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SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

MASTER

SOUTH DAKOTA SCHOOL OF MINES
Keystone, South Dakota
June 1980 through April 1981
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U.S. DEPARTMENT OF ENERGY
NATIONAL SOLAR DATA PROGRAM

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SOUTH DAKOTA SCHOOL OF MINES
KEYSTONE, SOUTH DAKOTA
SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION
JUNE 1980 THROUGH APRIL 1981

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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, prior to 1981, 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 assist in the development of solar technologies for buildings by providing data and information on the effectiveness of specific systems, the effectiveness of particular solar technologies, and the areas of potential improvement. Vitro Laboratories Division responsibility in the NSDN, under contract with the Department of Energy, is to collect data daily 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. 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.

SOUTH DAKOTA SCHOOL OF MINES

SOUTH DAKOTA SCHOOL OF MINES

The South Dakota School of Mines site is the Mount Rushmore National Memorial Visitor's Center in Keystone, South Dakota. The active solar energy system is designed to supply the following:

Annual Design Factors (Million BTU)

	<u>% Solar</u>
Heating	45
Observation Room Cooling	53

It is equipped with:

- Collector: 2,000 square feet of Lennox LSC18-1 flat-plate collector panels double-glazed with a black chrome absorber surface.
- Storage: 3,000 gallons of water in an insulated tank located in the solar system mechanical room.
- Auxiliary: Two-stage fuel oil furnace; cooling auxiliary from direct expansion electric air conditioning units. The solar system is a retrofit.

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TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
Foreword	
Site Summary	i
Table of Contents	iii
List of Illustrations	iv
List of Tables	v
 1. SOLAR SYSTEM PERFORMANCE	 1-1
1.1 Summary and Conclusions	1-2
1.2 System Operation	1-18
1.3 Solar Energy Utilization	1-25
 2. REFERENCES	 2-1
 <u>Appendices</u>	
A. System Description	A-1
B. Performance Evaluation Techniques	B-1
C. Performance Factors and Solar Terms	C-1
D. Performance Equations	D-1
E. Long-Term Weather Data	E-1
F. Fluid Sample Analysis	F-1
G. Conversion Factors	G-1
H. Sensor Technology	H-1
I. Typical Monthly Data	I-1

LIST OF ILLUSTRATIONS

<u>Figure Number</u>	<u>Title</u>	<u>Page</u>
1	Energy Flow Diagram for South Dakota School of Mines, June 1980 through April 1981	1-3
2	System Thermal Performance, South Dakota School of Mines, June 1980 through April 1981	1-5
3	Average Collector Efficiency, South Dakota School of Mines, April 1981	1-7
4	Cooling Load vs Hour of Day, South Dakota School of Mines, June 1980 through August 1980	1-13
5	Absorption Chiller Generator Inlet and Evaporator Outlet Temperatures vs Capacity, South Dakota School of Mines, June and August 1980 and Seasonal Average for June, July, and August 1980	1-14
6a	Typical Insolation Data, Winter Mode, South Dakota School of Mines, January 20, 1981	1-19
6b	Typical Storage Fluid Temperatures, Winter Mode, South Dakota School of Mines, January 20, 1981	1-20
6c	Typical Heating System Operation, South Dakota School of Mines, January 20, 1981	1-20
7a	Typical Insolation Data, Summer Mode, South Dakota School of Mines, July 16, 1980	1-21
7b	Typical Collector Array Temperatures, Inlet/Outlet, Summer Mode, South Dakota School of Mines, July 16, 1980	1-22
7c	Typical Generator/Collector Flow and Temperatures, Inlet/ Outlet, Summer Mode, South Dakota School of Mines, July 16, 1980	1-23
7d	Typical Absorption Chiller Evaporator Temperatures, Inlet/ Outlet, South Dakota School of Mines, July 16, 1980	1-23
8	Typical System Operating Sequence, Winter Mode, South Dakota School of Mines, January 20, 1981	1-24
9	Typical System Operating Sequence, Summer Mode, South Dakota School of Mines, July 16, 1980	1-25
10	Solar Energy Use, South Dakota School of Mines, June 1980 through April 1981	1-26

LIST OF ILLUSTRATIONS (Continued)

<u>Figure Number</u>	<u>Title</u>	<u>Page</u>
A-1	South Dakota School of Mines Solar Energy System Schematic	A-3
B-1	The National Solar Data Network	B-1

