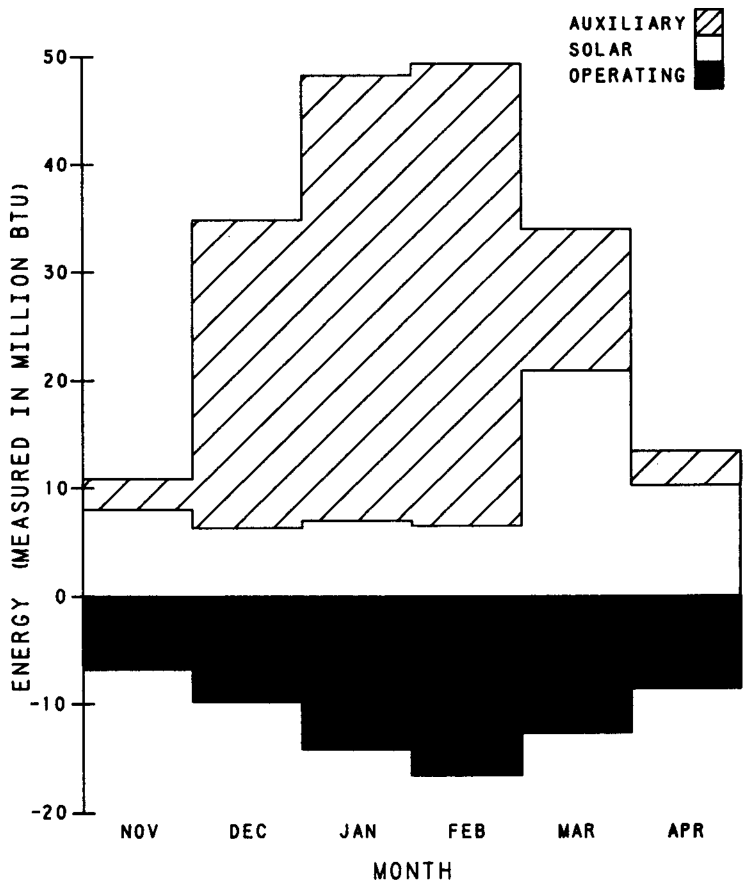


Figure 1. Energy Flow Diagram for Troy-Miami Library
November 1979 through April 1980
(Figures in million BTU)

A photocell cutoff was installed during the summer of 1980 to shut down the collector pumps at night and activate them when good insolation is available. This modification should reduce the system operating energy and the nighttime losses through the collector panels and associated piping.

The Troy-Miami Library solar system did save 11,421 kwh this past heating season. At an electrical cost of five cents per kwh, these savings amount to $571.05. The system is expected to save even more energy during the next heating season after system modifications are completed.



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
Troy-Miami Library
November 1979 through April 1980

The solar energy coefficient of performance (COP) is indicated in Table 2. The COP simply provides a numerical value for the relationship of solar energy used or collected and the energy required to collect or deliver it. The greater the COP value, the more efficient the subsystem. The solar energy system at the Troy-Miami Library functioned at a reporting period weighted average COP value of 2.96 for the period November 1979 through April 1980.

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

TROY-MIAMI LIBRARY
NOVEMBER 1979 THROUGH APRIL 1980

MONTH	SOLAR ENERGY SYSTEM	COLLECTOR SUBSYSTEM	SPACE HEATING SUBSYSTEM
NOV	2.30	7.37	13.03
DEC	2.58	7.64	23.30
JAN	2.10	6.94	18.39
FEB	2.35	4.70	8.84
MAR	5.03	15.68	9.75
APR	2.76	10.24	10.83
AVERAGE	2.96	8.63	11.58

The difference between the subsystem COPs and the system COP is due to the low solar utilization at the site and the power required to run the collector pumps. The COP for the collector subsystem is low, due to the power required by the collector pumps. System COP is calculated as the total solar energy supplied to loads divided by the total solar operating energy. The low system COP is expected, when one considers that less than one-half of the solar energy collected was used by the load.

1.3 ENERGY SAVINGS

Energy savings for this site for the reporting period, November 1979 to April 1980, are presented in Table 3 and shown graphically in Figure 3. For this six-month period, the total savings were 53.76 million BTU, for a monthly average of 8.96 million BTU. This is approximately 15,752 kwh of electricity. An energy expense of 14.78 million BTU was incurred during the reporting period for the operation of solar energy components.

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

Table 3. ENERGY SAVINGS

TROY-MIAMI LIBRARY
NOVEMBER 1979 THROUGH APRIL 1980

(All values in million BTU)

MONTH	SOLAR ENERGY USED	SOLAR ENERGY SAVINGS ATTRIBUTED TO SPACE HEATING: ELECTRICAL	ECSS OPERATING ENERGY	NET ENERGY SAVINGS
NOV	8.08	7.46	2.89	4.57
DEC	6.29	6.01	2.17	3.84
JAN	6.99	6.61	2.95	3.66
FEB	6.45	5.73	2.01	3.72
MAR	20.86	18.71	2.01	16.70
APR	10.18	9.24	2.75	6.49
TOTAL	58.85	53.76	14.78	38.98
AVERAGE	9.81	8.96	2.46	6.50

Operation of the solar system provided a net electrical savings of 38.98 million BTU. These savings are equivalent to 11,421 kwh of electrical energy. At an electrical cost of five cents per kwh, these savings amount to $571.05.

The low monetary value of energy savings at Troy-Miami Library may be due to the fact that in three of the air handling units the electric auxiliary heaters are situated in front of the solar heating coils. The heating system was able to draw upon the electric heaters before it could select the circulation of available solar-heated water through the air handling coils.

The auxiliary source at the Troy-Miami Library consists of electric heat strips and heating coils. These units are considered to be 100% efficient for computational purposes.

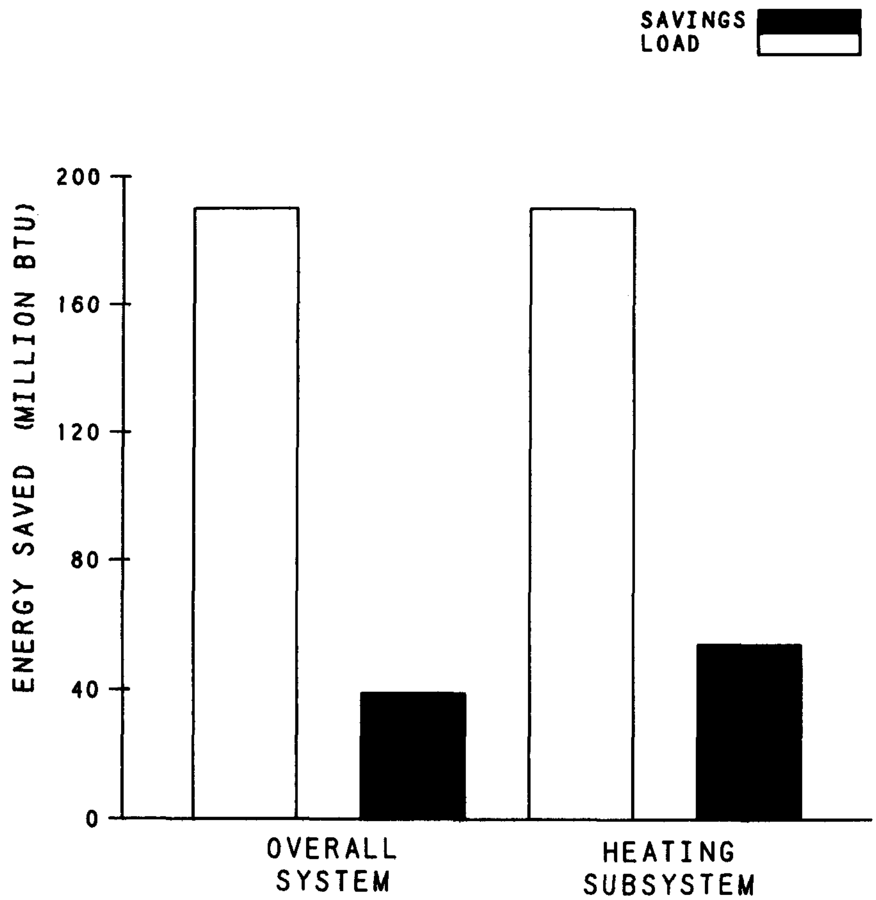


Figure 3. Combined Thermal Energy Savings Compared to Load
Troy-Miami Library
November 1979 through April 1980

1.4 SOLAR ENERGY UTILIZATION

Figure 4 shows the use of solar energy and the percentage of losses.

