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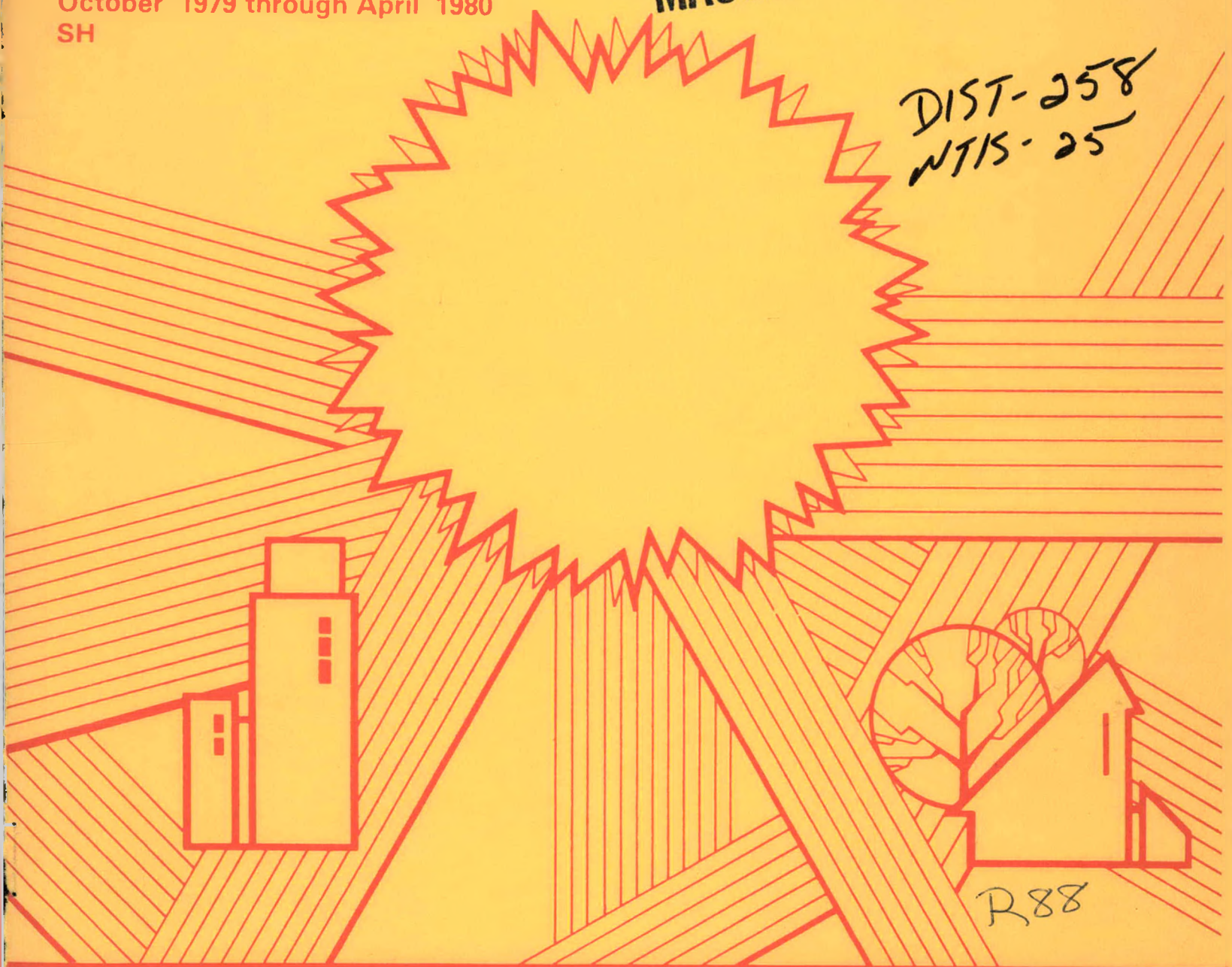
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SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

PAGE JACKSON ELEMENTARY SCHOOL
Charles Town, West Virginia
October 1979 through April 1980
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**U.S. DEPARTMENT OF ENERGY
NATIONAL SOLAR DATA PROGRAM**

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PAGE JACKSON ELEMENTARY SCHOOL
CHARLES TOWN, WEST VIRGINIA
SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION
OCTOBER 1979 THROUGH APRIL 1980

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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.

PAGE JACKSON ELEMENTARY SCHOOL

The Page Jackson Elementary School is an educational institution for children in Charles Town, West Virginia.

Design analysis predicted the following from October through April:

Heating total load - 1,061.1 million BTU

Hourly load factors which the equipment is designed to handle:

Heating load - 1.53 million BTU/hr

The solar energy system was designed to supply 85% of this heating load.

It is equipped with:

- | | |
|-----------|---|
| Collector | 11,215 sq. ft. of PPG flat-plate collectors of which 69% operate. |
| Storage | 2 tanks of 10,000 gallon capacity, 10 ft. diameter by 18 ft. long, filled with 8,500 gallons of water each and insulated with six inches of urethane. They are located in a special building. |
| Auxiliary | Natural gas-fired boiler for augmenting solar space-heating. Chiller with a centrifugal type compressor augmenting solar space-cooling. |

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SECTION 1

SOLAR SYSTEM PERFORMANCE PAGE JACKSON ELEMENTARY SCHOOL OCTOBER 1979 THROUGH APRIL 1980

The solar system performance can be briefly summarized: solar fraction¹, 23%; solar savings ratio², 0.17; conventional fuel savings³, 0.33 million ft³ of natural gas; system performance factor⁴, 0.70; solar system COP⁵, 3.37.

Solar energy was required only for space heating. The total heating load for the entire heating season was 1,226.55 million BTU of which 277.28 million BTU or 23% was supplied by solar energy.

Pertinent environmental data include the average outdoor temperature for the entire heating season, 43°F compared with the long-term average of 42°F; the average daily incident solar energy for the season, 1,168 BTU/ft² against the long-term 1,172 BTU/ft²; the total heating degree-days for the whole season, 4,686 against the long-term total of 4,831.

1.1 SUMMARY AND CONCLUSIONS

The Page Jackson Elementary School solar energy system supplied 23% of the space heating required for this public building during the heating season of October 1979 through April 1980.

The overall performance of the solar system was below expectations during this season. The overall solar fraction was measured at 23% while the design called for 85 percent. The thermal performance is summarized in Table 1.

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

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

$$^3 \text{ Conventional Fuel Savings} = (\text{Savings in BTU}) \times 979.4 \times 10^{-6} \text{ Ft}^3/\text{BTU}$$

$$^4 \text{ System Performance Factor} = \frac{\text{Heating Load}}{\text{Total Equivalent Fossil Energy Expended or Required to Support the System Load}}$$

$$^5 \text{ Solar System COP} = \frac{\text{Solar Energy Used}}{\text{Operating Energy Required For Collection and Distribution}}$$

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

PAGE JACKSON ELEMENTARY SCHOOL
OCTOBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	SOLAR ENERGY USED MEASURED	AUXILIARY ENERGY FOSSIL	OPERATING ENERGY	ENERGY SAVINGS FOSSIL	SOLAR FRACTION % MEASURED
OCT	66.86	126.75	35.67	83.96	16.69	42.76	28
NOV	69.03	137.78	34.43	141.52	18.82	38.56	25
DEC	61.76	219.52	55.73	269.31	26.62	66.26	25
JAN	28.63	274.74	12.45	405.91	25.75	-5.00	5
FEB	77.48	242.98	54.87	309.91	26.38	64.66	23
MAR	69.10	183.30	52.63	203.13	21.82	65.90	29
APR	51.79	41.48	31.50	15.79	8.04	44.46	76
TOTAL	424.65	1,226.55	277.28	1,429.53	144.12	317.60	-
AVERAGE	60.66	175.22	39.61	204.22	20.59	45.37	23

The quantity of collected solar energy that was used was 66%, which is poorer than predicted. The collector array efficiency was 21%. (This efficiency is based on the total solar radiation incident on the array.)

The collectors at this site show much evidence of physical damage. The absorber plates have buckled and piping has pulled loose from absorber plates. Water had leaked from the various joints, slip-on hoses and clamps. Some 31% of the collectors leaked so much that they were valved off. It was observed that the leaks in remaining components were more severe when the water in the collectors was cold. Thus, the water was not pumped through the collectors until the collectors were warmed by the sun. This reduced the leakage flow rate. The Jefferson County Board of Education has made an effort to have the collectors replaced under the manufacturer's warranty. However, even with this amount of damage, a significant quantity of solar energy was collected, 21% of the total energy which fell on the collectors. This was impressive considering the degradation and amount of leakage.

Location of the storage tanks in the flow loops presents at least one problem. Water required to meet a space heating or cooling load must come directly from the storage tanks and is returned to the tanks after passing through the air handling units. This presents a problem if the storage tanks are depleted of internal thermal energy. They must be heated by solar or auxiliary energy in the process of meeting the heating or cooling demand, and are a large load themselves, due to their large volume. Additional plumbing to bypass the tanks could allow loads to be met much more rapidly by the solar or auxiliary system when the tanks are cold, but it is only used in emergencies.

Limitations of the instrumentation suite created some uncertainties in the analysis. For example, the five-minute sampling rate of W400 (see Figure A-1, the system schematic) was not always sufficient to monitor the intermittent

fluid flows created by the action of modulating valve V1. Insufficient temperature sensors in each storage tank and between storage and pumps P4, P5, and P6 also created some uncertainty in analyzing the amount of boiler energy transferred to storage and in estimating the losses from storage. Additional solar system instrumentation has been requested to improve the analysis.