LIST OF TABLES

<u>Table Number</u>	<u>Title</u>	<u>Page</u>
1	Solar System Thermal Performance, South Dakota School of Mines, June 1980 through April 1981	1-4
2	Solar Coefficient of Performance, South Dakota School of Mines, June 1980 through April 1981	1-5
3	Collector Subsystem Performance, South Dakota School of Mines, June 1980 through April 1981	1-7
4	Storage Performance, South Dakota School of Mines, June 1980 through April 1981	1-10
5	Space Heating Subsystem, South Dakota School of Mines, June 1980 through April 1981	1-11
6	Space Cooling Subsystem, South Dakota School of Mines, June 1980 through September 1980	1-12
7	Solar Absorption Chiller, South Dakota School of Mines, June 1980 through September 1980	1-13
8	Solar Operating Energy, South Dakota School of Mines, June 1980 through April 1981	1-15
9	Energy Savings, South Dakota School of Mines, June 1980 through April 1981	1-16
10	Weather Conditions, South Dakota School of Mines, June 1980 through April 1981	1-17

SECTION 1

SOLAR SYSTEM PERFORMANCE

SOUTH DAKOTA SCHOOL OF MINES
JUNE 1980 THROUGH APRIL 1981

Solar Fraction ¹	33%
Solar Savings Ratio ²	32%
Conventional Fuel Savings ³	1,546 gallons of oil
Electrical Energy Expense ⁴	3,601 kwh
System Performance Factor ⁵	0.91
Solar System COP ⁶	8.60

Seasonal Energy Requirements
June 1980 through April 1981
(Million BTU)

	<u>Total Load</u>	<u>Solar Contribution</u>	<u>% Solar</u>
Heating	303.13	128.63	42
Cooling	131.71	15.87	12

Environmental Data

	<u>Measured Average</u>	<u>Long-Term Average</u>
Outdoor temperature	49°F	46°F
Heating degree-days (Total)	5,705	7,005
Cooling degree-days (Total)	591	646
Daily incident solar energy	1,359 BTU/ft ²	1,537 BTU/ft ²

1. Solar Fraction = $\frac{\text{Solar Energy Supplied to Loads}}{\text{Total Load}} \times 100$
2. Solar Savings Ratio = $\frac{\text{Solar Energy Supplied to Load} - \text{Solar System Operating Energy}}{\text{Total Load}} \times 100$
3. Conventional Fuel Savings = $\frac{\text{Fossil Energy Savings in Million BTU} \times 7.21 \text{ Gallons of Oil/}}{\text{Million BTU}}$
4. Electrical Energy Expense = $\frac{\text{Electrical Expense in Million BTU} \times 292.8 \text{ kwh/}}{\text{Million BTU}}$
5. Ratio of system load to the total equivalent fossil energy expended or required to support the system load.
6. Solar System COP = $\frac{\text{Solar Energy Used}}{\text{Solar-Unique Operating Energy}}$

1.1 SUMMARY AND CONCLUSIONS

The South Dakota School of Mines site is the Mount Rushmore National Memorial Visitor's Center located in Keystone, South Dakota. The solar energy system includes a collector array of 112 double-glazed flat-plate collectors manufactured by Lennox Industries Incorporated, with a gross area of 2,000 square feet. The collectors are mounted in six subarrays, plumbed in parallel, on the roof of the building, and face 18.8 degrees West of South with a tilt of 45.7 degrees from the horizontal. Solar energy storage is provided by a 3,000-gallon steel water tank which is insulated with three inches of fiberglass. Solar heating is accomplished by transferring energy either from the collector or storage to heating coils in the building multizone air handler. Auxiliary heating is provided by a two-stage fuel oil furnace. Thermal energy directly from the collectors is used to operate the three three-ton ARKLA absorption chillers. Chilled water from the chillers is circulated through a cooling coil in the Observation Room air handler. Auxiliary cooling is provided to both the multi-zone and single-zone air handlers by vapor compression units.

The solar energy system supplied 12% of the space cooling load for the building for the months June through September 1980. The space heating solar fraction for the reporting period was 42%.

The quantity of collected solar energy that was delivered to the load was 81% and the collector efficiency was 22%. Use of solar energy saved 214.40 million BTU of fossil fuel energy for a seasonal total of 1,546 gallons of oil. Electrical energy savings of 2.17 million BTU are considered to have been accredited to operation of the solar space cooling system for the season, but these were more than offset by operating energy expenses for operation of the collector and space heating systems. These expenses totaled 14.47 million BTU; thus, a net electrical energy expense of 12.30 million BTU was incurred during the reporting period due to the operation of solar energy components. This expense is equivalent to 3,601 kwh. The overall savings in dollars are approximately \$1,371.00, based on estimated fuel rates at the site of \$0.07 per kwh and \$1.05 per gallon of oil.

Due to a control problem which caused the collector pump to run for 24 hours each day from June 1 through June 18, 1980, the solar system incurred an electrical expense larger than the electrical savings realized through the use of solar space cooling during the month of June.

The flow of solar energy through the South Dakota School of Mines site for the reporting period 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 incident solar energy was 907.24 million BTU of which 202.31 million BTU (22%) were collected. Of the collected energy, 164.74 million BTU (81%) were transferred to the solar space heating and space cooling subsystems. Of the 164.74 million BTU, 2.40 million BTU were uncontrolled losses within the conditioned space, which helped offset purchased energy requirements. Eighty-six percent (102.17 million BTU) of the stored energy was withdrawn from storage. To prevent overheating of the collector array, 7.79 million BTU of solar energy were intentionally rejected through the collector subsystem cooling towers.