The losses of solar energy at the different stages through the system, from incident radiation to the load, are also presented in Table 4.

Of the total incident solar energy, 16% was lost for two reasons:

1. The low level of insolation in the early morning and late afternoon was not enough to initiate flow in the collector pumps, and

2. The space heating pump P1 was sometimes on during periods of good insolation, thus preventing the collector pump P2/P3 from operating. Both pumps (P1 and P2/P3) cannot be on simultaneously in a heating mode. If energy from storage is called for, then there can be no solar energy collection until either of the collector-to-space heating modes is activated.

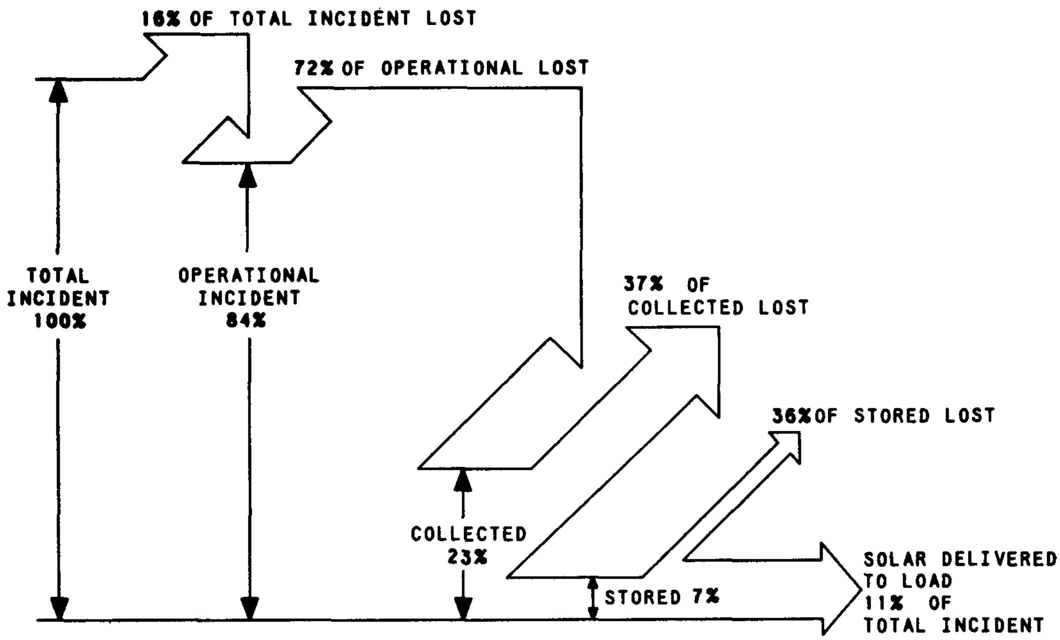


Figure 4. Solar Energy Use
Troy-Miami Library
November 1979 through April 1980

Of the operational incident energy, 72% was lost due to collector inefficiency. Energy rejected through the collector subsystem (see Collector) is defined as a negative value. This energy accounts for 11% of the operational incident energy lost.

The loss of 37% of the collected energy was primarily due to line losses in the collector subsystem loop.

The storage tank lost 36% of its stored energy. This was due to the storage tank being buried outside the library, possible wet tank insulation, and low demand for energy from storage.

Energy can go directly from the collectors to the space heating load. This accounts for the arrow widening from Stored to Solar Delivered to Load.

Table 4. SOLAR ENERGY LOSSES

TROY-MIAMI LIBRARY
NOVEMBER 1979 THROUGH APRIL 1980

		MONTH					
		NOV	DEC	JAN	FEB	MAR	APR
1.	SOLAR ENERGY (SE) COLLECTED - SE DIRECTLY TO LOADS (million BTU)	13.22	10.29	13.94	5.24	20.66	21.46
2.	SE TO STORAGE (million BTU)	1.88	1.98	9.84	3.37	14.28	6.12
3.	LOSS - COLLECTOR TO STORAGE (%)	53	50	20	20	20	54
4.	CHANGE IN STORED ENERGY (million BTU)	-1.16	-0.33	3.83	0.38	3.06	1.90
5.	SOLAR ENERGY - STORAGE TO SPACE HEATING SUBSYSTEM (million BTU)	0.00	0.00	0.46	2.24	10.00	3.48
6.	LOSS FROM STORAGE (%)	162	117	56	22	9	12
7.	HEATING SOLAR ENERGY (HSE) FROM STORAGE (million BTU)	0.00	0.00	0.46	2.24	10.00	3.48

1.5 SOLAR SYSTEM AVAILABILITY

The solar system was operational for the entire heating season of November 1979 through April 1980.

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The Troy-Miami Library collector array is composed of 102 Owens-Illinois Sunpak Shaped Reflector evacuated glass tube collectors which use water as the heat transfer fluid. Collector subsystem performance for the Troy-Miami Library is presented in Table 5.

Table 5. COLLECTOR SUBSYSTEM PERFORMANCE

TROY-MIAMI LIBRARY
NOVEMBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY	OPERATIONAL COLLECTOR EFFICIENCY (%)	ECSS OPERATING ENERGY	SOLAR ENERGY DIRECTLY TO LOAD SUBSYSTEMS	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE (°F)
NOV	93.62	21.30	23	86.48	25	2.89	8.08	1.88	47
DEC	75.32	16.58	22	60.10	28	2.17	6.29	1.98	37
JAN	92.85	20.47	22	77.08	27	2.95	6.53	9.84	30
FEB	72.79	9.45	13	43.58	22	2.01	4.21	3.37	-
MAR	96.66	31.52	33	81.73	39	2.01	10.86	14.28	45
APR	119.54	28.16	24	114.46	25	2.75	6.70	6.12	57
TOTAL	550.78	127.48	-	463.43	-	14.78	42.67	37.47	-
AVERAGE	91.80	21.25	23	77.24	28	2.46	7.11	6.25	43*

* NOTE: THIS IS A FIVE MONTH AVERAGE.

The operational collector efficiency for March was greater than previous months despite the decrease in available solar energy due to abnormal cloud cover in March. Low storage temperatures (the average storage temperature for March was 107°F) helped the collectors achieve an average 20-25°F temperature difference across the array. The use of Mode 1B (collector-to-load-to-storage) for a large part of March lowered the storage inlet temperature enough to maintain storage at a moderate temperature. The moderate water temperature from storage to the collector array inlet caused the collector efficiency to increase.

Since the collector pumps operated during periods when there was no insolation, a total of 37.78 million BTU was unintentionally rejected from the collector subsystem to the external environment. This rejected energy is sometimes used as collector array freeze protection but is primarily unintentional rejection due to control problems. The unintentionally rejected energy contributes to the collector subsystem losses.

The operating results for the collector subsystem are as follows:

Incident solar radiation for the entire collector array for the six-month period (November 1979-April 1980) was 550.78 million BTU. The incident solar radiation was 463.43 million BTU during the time the collector pumps were operating. Of this amount, 127.48 million BTU were collected and, in turn, 42.67 million BTU were delivered directly to the loads. The collected solar energy transferred to storage was 37.47 million BTU.

The overall collector subsystem efficiency was 23% based on incident solar radiation, and 28% based on solar radiation during the time the collector pumps were operating.

The energy collection and storage subsystem (ECSS) pumps P1, P2, and P3, and the heat purge unit required 14.78 million BTU of operating energy. This includes the solar unique portion of the space heating subsystem's operating energy. The losses from the collector to storage subsystems totaled 47.34 million BTU or 37% of the collected energy.

Low collector subsystem efficiencies for every month but March may be attributed to cloudy weather and control problems that allowed the collectors to activate during periods of no insolation.

2.2 STORAGE

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

During the reporting period, total solar energy delivered to storage was 37.47 million BTU. There were 16.18 million BTU delivered from storage to the space heating subsystem. Energy loss from storage was 13.61 million BTU. This loss represented 36% of the energy delivered to storage. The storage efficiency was 64%. (See Footnote 1.)