1.2 OVERALL SYSTEM PERFORMANCE

The flow of solar energy through the Page Jackson Elementary School for the seven-month period from October 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 auxiliary energy was supplied by the gas-fired boiler to both storage and directly to space heating. Auxiliary energy supplied to storage was later transferred to space heating.

The overall thermal performance of the solar energy system presented in Table 1 is shown graphically in Figure 2. Comparison with performance predicted by the f-Chart technique is not shown because of the damaged collectors at this site.

The "System Load" in Figure 1 was the requirement placed on the air handling units to heat the instruction and working spaces. "Solar Energy Used" refers to the portion of the system load which was satisfied by solar. "Auxiliary Energy" was supplied to the boiler in the form of natural gas. "Operating Energy" was the electrical energy used in operating pumps and air handling units. The "System Load" was made up of solar energy, auxiliary energy and the frictional heating of water and air caused by the pumps and air handling units. "Energy Savings" were computed from fossil fuel savings, as a result of "Solar Energy Used," which exceeded a portion of the operating energy expended. "Solar Fraction" was the ratio of "Solar Energy Used" to "System Load." Dividing savings by 5.8 million BTU per barrel of distillate fuel oil yields close to 55 barrels; not an impressive saving in terms of energy independence from imports.

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 Page Jackson Elementary School functioned at a reporting period average COP value of 3.37 for the period October 1979 through April 1980.

The collection subsystem COP average of 36.08 means little energy was required to pump fluid through the flat-plate collectors. The solar space heating subsystem delivered an average of 3.90 BTU of solar energy to the air handlers for every BTU of pumping energy. If this COP were increased, the benefit/cost ratio would increase.

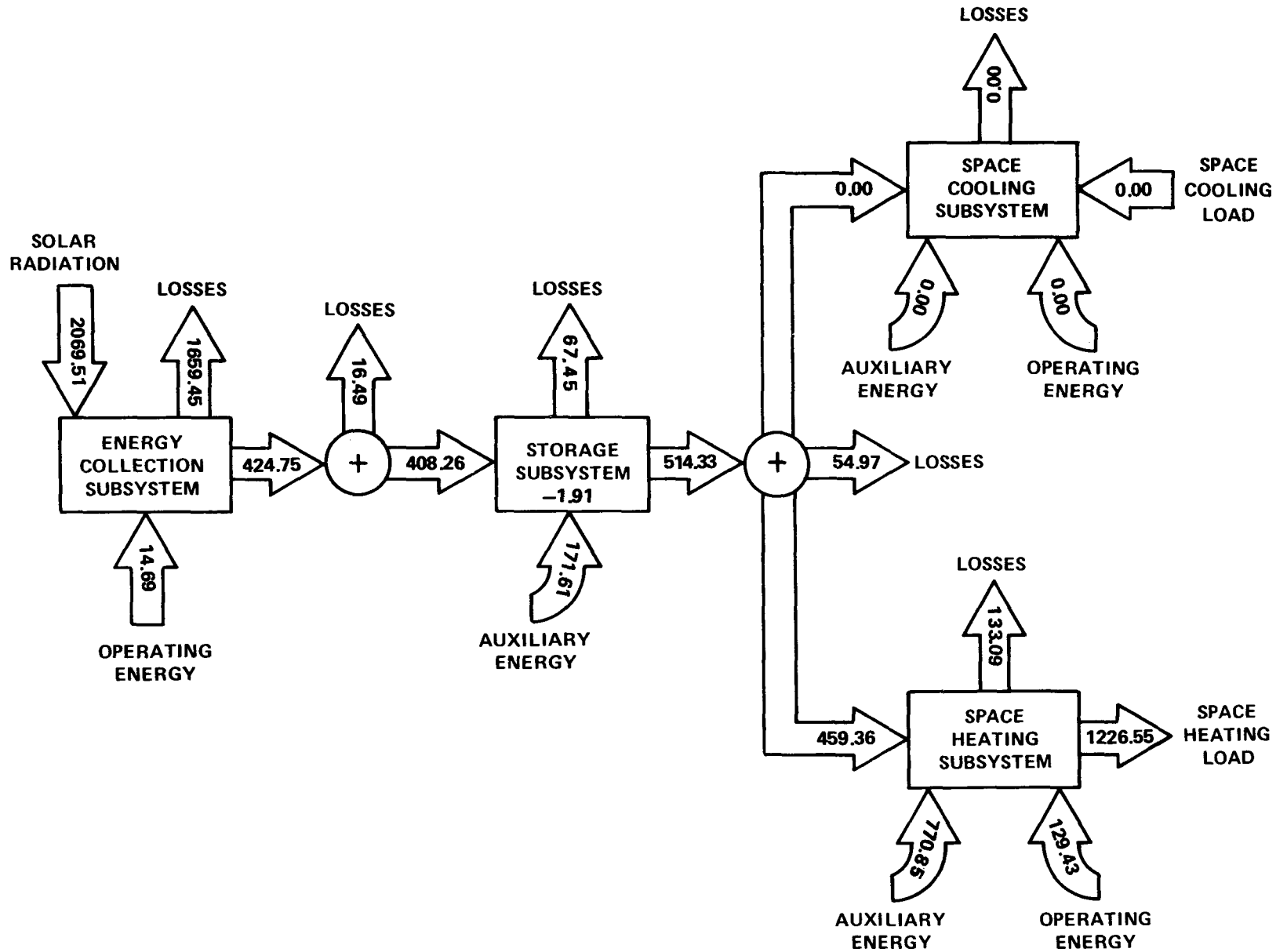
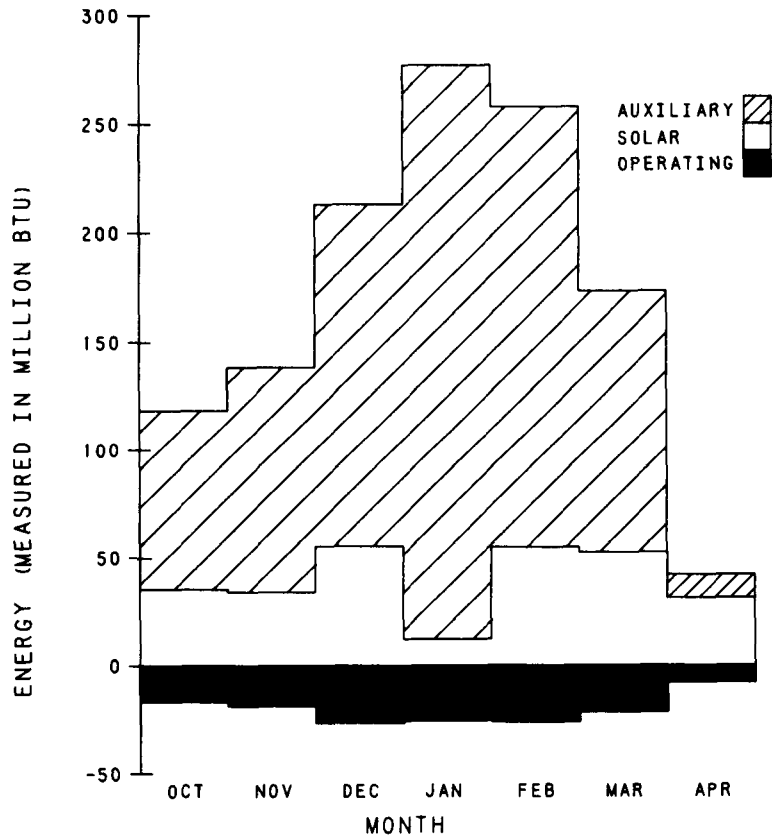


Figure 1. Energy Flow Diagram for Page Jackson Elementary School
October 1979 through April 1980



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
Page Jackson Elementary School
October 1979 through April 1980

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

PAGE JACKSON ELEMENTARY SCHOOL
OCTOBER 1979 THROUGH APRIL 1980

<u>MONTH</u>	<u>TOTAL SOLAR ENERGY SYSTEM</u>	<u>SOLAR COLLECTION SUBSYSTEM</u>	<u>SOLAR SPACE HEATING SUBSYSTEM</u>
OCT	4.80	40.15	5.46
NOV	3.74	32.90	4.22
DEC	3.88	50.34	4.19
JAN	1.16	47.13	1.22
FEB	2.87	34.75	3.13
MAR	3.12	32.86	3.54
APR	4.00	14.43	5.54
AVERAGE	3.37	36.08	3.90

1.3 ENERGY SAVINGS

Energy savings for this site for the reporting period, October 1979 through April 1980, are presented in Table 3 and shown graphically in Figure 3. For this seven-month period, the total savings were 317.6 million BTU, for a monthly average of 45.37 million BTU. This is equivalent to 311,100 cubic feet of natural gas. The Department of Energy reported the price of natural gas to industrial users averaged \$2.25/1,000 cubic feet during this time. The result was a \$700 savings for seven months. An electrical energy expense of 14.69 million BTU was incurred during the reporting period for the operation of solar energy components.

Table 3. ENERGY SAVINGS

PAGE JACKSON ELEMENTARY SCHOOL
OCTOBER 1979 THROUGH APRIL 1980

(All values in million BTU)

MONTH	SOLAR ENERGY SAVINGS ATTRIBUTED TO		ECSS OPERATING ENERGY	NET ENERGY SAVINGS FOSSIL FUEL
	SOLAR ENERGY USED	SPACE HEATING FOSSIL FUEL SAVINGS		
OCT	35.67	44.76	2.00	42.76
NOV	34.43	40.70	2.14	38.56
DEC	55.73	68.21	1.95	66.26
JAN	12.45	-3.64	1.36	-5.00
FEB	54.87	67.06	2.40	64.66
MAR	52.63	68.51	2.61	65.90
APR	31.50	46.69	2.23	44.46
TOTAL	277.28	332.29	14.69	317.60
AVERAGE	39.61	47.47	2.10	45.37

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.

