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SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

BILLINGS SHIPPING
Billings, Montana
October 1979 through April 1980
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**U.S. DEPARTMENT OF ENERGY
NATIONAL SOLAR DATA PROGRAM**

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BILLINGS SHIPPING
BILLINGS, MONTANA
SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION
OCTOBER 1979 THROUGH APRIL 1980

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for

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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.

BILLINGS SHIPPING

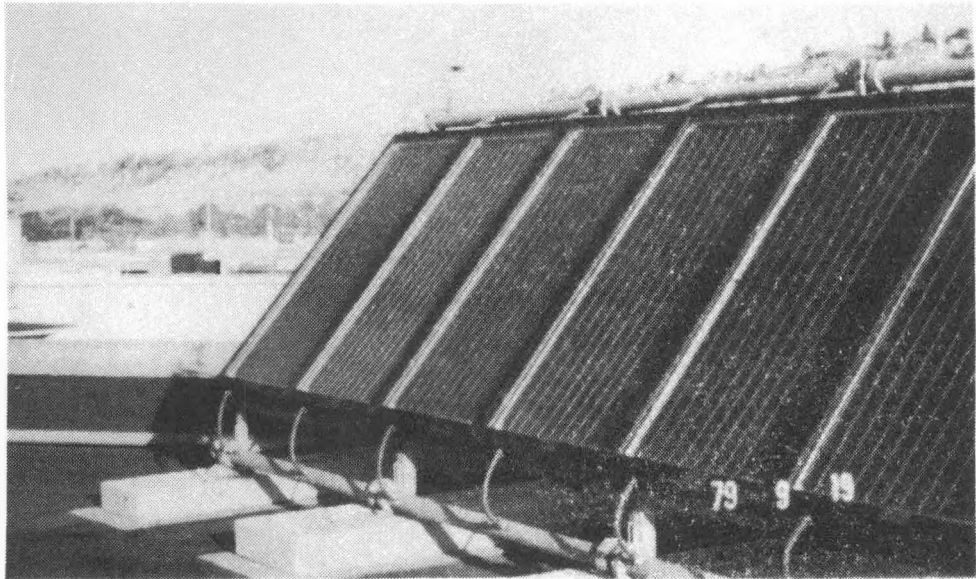
The Billings Shipping site is an office building in Billings, Montana. The active solar energy system is designed to supply the following:

Seasonal Design Factors (Million BTU)

	<u>Total Load</u>	<u>Solar Contribution</u>	<u>% Solar</u>
Heating	359	194	54

It is equipped with:

Collector	1,968 square foot, liquid flat-plate LSC18-1S collectors made by Lennox Industries
Storage	2,500 gallon steel tank buried underground
Auxiliary	Gas-fired hot water boiler equipped to deliver 360,000 BTU/hr



BILLINGS SHIPPING

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SECTION 1

SOLAR SYSTEM PERFORMANCE

BILLINGS SHIPPING
OCTOBER 1979 THROUGH APRIL 1980

Solar Fraction ¹	24%
Solar Savings Ratio ²	23%
Conventional Fuel Savings ³	144,000 ft ³ of gas
System Performance Factor ⁴	0.88
Solar System COP ⁵	23.0

Seasonal Energy Requirements
October 1979 through April 1980
(million BTU)

	<u>Total Load</u>	<u>Solar Contribution</u>	<u>% Solar</u>
Heating	364.71	88.43	24

Environmental Data

	<u>Measured Average</u>	<u>Long-Term Average</u>
Outdoor temperature	37°F	34°F
Heating degree-days	6,062	6,555
Daily incident solar energy	1,266 BTU/ft ²	1,316 BTU/ft ²

1. Solar Fraction = $\frac{\text{Solar Energy Supplied to Loads}}{\text{Total Load}}$
2. Solar Savings Ratio = $\frac{\text{Solar Energy Supplied to Load} - \text{Solar System Operating Energy}}{\text{Total Load}}$
3. Conventional Fuel Savings = Number BTUs Saved x 979.43×10^{-6} cubic feet/BTU
4. Ratio of system load to the total equivalent fossil energy expended or required to support the system load.
5. Solar System COP = $\frac{\text{Solar Energy Used}}{\text{Operating Energy Required For Collection}}$

1.1 SUMMARY AND CONCLUSIONS

The Billings Shipping site is an enclosed freight distribution facility with 4,900 square feet of heated office space. The solar energy system consists of an array of 1,968 square feet of flat-plate, liquid (glycol, 50/50 Dowtherm) collectors made by Lennox Industries. The collectors face 10 degrees east of south and solar energy is delivered to a 2,500-gallon steel tank, buried five feet underground. Solar energy may be transferred to the space heating subsystem from this tank or transferred directly from the the energy collection subsystem. Auxiliary energy is supplied by a gas-fired hot water boiler.

The solar energy system has two separate heating controls. During the business day, a multizone system in the conditioned space reacts to each thermostat and maintains comfort level temperatures. At night and on weekends, the system provides heat only when the conditioned space falls below the maintenance temperature, which is currently set near 60°F.

The Billings Shipping solar energy system supplied 24% of the space heating requirements for this office building during the season of October 1979 through April 1980. The energy supplied (24%) is significantly lower than the estimated design contribution (54%) for the solar energy system, but is closer to the prediction of the f-Chart model (38%). The design goal appears to be obtainable only during the more temperate winter months. At that time, the solar fraction ranged from 48% to 64%. During the colder months, the solar fraction was substantially reduced because of the need for much greater thermal energy.

The quantity of collected solar energy that was used was 65% and the collector array efficiency was 21%. (This efficiency is based on the total solar energy incident on the array.) This efficiency is low because the collectors were not operating as much as they could have, because there were 243.37 million BTU of solar energy incident on the array. This was lost because the collectors do not activate until the collector plate temperature reaches 130°F and there is a time delay to prevent the collectors from cycling on and off. The collector efficiency decreased during the colder months, probably due to the colder temperature. There is also less insolation available during these months.

Use of solar energy saved 147.36 million BTU for the seven-month period. This is approximately equal to \$300.00.*

The system, however, performed better than is indicated by the solar fraction of 24%. The largest space heating demand occurs in the morning before the start of the business day, when the conditioned space is brought up to comfort level. Most of the solar energy is used in the early morning hours before the system starts collecting. When the collector subsystem is in full operation, such that there is plenty of solar energy available, there is very little or no space heating load.

* This was estimated using an average cost of \$2.14 per 1,000 cubic feet of natural gas.

For the first part of the heating season (October to January), the boiler came on at about the same time as the solar heating came on. This condition was repaired in January by adding an adjustable delay timer to allow solar energy to satisfy the space heating requirements before using the auxiliary energy from the boiler. This decreased the amount of auxiliary energy used.

The plumbing and heat exchangers in the equipment room were insulated and thicker insulation on the plumbing to and from the collector panels was added in January. There was not a noticeable change in system performance.

During October and April, some of the collected energy was not transferred to storage or the load because there was no demand. This energy was rejected to the atmosphere to protect the collectors and the storage tank.

The incident solar energy in April was much higher than the long-term average, and, therefore, more solar energy was collected and more solar energy was rejected due to the small space heating load.

The solar energy incident on the collector array was 530.45 million BTU, of which 135.65 million BTU were collected with an operating energy expense of 3.84 million BTU. Of the collected energy, 7.80 million BTU were rejected to the atmosphere to protect the collectors and the storage tank. The solar energy delivered directly to the loads was 40.20 million BTU, while 69.84 million BTU were delivered to the storage tank. The transport losses from the collectors to storage were 17.81 million BTU. Energy loss from storage was 20.28 million BTU. The change in stored energy increased by 1.33 million BTU, while 48.23 million BTU were delivered from storage to the space heating subsystem.