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

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

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

Table 6. STORAGE PERFORMANCE

TROY-MIAMI LIBRARY
NOVEMBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY TO STORAGE	ENERGY FROM STORAGE	CHANGE IN STORED ENERGY	STORAGE EFFICIENCY (%)	AVERAGE STORAGE TEMP. (°F)	LOSS FROM STORAGE
NOV	1.88	0.00	-1.16	-62	141	3.04
DEC	1.98	0.00	-0.33	-17	114	2.31
JAN	9.84	0.46	3.83	44	95	5.55
FEB	3.37	2.24	0.38	78	86	0.75
MAR	14.28	10.00	3.06	91	107	1.22
APR	6.12	3.48	1.90	88	137	0.74
TOTAL	37.47	16.18	7.68	-	-	13.61
AVERAGE	6.25	2.70	1.28	64	113	2.27

Due to the extensive data loss in January (16 days of data), the loss from storage value is suspect. The true loss is probably smaller.

Storage performance at Troy-Miami Library was poor from November 1979 through most of February 1980. A differential controller that senses the water temperature in storage with respect to the water temperature in the rest of the system was malfunctioning during this period. As a result, little or no energy was able to go from storage to the heating load. A definite improvement was seen in March after the controller was repaired.

The storage tank losses do not contribute to the heating load because the tank is buried outside the building.

2.3 SPACE HEATING

The space heating performance for the Troy-Miami Library for the reporting period is shown in Table 7 and presented graphically in Figure 5.

The space heating load of 190.35 million BTU was satisfied by 58.85 million BTU of solar energy and 131.50 million BTU of auxiliary energy. The solar fraction of this load was 31% with an operating energy expense of 53.73 million BTU.

The electrical energy savings, for the space heating subsystem only, were 53.76 million BTU or 15,752 kwh. At an electrical cost of five cents per kwh, these savings amount to $787.60. The average building temperature for the season was 72°F.

Table 7. SPACE HEATING SUBSYSTEM

TROY-MIAMI LIBRARY
NOVEMBER 1979 THROUGH APRIL 1980

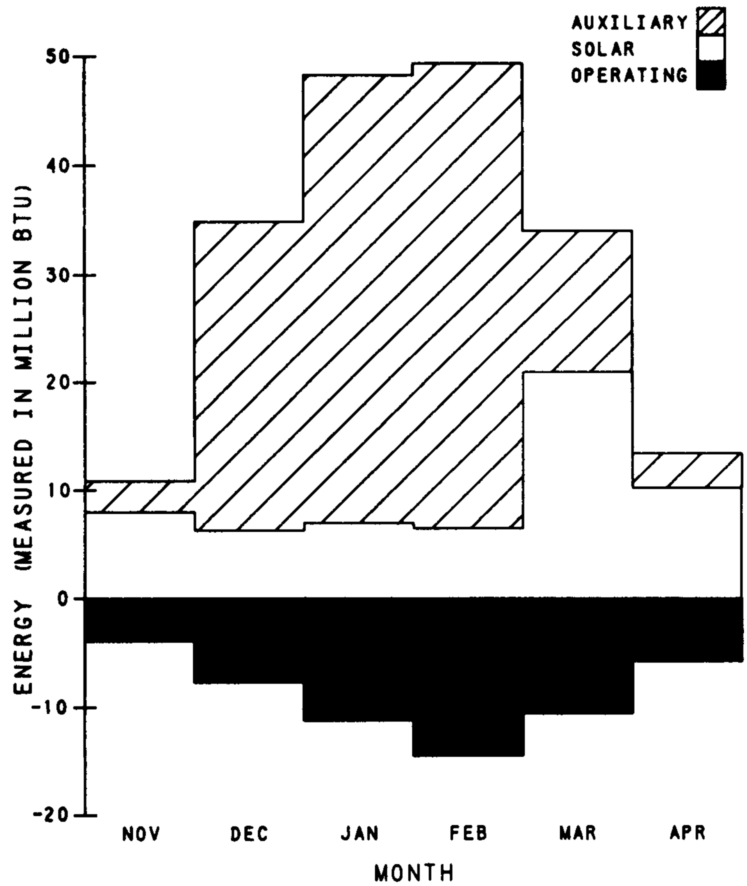
(All values in million BTU, unless otherwise indicated)

MONTH	SPACE HEATING LOAD	ENERGY CONSUMED SOLAR	ENERGY CONSUMED AUXILIARY THERMAL	ENERGY CONSUMED AUXILIARY ELECTRICAL	ENERGY CONSUMED OPERATING ENERGY	SOLAR FRACTION (%)	BUILDING TEMPERATURE (%)
NOV	10.85	8.08	2.77	2.77	3.89	74	72
DEC	34.78	6.29	28.50	28.50	7.67	19	69
JAN	48.19	6.99	41.20	41.20	11.18	15	68
FEB	49.22	6.45	42.77	42.77	14.52	13	69
MAR	33.96	20.86	13.10	13.10	10.63	61	75
APR	13.35	10.18	3.16	3.16	5.84	76	78
TOTAL	190.35	58.85	131.50	131.50	53.73	-	-
AVERAGE	31.73	9.81	21.92	21.92	8.96	31	72

The space heating subsystem did not use solar energy very effectively at Troy-Miami Library. The solar fraction of 31% was low compared to the design solar fraction of 69%.

The problems affecting solar energy use at this site included the previously discussed storage differential controller. Also, electric auxiliary heaters were installed in front of the solar heating coils in three of the air handling units. Plans are now underway to place the three electric heaters in their proper position downstream of the solar coils. These changes should improve the performance of the space heating subsystem. Solar energy will be the primary rather than the secondary supplier of energy to the space heating subsystem.

Energy was sometimes delivered to the space heating subsystem but was never used, because all the air handler fans were off. This happened at night and resulted in some rejection of energy to the external environment and an increase in operational energy.



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

Figure 5. Space Heating Performance
Troy-Miami Library
November 1979 through April 1980

SECTION 3

OPERATING ENERGY

Measured monthly values of the Troy-Miami Library solar energy system and subsystem operating energy for the report period are presented in Table 8. A total 68.51 million BTU of operating energy were consumed by the entire system during the reporting period. A distribution of this operating energy among the subsystems is illustrated in Figure 6.

Total system operating energy for the Troy-Miami Library is the electrical energy required to support the collector and heating subsystems without affecting their thermal states.

Table 8. OPERATING ENERGY

TROY-MIAMI LIBRARY
NOVEMBER 1979 THROUGH APRIL 1980

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY (SOLAR UNIQUE)	SHS OPERATING ENERGY		TOTAL SOLAR UNIQUE OPERATING ENERGY	TOTAL SYSTEM OPERATING ENERGY
		TOTAL	SOLAR UNIQUE		
NOV	2.89	3.89	0.62	3.51	6.78
DEC	2.17	7.67	0.27	2.44	9.84
JAN	2.95	11.18	0.38	3.33	14.13
FEB	2.01	14.52	0.73	2.74	16.53
MAR	2.01	10.63	2.14	4.15	12.64
APR	2.75	5.84	0.94	3.69	8.59
TOTAL	14.78	53.73	5.08	19.86	68.51
AVERAGE	2.46	8.96	0.85	3.31	11.42

All of the solar unique operating energy is due to the collector pumps and the storage pump. The main components in the total system operating energy are the air handling fans.