The auxiliary source at the Page Jackson Elementary School consists of a natural gas-fired boiler. This unit is considered to be 60% efficient for computational purposes, thus the solar energy used is divided by 0.6 to allow for burning natural gas. The electric operating energy for the solar heating system is subtracted from the result to give "space heating fossil fuel savings."

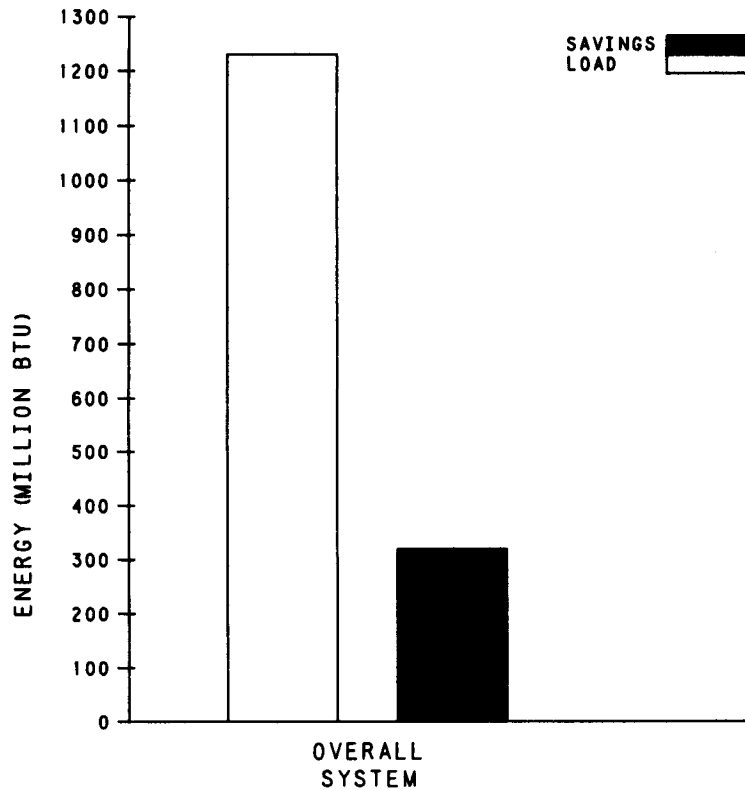


Figure 3. Combined Thermal Energy Savings Compared to Load
 Page Jackson Elementary School
 October 1979 through April 1980

1.4 SOLAR ENERGY UTILIZATION

The losses of solar energy at the different stages through the system, after collection and before utilization for space heating, are presented in Table 4. Line 4 reflects the change in energy due to the temperature change in the 17,080 gallons of storage water. The difference between Lines 5 and 7 is the loss of solar energy from the time it left the storage tank until the time it heated the conditioned space. The percentage of this loss is given on Line 8. The rest of the table should be self-explanatory.

Figure 4 shows the use of solar energy and the percentage of losses. The 19% of total incident solar energy lost is the result of the collector pumps not operating, which is in turn due to the low temperature of the collectors in the early morning, late afternoon, and on cloudy days. The 75% of operational solar energy lost is due to several reasons. Even though the collector pumps were operating, the storage tank temperature was so high that the heat transfer rate was low, or the heat exchanger surface area was too small to allow energy transfer, or the ambient temperature was so low that the collectors transferred heat to the atmosphere. The four percent of collected energy was lost through insulation as was the 32% of stored energy.

Table 4. SOLAR ENERGY LOSSES
PAGE JACKSON ELEMENTARY SCHOOL
OCTOBER 1979 THROUGH APRIL 1980

	<u>OCT</u>	<u>NOV</u>	<u>DEC</u>	<u>JAN</u>	<u>FEB</u>	<u>MAR</u>	<u>APR</u>
1. SOLAR ENERGY (SE) COLLECTED MINUS SE DIRECTLY TO LOADS (million BTU)	66.86	69.03	61.76	28.63	77.48	69.10	51.79
2. SE TO STORAGE (million BTU)	64.16	67.55	56.91	27.25	76.15	65.98	50.26
3. LOSS - COLLECTOR TO STORAGE (million BTU)	2.70	1.48	4.85	1.38	1.33	3.12	1.53
(%)	4	2	8	5	2	5	3
4. CHANGE IN STORED ENERGY (million BTU)	-6.91	-1.41	+1.98	-1.13	0	-0.56	+6.12
5. SOLAR ENERGY - STORAGE TO SPACE HEATING SUBSYSTEM (million BTU)	35.67	34.43	55.73	26.80	60.88	66.37	31.50
6. LOSS FROM STORAGE (%)	44	49	2.1	1.6	20	0	37
7. HEATING SOLAR ENERGY (HSE) FROM STORAGE (million BTU)	35.67	34.43	55.73	12.45	54.87	52.63	31.50
8. LOSS - STORAGE TO HSE (%)	0	0	0	54	10	21	0

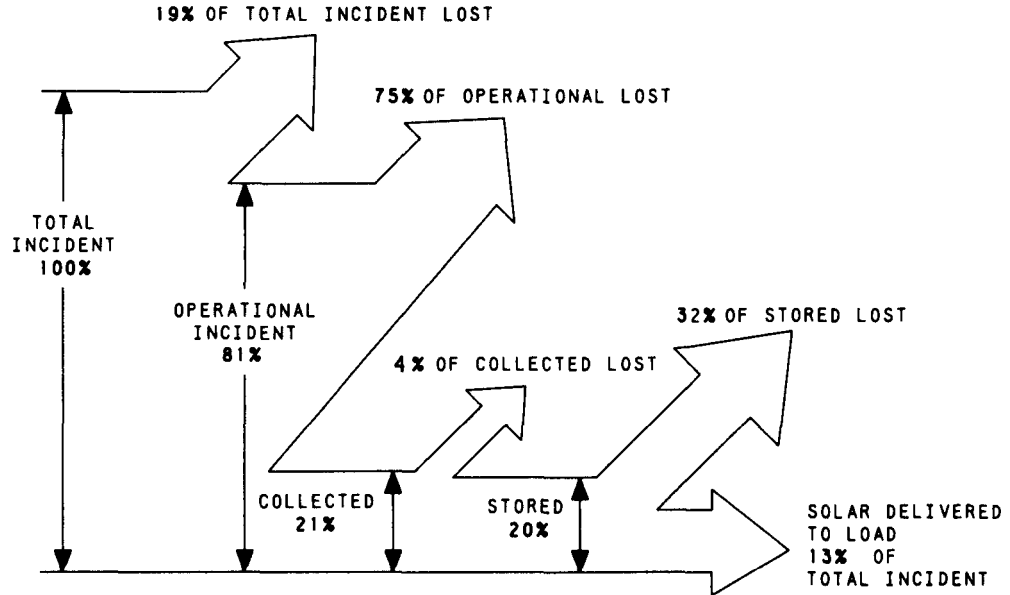


Figure 4. Solar Energy Use
Page Jackson Elementary School
October 1979 to April 1980

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The collector array of the Page Jackson Elementary School is composed of 620 flat-plate collectors manufactured by PPG, which use water as the heat transfer fluid. This is a "drain-down" system and thus no antifreeze is required. Collector subsystem performance for the Page Jackson Elementary School site is presented in Table 5.

Table 5. COLLECTOR SUBSYSTEM PERFORMANCE

PAGE JACKSON ELEMENTARY SCHOOL
OCTOBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR SUBSYSTEM EFFICIENCY %	OPERATIONAL INCIDENT ENERGY	OPERATIONAL SUBSYSTEM EFFICIENCY %	ECSS OPERATING ENERGY	SOLAR ENERGY DIRECTLY TO LOADS	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE °F
OCT	282.69	66.86	24	211.23	32	2.00	0	64.16	59
NOV	249.83	69.03	28	218.04	32	2.14	0	67.55	54
DEC	353.26	61.76	17	282.82	22	1.95	0	56.91	44
JAN	251.10	28.63	11	175.82	16	1.36	0	27.25	35
FEB	282.38	77.48	27	240.14	32	2.40	0	76.15	35
MAR	309.25	69.10	22	273.69	25	2.61	0	65.98	45
APR	341.10	51.79	15	274.81	19	2.23	0	50.26	59
TOTAL	2,069.51	424.75	-	1,676.05	-	14.69	0	408.26	-
AVG.	295.64	60.68	21	239.44	25	2.10	0	58.32	47

Incident solar radiation for the entire collector array for seven months was 2,069.51 million BTU, whereas the radiation was 1,676.05 million BTU during the time the collector pumps were operating. Of this, 424.75 million BTU were collected and in turn 408.26 million BTU were delivered to the storage tank, but the design of the system did not allow solar energy to be delivered directly to loads. The collector efficiency was 21% based on incident solar radiation, and 25% based on solar radiation during the time the pumps were operating. The Energy Collection and Storage Subsystem (ECSS) pumps, P4, P5, P6, P7 and P8 (Figure A-1) required 14.69 million BTU. Thus, 1,675.94 million BTU of solar energy were lost between the time it fell on the collectors and the time it was transferred to the storage tanks.