A total of 88.43 million BTU of solar energy and 276.28 million BTU of auxiliary energy were delivered to the space heating subsystem to satisfy the load of 364.71 million BTU. The operating energy required to deliver this thermal energy to the space heating subsystem was 23.10 million BTU. (See Figure 1).

Solar energy is more efficient during spring and fall than during the extremely cold months. Efficiency could be improved by better control balance between solar energy and auxiliary energy usage. If the repairs that were performed in January had been done for the whole season, the solar system could have performed better than it did.

1.2 OVERALL SYSTEM PERFORMANCE

The flow of solar energy through the Billings Shipping site for the seven-month period from October 1979 through April 1980 is presented in Figure 1. The solar energy collected was 135.65 million BTU and 88.43 million BTU were delivered to the space heating subsystem. The solar energy used was below the predicted value of 139.42 million BTU because less solar energy was collected than predicted (135.65 as compared to 194.00 million BTU). The predicted performance was determined from a modified f-Chart computer simulation using measured weather, measured subsystem loads, and computed losses as input. The auxiliary thermal energy used was 276.28 million BTU, with an expenditure of 414.85 million BTU of fossil fuel. The solar fraction was 24% of the space heating load of 364.71 million BTU. This was below the predicted value of

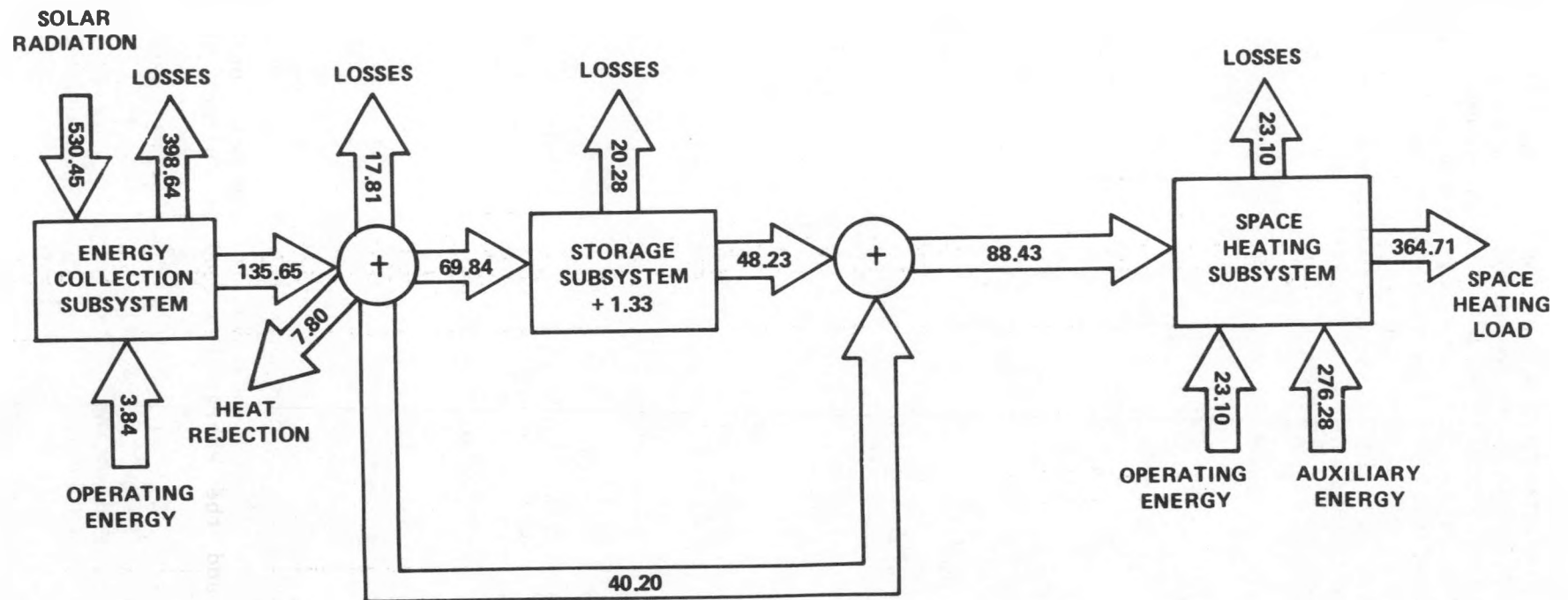


Figure 1. Energy Flow Diagram for Billings Shipping
 October 1979 through April 1980
 (Figures in million BTU)

38%. The f-Chart predicted solar fraction is a more accurate indication of how the system should have performed than the design solar fraction. The f-Chart predicted solar fraction is based on the measured weather whereas the design solar fraction is based on the long-term weather averages. The system had a total operating energy of 26.95 million BTU. The fossil fuel energy saved was 147.36 million BTU, with an electrical energy expense of 4.71 million BTU. (See Table 1.) The solar energy system savings are approximately equal to \$300.00 for the year.

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

BILLINGS SHIPPING
OCTOBER 1979 THROUGH APRIL 1980

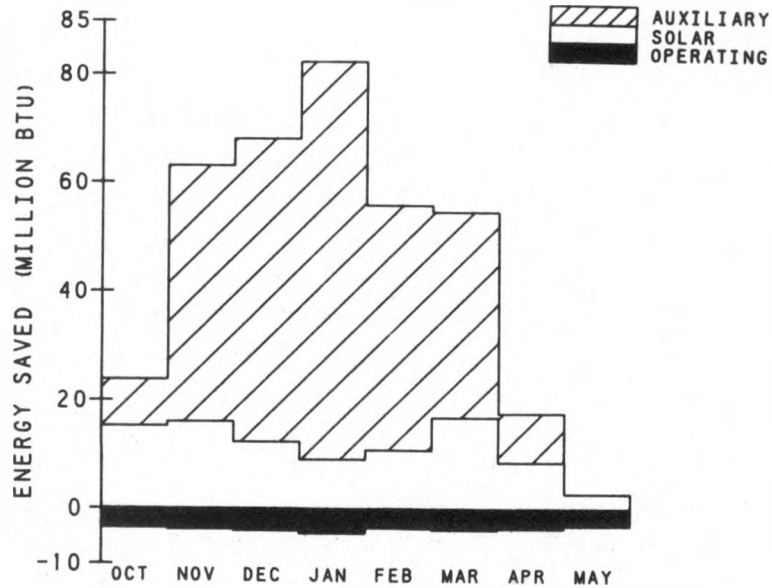
(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	SOLAR ENERGY USED*		AUXILIARY ENERGY		OPERATING ENERGY	ENERGY SAVINGS		SOLAR FRACTION (PERCENT)	
			PREDICTED	MEASURED	THERMAL	FOSSIL		FOSSIL	ELECTRICAL	PREDICTED	MEASURED
OCT	23.56	23.65	18.84	15.24	8.41	20.01	3.64	25.40	-1.00	80	64
NOV	20.61	63.06	21.69	16.02	47.04	73.09	3.82	26.69	-0.69	34	25
DEC	16.20	67.92	17.24	12.21	55.71	83.73	4.13	20.34	-0.58	25	18
JAN	11.86	82.41	18.80	8.95	73.46	104.38	4.64	14.91	-0.42	23	11
FEB	14.97	55.74	18.96	10.89	44.85	64.47	3.41	18.14	-0.43	34	20
MAR	22.09	54.43	27.04	16.70	37.73	53.11	3.81	27.84	-0.65	50	31
APR	26.36	17.50	16.85	8.42	9.08	14.06	3.50	14.04	-0.94	96	48
TOTAL	135.65	364.71	139.42	88.43	276.20	414.85	26.95	147.36	-4.71	-	-
AVERAGE	19.38	52.10	19.92	12.63	39.47	59.26	3.85	21.05	-0.67	49	31

More auxiliary energy was used in January because of the higher space heating load. Less auxiliary energy was used after January because of the addition of an adjustable delay timer between valves V2 and V3 to let the solar contribution satisfy the whole load, if possible. Less solar energy was used in the middle of the season (December to February) because less solar energy was collected.