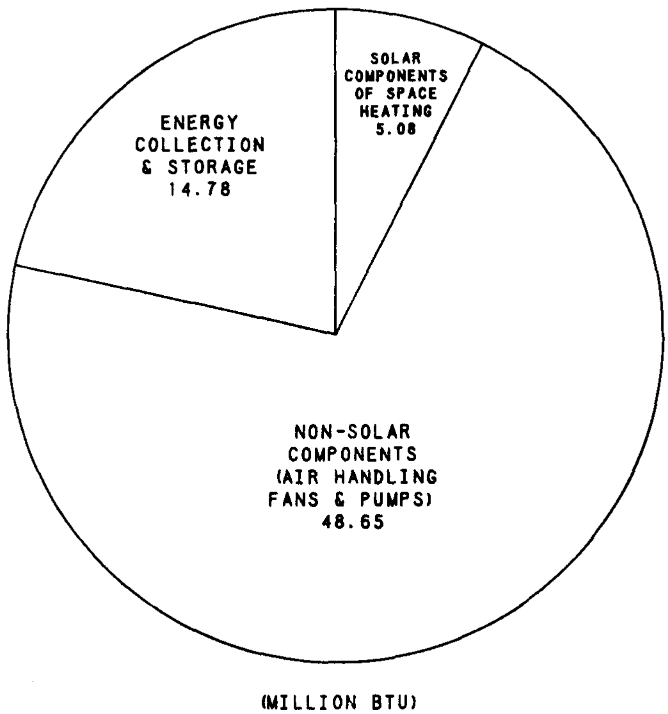


Figure 6. Total Operating Energy
Troy-Miami Library
November 1979 through April 1980

SECTION 4

WEATHER CONDITIONS

The Troy-Miami Library site is located in Troy, Ohio at 40 degrees N latitude and 84 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 9. 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 9. WEATHER CONDITIONS

TROY-MIAMI LIBRARY
NOVEMBER 1979 THROUGH APRIL 1980

	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT^2-DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS	
MONTH	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
NOV	956	800	40	42	743	696
DEC	744	587	33	31	999	1,057
JAN	918	706	28	28	1,144	1,144
FEB	769	943	25	30	1,160	969
MAR	955	1,170	39	39	806	806
APR	1,221	1,413	50	51	451	413
TOTAL	-	-	-	-	5,303	5,085
AVERAGE	927	937	36	37	884	848

During the period from November 1979 through April 1980, the average daily total incident solar radiation on the collector array was 927 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 937 BTU per square foot per day for a plane 27 degrees west of south with a tilt of 40 degrees to the horizontal. During the period, the highest monthly average insolation was 1,221 BTU per square foot per day during April. The average ambient temperature during the reporting period was 36°F as compared with the long-term average for November through April of 37°F. The highest monthly average ambient temperature was 50°F during April, and the lowest monthly average ambient temperature was 25°F during February. The number of heating degree-days for the period (based on a 65°F reference) was 5,303 as compared with the long-term average of 5,085. The range of heating degree-days was from a high of 1,160 during February to a low of 451 during April.

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 38% during April to a low of 26% during February.

MONTH	NOV	DEC	JAN	FEB	MAR	APR
Extra-terrestrial Insolation	*	2,583	2,683	2,937	3,165	3,239
$\frac{\text{TTL INS}}{\text{EXT INS}}$ (%)	*	29	34	26	30	38

* DENOTES UNAVAILABLE DATA.

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

The diffuse insolation data for November 1979 and February 1980 through April 1980 was deleted from this report because the shadow band on the diffuse pyranometer was out of adjustment. See Appendix E under the "Diffuse Insolation" heading for available data.

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

SECTION 5

REFERENCES

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

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

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

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

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

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

*6B. Instrumentation Installation Guidelines, July 1980, Parts 1, 2, and 3, SOLAR/0001-80/15, Vitro Laboratories, Silver Spring, Maryland.

*7. Monthly Performance Report, Troy-Miami Library, November 1979, SOLAR/2029-79/11, IBM, Huntsville, Alabama.

*8. Monthly Performance Report, Troy-Miami Library, January 1980, SOLAR/2029-80/01, Vitro Laboratories, Silver Spring, Maryland.

*9. Monthly Performance Report, Troy-Miami Library, February 1980, SOLAR/2029-80/02, Vitro Laboratories, Silver Spring, Maryland.

*10. Monthly Performance Report, Troy-Miami Library, March 1980, SOLAR/2029-80/03, Vitro Laboratories, Silver Spring, Maryland.

*11. Monthly Performance Report, Troy-Miami Library, April 1980, SOLAR/2029-80/04, 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

SYSTEM

The Troy-Miami Library site is a county library located in Troy, Ohio. The building is a one-story structure with very high ceilings and a basement containing offices and meeting rooms. The total floor area is 23,000 square feet, which is divided into five zones for heating and cooling. The solar energy system is designed to supply 69% of the space heating requirements. No domestic hot water or space cooling is provided by solar energy. Auxiliary energy is provided by electric heating coils in the air-handling units, supplemented by electric baseboard heaters and unit heaters near entryways and in the garage area. The solar heating system and the central chilled water system share common piping through the air handlers, and are isolated from each other by three-way valves which are controlled automatically according to heating or cooling demands. The solar energy system is shown in the site schematic.

The 102 collectors are Owens-Illinois Sunpak, evacuated glass tube type. The collectors face 27 degrees west of south and are tilted 40 degrees from the horizontal. The gross collector area is 3,264 square feet. The collection fluid medium is water with anticorrosion additives. No collector drain-down is utilized, and the collector pumping system is controlled by the tube temperature set point method.

Storage consists of a 5,000-gallon water tank buried outside the building. The tank is insulated by three inches of expanded urethane foam and enclosed in a water-resistant fiberglass jacket.

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

Equipment/Components	Manufacturer	Model No.
Evacuated Tube Collectors	Owens-Illinois	Sunpak Series
Water Storage Tank	Owens-Corning	Noncorroding underground storage tank
Controls	Honeywell	Pneumatic
Air Handling Units	Chrysler Corp.	Airtemp
Circulation pump	Thrush	F
Electric Duct Heaters	Thermatrol Chromalox	MF (open coil) DHOC1 (open coil)
Electric Chiller	Chrysler Corp.	HAW 75-1

The system is shown schematically. It has three primary modes of operation using solar energy. In addition to these primary modes, there are three collector conditioning/protection modes. Also, space heating can be provided by a conventional heating mode which uses electrical power. The solar modes are described in the following paragraphs.

Solar collection is enabled when the water temperature inside the evacuated tubes is raised above 80°F by insolation to the array. The following modes are then selected by control logic.

Mode 1 - Collectors-to-Space Heating - Mode 1 is activated whenever the temperature at temperature control sensor T1 is at or above 120°F and the heating mode has been selected. Once entered, this mode continues until the temperature at temperature control sensor T1 drops to 80°F or until heating requirements are met. In this mode, the water from the collectors is delivered by pumps P2 and P3 through valves V13, V8, and V6 to air handlers AHU1 through AHU5. The return water passes through V1, V9 and V12 and back to the collectors. Mode 1 incorporates two submodes which differ by the path of the heating return water. In submode 1A, the return water bypasses storage, flowing straight through valve V12 back to the collectors. In submode 1B, return water is directed to the water thermal storage through V10, then through V11, the bottom port of V12, and back to the collectors. The selection of submode 1A or 1B is determined by the difference between temperature control sensors T5 and T6. Submode 1B is entered when the temperature of temperature control sensor T5 exceeds that of temperature control sensor T6 by at least five degrees, and continues as long as the temperature of temperature control sensor T5 is at least two degrees greater than that of temperature control sensor T6. In submode 1B, valves V10 and V11 are set to deliver water to the storage tank at the upper level and extract water from storage at the lower level.

Mode 2 - Storage-to-Space Heating - This mode is entered when the temperature at temperature control sensor T1 drops below 80°F. The system continues in this mode as long as the temperature of temperature control sensor T1 is less than 120°F, the temperature of temperature control sensor T4 is greater than 75°F, and heating is selected. In mode 2, pump P1 is on and pumps P2 and P3 are off. Flow for this mode goes from the upper level of water thermal storage through valves V11, V12, V13, and V8, through pump P1 to the air handlers, and returns to the lower level of storage through valves V9 and V10. If the temperature of temperature control sensor T1 again rises to 120°F, mode 1 is reactivated by opening valve V6, turning off pump P1, turning on pumps P2 and P3, and repositioning valve V13. If the temperature of temperature control sensor T4 drops below 75°F, valve V8 is closed, pump P1 is turned off, and valve V9 is repositioned to block return flow from the air handlers. In the latter condition, conventional electric heat is used to support the heating load.

Mode 3 - Collectors-to-Storage - This mode is entered when the temperature at temperature control sensor T1 is at or above 120°F and the heating mode has not been selected. The mode is terminated when the controller-sensed temperature at temperature control sensor T1 drops below 120°F or when the heating system is activated.