2.2 STORAGE

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

Table 6. STORAGE PERFORMANCE

PAGE JACKSON ELEMENTARY SCHOOL
OCTOBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY TO STORAGE	ENERGY FROM STORAGE	CHANGE IN STORED ENERGY	STORAGE EFFICIENCY (%)	AVERAGE STORAGE TEMP. (°F)	AUXILIARY ENERGY TO STORAGE	LOSS FROM STORAGE
OCT	64.16	80.32	-6.91	86	132	20.75	11.50
NOV	67.55	70.36	-1.41	78	113	21.04	19.64
DEC	56.91	98.17	+1.98	100	112	43.33	0.09
JAN	27.25	64.14	-1.13	97	109	37.96	2.20
FEB	76.15	83.41	0	80	107	28.18	20.92
MAR	65.98	85.76	-0.56	100	110	19.28	0.06
APR	50.26	32.17	+6.12	75	160	1.07	13.04
TOTAL	408.26	514.33	-1.91	-	-	171.61	67.45
AVERAGE	58.32	73.48	-0.27	88	120	24.52	9.64

During the reporting period, total solar energy delivered to storage was 408.26 million BTU and auxiliary energy contribution to storage was 171.61 million BTU. There were 514.33 million BTU delivered from storage to the space heating subsystems. Energy loss from storage was 67.45 million BTU. The loss represented 17% of the energy delivered to storage. The storage efficiency was 88%. (See Footnote 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:

$$\text{STEFF} = (\text{STECH} + \text{STEO})/\text{STEI}$$

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

2.3 SPACE HEATING

The space heating performance for the Page Jackson Elementary School for the reporting period is shown in Table 7 and presented graphically in Figure 5.

Table 7. SPACE HEATING SUBSYSTEM PERFORMANCE

PAGE JACKSON ELEMENTARY SCHOOL
OCTOBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

MONTH	ACTUAL SPACE HEATING LOAD	MONTHLY DESIGN LOAD*	ENERGY CONSUMED				SOLAR FRACTION (%)	BUILDING TEMPERATURE °F
			SOLAR	AUXILIARY THERMAL	AUXILIARY FOSSIL	OPERATING ENERGY		
OCT	126.75	68.9	35.67	82.88	83.96	14.69	28	76
NOV	137.78	133.9	34.43	104.11	141.52	16.68	25	76
DEC	219.52	216.9	55.73	157.18	269.31	14.67	25	73
JAN	274.74	228.7	12.45	264.52	405.91	24.39	4.5	74
FEB	242.98	175.7	54.87	202.50	309.91	23.98	23	74
MAR	183.30	159.2	52.63	120.46	203.13	19.21	29	72
APR	41.48	77.8	31.50	10.81	15.79	5.81	76	72
TOTAL	1,226.55	1,061.1	277.28	942.46	1,429.53	129.43	23	-
AVERAGE	175.22	151.6	39.61	134.64	305.33	18.49	23	74

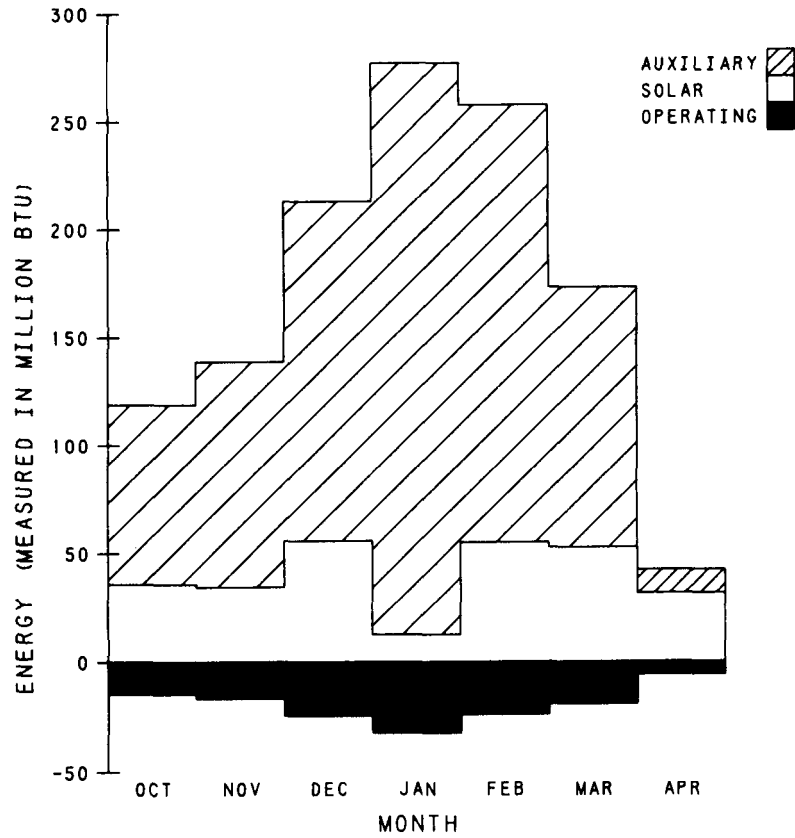
* These are the loads computed by the mechanical engineering firm that specified the space heating equipment.

The space heating load of 1,226.55 million BTU was satisfied by 277.28 million BTU of solar energy and 942.46 million BTU of auxiliary thermal energy from the gas-fired boiler. The auxiliary thermal energy is the amount of auxiliary fossil energy, 1,429.53 million BTU, actually transferred to the space heating subsystem. The solar fraction of this load was 23%. The total operating energy expense was 129.43 million BTU. The operating energy required to transport the solar energy was 64.00 million BTU.

The fossil fuel energy savings were 317.6 million BTU. The average building temperature for the season was 74°F. Referring to the section on Energy Savings, this resulted in a \$700 savings in natural gas.

The design loads for the air handling units for heating the five zones of the school are as follows.

Zone	Design Load (Million BTU Per Hour)
1	0.301
2	0.567
3	0.228
4	0.374
5	0.0646
TOTAL	1.5346



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
Page Jackson Elementary School
October 1979 through April 1980

SECTION 3

OPERATING ENERGY

Measured monthly values of the Page Jackson Elementary School solar energy system and subsystem operating energy for the report period are presented in Table 8. A total 144.12 million BTU of operating energy was consumed by the entire system during the reporting period. A distribution of this operating energy among the subsystems is illustrated in Figure 6.

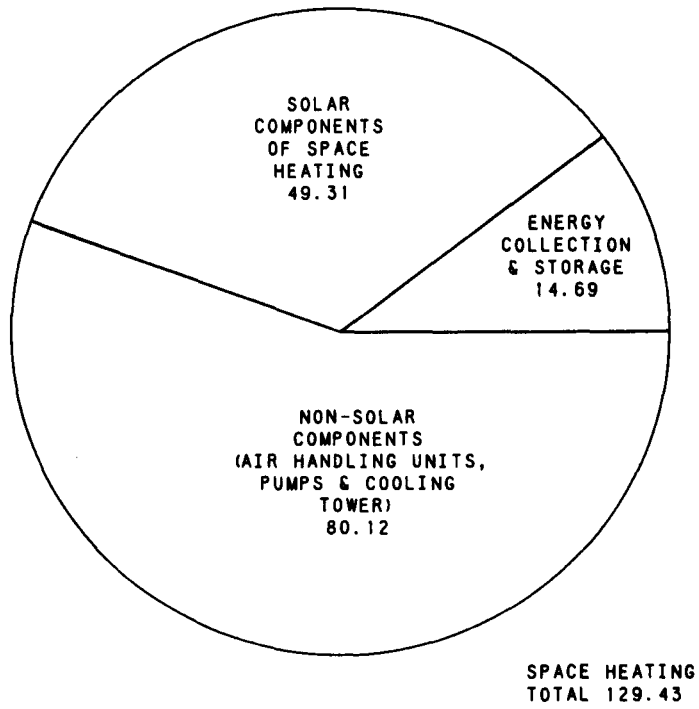
Total system operating energy for the Page Jackson Elementary School is the electrical energy required to support the energy collecting and storage subsystem (ECSS), and Solar Heating Subsystem (SHS).

Table 8. OPERATING ENERGY

PAGE JACKSON ELEMENTARY SCHOOL
OCTOBER 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		
OCT	2.00	14.69	5.43	7.43	16.69
NOV	2.14	16.68	7.00	9.14	18.82
DEC	1.95	14.67	7.99	9.94	26.62
JAN	1.36	24.39	9.44	10.80	25.75
FEB	2.40	23.98	8.30	10.70	26.38
MAR	2.61	19.21	8.81	11.42	21.82
APR	2.23	5.81	2.34	4.67	8.04
TOTAL	14.69	129.43	49.31	64.00	144.12
AVERAGE	2.10	18.49	7.04	9.14	20.59



**Figure 6. Total Operating Energy
Page Jackson Elementary School
October 1979 to April 1980**

SECTION 4

WEATHER CONDITIONS

The Page Jackson Elementary School is located in Charles Town, West Virginia at 39 degrees N latitude and 78 degrees W longitude.