The operating energy is included as a negative value because this is the solar unique operating energy. This is the energy expended to collect and deliver solar energy to the load. If the Billings Shipping site did not have a solar energy system to assist in heating the office space, this energy would not have been lost. (See Figure 2.)

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 Billings Shipping functioned at a reporting period weighted average COP value of 22.97 for the period October 1979 through April 1980. This value is low because the system did not perform as well as expected.



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
Billings Shipping
October 1979 through April 1980

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

BILLINGS SHIPPING OCTOBER 1979 THROUGH APRIL 1980			
MONTH	SOLAR ENERGY SYSTEM	COLLECTOR SUBSYSTEM	SPACE HEATING SOLAR
OCT	15.24	27.65	102.97
NOV	23.25	38.60	103.35
DEC	21.16	36.24	93.92
JAN	21.31	34.68	114.74
FEB	25.15	43.90	117.10
MAR	25.77	45.74	101.21
APR	8.93	30.94	95.53
AVERAGE	22.97	35.23	102.83

1.3 ENERGY SAVINGS

Energy savings for this site for the reporting period, October 1979 to April 1980, are presented in Table 3. For this seven-month period, the total savings were 147.36 million BTU, for a monthly average of 21.05 million BTU. This is approximately 1,650 gallons of oil, or 144,000 cubic feet of natural gas, or 43,177 kwh of electricity. An electrical energy expense of 4.71 million BTU was incurred during the reporting period for the operation of solar energy components.

Table 3. ENERGY SAVINGS
BILLINGS SHIPPING
OCTOBER 1979 THROUGH APRIL 1980

(All values in million BTU)

MONTH	SOLAR ENERGY USED	SOLAR ENERGY SAVINGS ATTRIBUTED TO SPACE HEATING		ECSS OPERATING ENERGY	NET ENERGY SAVINGS	
		ELECTRICAL	FOSSIL FUEL		ELECTRICAL	FOSSIL FUEL
OCT	15.24	-0.15	25.40	0.85	-1.00	25.40
NOV	16.02	-0.16	26.69	0.53	-0.69	26.69
DEC	12.21	-0.13	20.34	0.45	-0.58	20.34
JAN	8.95	-0.08	14.91	0.34	-0.42	14.91
FEB	10.89	-0.09	18.14	0.34	-0.43	18.14
MAR	16.70	-0.17	27.84	0.48	-0.65	27.84
APR	8.42	-0.09	14.04	0.85	-0.94	14.04
TOTAL	88.43	-0.87	147.36	3.84	-4.71	147.36
AVERAGE	12.63	-0.12	21.05	0.55	-0.67	21.05

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 storage is subtracted from the solar energy contribution to the loads to determine net savings.

The auxiliary source at the Billings Shipping site consists of a gas-fired hot water boiler. This unit is considered to be 60% efficient for computational purposes.

The solar energy used is divided by the boiler efficiency (60%) to get the fossil fuel energy savings. The electrical energy expense is the operating energy required to deliver solar energy to the space heating subsystem. The operating energy that would normally be required to heat this office building is not considered an electrical expense because this energy would be used with or without the solar energy subsystem.

The overall energy savings for the site were slightly less than the energy savings for the space heating subsystem because the space heating subsystem savings did not take into account the electrical energy expended for the collection of solar energy. (See Figure 3.)

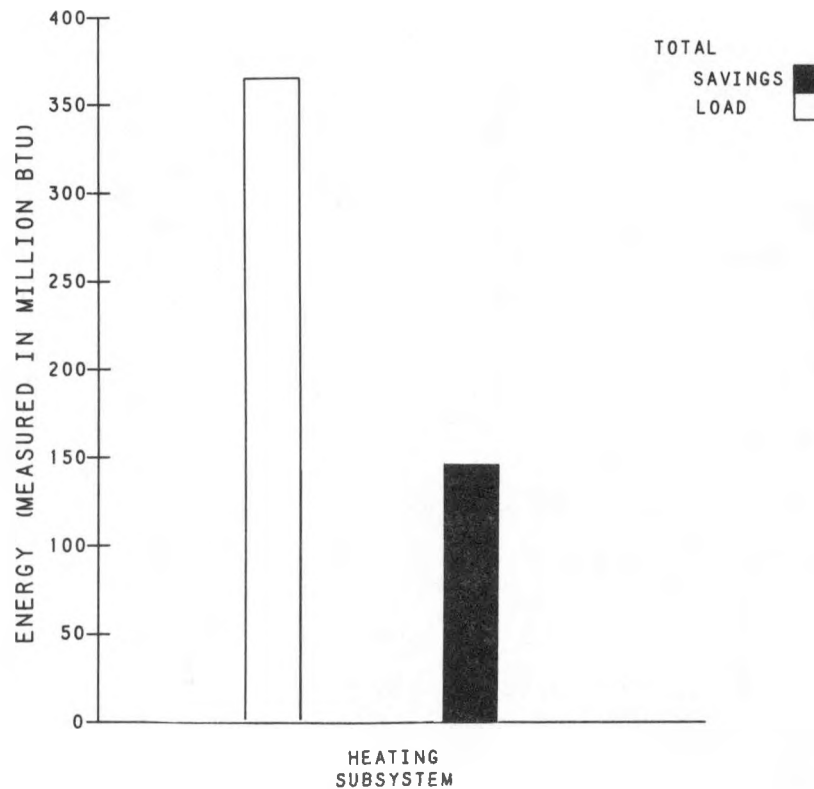


Figure 3. Combined Thermal Energy Savings Compared to Load
Billings Shipping
October 1979 through April 1980

The solar energy used was 88.43 million BTU, resulting in a fossil fuel savings of 147.36 million BTU. The energy collector subsystem required 3.84 million BTU for the collection of solar energy and 0.87 million BTU were required to deliver solar energy from storage to the space heating subsystem. The total electrical energy expended was 4.71 million BTU. The total net energy savings for the system were 142.65 million BTU. This is approximately

139,720 cubic feet of natural gas or 41,797 kwh of electricity. This amounts to approximately \$300.00* saved.

1.4 SOLAR ENERGY UTILIZATION

The total incident solar radiation for the heating season was 530.45 million BTU, of which 392.67 million BTU were incident while the collector loop was operating. Total solar energy collected was 135.65 million BTU for an overall collector array efficiency of 21%. Of the collected energy, 25.61 million BTU were lost, some of which (7.80 million BTU) were intentionally rejected to the atmosphere, while 110.04 million BTU were delivered directly to the loads or the storage tank. The solar energy delivered to the load was 88.43 million BTU or 17% of the total incident solar energy. (See Figure 4.)