In mode 3, valve V8 is closed and valve V9 is repositioned so that water from the collectors (after passing valve V13) flows through the top port of valve V9.

As in the case of mode 1, there are two submodes for mode 3. The selection of the submodes is determined by the difference between the temperatures of temperature constrol sensors T5 and T6. If the temperature at temperature control sensor T5 exceeds that of temperature control sensor T6 by at least five degrees, the flow passes through valve V10, into storage, and returns to the collectors through valves V11 and V12. When the temperature at temperature control sensor T5 no longer exceeds that of temperature control sensor T6 by at least two degrees, the water thermal storage is bypassed.

COLLECTOR ARRAY - FREEZE PROTECTION-CONDITIONING

The collector conditioning/protection modes are used to prevent freezing of the collectors in the winter and overheating of the collectors during summer or other high collection/low load times.

Freeze Protection Mode A - When the outside air temperature falls below 40°F while valve V13 is set to bypass the collectors, valve V14 opens and pumps P2 and P3 run for ten minutes out of every four hours. This mode continues until the collector discharge temperature (T2) cannot be maintained above 40°F. Under that condition, Freeze Protection Mode B is entered.

Freeze Protection Mode B - This mode is entered when the collector discharge temperature cannot be maintained above 40°F by Freeze Protection Mode A. When this mode is entered, valve V13 is positioned to allow flow straight through toward valve V8, valve V8 is closed, and valve V9 is positioned to accept flow through its top port and return the flow to the water thermal storage through valve V10. Storage tank water is then drawn through valves V11 and V12 and through the collectors by pumps CP2 and CP3. This mode remains in operation until the collector discharge temperature (T2) reaches 55°F. The system then returns to the normal operating sequence, with Freeze Protection Mode A enabled if adverse conditions still prevail.

Collector Heat Purge Conditioning Mode - This mode is entered when collector discharge temperature (T2) rises to 225°F. At this point, the purge fan is turned on, and its exhaust dampers are opened. This reduces excessive heat buildup in the collection system, preventing damage to the collector array and/or venting of steam to the atmosphere.

SUBSYSTEMS

Collector

The gross collector array area (gross panel area x number of panels) is 3,264 ft^2. The collectors face in a southwesterly direction at an azimuth angle of 27 degrees west of south. The collectors are tilted to an altitude angle of 40 degrees from the horizontal. The collector is positioned for solar heating and the possible future addition of solar cooling.

The 102 Owens-Illinois Sunpak Shaped Reflector collector panels have borosilicate glass cylinders and a selective absorber tube. The specular reflectors collect diffuse radiation and reflect it to the tubes. The absorber surface has a solar absorptivity of 0.86 and an infrared emissivity of 0.07. Total solar transmissivity of the glazing is 0.92. The absorber surface is plated with a semiconductor type coating. The fluid circulated through the collectors is water with anticorrosion inhibitors added.

Storage

Solar energy storage is provided by a 5,000-gallon steel storage tank which is encased in a fiberglass shell and buried about four feet deep outside the building. The tank has three inches of polyurethane foam at the bottom and three inches of polyurethane foam on the top and side. Water is used as the medium to transfer solar energy to the space heating subsystem.

Space Heating

The space heating subsystem consists of three Thermatrol open-coil electric duct heaters (Model MF) and five Chromalox DHOC1 open-coil electric duct heaters. Both solar energy and auxiliary energy are utilized through five Chrysler Airtemp air handling units. The system has five air handling units designed to deliver a total of 0.48 million BTU/hour to satisfy the building heating load. The design solar fraction is 69%.

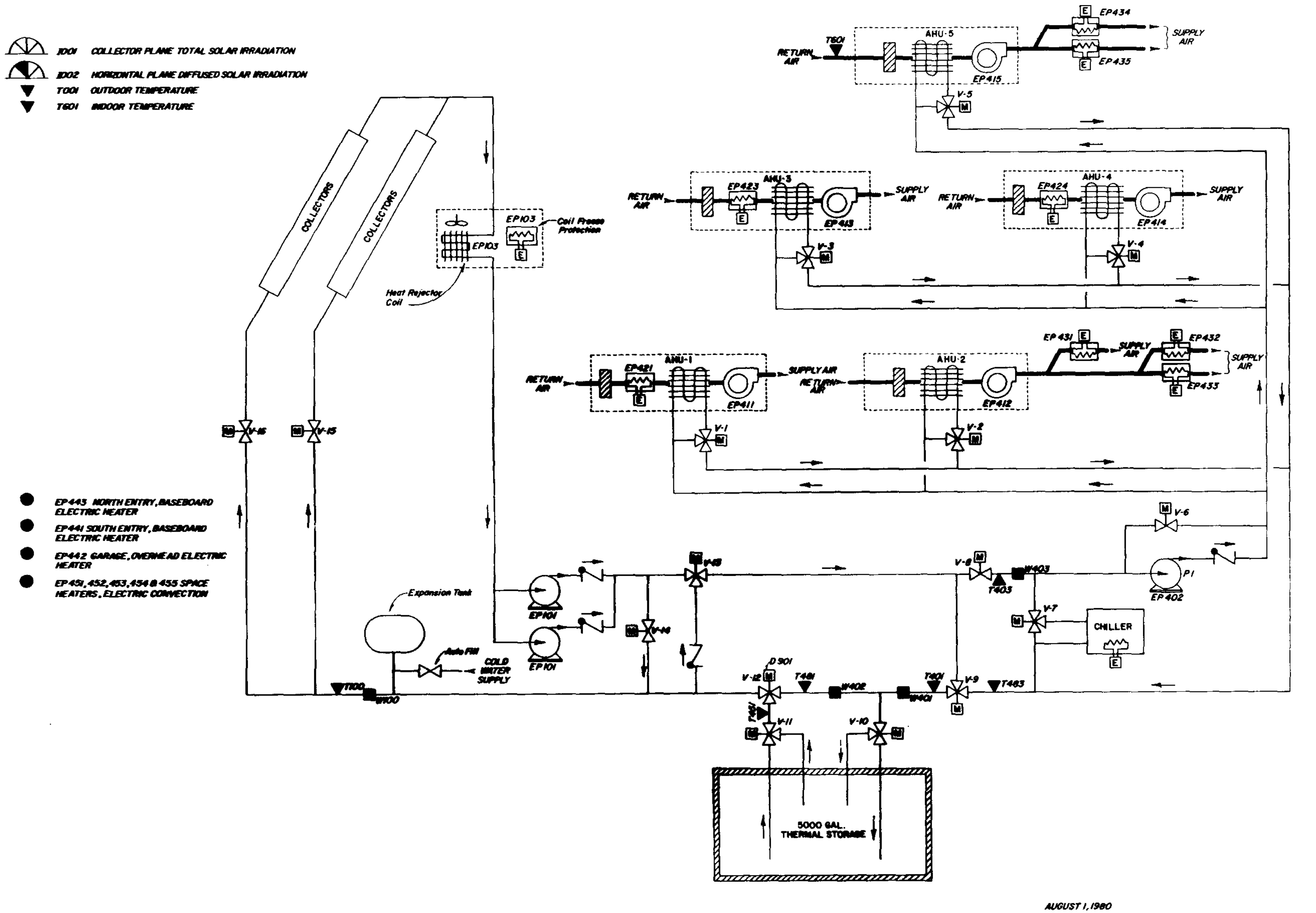


Figure A-1. Troy-Miami Library Solar Energy System Schematic

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Troy-Miami Library 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.