Monthly values of the total solar energy incident in the plane of the collector array, 45° to the horizontal, 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

PAGE JACKSON ELEMENTARY SCHOOL
OCTOBER 1979 THROUGH APRIL 1980

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT ² -DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS	
	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
OCT	1,178	1,387	53	56	370	291
NOV	1,076	1,068	48	45	506	609
DEC	1,036	836	44	34	651	961
JAN	736	963	31	32	1,054	1,020
FEB	1,389	1,170	30	34	983	874
MAR	1,289	1,338	40	42	776	719
APR	1,469	1,442	53	53	346	357
TOTAL	8,173	8,204	-	-	4,686	4,831
AVERAGE	1,168	1,172	43	42	669	690

During the period from October 1979 through April 1980, the average daily total incident solar radiation on the collector array was 1,168 BTU per square foot per day. This radiation was slightly below the estimated average daily solar radiation for this geographical area during the reporting period of 1,172 BTU per square foot per day for a south-facing plane with a tilt of 45 degrees to the horizontal. During the period, the highest monthly average insolation was 1,469 BTU per square foot per day during April. The average ambient temperature during the reporting period was 43°F as compared with the long-term average of 42°F. The highest monthly average ambient temperature was 53°F during October and April, and the lowest monthly average ambient temperature was 30°F during February. The number of heating degree-days for the period (based on a 65°F reference) was 4,686 as compared with the long-term average of 4,831. The range of heating degree-days was from a high of 1,054 during January to a low of 346 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 50% during October to a low of 39% during December.

	<u>OCTOBER</u>	<u>NOVEMBER</u>	<u>DECEMBER</u>	<u>JANUARY</u>	<u>FEBRUARY</u>	<u>MARCH</u>	<u>APRIL</u>
Extra- terrestrial Insolation BTU/day-ft ²	1,997	1,471	1,237	1,364	1,826	2,420	3,036
$\frac{\text{TTL INS}}{\text{EXT INS}}$ (%)	0.50	0.44	0.39	0.42	0.45	0.46	0.48

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

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

SECTION 5

REFERENCES

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, Page Jackson Elementary School, October 1979, SOLAR/2036-79/10, IBM, Huntsville, Alabama.
- *8. Monthly Performance Report, Page Jackson Elementary School, November 1979, SOLAR/2036-79/11, IBM, Huntsville, Alabama.
- *9. Monthly Performance Report, Page Jackson Elementary School, December 1979, SOLAR/2036-79/12, Vitro Laboratories, Silver Spring, Maryland.
- *10. Monthly Performance Report, Page Jackson Elementary School, January 1980, SOLAR/2036-80/01, Vitro Laboratories, Silver Spring, Maryland.
- *11. Monthly Performance Report, Page Jackson Elementary School, February 1980, SOLAR/2036-80/02, Vitro Laboratories, Silver Spring, Maryland.
- *12. Monthly Performance Report, Page Jackson Elementary School, March 1980, SOLAR/2036-80/03, Vitro Laboratories, Silver Spring, Maryland.
- *13. Monthly Performance Report, Page Jackson Elementary School, April 1980, SOLAR/2036-80/04, 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

APPENDIX A

SYSTEM DESCRIPTION

SYSTEM

Page Jackson School is an elementary school located in Charles Town, West Virginia. The space conditioned floor area is 50,600 square feet. The solar energy system is designed to provide approximately 85% of the space heating and 50% of the space cooling energy requirements of the school. It has an array of flat-plate collectors (69% of which are capable of collecting energy) with a gross area of 11,215 square feet that faces south at an angle of 45 degrees from the horizontal. Water is used as the medium for delivering solar energy from the collector array to storage. The solar-heated water is stored in two interconnected 10,000-gallon capacity storage tanks and is used for space heating and cooling. When the solar energy is insufficient to meet the heating demands, an oil-fired boiler is used to provide auxiliary hot water to the tanks for heating. In the space cooling mode, the hot water from the tanks is supplied to the generator of an absorption chiller. A conventional centrifugal chiller is used as backup whenever solar energy is insufficient to meet the space cooling demand.

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

Mode 1 - Collector-to-Storage - The collector subsystem operates independently of the other subsystems. It is active whenever the solar collector temperature is higher than the temperature in hot water storage tanks. When the hot water storage tank temperature is equal to or greater than the collector temperature, solar pump P7 is shut down. An emergency mode of operation to prevent overheating of the collectors is manually activated to allow water to continuously circulate through the collectors.

Mode 2 - Space Heating - This mode is entered when the manual Summer-Winter Automatic switch is set to Automatic and the outside ambient temperature is below 60°F, or when the switch is set to Winter. Whenever the temperature of the air returning from the air-handling units is below 68°F and the hot water thermal storage temperature is less than 123°F, auxiliary heating is activated. The burner for the boiler is cycled to maintain a water temperature of 160°F. When the hot water thermal storage temperature rises above 123°F, or the return air temperature rises above 68°F, auxiliary heating is shut off. Auxiliary heating of storage can occur anytime boiler heating is required and the return water temperature to storage is greater than the storage water temperature.

Mode 3 - Space Cooling - This mode is entered when the manual Summer-Winter Automatic switch is set to Automatic and the outside ambient temperature is above 68°F, or when the switch is set to Summer. There are two modes of space cooling; one utilizes the absorption chiller, the other the backup centrifugal chiller. When the hot water thermal storage temperature rises above 180°F, system pumps P4, P5, and P6 are activated to generate flow through the absorption chiller. As the inlet water temperature to the chiller rises above

180°F, the chilled water temperature out of the absorption chiller will become colder. As the temperature from hot water thermal storage drops below 180°F, the reverse will occur. When the hot water thermal storage temperature drops below 171°F, system pumps will stop, and the absorption chiller will no longer be used for space cooling. If there is a demand for space cooling and the storage temperature is below 171°F, the backup centrifugal chiller is used to satisfy the demand.

SUBSYSTEMS

Collector - There are 620 flat plate collectors, model A529 manufactured by PPG. The gross collector array area is 11,215 ft². The collectors face directly south; azimuth angle of zero degrees. The collectors are tilted to an angle of 45 degrees from the horizontal. Orientation of the collectors is close to the optimum orientation for a system of this type, at a site latitude of 39 degrees North. Optimum collector azimuth at this site is estimated to be zero degrees, at a tilt of 29 degrees for winter collection.

The collector panels have two water white glazings with selective coatings of black nonelectrolytic thin oxide film. The absorber surface has an absorptivity of 0.87 and an emissivity of 0.12. Total solar transmissivity of the glazing is 0.85 with a reflectance of 0.08. The absorber surface is composed of 0.06 inch thick copper. Reflectors made of mirror glass are mounted on the north side of the collector support and total 9,215 square feet.

Solar energy storage is provided by 2 steel storage tanks located in a special building. The storage has 6 inches of urethane on the top and sides. Water is used as the medium to transfer solar energy to the space heating and space cooling systems.

Space Heating - The space heating subsystem consists of a natural gas fired boiler designed to utilize solar energy through five air handling units. The system has five air handling units sized to deliver a total of 1.53 million BTU/hr. The design solar fraction is 85%.

- 1001 COLLECTOR PLANE TOTAL INSOLATION
- ▶ T001 OUTDOOR TEMPERATURE
- ▶ T600 INDOOR TEMPERATURE
- ▶ T601 INDOOR TEMPERATURE
- ▶ T602 INDOOR TEMPERATURE