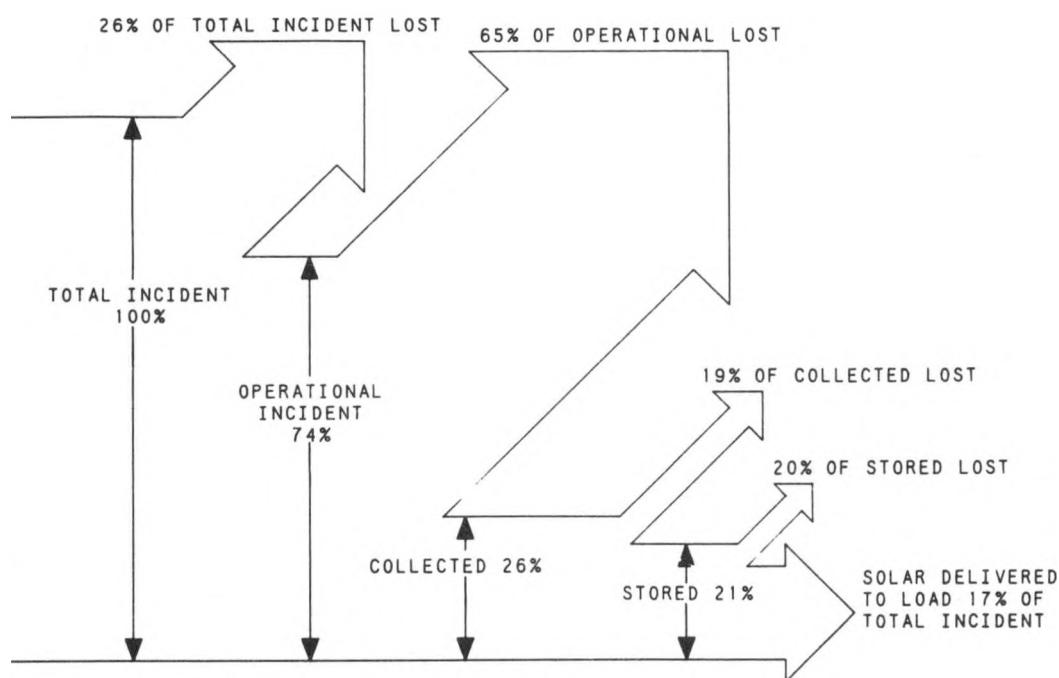


Figure 4. Solar Energy Use
Billings Shipping
October 1979 through April 1980

The solar energy lost from the collectors to storage was 25.61 million BTU, while the loss from storage amounted to 20.28 million BTU. No energy was lost from storage to the space heating subsystem because that is how it is calculated. The space heating load is calculated by adding the solar energy used and the auxiliary energy used. Any transport losses that occur go into heating the interior of the office building. (See Table 4.)

* This was estimated by using a value of \$2.14 per 1,000 cubic feet of natural gas.

Table 4. SOLAR ENERGY LOSSES
 BILLINGS SHIPPING
 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 - SE DIRECTLY TO LOADS (million BTU)	21.02	11.42	8.96	6.35	8.96	14.53	24.24
2. SE TO STORAGE (million BTU)	15.60	9.00	7.53	5.07	7.60	12.32	12.72
3. LOSS - COLLECTOR TO STORAGE (%)	26	21	16	30	15	15	48
4. CHANGE IN STORED ENERGY (million BTU)	-1.57	-0.04	0.43	0.07	0.50	0.11	1.83
5. SOLAR ENERGY - STORAGE TO SPACE HEATING SUBSYSTEM (million BTU)	12.70	6.83	4.97	3.44	4.88	9.14	6.30
6. LOSS FROM STORAGE (%)	29	25	28	31	29	25	36
7. HEATING SOLAR ENERGY (HSE) FROM STORAGE (million BTU)	12.70	6.83	4.97	3.44	4.88	9.14	6.30
8. LOSS - STORAGE TO HSE (%)	0	0	0	0	0	0	0

1.5 SOLAR SYSTEM AVAILABILITY

The solar system was operational for the whole heating season of October 1979 through April 1980.

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The Billings Shipping collector array is composed of 120 LSC18-1S flat-plate collectors made by Lennox Industries which use glycol (50/50 Dowtherm) as the heat transfer fluid. The total collector area is 1,968 square feet and faces 10 degrees east of south with a tilt of 50 degrees to the horizontal.

The total solar energy incident on the collector array was 530.45 million BTU and 392.67 million BTU were incident on the collector array while the collector loop was operating. Total solar energy collected was 135.65 million BTU for a collector array efficiency of 21% based on the incident solar energy or 35% based on operational incident solar energy. The collector array efficiency of 21% is low because the collectors were not operating as much as they could have. There were 243.37 million BTU of solar energy incident while the collectors were not operating. This was lost because the collectors do not activate until the collector plate temperature reaches 130°F and there is a time delay to prevent the collector from cycling on and off.

The collected solar energy delivered directly to the loads was 40.20 million BTU and 69.84 million BTU were delivered to storage. Of the collected solar energy, 17.81 million BTU were lost and 7.80 million BTU were intentionally rejected to the atmosphere. The operating energy required to support the collector subsystem was 3.84 million BTU. (See Table 5.)

Table 5. COLLECTOR SUBSYSTEM PERFORMANCE

BILLINGS SHIPPING
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 COLLECTOR EFFICIENCY %	ECSS OPERATING ENERGY	SOLAR ENERGY DIRECTLY TO LOADS	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE °F
OCT	84.72	23.56	28	74.78	32	0.85	2.57	15.60	61
NOV	71.10	20.61	29	57.45	36	0.53	9.19	9.00	40
DEC	60.81	16.20	27	45.74	35	0.45	7.24	7.53	41
JAN	59.41	11.86	20	36.26	33	0.34	5.51	5.07	24
FEB	62.12	14.97	24	37.93	39	0.34	6.01	7.60	36
MAR	84.18	22.09	26	55.77	40	0.48	7.56	12.32	41
APR	108.11	26.36	24	84.76	31	0.85	2.12	12.72	65
TOTAL	636.06	135.65	-	392.69	-	3.84	40.20	69.84	-
AVERAGE	90.87	19.38	21	56.10	35	0.55	6.70	9.98	44

2.2 STORAGE

The storage tank is a 2,500-gallon steel tank buried five feet underground and insulated with two inches of polystyrene.

During the heating season of October 1979 through April 1980, the total solar energy delivered to storage was 69.84 million BTU. There were 48.23 million BTU delivered from storage to the space heating subsystem. Energy loss from storage was 20.28 million BTU, resulting in a storage efficiency of 71%. (See Footnote 1.) Storage efficiency is defined as the energy removed from storage, plus the change in stored energy, divided by the energy added to storage. The storage efficiency is low because solar energy is collected in the daytime, but much of it goes unused until the early morning hours. This causes high standby losses. The average storage temperature was 106°F. The average storage temperature for November to February was lower because more solar energy was used for space heating. In October, March, and April, there was less demand for space heating and, therefore, not all the solar energy was used maintaining a higher storage temperature. (See Table 6.)

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
 STEI = Energy added to storage

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

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

Where: c = effective storage heat loss coefficient
 T_s = average storage temperature
 T_a = average ambient temperature in the vicinity of storage
 t = number of hours in the month

SECTION 3

OPERATING ENERGY

Measured monthly values of the Billings Shipping solar energy system and sub-system operating energy for the report period are presented in Table 8. A total 26.94 million BTU of operating energy was consumed by the entire system during the reporting period.

Total system operating energy for Billings Shipping is the electrical energy required to support the space heating subsystem without affecting its thermal state.

Table 8. OPERATING ENERGY

BILLINGS SHIPPING
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	0.85	2.79	0.15	1.00	3.64
NOV	0.53	3.28	0.16	0.69	3.81
DEC	0.45	3.68	0.13	0.58	4.13
JAN	0.34	4.30	0.08	0.42	4.64
FEB	0.34	3.07	0.09	0.43	3.41
MAR	0.48	3.33	0.17	0.65	3.81
APR	0.85	2.65	0.09	0.94	3.50
TOTAL	3.84	23.10	0.87	4.71	26.94
AVERAGE	0.59	3.10	0.12	0.67	3.85

SECTION 4

WEATHER CONDITIONS

Billings Shipping is located in Billings, Montana at 46 degrees N latitude and 108 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

BILLINGS SHIPPING 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	1,389	1,597	52	49	414	487
NOV	1,204	1,134	34	36	943	879
DEC	997	971	35	27	920	1,184
JAN	974	1,042	18	22	1,444	1,336
FEB	1,088	1,297	29	27	1,052	1,053
MAR	1,380	1,587	35	33	943	1,004
APR	1,831	1,584	54	45	346	612
TOTAL	-	-	-	-	6,062	6,555
AVERAGE	1,266	1,316	37	34	866	936

During the period from October 1979 to April 1980, the average daily total incident solar radiation on the collector array was 1,266 BTU per square foot per day. This radiation was below the estimated average daily solar radiation for this geographical area during the reporting period of 1,316 BTU per square foot per day for a plane facing 10 degrees east of south with a tilt of 50 degrees to the horizontal. During the period, the highest monthly average insolation was 1,831 BTU per square foot per day during April. The average ambient temperature during the reporting period was 37°F as compared with the long-term average of 34°F. The highest monthly average ambient temperature was 54°F during April and the lowest monthly average ambient temperature was 18°F during January. The number of heating degree-days for the period, based on a 65°F reference, was 6,062 as compared with the long-term average of 6,555. The range of heating degree-days was from a high of 1,444 during January to a low of 346 during April.