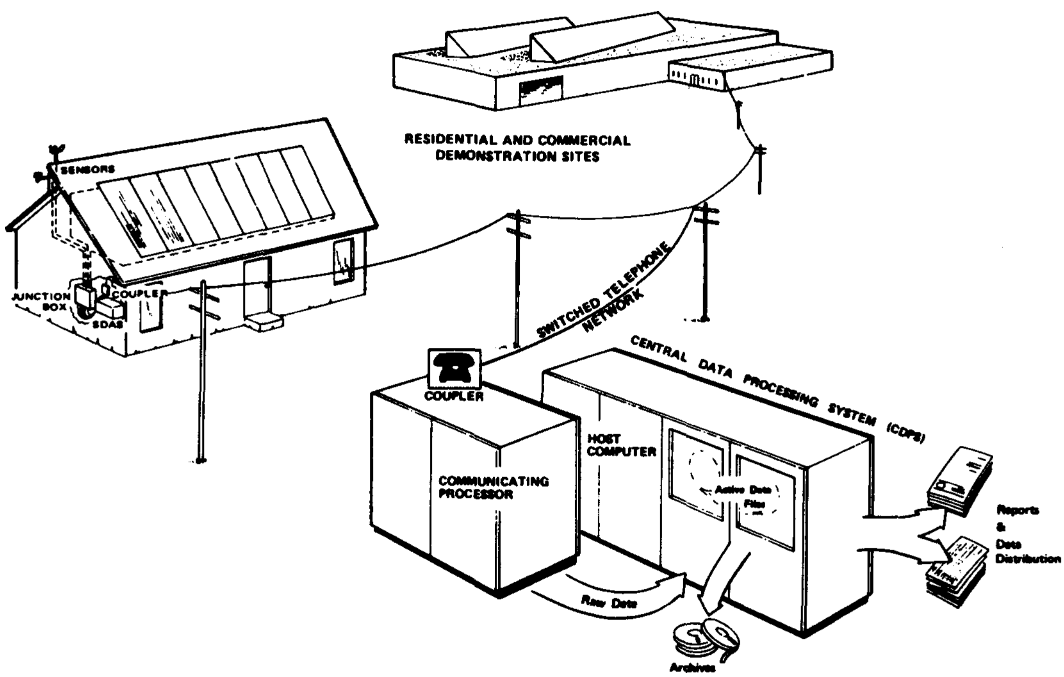


Figure B-1. The National Solar Data Network

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 Troy-Miami Library solar energy system from November 1979 through April 1980 was analyzed during the heating 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.

The performance factors in this report will differ from the values in the published reports. The site software was revised to reflect a better understanding of the solar system operation at Troy-Miami Library.

OTHER DATA REPORTS ON THIS SITE*

Monthly Performance Reports:

June 1979, SOLAR/2029-79/06
July 1979, SOLAR/2029-79/07
August 1979, SOLAR/2029-79/08
September 1979, SOLAR/2029-79/09
November 1979, SOLAR/2029-79/11
January 1980, SOLAR/2029-80/01
February 1980, SOLAR/2029-80/02
March 1980, SOLAR/2029-80/03
April 1980, SOLAR/2029-80/04
September 1980, SOLAR/2029-80/09

* 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

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.

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

Fixed Collector	A solar collector that is fixed in position and cannot be rotated to follow the sun daily or seasonably.
Flat Plate Collector	A solar energy collecting device consisting of a relatively thin panel of absorbing material. A container with insulated bottom and sides and covered with one or more covers transparent to visible solar energy and relatively opaque to infrared energy. Visible energy from the sun enters through the transparent cover and raises the temperature of the absorbing panel. The infrared energy re-radiated from the panel is trapped within the collector because it cannot pass through the cover. Glass is an effective cover material (see Selective Surface).
Focusing Collector	A concentrating type collector using parabolic mirrors or optical lenses to focus the energy from a large area onto a small absorbing area.
Fossil Fuel	Petroleum, coal, and natural gas derived fuels.

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

Nocturnal Radiation	The loss of thermal energy by the solar collector to the night sky.
Operating Energy	The amount of energy (usually electrical energy) required to operate the solar and auxiliary equipments and to transport the thermal energy to the point of use, and which is not intended to directly affect the thermal state of the system.
Operating Point	A solar energy system has a dynamic operating range due to changes in level of insolation (I), fluid input temperature (T), and outside ambient temperature (Ta). The operating point is defined as: $\frac{Ti-Ta}{I}$ $\frac{°F \times hr. \times sq. ft.}{BTU}$
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 parameter in a system, such as temperature or flow rate, for the purpose of measurement or control.
Solar Conditioned Space	The area in a building that depends on solar energy to provide a fraction of the heating and cooling needs.
Solar Fraction	The fraction of the total load supplied by solar energy. The ratio of solar energy supplied to loads divided by total load. Often expressed as a percentage.
Solar Savings Ratio	The ratio of the solar energy supplied to the load minus the solar system operating energy, divided by the system load.
Storage Efficiency, N_s	Measure of effectiveness of transfer of energy through the storage subsystem taking into account system losses.
Storage Subsystem	The assembly of components used to store solar-source energy for use during periods of low insolation.
Stratification	A phenomenon that causes a distinct thermal gradient in a heat transfer fluid, in contrast to a thermally homogeneous fluid. Results in the layering of the heat transfer fluid, with each layer at a different temperature. In solar energy systems, stratification can occur in liquid storage tanks or rock beds, and may even occur in pipes and ducts. The temperature gradient or layering may occur in a horizontal, vertical or radial direction.
System Performance Factor	Ratio of system load to the total equivalent fossil energy expended or required to support the system load.
Ton of Refrigeration	The heat equivalent to the melting of one ton (2,000 pounds) of ice at 32°F in 24 hours. A ton of refrigeration will absorb 12,000 BTU/hr, or 288,000 BTU/day.
Tracking Collector	A solar collector that moves to point in the direction of the sun.
Zone	A portion of a conditioned space that is controlled to meet heating or cooling requirements separately from the other space or other zones.

SECTION 3. ABBREVIATIONS

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

APPENDIX D

PERFORMANCE EQUATIONS

TROY-MIAMI LIBRARY

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 $\bar{C}_p$ 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

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

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

Letter Designations

C	=	Specific Heat
D	=	Direction or Position
EE	=	Electric Energy
EP	=	Electric Power
F	=	Fuel Flow Rate
I	=	Incident Solar Flux (Insolation)
N	=	Performance Parameter
P	=	Pressure
PD	=	Differential Pressure
Q	=	Thermal Energy
T	=	Temperature
TD	=	Differential Temperature
V	=	Velocity
W	=	Heat Transport Medium Mass Flow Rate
TI	=	Time

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

EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

AVERAGE AMBIENT TEMPERATURE (°F)

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

AVERAGE BUILDING TEMPERATURE (°F)

$TB = (1/60) \times \Sigma\ [T601] \times \Delta\tau$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

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

for ± three hours from solar noon

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

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

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

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

when the collector loop is active

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$SECA = \Sigma\ [M100 \times HWD \times (T180 - T100)] \times \Delta\tau$

where HWD is the abbreviation for:

$1.01146\ (TH-TL) - 1.17403 \times 10^{-4}\ (TH^2 - TL^2) + 3.457 \times 10^{-7}\ (TH^3 - TL^3)$
and TH is the first temperature in parentheses and TL is the second.

SOLAR ENERGY TO STORAGE (BTU)

If M100 > zero, than $STEI = \Sigma\ M100 \times HWD \times (T401 - T451)$

If M403 > zero, than $STEI = \Sigma\ M403 \times HWD \times (T401 - T451)$

SOLAR ENERGY FROM STORAGE (BTU)

$STEO = \Sigma\ M403 \times HWD \times (T451 - T401)$

AVERAGE TEMPERATURE OF STORAGE (°F)

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

ENERGY DELIVERED FROM ECSS TO SPACE HEATING SUBSYSTEM (BTU)

$CSEO = \Sigma\ [M403 \times HWD \times (T403 - T483)] \times \Delta\tau$

ECSS OPERATING ENERGY (BTU)

$$CSOPE = 56.8833 \times \Sigma\ [(1 - 0.5 \times SHFL) \times EP101 + EP103]$$

where SHFL is the space heating flag which is equal to one for space heating and equal to zero when not in the space heating mode.