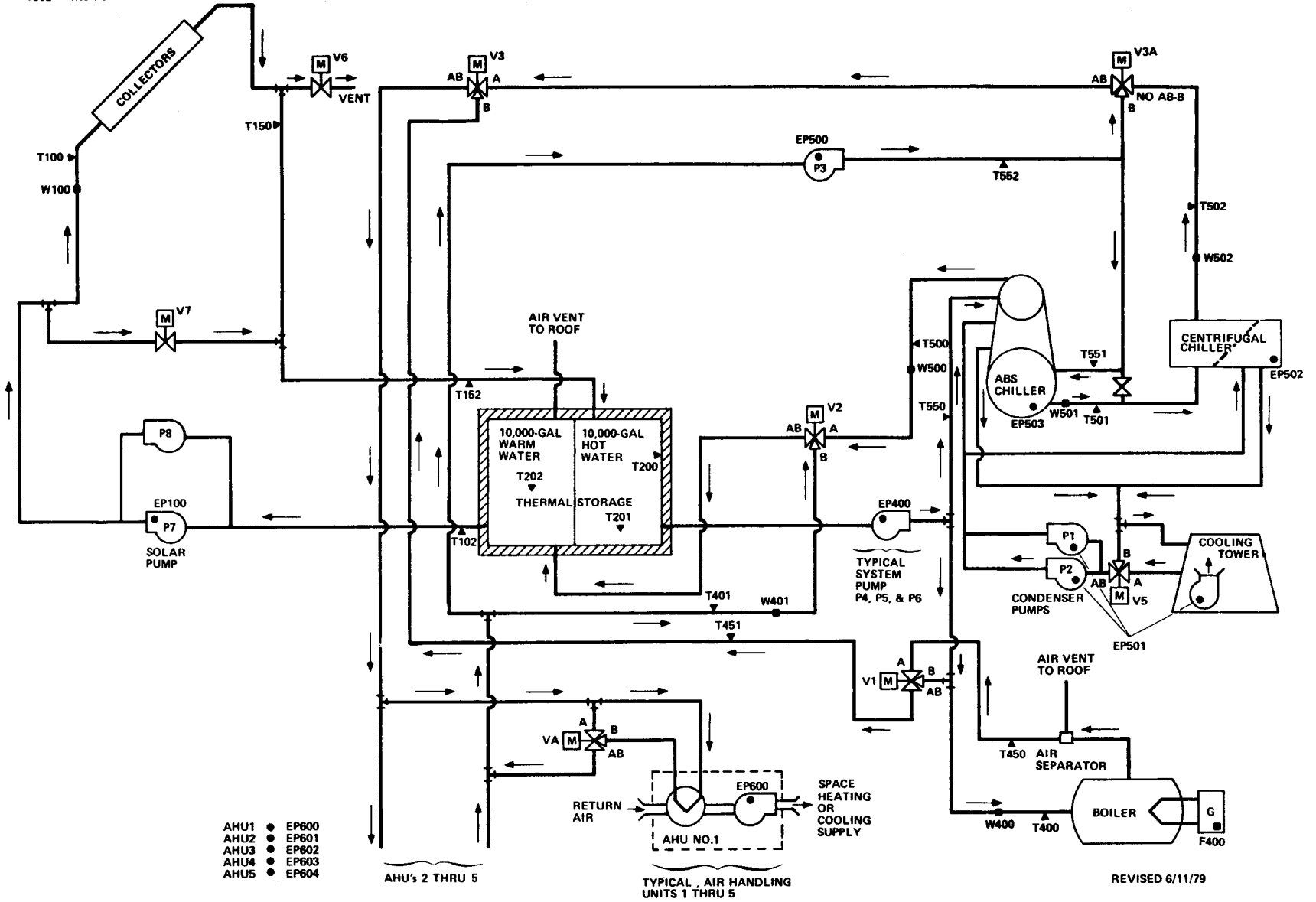


Figure A-1. Page Jackson Solar System Schematic

APPENDIX B
PERFORMANCE EVALUATION TECHNIQUES

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

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

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

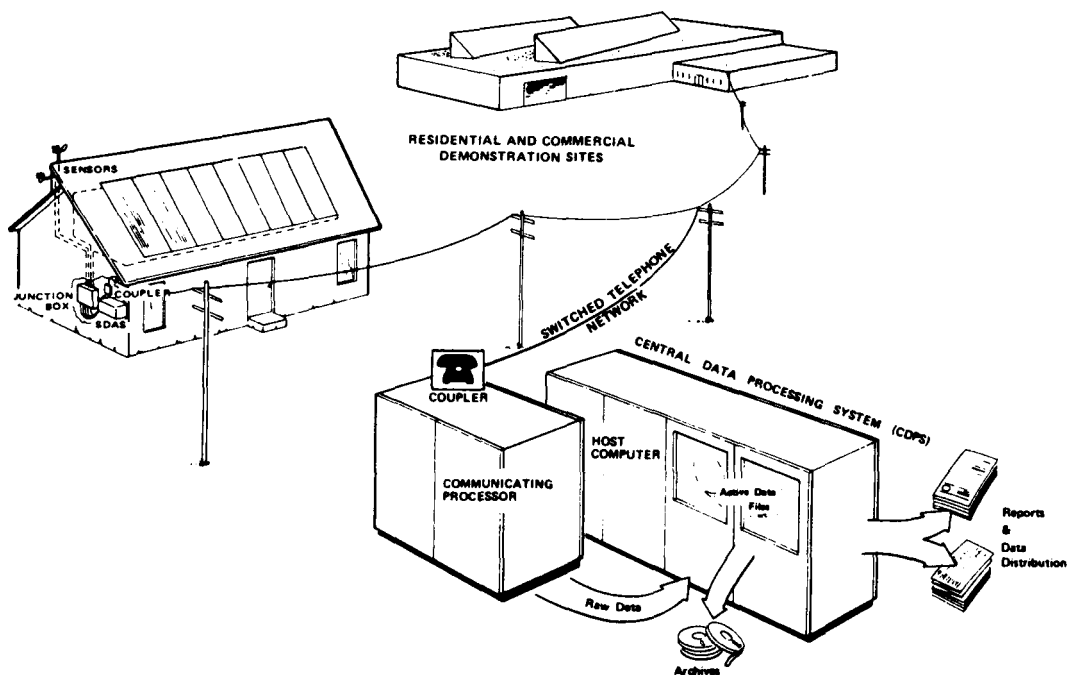


Figure B-1. The National Solar Data Network

DATA COLLECTION AND PROCESSING

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

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

The data received by the System 7 are in the form of digital counts in the range of 0-1023. These counts are then processed by software in the CDPS, where they are converted from counts to engineering units (EU) by applying appropriate calibration constants. The engineering unit data called "detailed measurements" in the software are then tabulated on a daily basis for the site analyst, and these tabulations are also called "tab data." The CDPS is also capable of transforming this data into plots or graphs.

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 Page Jackson solar energy system from October 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.

OTHER DATA REPORTS ON THIS SITE*

Monthly Performance Reports:

November 1978, SOLAR/2036-78/11
December 1978, SOLAR/2036-78/12
January 1979, SOLAR/2036-79/01
February 1979, SOLAR/2036-79/02
March 1979, SOLAR/2036-79/03
April 1979, SOLAR/2036-79/04
May 1979, SOLAR/2036-79/05
June 1979, SOLAR/2036-79/06
July 1979, SOLAR/2036-79/07
August 1979, SOLAR/2036-79/08
September 1979, SOLAR/2036-79/09
October 1979, SOLAR/2036-79/10
November 1979, SOLAR/2036-79/11
December 1979, SOLAR/2036-79/12
January 1980, SOLAR/2036-80/01
February 1980, SOLAR/2036-80/02
March 1980, SOLAR/2036-80/03
April 1980, SOLAR/2036-80/04
May 1980, SOLAR/2036-80/05
June 1980, SOLAR/2036-80/06

Solar Project Description, January 1979, SOLAR/2036-79/50.

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

APPENDIX C
PERFORMANCE FACTORS AND SOLAR TERMS

APPENDIX C

PERFORMANCE FACTORS AND SOLAR TERMS

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

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

Section 3 describes abbreviations used in this report.

- Section 1. Performance Factor Definitions
- Section 2. Solar Terminology
- Section 3. Abbreviations

SECTION 1. PERFORMANCE FACTOR DEFINITIONS

<u>SYMBOL</u>	<u>NAME</u>	<u>DEFINITION</u>
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

<u>SYMBOL</u>	<u>NAME</u>	<u>DEFINITION</u>
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

<u>SYMBOL</u>	<u>NAME</u>	<u>DEFINITION</u>
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

<u>SYMBOL</u>	<u>NAME</u>	<u>DEFINITION</u>
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

<u>SYMBOL</u>	<u>NAME</u>	<u>DEFINITION</u>
* 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

<u>SYMBOL</u>	<u>NAME</u>	<u>DEFINITION</u>
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

<u>SYMBOL</u>	<u>NAME</u>	<u>DEFINITION</u>
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 (absorbance?)	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 <u>above</u> 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.
	$FMS = \frac{\text{Solar Energy Supplied to Load} - \text{Solar System Operating Energy}}{\text{Solar Energy Supplied to Load}}$
Fixed Collector	A solar collector that is fixed in position and cannot be rotated to follow the sun daily or seasonably.
Flat Plate Collector	A solar energy collecting device consisting of a relatively thin panel of absorbing material. A container with insulated bottom and sides and covered with one or more covers transparent to visible solar energy and relatively opaque to infrared energy. Visible energy from the sun enters through the transparent cover and raises the temperature of the absorbing panel. The infrared energy re-radiated from the panel is trapped within the collector because it cannot pass through the cover. Glass is an effective cover material (see Selective Surface).
Focusing Collector	A concentrating type collector using parabolic mirrors or optical lenses to focus the energy from a large area onto a small absorbing area.
Fossil Fuel	Petroleum, coal, and natural gas derived fuels.

Glazing	In solar/energy technology, the transparent covers used to reduce energy losses from a collector panel.
Heat Exchanger	A device used to transfer energy from one heat transfer fluid to another while maintaining physical segregation of the fluids. Normally used in systems to provide an interface between two different heat transfer fluids.
Heat Transfer Fluid	The fluid circulated through a heat source (solar collector) or heat exchanger that transports the thermal energy by virtue of its temperature.
Heating Degree Days	The sum over a specified period of time of the number of degrees the average daily temperature is <u>below</u> 65°F.
Instantaneous Efficiency	The efficiency of a solar collector at one operating point, $\frac{T_i - T_a}{I}$, under steady state conditions (see Operating Point).
Instantaneous Efficiency Curve	A plot of solar collector efficiency against operating point, $\frac{T_i - T_a}{I}$ (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: $\frac{T_i - T_a}{I} \quad \frac{^{\circ}\text{F} \times \text{hr.} \times \text{sq. ft.}}{\text{BTU}}$
Operational Collector Efficiency	Ratio of collected solar energy to incident solar energy <u>only during the time the collector fluid is being circulated with the intention of delivering solar-source energy to the system.</u>
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 3410.6412 BTU of heat energy.
NSDN	National Solar Data Network.
SCS	Space Cooling Subsystem.
SHS	Space Heating Subsystem.
SOLMET	Solar Radiation/Meteorology Data.