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

SECTION 5

REFERENCES

- *1. National Solar Data Network, Department of Energy, prepared under Contract Number DE-AC01-79CS30027, Vitro Laboratories, Silver Spring, Maryland, January 1980.
2. J. T. Smok, V. S. Sohoni, J. M. Nash, "Processing of Instrumented Data for the National Solar Heating and Cooling Demonstration Program," Conference on Performance Monitoring Techniques for Evaluation of Solar Heating and Cooling Systems, Washington, D.C., April 1978.
3. E. Streed, et al, Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program, NBSIR-76-1137, National Bureau of Standards, Washington, D.C., 1976.
4. Mears, J. C., Reference Monthly Environmental Data for Systems in the National Solar Data Network. Department of Energy report SOLAR/0019-79/36. Washington, D.C., 1979.
5. ASHRAE Standard 93-77, Methods of Testing to Determine the Thermal Performance of Solar Collectors, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, N.Y., 1977.
- **6. ASHRAE Standard 94-77, Methods of Testing Thermal Storage Devices Based on Thermal Performance, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, N.Y., 1977.
- *6A. User's Guide to Monthly Performance Reports, June 1980, SOLAR/0004-80/18, Vitro Laboratories, Silver Spring, Maryland.
- *6B. Instrumentation Installation Guidelines, July 1980, Parts 1, 2, and 3, SOLAR/0001-80-15, Vitro Laboratories, Silver Spring Maryland.
- *7. Monthly Performance Report, October 1979, SOLAR/2066-79/10, IBM, Huntsville, Alabama.
- *8. Monthly Performance Report, November 1979, SOLAR/2066-79/11, IBM, Huntsville, Alabama.
- *9. Monthly Performance Report, November 1979, SOLAR/2066-79/12, Vitro Laboratories, Silver Spring, Maryland.
- *10. Monthly Performance Report, January 1980, SOLAR/2066-80/01, Vitro Laboratories, Silver Spring, Maryland.

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

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

- *11. Monthly Performance Report, February 1980, SOLAR/2066-80/02, Vitro Laboratories, Silver Spring, Maryland.
- *12. Monthly Performance Report, March 1980, SOLAR/2066-80/03, Vitro Laboratories, Silver Spring, Maryland.
- *13. Monthly Performance Report, April 1980, SOLAR/2066-80/04, 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

The Billings Shipping solar energy site, located in Billings, Montana, is an enclosed freight distribution facility with 4,900 square feet of heated office space. The system has a roof-mounted flat-plate collector array that faces 10 degrees east of south at an angle of 50 degrees to the horizontal. The collector array has a gross area of 1,968 square feet and uses a 50% propylene glycol and water solution for the energy transport fluid.

The collected solar energy is stored in a 2,500-gallon water tank which is insulated with two inches of polystyrene and buried five feet below the surface of the ground. Solar energy may be transferred to the space heating subsystem from this tank or transferred directly from the energy collection subsystem. This solar-heated water passes through the solar portion of the air-handler unit space heating coil to provide space heating. Auxiliary space heating is obtained from heated water flowing through a separate loop of the air-handler unit. Auxiliary energy is supplied by a gas-fired hot water boiler.

The system, shown schematically, has four modes of solar operation.

Mode 1 - Collector-to-Heat Exchanger - This mode activates when the collector surface reaches 130°F. Pump P1 is activated at this temperature and turns off whenever the surface temperature falls below 100°F. Collector loop fluid circulates through the collector and heat exchanger. If the temperature of the collector fluid exceeds 195°F, the heat rejectors activate to cool the fluid and protect the collectors.

Mode 2 - Heat Exchanger-to-Storage - This mode activates when mode 1 is active and the collector fluid temperature at the collector outlet is higher than the temperature of storage. Water is circulated by pump P2 through the collector heat exchanger, valve V2, storage, and valve V1.

Mode 3 - Heat Exchanger-to-Load - This mode activates when mode 1 is active and a space heating demand exists. Water is circulated by pump P2 through the collector heat exchanger, the air handler space heating coils, and valve V2. When the temperature of the water leaving valve V2 is lower than the storage temperature, V1 bypasses storage; otherwise, the flow passes through storage and then valve V1.

Mode 4 - Storage-to-Load - This mode activates when mode 1 is not active, a space heating demand exists, and the storage temperature is greater than 90°F. Water is circulated by pump P3 from storage through valve V1, the space heating coils, valve V2, and returned to storage.

SUBSYSTEMS

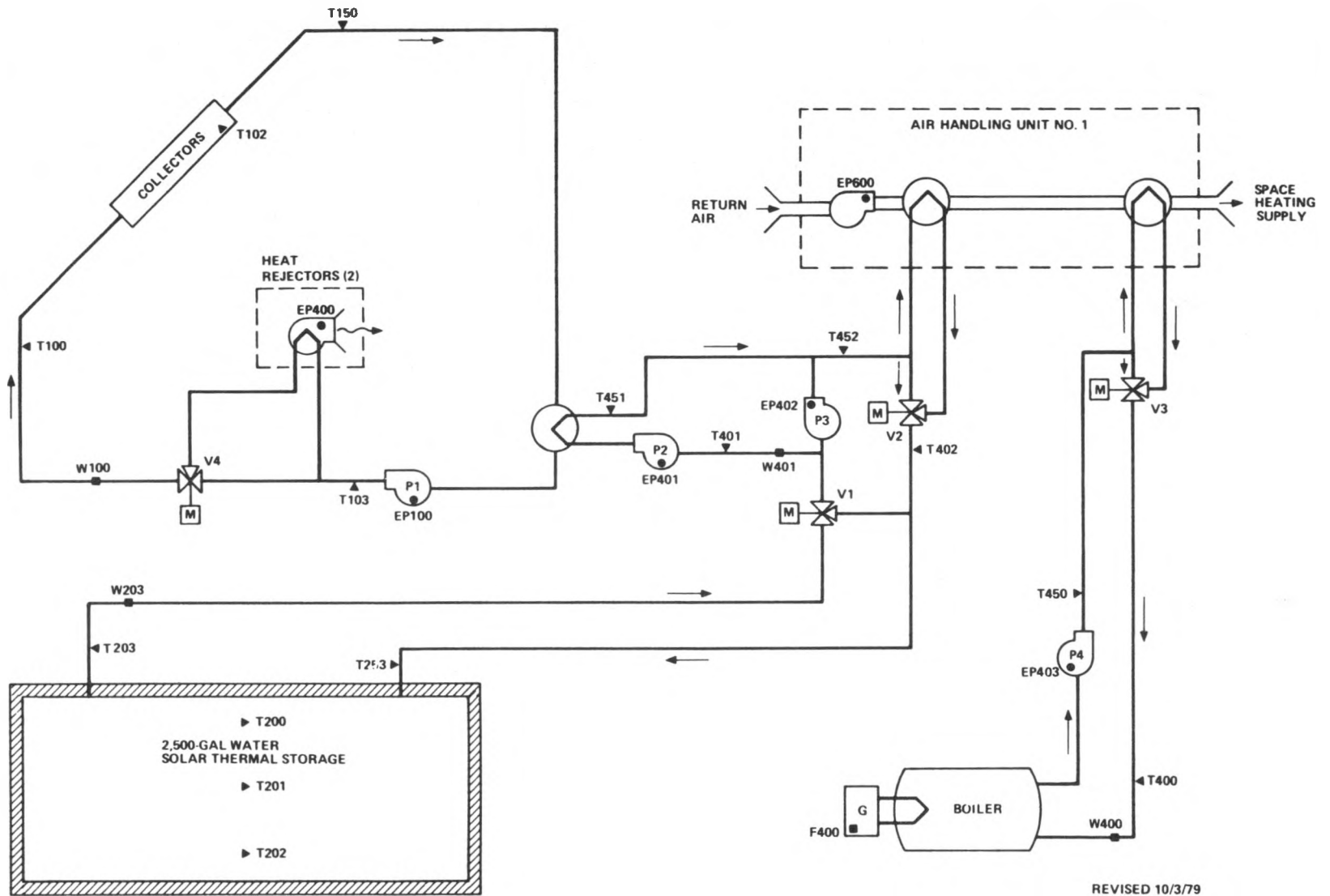
Collector - The gross collector array area is 1,968 ft². The 120 LSC 18-1S collectors made by Lennox Industries face in a southeasterly direction at an azimuth angle of 10 degrees east of south. The collectors are tilted to an altitude angle of 50 degrees from the horizontal. Orientation of the collectors is close to the optimum orientation for a system of this type, at a site latitude of 46 degrees North. Optimum collector orientation at this site is estimated to be 10 degrees east of south at a tilt of 60 degrees.