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$$HOPE = 56.8833 \times \Sigma\ [EP411 + EP412 + EP413 + EP414 + EP415 + EP402 + 0.5 \times SHFL \times EP101] \times \Delta\tau$$

when system is in the storage-to-space heating mode

$$HOPE1 = 56.8833 \times 0.5 \times \Sigma\ EP101 \times \Delta\tau$$

if EP101 is on and EP402 is off

SOLAR UNIQUE OPERATING ENERGY

$$HOPE1 = 56.8833 \times EP402$$

if EP101 is off and EP402 is on

SOLAR ENERGY TO SPACE HEATING SUBSYSTEM (BTU)

$$HSE = CSEO$$

SPACE HEATING DIRECT FROM COLLECTOR

$$SHDF\_COL = \Sigma\ (M403) \times HWD \times (T403 - T483)$$

SPACE HEATING SUBSYSTEM AUXILIARY ELECTRICAL FUEL ENERGY (BTU)

$$HAE = 56.8833 \times \Sigma\ (EP421 + EP423 + EP424 + EP431 + EP432 + EP433 + EP434 + EP435 + EP441 + EP442 + EP443 + EP451 + EP452 + EP453 + EP454 + EP455) \times \Delta\tau$$

SPACE HEATING SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$$HAT = HAE$$

SPACE HEATING SUBSYSTEM LOAD (BTU)

$$HL = CSEO + HAE$$

BUILDING TEMPERATURE (°F)

$$TOFF = (1/60) \times \Sigma\ T601 \times \Delta\tau$$

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$$SEA = CLAREA \times SE$$

COLLECTED SOLAR ENERGY (BTU)

SEC = SECA/CLAREA

COLLECTOR ARRAY EFFICIENCY

CAREF = SECA/SEA

CHANGE IN STORED ENERGY (BTU)

$STECH = STECH1 - STECH1_p$

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

STORAGE EFFICIENCY

STEFF = (STECH + STEO)/STEI

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

SEL = CSEO

ESCC SOLAR CONVERSION EFFICIENCY

CSCEF = SEL/SEA

SPACE HEATING SUBSYSTEM SOLAR FRACTION (PERCENT)

HSFR = 100 x HSE/HL

SPACE HEATING SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

HSVE = HSE - HOPE1

SYSTEM LOAD (BTU)

SYSL = HL

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

SFR = HSFR

AUXILIARY ELECTRICAL ENERGY TO LOADS (BTU)

AXE = HAE

SYSTEM OPERATING ENERGY (BTU)

SYSOPE = HOPE + CSOPE

TOTAL ENERGY CONSUMED (BTU)

TECSM = SYSOPE + AXE + SECA

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

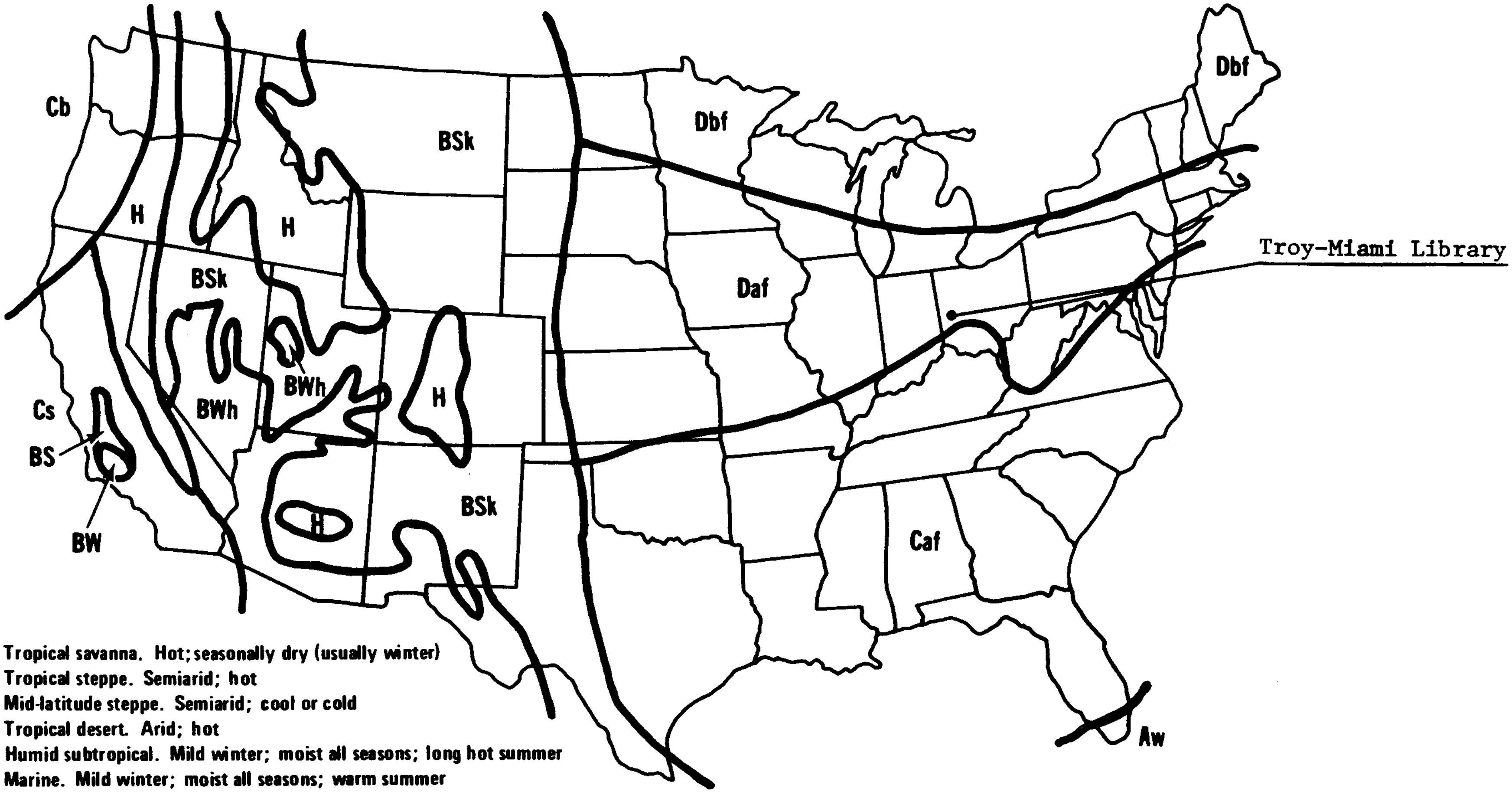
TSVE = HSVE - CSOPE

SYSTEM PERFORMANCE FACTOR

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

APPENDIX E

METEOROLOGICAL CONDITIONS



KEY

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

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

Figure E-1. Meteorological Map of the United States Showing Troy-Miami Library Location

TROY-MIAMI LIBRARY LONG-TERM WEATHER DATA

COLLECTOR TILT: 40 DEGREES
LATITUDE: 39 DEGREES

LOCATION: TROY, OHIO
COLLECTOR AZIMUTH: 27 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
NOV	1,513	564	0.37295	1.417	800	696	0	42
DEC	1,281	406	0.31669	1.447	587	1,057	0	31
JAN	1,407	490	0.34856	1.439	706	1,144	0	28
FEB	1,865	726	0.38940	1.299	943	969	0	30
MAR	2,452	1,025	0.41806	1.141	1,170	806	0	39
APR	3,054	1,405	0.46000	1.006	1,413	413	5	51

LEGEND:

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

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

KBAR - Ratio of HBAR to HOBAR.

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

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

HDD - Number of heating degrees-days per month.

CDD - Number of cooling degrees-days per month.

TBAR - Average ambient temperature in degrees Fahrenheit.

MONTHLY REPORT: TROY-MIAMI LIBRARY
NOVEMBER 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	DIFFUSE INSOLATION BTU/SQ. FT	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	95	I	49	*
2	1012	I	41	49
3	1491	I	40	48
4	1808	I	39	48
5	*	I	*	*
6	*	I	*	*
7	746	I	38	41
8	*	I	*	*
9	*	I	*	*
10	133	I	39	39
11	800	I	33	37
12	1790	I	33	41
13	705	I	35	40
14	1623	I	35	*
15	*	I	*	*
16	1380	I	40	45
17	1633	I	45	55
18	1566	I	48	59
19	*	I	*	*
20	1212	I	51	59
21	497	I	56	63
22	*	I	*	*
23	*	I	*	*
24	*	I	*	*
25	30	I	42	43
26	*	I	*	*
27	1119	I	44	*
28	233	I	33	35
29	292	I	26	*
30	*	I	*	*
SUM	28682	-	-	-
AVG	956	I	40	47

* DENOTES UNAVAILABLE DATA.
I DENOTES INVALID DATA.