APPENDIX D
PERFORMANCE EQUATIONS

APPENDIX D

PERFORMANCE EQUATIONS

PAGE JACKSON ELEMENTARY SCHOOL

INTRODUCTION

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

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

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

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

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

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

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

For a liquid system ΔH is generally given by

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

where C_p is the average specific heat, in $\text{BTU}/\text{lb}_m\text{-}^\circ\text{F}$, of the heat transfer fluid and ΔT , in $^\circ\text{F}$, 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

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

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)

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

AVERAGE BUILDING TEMPERATURE (°F)

$$TB = (1/180) \times \sum (T600 + T601 + T602) \times \Delta\tau$$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

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

FOR ± 3 HOURS FROM SOLAR NOON

INCIDENT SOLAR ENERGY PER SQUARE FOOT (BTU/FT²)

$$SE = (T/60) \times \sum I001 \times \Delta\tau$$

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

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

when the collector loop pumps are active

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \sum [M100 \times HWD (T150, T100)] \times \Delta\tau$$

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

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \sum M100 \times HWD (T152, T102)$$

SOLAR ENERGY FROM STORAGE (BTU)

$$STEO = \sum [M500 \times HWD (T550, T500)] + HL - HAT$$

AVERAGE TEMPERATURE OF STORAGE (°F)

$$TST = (1/60) \times \sum [(T202 + (T200 + T201)/2)/2] \times \Delta\tau$$

ENERGY DELIVERED FROM ECSS TO SPACE HEATING SUBSYSTEM (BTU)

$$CSEO = STEO$$

ECSS OPERATING ENERGY (BTU)

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

when system is in the collector-to-storage mode

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$$HOPE = 56.8833 \times \sum (EP400 + EP600 + EP601 + EP602 + EP603 + EP604)$$

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

SOLAR ENERGY TO SPACE HEATING SUBSYSTEM (BTU)

$$HSE = HL - HAT$$

AUXILIARY ENERGY DIRECT TO HL (BTU)

$$HAT1 = HAT - CSAUX$$

SPACE HEATING SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$$HAT = \sum M401 \times HWD (T451, T400)$$

SPACE HEATING SUBSYSTEM LOAD (BTU)

$$HL = \sum M401 \times HWD (T451, T401)$$

BUILDING TEMPERATURE (°F)

$$TB = (1/60) \times \sum T601 \times \Delta\tau$$

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

$$\text{STEFF} = (\text{STECH} + \text{STEO})/\text{STEI}$$

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

$$\text{SEL} = \text{HSE} + \text{CSE}$$

ESCC SOLAR CONVERSION EFFICIENCY

$$\text{CSCEF} = \text{SEL}/\text{SEA}$$

SPACE HEATING SUBSYSTEM SOLAR FRACTION (PERCENT)

$$\text{HSFR} = 100 \times \text{HSE}/\text{HL}$$

SPACE COOLING SUBSYSTEM LOAD (BTU)

$$\text{CL} = \sum \text{M502} \times \text{HWD} (\text{T552}, \text{T502})$$

SPACE COOLING SUBSYSTEM OPERATING ENERGY (BTU)

$$\text{COPE} = 56.8833 \times \sum (\text{EP400} + \text{EP600} + \text{EP601} + \text{EP602} + \text{EP603} + \text{EP604} \\ + \text{EP500} + \text{EP501} + \text{EP503})$$

SPACE HEATING SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

$$\text{HSVE} = - \text{HSFR} \times \text{HOPE}/100$$

SYSTEM LOAD (BTU)

$$\text{SYSL} = \text{HL} + \text{CL}$$

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

$$\text{SFR} = (\text{HSFR} \times \text{HL} + \text{CL} \times \text{CSFR})/\text{SYSL}$$

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

$$\text{AXT} = \text{HAT} + \text{CAT}$$

AUXILIARY ELECTRICAL ENERGY TO LOADS (BTU)

$$\text{AXE} = \text{CAE}$$

SYSTEM OPERATING ENERGY (BTU)

$$\text{SYSOPE} = \text{HOPE} + \text{CSOPE} + \text{COPE}$$

TOTAL ENERGY CONSUMED (BTU)

$$TECSM = SYSOPE + AXE + SECA + AXF$$

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

$$TSVE = HSVE - CSOPE + CSVE$$

SYSTEM PERFORMANCE FACTOR

$$SYSPF = SYSL / [(AXE + SYSOPE) \times 3.33 + AXF]$$

THERMODYNAMIC CONVERSION EQUIPMENT LOAD (BTU) (ABSORPTION CHILLER)

$$TCEL = \sum M502 \times HWD (T552, T502)$$

THERMODYNAMIC CONVERSION EQUIPMENT OPERATIONS ENERGY (BTU)

$$TCEOPE = 56.8833 \times \sum (EP400 + EP500 + EP501 + EP503)$$

when operating without centrifugal chiller

$$TCEL = M501 \times HWD (T551, T501)$$

when operating with centrifugal chiller

AUXILIARY THERMODYNAMIC CONVERSION EQUIPMENT LOAD (BTU) (CENTRIFUGAL CHILLER)

$$ATCEL = \sum M502 \times HWD (T552, T502)$$

when operating without absorption chiller

$$ATCEL = \sum CL - TCEL$$

when operating with absorption chiller

AUXILIARY THERMODYNAMIC CONVERSION EQUIPMENT OPERATING ENERGY (BTU)
(CENTRIFUGAL CHILLER)

$$ATCEOPE = 56.8833 \times \sum (EP502 + EP501)$$

AUXILIARY THERMODYNAMIC CONVERSION EQUIPMENT INPUT (BTU) (CENTRIFUGAL CHILLER)

$$ATCEI = 56.8833 \times \sum EP502$$

AUXILIARY ENERGY TRANSFERRED TO STORAGE TANK (BTU)

$$CSAUX = \sum (HAT - HL)$$

SPACE HEATING SUBSYSTEM SAVINGS OF FOSSIL FUEL (BTU)

$$\text{HSVF} = \text{HSE}/0.6$$

TOTAL SYSTEM SAVINGS OF FOSSIL FUEL (BTU)

$$\text{TSVF} = \text{HSVF}$$

SOLAR ENERGY USED IN SPACE COOLING SUBSYSTEM (BTU)

$$\text{CSE} = \sum \text{M500} \times \text{HWD} (\text{T550}, \text{T500})$$

AUXILIARY FOSSIL FUEL ENERGY TO LOADS (BTU)

$$\text{AXF} = \text{HAF}$$

AUXILIARY FOSSIL FUEL ENERGY SUPPLIED TO HEATING SUBSYSTEM

$$\text{HAF} = 140,000 \times \text{GAS FLOW RATE}$$

AUXILIARY ELECTRIC ENERGY ADDED TO THE COOLING SUBSYSTEM

$$\text{CAE} = 56.8833 \times \sum \text{EP502}$$

AUXILIARY THERMAL ENERGY ADDED TO THE COOLING SUBSYSTEM (BTU)

$$\text{CAT} = 0.7 \times \text{CAE}$$

SPACE COOLING SUBSYSTEM SAVINGS OF ELECTRIC ENERGY (BTU)

$$\text{CSVE} = \text{CL}/\text{COPC} - \text{COPE1} - \text{CAE}$$

where COPC = 2.5, the coefficient of performance of the centrifugal chiller; COPE1 = $56.8833 \times \sum (\text{EP400} + \text{EP503})$, the operating energy for the solar components

SPACE COOLING SUBSYSTEM SOLAR ENERGY USED AS A PERCENT OF COOLING REQUIREMENTS

$$\text{CSFR} = 100 \times \text{TCEL}/\text{CL}$$

THERMODYNAMIC CONVERSION EQUIPMENT INPUT ENERGY (BTU) (ABSORPTION CHILLER)