The collector panels have one glass cover and a non-selective absorber surface. The absorber surface has a solar absorptivity of 0.94 and an infrared emissivity of 0.10. Total solar transmissivity of the glazing is 0.89. The absorber surface is composed of black chrome on bright nickel. The fluid circulated through the collectors is glycol (50/50 Dowfrost). If the temperature of the collector fluid exceeds 195°F, the heat rejectors activate to cool the fluid and protect the collectors.

Storage - Solar energy storage is provided by a 2,500-gallon steel storage tank located five feet underground. The storage has two inches polystyrene at the bottom and two inches polystyrene 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 is designed to utilize solar energy through air handling unit number 1. The system has a Weil-McLain E6H-105-W boiler designed to deliver 0.36 million BTU/hour to satisfy the building heat load. The design solar fraction is 54%. If solar energy cannot supply the whole load, the boiler activates to supply energy through air handling unit number 1.

- I001 COLLECTOR PLANE TOTAL INSOLATION
- ▶ T001 OUTDOOR TEMPERATURE
- ▶ T600 INDOOR TEMPERATURE



REVISED 10/3/79

A-3

Figure A-1. Billings Shipping Solar Energy System Schematic

APPENDIX B
PERFORMANCE EVALUATION TECHNIQUES

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Billings Shipping 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.

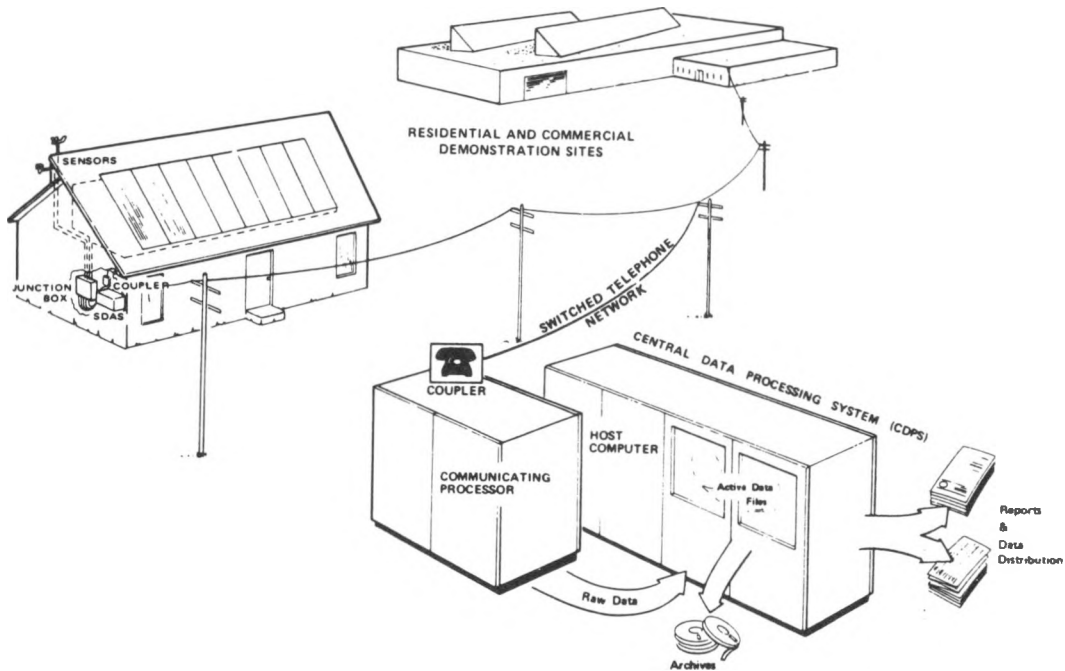


Figure B-1. The National Solar Data Network

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 Billings Shipping 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:

December 1978, SOLAR/2066-78/12
January 1979, SOLAR/2066-79/01
February 1979, SOLAR/2066-79/02
March 1979, SOLAR/2066-79/03
April 1979, SOLAR/2066-79/04
May 1979, SOLAR/2066-79/05
October 1979, SOLAR/2066-79/10
November 1979, SOLAR/2066-79/11
December 1979, SOLAR/2066-79/12
January 1980, SOLAR/2066-80/01
February 1980, SOLAR/2066-80/02
March 1980, SOLAR/2066-80/03
April 1980, SOLAR/2066-80/04
May 1980, SOLAR/2066-80/05

Solar Project Description, July 1979, SOLAR/2066-79/50

Solar Project Cost Report, July 1979, SOLAR/2066-79/60

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

Glazing	In solar/energy technology, the transparent covers used to reduce energy losses from a collector panel.
Heat Exchanger	A device used to transfer energy from one heat transfer fluid to another while maintaining physical segregation of the fluids. Normally used in systems to provide an interface between two different heat transfer fluids.
Heat Transfer Fluid	The fluid circulated through a heat source (solar collector) or heat exchanger that transports the thermal energy by virtue of its temperature.
Heating Degree Days	The sum over a specified period of time of the number of degrees the average daily temperature is <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
BILLINGS SHIPPING

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

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

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, Δt 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

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

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 $\text{BTU}/\text{lb}_m\text{-}^\circ\text{F}$, 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

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

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

BILLINGS SHIPPING

EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

AVERAGE AMBIENT TEMPERATURE (°F)

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

AVERAGE BUILDING TEMPERATURE (°F)

$$TB = (1/60) \times \sum T600 \times \Delta\tau$$

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 is active

HUMIDITY RATIO FUNCTION (BTU/lb_m -°F)

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

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

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \sum [M100 \times CP \ ((T100 + T150) / 2) \times (T150 - T100)] \times \Delta\tau$$

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \sum [M203 \times CP \times (T253 - T203)] \times \Delta\tau$$

SOLAR ENERGY FROM STORAGE (BTU)

$$STEO = \sum [M203 \times CP \times (T203 - T253)] \times \Delta\tau$$

AVERAGE TEMPERATURE OF STORAGE (°F)

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

ENERGY DELIVERED FROM ECSS TO SPACE HEATING SUBSYSTEM (BTU)