MONTHLY REPORT: TROY-MIAMI LIBRARY
DECEMBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	DIFFUSE INSOLATION BTU/SQ. FT	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	345	I	28	*
2	1715	I	23	28
3	1494	I	25	*
4	*	I	*	*
5	*	I	*	*
6	*	I	*	*
7	*	I	*	*
8	569	I	31	*
9	1013	I	33	38
10	*	I	*	*
11	980	I	52	57
12	*	I	*	*
13	167	I	32	32
14	1606	I	30	35
15	1546	I	30	38
16	373	I	32	39
17	*	*	*	*
18	1299	178	26	*
19	1310	170	33	*
20	1421	247	30	42
21	266	189	38	*
22	38	47	44	*
23	71	69	50	51
24	*	*	*	*
25	*	*	*	*
26	158	155	35	35
27	37	22	33	*
28	128	128	29	30
29	696	392	29	33
30	944	243	28	32
31	200	178	28	29
SUM	23076	10421	-	-
AVG	744	336	33	37

* DENOTES UNAVAILABLE DATA.
I DENOTES INVALID DATA.

MONTHLY REPORT: TROY-MIAMI LIBRARY
JANUARY 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	DIFFUSE INSOLATION BTU/SQ. FT	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	*	*	*	*
2	*	*	*	*
3	131	128	31	32
4	*	*	*	*
5	393	354	24	25
6	360	326	26	27
7	1626	235	28	*
8	1216	308	20	23
9	1585	182	22	26
10	589	334	32	37
11	*	*	*	*
12	*	*	*	*
13	*	*	*	*
14	*	*	*	*
15	*	*	*	*
16	*	*	*	*
17	470	312	47	47
18	*	*	*	*
19	995	421	34	37
20	1302	344	32	35
21	816	326	29	33
22	*	*	*	*
23	*	*	*	*
24	151	138	22	23
25	*	*	*	*
26	1239	329	25	*
27	1025	486	26	31
28	*	*	*	*
29	*	*	*	*
30	*	*	*	*
31	1867	635	16	20
SUM	28448	10039	-	-
AVG	918	324	28	30

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: TROY-MIAMI LIBRARY
FEBRUARY 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	DIFFUSE INSOLATION BTU/SQ. FT	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	*	I	*	*
2	1048	I	17	22
3	717	I	15	23
4	*	I	*	*
5	396	I	21	*
6	*	I	*	*
7	*	I	*	*
8	587	I	23	29
9	297	I	26	*
10	532	I	24	27
11	781	I	22	*
12	1996	I	16	23
13	*	I	*	*
14	*	I	*	*
15	*	I	*	*
16	1295	I	21	25
17	2087	I	11	16
18	491	I	17	*
19	*	I	*	*
20	132	I	38	*
21	103	I	40	*
22	288	I	42	*
23	255	I	39	41
24	447	I	34	35
25	246	I	30	*
26	1017	I	18	20
27	912	I	28	34
28	169	I	21	*
29	2356	I	13	*
SUM	22302	-	-	-
AVG	769	I	25	*

* DENOTES UNAVAILABLE DATA.
I DENOTES INVALID DATA.

MONTHLY REPORT: TROY-MIAMI LIBRARY
MARCH 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	DIFFUSE INSOLATION BTU/SQ. FT	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	*	I	*	*
2	*	I	*	*
3	*	I	*	*
4	796	I	33	41
5	*	I	*	*
6	1462	I	31	36
7	279	I	35	39
8	*	I	*	*
9	*	I	*	*
10	*	I	*	*
11	2187	I	27	31
12	1033	I	28	*
13	*	I	*	*
14	1162	I	31	*
15	2052	I	42	53
16	573	I	52	61
17	115	I	46	*
18	2295	I	38	*
19	*	I	*	*
20	*	I	*	*
21	968	I	41	*
22	2128	I	38	45
23	996	I	44	51
24	150	I	45	47
25	295	I	36	37
26	353	I	36	38
27	2068	I	44	56
28	220	I	47	51
29	179	I	44	43
30	355	I	44	48
31	393	I	45	48
SUM	29613	-	-	-
AVG	955	I	39	45

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: TROY-MIAMI LIBRARY
APRIL 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	DIFFUSE INSOLATION BTU/SQ. FT	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	254	I	44	45
2	1660	I	50	62
3	510	I	52	58
4	94	I	41	41
5	2246	I	46	56
6	1977	I	51	62
7	792	I	55	60
8	827	I	57	65
9	326	I	46	50
10	697	I	42	44
11	1049	I	49	60
12	618	I	48	48
13	534	I	41	45
14	438	I	41	47
15	551	I	38	38
16	2313	I	40	46
17	2010	I	47	59
18	2169	I	55	68
19	2100	I	60	74
20	1473	I	61	74
21	2277	I	59	70
22	2091	I	66	77
23	1900	I	64	66
24	1806	I	51	64
25	1308	I	46	51
26	1325	I	51	60
27	738	I	48	54
28	516	I	46	49
29	1127	I	52	61
30	899	I	53	62
SUM	36625	-	-	-
AVG	1221	I	50	57

APPENDIX F

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

The Troy-Miami Library was utilized for all of the reporting period. During this time, the solar system operated for the entire period. This system has been in operation since March 1978. Since being put into operation, there has been one major operational problem.

The differential controller in the storage line was broken during November 1979, December 1979, January 1980, and part of February 1980. As a result, very little energy went from storage to the load. The problem was corrected in February 1980.

- Since March 1980, flow meter W401 has been reading about 12-15 gpm lower than it should. The flow meter should read approximately the same as flow meters W100 and W403 (37 gpm).

- The shadow band on the diffuse pyranometer (sensor I002) was not adjusted as frequently as it should have been. Diffuse radiation data for November 1979 and February through April 1980 were invalidated because of the adjustment problem.

Large data losses occurred during December 1979, which precluded writing a monthly report; significant data losses continued from January 1980 through March 1980.

Date	Event
December 1979	SDAS problems for 18 days
January 1980	SDAS failure for 16 days
February 1980	SDAS failure for eight days
March 1980	SDAS failure for 10 days

The tabulated measurement data for November 1979 through April 1980 were rerun on updated software. As a result, most of the performance factors will be different from the ones in the published reports.

APPENDIX G

CONVERSION FACTORS

Energy Conversion Factors[1]

Fuel Type	Energy Content	Fuel Source Conversion Factor
Distillate fuel oil[2]	138,690 BTU/gallon	7.21×10^{-6} gallon/BTU
Residual fuel oil[3]	149,690 BTU/gallon	6.68×10^{-6} gallon/BTU
Kerosene	135,000 BTU/gallon	7.41×10^{-6} gallon/BTU
Propane	91,500 BTU/gallon	10.93×10^{-6} gallon/BTU
Natural gas	1,021 BTU/cubic feet	979.43×10^{-6} cubic feet/ BTU
Electricity	3,413 BTU/kilowatt-hour	293.08×10^{-6} kwh/BTU

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

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

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

APPENDIX H

SENSOR TECHNOLOGY

Temperature Sensors

Temperatures are measured by a Minco Products S53P platinum Resistance Temperature Detector (RTD). Because the resistance of platinum wire varies as a function of temperature, measurement of the resistance of a calibrated length of platinum wire can be used to accurately determine the temperature of the wire. This is the principle of the platinum RTD which utilizes a tiny coil of platinum wire encased in a copper-tipped probe to measure temperature. The probes are designed to have a normal resistance of 100 Ohms at 32°F.

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

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

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

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

Wind Sensor

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

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

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

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

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

Humidity Sensors

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

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

The sensor is based upon the capacitance change of a polymer thin-film capacitor. A one-micron thick dielectric polymer layer absorbs water molecules through a thin metal electrode and causes capacitance change proportional to relative humidity. The thin polymer layer reacts very quickly and, therefore, the response time is very short (one second to 90% humidity change at 68°F).

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

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

Insolation Sensors

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

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

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

Flow Sensors

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

Power Sensors

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

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

The resultant measurements of the wattmeter are summarized below:

1. Output is directly proportional to the flux in the magnetic core which in turn is directly proportional to the load current (I).

2. Output is directly proportional to the load voltage (E).

3. Final output is directly proportional to the vector product of E, I, and cos ϕ (power factor angle). This output is read into the SDAS as an electrical power in watts.