$$\text{TCEI} = \text{CSE}$$

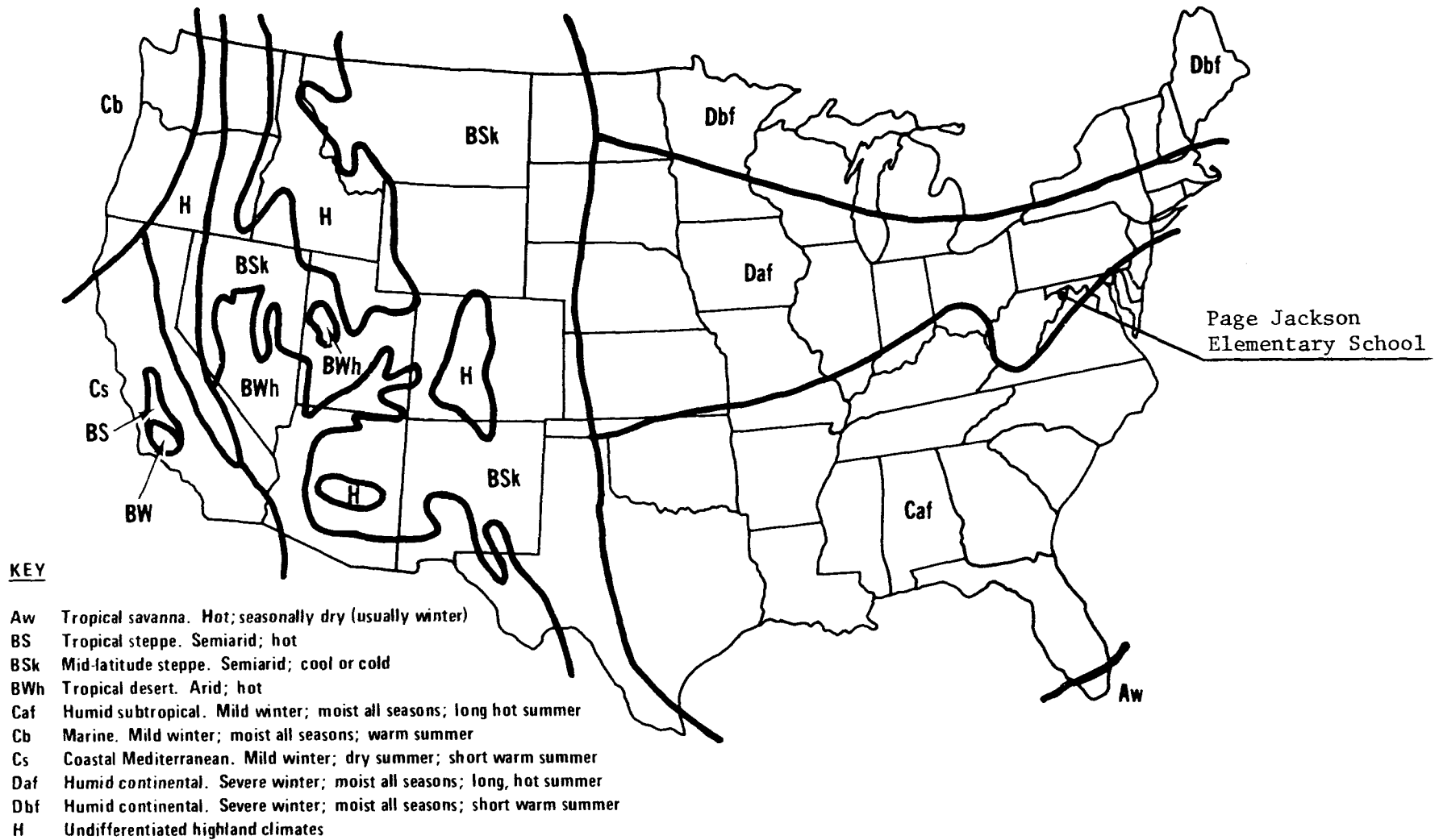
THERMODYNAMIC CONVERSION EQUIPMENT COEFFICIENT OF PERFORMANCE

$$\text{TCECOP} = \text{TCEL}/\text{TCEI}$$

AUXILIARY THERMODYNAMIC CONVERSION EQUIPMENT COEFFICIENT OF PERFORMANCE

$$\text{ATCECOP} = \text{ATCEL}/\text{ATCEI}$$

APPENDIX E
METEOROLOGICAL DATA



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

Figure E-1. Meteorological Map of the United States
Showing Page Jackson Elementary School Location

Table E-1. HEATING DEGREE-DAYS

PAGE JACKSON ELEMENTARY SCHOOL
OCTOBER 1979 THROUGH APRIL 1980

<u>Month</u>	<u>Measured Heating Degree-Days</u>
OCT	370
NOV	506
DEC	651
JAN	1,054
FEB	983
MAR	776
APR	346

MONTHLY REPORT: PAGE JACKSON SCHOOL
 OCTOBER 1979
 ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	324	64	66
2	717	64	*
3	1692	61	67
4	1586	62	69
5	125	52	52
6	1836	53	60
7	863	52	56
8	2435	53	*
9	*	*	*
10	714	36	61
11	1841	44	50
12	269	49	53
13	511	47	48
14	874	44	50
15	2141	48	57
16	624	55	*
17	940	56	*
18	1588	57	68
19	1574	60	71
20	1737	67	80
21	1848	70	82
22	1868	71	82
23	342	58	66
24	125	44	46
25	778	45	48
26	814	39	44
27	1866	41	49
28	257	50	54
29	1996	54	64
30	1875	48	59
31	1177	49	*
SUM	36514	-	-
AVG	1178	53	59

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: PAGE JACKSON SCHOOL
 NOVEMBER 1979
 ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1414	55	61
2	37	54	54
3	1246	45	50
4	1944	42	53
5	1875	42	53
6	1845	49	57
7	662	47	49
8	679	43	48
9	907	53	58
10	111	57	59
11	52	44	45
12	456	42	43
13	81	42	43
14	1059	39	43
15	423	40	42
16	1750	43	48
17	1791	48	58
18	1800	57	67
19	1732	50	63
20	1793	55	67
21	1265	52	64
22	1358	54	68
23	1189	54	66
24	181	61	*
25	1085	63	69
26	568	58	61
27	1491	50	55
28	559	46	53
29	1126	31	33
30	1790	28	35
SUM	32269	-	-
AVG	1076	48	54

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: PAGE JACKSON SCHOOL
 DECEMBER 1979
 ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1649	30	39
2	808	30	35
3	1876	29	37
4	1505	39	46
5	1652	43	52
6	257	48	54
7	1402	45	49
8	776	39	40
9	1194	34	40
10	1293	45	55
11	1700	53	63
12	786	56	66
13	27	44	42
14	1472	34	39
15	1553	31	*
16	331	42	47
17	1838	24	26
18	708	25	28
19	174	30	32
20	67	26	26
21	420	30	34
22	702	34	41
23	1088	43	53
24	167	48	49
25	924	46	48
26	570	38	41
27	346	36	39
28	1668	36	41
29	1792	42	49
30	1657	42	52
31	1712	34	44
SUM	32115	-	-
AVG	1036	38	44

MONTHLY REPORT: PAGE JACKSON SCHOOL
 JANUARY 1980
 ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	815	29	39
2	537	30	34
3	559	34	38
4	130	28	*
5	119	24	26
6	1521	23	31
7	254	33	36
8	867	32	35
9	276	27	30
10	812	23	30
11	219	40	41
12	790	32	*
13	536	28	30
14	51	32	32
15	247	37	42
16	1416	39	48
17	189	40	41
18	54	40	41
19	1537	37	42
20	1373	36	41
21	2029	34	40
22	103	37	41
23	1199	32	35
24	802	20	25
25	297	28	31
26	1792	30	36
27	536	27	31
28	443	32	35
29	963	27	31
30	641	20	24
31	1721	21	23
SUM	22828	-	-
AVG	736	31	35

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: PAGE JACKSON SCHOOL
 FEBRUARY 1980
 ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	*	*	*
2	2035	18	23
3	2005	19	*
4	1725	23	28
5	2006	26	31
6	221	24	25
7	1939	24	32
8	1831	29	33
9	405	29	32
10	2098	25	29
11	1422	28	36
12	2144	26	30
13	2087	27	36
14	1446	35	49
15	815	37	42
16	837	33	37
17	2051	21	25
18	2052	26	35
19	1496	36	47
20	1608	40	*
21	922	46	53
22	208	41	42
23	617	44	52
24	1484	44	49
25	1503	40	44
26	2076	27	28
27	391	29	34
28	276	25	29
29	1966	15	20
SUM	41080	-	-
AVG	1417	30	35

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: PAGE JACKSON SCHOOL
 MARCH 1980
 ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	474	11	13
2	2071	16	16
3	2406	23	30
4	1502	34	44
5	1070	45	50
6	1935	39	42
7	1052	50	60
8	1017	60	68
9	2007	44	47
10	1870	46	58
11	2698	33	35
12	1864	29	31
13	156	26	25
14	1617	33	38
15	2376	39	44
16	2171	43	53
17	198	52	52
18	2212	44	44
19	1864	44	53
20	718	53	58
21	235	49	54
22	664	35	37
23	2263	41	50
24	175	44	48
25	427	44	47
26	1170	37	40
27	2312	43	53
28	339	44	48
29	355	47	51
30	621	50	54
31	106	41	41
SUM	39945	-	-
AVG	1289	40	45

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: PAGE JACKSON SCHOOL
 APRIL 1980
 ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1525	45	52
2	1848	53	*
3	2022	53	63
4	1631	54	65
5	2254	48	53
6	2294	54	63
7	1333	55	63
8	693	58	65
9	1780	60	67
10	637	53	59
11	2283	56	65
12	522	58	65
13	1673	52	58
14	103	52	49
15	560	47	49
16	1980	42	46
17	2377	43	52
18	2248	52	63
19	2220	58	70
20	1800	59	*
21	2339	61	66
22	2013	61	68
23	1913	62	70
24	1587	59	70
25	1816	56	61
26	189	47	48
27	123	48	49
28	167	50	52
29	1540	56	62
30	587	52	54
SUM	44058	-	-
AVG	1469	53	59

* DENOTES UNAVAILABLE DATA.

APPENDIX F

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

APPENDIX F

SITE HISTORY, PROBLEMS AND CHANGES IN SOLAR SYSTEM

The Page Jackson Elementary School was occupied during all the reporting period except weekends and holidays. During this time the solar system operated the whole time. This system has been in operation since November 1978. Since being put into operation, there have been major operational problems.

<u>DATE</u>	<u>EVENT</u>
October 79	<p>Damaged collectors prevented collection of sufficient solar energy to support design loads. This also resulted in circumvention of collector pump control system to prevent leaking.</p> <p>Lack of sufficient number of temperature sensors in solar storage tanks prevented accurate assessment of stored energy.</p> <p>Lack of temperature sensor between solar storage tank and pumps P4, P5, and P6 prevented accurate computation of heating energy supplied by boiler and solar energy supplied by storage tank.</p> <p>Flowmeter W400 was not correct type to register intermittent flow to boiler preventing accurate determination of heating energy supplied by boiler.</p>

APPENDIX G
CONVERSION FACTORS

ENERGY CONVERSION TABLE

Energy Conversion Factors¹

<u>Fuel Type</u>	<u>Energy Content</u>	<u>Fuel Source Conversion Factor</u>
Distillate fuel oil ²	138,690 BTU/gallon	7.21×10^{-6} gallon/BTU
Residual fuel oil ³	149,690 BTU/gallon	6.68×10^{-6} gallon/BTU
Kerosene	135,000 BTU/gallon	7.41×10^{-6} gallon/BTU
Propane		
Natural gas	1021 BTU/cubic feet	979.43×10^{-6} cubic feet/ BTU
Electricity	3412 BTU/kilowatt-hour	293.08×10^{-6} kwh/BTU

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

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

³No. 5 and No. 6 fuel oils

APPENDIX H
SENSOR TECHNOLOGY

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/ft²-hr.

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

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

Flow Sensors

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

Power Sensors

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

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

The resultant measurements of the watt meter are summarized below:

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