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

ECSS OPERATING ENERGY (BTU)

$$CSOPE = 56.8833 \times \sum (EP400 + EP401 + EP100) \times \Delta\tau$$

when system is in the collector-to-storage mode

$$CSOPE = 56.8833 \times \sum (EP100 + EP401/2.0 + EP400) \times \Delta\tau$$

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

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$$HOPE = 56.8833 \times \sum (EP402 + EP403 + EP600) \times \Delta\tau$$

$$HOPE1 = 56.8833 \times \sum EP402 \times \Delta\tau$$

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

$$HOPE = 56.8833 \times \sum (EP402 + EP403 + EP401/2.0 + EP600) \times \Delta\tau$$

$$HOPE1 = 56.8833 \times \sum (EP402 + EP401/2.0) \times \Delta\tau$$

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

SOLAR ENERGY TO SPACE HEATING SUBSYSTEM (BTU)

$$HSE = M401 \times CP \times (T452 - T402) \times \Delta\tau$$

SPACE HEATING SUBSYSTEM AUXILIARY FOSSIL FUEL ENERGY (BTU)

$$HAF = 1000 \times FD400$$

SPACE HEATING SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$$HAT = M400 \times CP \times (T450 - T400) \times \Delta\tau$$

SPACE HEATING SUBSYSTEM LOAD (BTU)

$$HL = HSE + HAT$$

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$$SEA = CLAREA \times SE$$

COLLECTED SOLAR ENERGY (BTU)

$$SEC = SECA/CLAREA$$

COLLECTOR ARRAY EFFICIENCY

$$\text{CAREF} = \text{SECA}/\text{SEA}$$

CHANGE IN STORED ENERGY (BTU)

$$\text{STECH} = \text{STECH1} - \text{STECH1}_p$$

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)

$$\text{SEL} = \text{CSEO}$$

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 HEATING SUBSYSTEM FOSSIL ENERGY SAVINGS (BTU)

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

SPACE HEATING SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

$$\text{HSVE} = \text{HOPE} - 1$$

SYSTEM LOAD (BTU)

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

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

$$\text{SFR} = \text{HSFR}$$

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

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

AUXILIARY FOSSIL ENERGY TO LOADS (BTU)

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

SYSTEM OPERATING ENERGY (BTU)

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

TOTAL ENERGY CONSUMED (BTU)

$$\text{TECSM} = \text{SYSOPE} + \text{AXF} + \text{SECA}$$

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

$$\text{TSVE} = \text{HSVE} - \text{CSOPE}$$

SYSTEM PERFORMANCE FACTOR

$$\text{SYSPF} = \text{SYSL} / [(\text{AXE} + \text{SYSOPE}) \times 3.33]$$

APPENDIX E
CALCULATION OF PREDICTED VALUES

APPENDIX E

CALCULATION OF PREDICTED VALUES

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

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

Ref:

- (1) Solar Heating Design by the F-Chart Method. William A. Beckman, Sanford A. Klein, John A. Duffie, Wiley Interscience, N.Y. (1977)
- (2) F-Chart User's Manual. EES Report 49-3, SERI, Department of Energy, (June 1978)

SYSTEM PERFORMANCE SUMMARY (f-CHART)*

BILLINGS SHIPPING OCTOBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

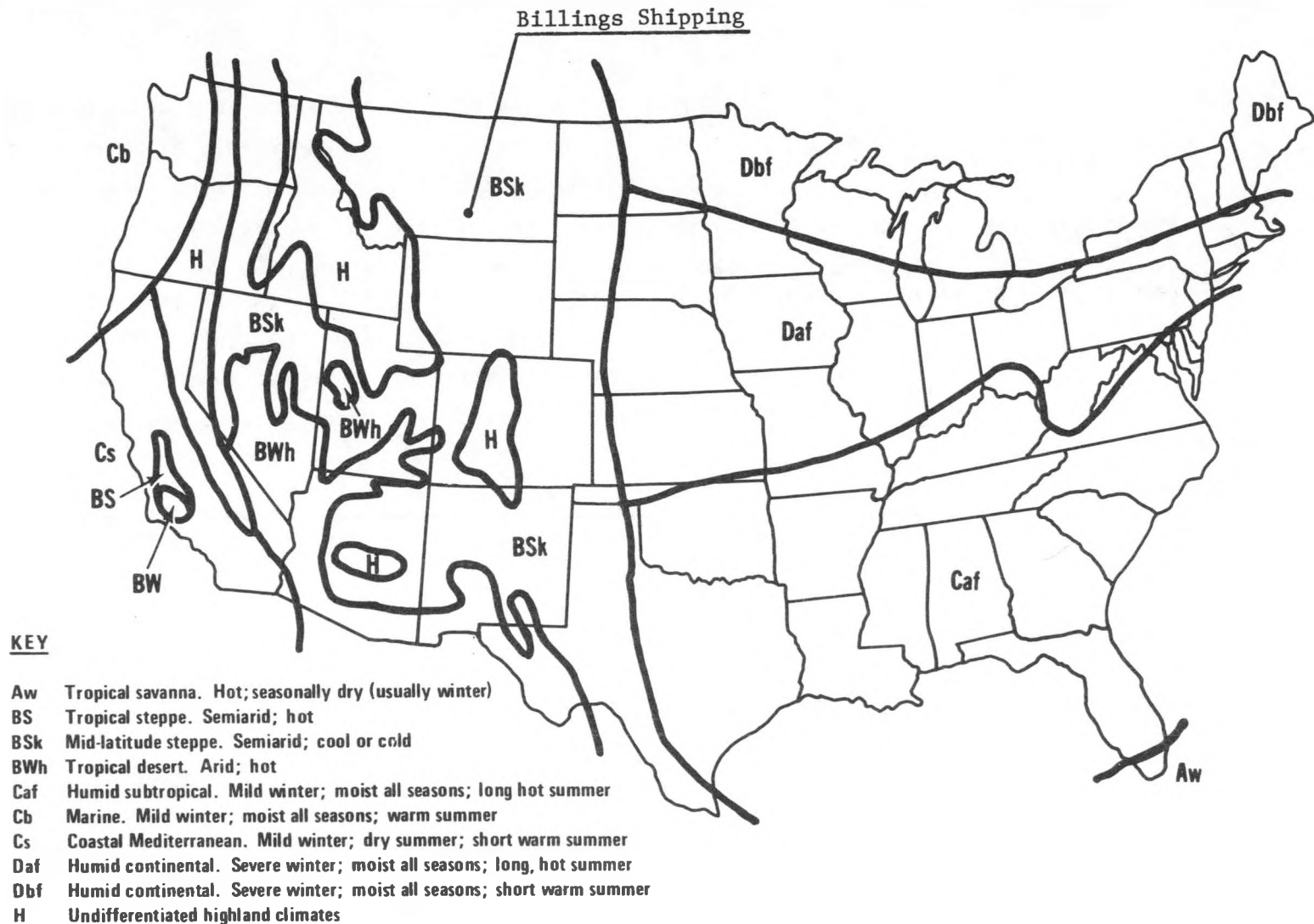
MONTH	ESFR (%)	ASFR (%)	LOAD	LOSS	STECH	ESECA	ASECA	ESEU	ASEU	LOSS (%)
OCT	80	64	23.65	9.53	-1.57	28.45	23.56	18.84	15.24	35
NOV	34	25	63.06	4.63	-0.04	27.91	20.61	21.69	16.02	22
DEC	25	18	67.92	3.57	0.43	22.91	16.14	17.24	12.21	24
JAN	23	11	82.41	2.84	0.07	24.93	11.87	18.80	8.95	25
FEB	34	20	55.74	3.58	0.50	26.05	14.98	18.96	10.89	27
MAR	50	31	54.43	5.28	0.11	35.75	22.09	27.04	16.70	24
APR	96	48	17.50	8.67	1.83	28.01	26.36	16.85	8.42	68
TOTAL	-	-	364.71	38.10	1.33	194.01	135.61	139.42	88.43	-
AVERAGE	38	24	52.10	5.44	0.19	27.72	19.37	19.92	12.63	32

* See next page for Glossary of f-Chart Terms.

GLOSSARY OF f-CHART TERMS

- ESFR - Expected (predicted) solar fraction
- ASFR - Actual (measured) solar fraction
- LOAD - Measured total system load
- LOSS - Total system losses (transport and storage)
- STECH - Change in stored energy
- ESECA - Expected (predicted) solar energy collected
- ASECA - Actual (measured) solar energy collected
- ESEU - Expected (predicted) solar energy used
- ASEU - Actual (measured) solar energy used
- LOSS (%) - $100 \times (ASECA - ASEU)/ASECA$

APPENDIX F
METEOROLOGICAL CONDITIONS



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

Figure F-1. Meteorological Map of the United States Showing Location of Billings Shipping

BILLINGS SHIPPING LONG-TERM WEATHER DATA

COLLECTOR TILT: 50 DEGREES
LATITUDE: 46 DEGREES

LOCATION: BILLINGS, MONTANA
COLLECTOR AZIMUTH: 10 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
OCT	1,686	988	0.58623	1.616	1,597	487	0	49
NOV	1,126	560	0.49756	2.024	1,134	879	0	36
DEC	889	420	0.47279	2.310	971	1,184	0	27
JAN	1,015	487	0.47943	2.141	1,042	1,336	0	22
FEB	1,496	763	0.51027	1.699	1,297	1,053	0	27
MAR	2,149	1,191	0.55407	1.332	1,587	1,004	0	33
APR	2,869	1,526	0.53200	1.038	1,584	612	0	45

LEGEND:

HOBAR - Monthly average daily extraterrestrial radiation (ideal) in BTU/day-Ft².

HBAR - Monthly average daily radiation (actual) in BTU/day-Ft².

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-Ft².

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: BILLINGS SHIPPING
 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	1741	56	71
2	810	53	60
3	2260	52	64
4	2252	64	74
5	1869	63	74
6	2132	62	78
7	1012	67	78
8	137	44	42
9	1998	45	51
10	1944	62	71
11	2019	63	77
12	1464	52	62
13	2057	53	66
14	1747	63	75
15	295	57	64
16	1335	52	59
17	832	52	60
18	1496	50	57
19	922	51	58
20	331	39	46
21	1111	39	43
22	1568	44	54
23	712	50	57
24	1382	52	59
25	1392	54	69
26	1778	55	60
27	1959	50	58
28	236	46	52
29	841	42	49
30	2019	37	47
31	1400	34	42
SUM	43051	-	-
AVG	1389	52	61

MONTHLY REPORT: BILLINGS SHIPPING
 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	747	34	41
2	1845	38	46
3	1451	41	50
4	325	35	38
5	265	30	31
6	1493	34	39
7	1699	33	42
8	1232	37	45
9	503	31	34
10	1220	40	47
11	339	35	39
12	1870	36	45
13	1860	39	46
14	1840	44	53
15	1762	44	56
16	1396	46	58
17	70	47	51
18	290	41	47
19	73	32	33
20	1499	20	25
21	1621	17	22
22	1577	28	32
23	1783	33	39
24	895	36	39
25	1802	34	39
26	1336	27	33
27	278	24	26
28	1577	20	29
29	1748	22	29
30	1735	29	36
SUM	36129	-	-
AVG	1204	34	40

F-3

MONTHLY REPORT: BILLINGS SHIPPING
 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	1661	30	38
2	621	42	49
3	358	44	47
4	509	55	64
5	921	43	47
6	1561	51	56
7	*	*	*
8	1592	44	52
9	402	49	55
10	148	35	35
11	1664	18	23
12	1067	33	40
13	1087	31	33
14	279	47	51
15	542	5	2
16	815	6	11
17	196	44	47
18	1585	49	*
19	1592	44	53
20	166	41	45
21	1019	31	39
22	331	32	36
23	658	32	37
24	543	31	39
25	795	39	44
26	2404	37	44
27	1603	28	37
28	1426	26	37
29	1660	29	37
30	1363	28	36
31	1333	36	44
SUM	30897	-	-
AVG	997	35	41

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: BILLINGS SHIPPING
 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	975	37	42
2	953	34	39
3	1314	35	46
4	408	26	30
5	107	23	32
6	1631	3	8
7	715	6	12
8	396	-9	-8
9	338	-7	-5
10	130	0	5
11	825	-7	-6
12	712	34	49
13	727	39	43
14	1363	42	51
15	369	37	43
16	1504	33	39
17	586	34	41
18	254	21	22
19	1368	6	12
20	1683	19	23
21	787	33	37
22	1344	29	33
23	797	39	42
24	1352	42	46
25	735	13	12
26	1320	1	6
27	1140	-6	0
28	1572	-6	3
29	1446	-5	2
30	1629	6	12
31	1707	19	27
SUM	30185	-	-
AVG	974	18	24

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MONTHLY REPORT: BILLINGS SHIPPING
 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	948	34	40
2	1488	39	46
3	194	41	45
4	852	41	47
5	1672	34	42
6	292	34	40
7	174	24	22
8	1410	25	29
9	791	31	37
10	574	26	31
11	1713	25	32
12	270	29	32
13	407	15	19
14	801	1	3
15	903	3	9
16	1813	4	16
17	694	22	30
18	684	38	46
19	1819	38	51
20	583	33	40
21	1239	35	42
22	1398	35	41
23	1887	36	43
24	2248	35	46
25	1575	37	48
26	1873	46	55
27	984	54	62
28	137	32	31
29	1606	17	19
SUN	31028	-	-
AVG	1070	30	36

MONTHLY REPORT: BILLINGS SHIPPING
 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	*	*	*
2	*	*	*
3	610	19	21
4	583	6	8
5	983	11	18
6	2441	19	31
7	1781	28	38
8	1071	31	38
9	646	41	45
10	2029	35	38
11	620	41	50
12	1519	35	40
13	1618	37	49
14	2042	45	60
15	384	35	35
16	1895	34	40
17	2101	39	49
18	*	*	*
19	787	40	42
20	2273	43	50
21	1205	41	49
22	2136	42	51
23	1433	43	54
24	1428	40	48
25	450	31	32
26	2435	33	41
27	1723	39	51
28	1459	42	51
29	2331	45	55
30	232	39	41
31	423	33	34
SUN	42774	-	-
AVG	1380	35	41

* DENOTES UNAVAILABLE DATA.

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MONTHLY REPORT: BILLINGS SHIPPING
 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	667	36	39
2	460	35	37
3	1595	38	46
4	2445	44	54
5	1379	48	59
6	1947	48	56
7	1263	41	*
8	2402	42	52
9	1420	50	63
10	1371	46	52
11	1939	42	47
12	1458	43	52
13	2429	52	63
14	2220	60	74
15	879	53	54
16	2389	55	65
17	2393	61	75
18	1440	63	76
19	2145	65	81
20	2314	71	88
21	1960	70	86
22	1972	58	62
23	2173	59	71
24	1895	63	74
25	2460	59	69
26	2305	60	70
27	2267	62	72
28	2046	65	81
29	1928	68	83
30	1372	61	72
SUM	54934	-	-
AVG	1831	54	65

* DENOTES UNAVAILABLE DATA.

APPENDIX G

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

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Billings Shipping was occupied for all of the reporting period. During this time, the solar system operated throughout the season. 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>
1/80	The grantee insulated the pipes in the equipment room and added a delay timer between valves V2 and V3, so that solar energy could supply the whole load, if possible.

APPENDIX H
CONVERSION FACTORS

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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 I
SENSOR TECHNOLOGY

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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.

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 $\cos \phi$ (power factor angle). This output is read into the SDAS as an electrical power in watts.