Figure 1. Energy Flow Diagram for South Dakota School of Mines
June 1980 through April 1981
(Figures in million BTU)

The overall thermal performance of the solar energy system is presented in Table 1 and shown graphically in Figure 2. The operating energy required by the solar system is considered an expense and is, therefore, shown on the negative axis of Figure 2.

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

SOUTH DAKOTA SCHOOL OF MINES
JUNE 1980 THROUGH APRIL 1981

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SOLAR ENERGY USED	AUXILIARY ENERGY		OPERATING ENERGY	ENERGY SAVINGS	
		MEASURED	FOSSIL	ELECTRICAL		FOSSIL	ELECTRICAL
JUN	16.62	11.25	2.23	12.90	6.67	6.95	-2.54
JUL	14.66	12.72	1.31	14.11	4.92	3.42	0.47
AUG	21.48	14.00	2.74	13.55	5.03	4.37	0.03
SEP	11.70	8.28	6.43	5.77	2.99	2.17	0.36
OCT	17.29	12.49	16.04	0.00	3.63	20.82	-1.12
NOV	16.72	16.78	21.68	0.00	4.48	27.97	-1.21
DEC	14.11	11.84	27.16	0.00	5.05	19.73	-1.08
JAN	24.57	21.43	25.77	0.00	5.71	35.72	-1.72
FEB	21.73	16.39	23.69	0.00	5.37	27.32	-1.52
MAR	22.31	23.04	15.16	0.00	5.51	38.40	-2.24
APR	21.12	16.52	5.96	0.00	3.41	27.53	-1.73
TOTAL	202.31	164.74	148.17	46.33	52.77	214.40	-12.30
AVERAGE	18.39	14.98	13.47	4.21	4.80	19.49	-1.12

The solar energy coefficient of performance (COP) is indicated in Table 2. The COP simply provides a numerical value for the relationship of thermal solar energy used or collected and the electrical energy required to collect or deliver it. The greater the COP value, the more efficient the subsystem. The solar energy system at the South Dakota School of Mines site functioned at a reporting period weighted average COP value of 8.60 for the period June 1980 through April 1981.

The low solar energy system and collector subsystem COPs in June were due to a control malfunction which caused the collector loop pump to run 24 hours per day for the first 18 days of the month. The solar energy system COP was higher during the winter months than summer months due to the large requirement of electrical power use to run the pumps, chillers, and cooling towers associated with the solar absorption chiller subsystem. The high collector subsystem COPs for July through September were due to the allocation of half of the collection loop pump's electrical operating power to the absorption chiller operation and the other half to the collector array. This allocation was done because the collection loop pump provides flow to the generators of the absorption chillers during

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
South Dakota School of Mines
June 1980 through April 1981

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

SOUTH DAKOTA SCHOOL OF MINES
JUNE 1980 THROUGH APRIL 1981

MONTH	SOLAR ENERGY SYSTEM	COLLECTOR SUBSYSTEM	SPACE HEATING SOLAR	SPACE COOLING SOLAR
JUN	3.16	6.35	44.59	11.61
JUL	6.89	35.84	60.45	9.20
AUG	6.73	50.30	42.45	8.75
SEP	7.45	63.60	55.45	9.69
OCT	8.16	20.58	44.18	-
NOV	13.87	19.00	50.52	-
DEC	10.97	18.09	39.33	-
JAN	12.45	19.98	43.39	-
FEB	10.72	19.58	38.74	-
MAR	10.30	20.25	19.85	-
APR	9.54	20.31	22.83	-
WEIGHTED AVERAGE	8.60	19.05	32.79	9.53

summer mode operation. The space heating solar COP dropped down low in March and April 1981 due to a control strategy which allowed the storage/space heating pump to run almost continuously for both months. The temperature differences across the space heating heat exchanger were very low during this period, averaging about 2°F. The control strategy proved effective in utilizing stored solar energy for space heating.

The collector array composed of 112 double-glazed, flat-plate, selective-surface Lemnox LSC18-1 collectors uses 150 gallons of 35% ethylene glycol and water solution as the heat transfer fluid. The panels are mounted with a tilt of 46 degrees on a flat roof with parallel flow manifolding. The flow to the collector array ranges from 31 to 47 gallons per minute, which, assuming equal flow distribution, yields a range of 0.28 to 0.42 gallons per minute per panel. The manufacturer's recommended flow rate through a collector is 0.3 to 0.7 gallons per minute. The array's single panel flow rates of 0.016 gpm/ft² to 0.024 gpm/ft² are 41% to 11% lower than the ASHRAE 93-77 test flow rate of 0.027 gpm/ft² of gross collector area.

Collector subsystem performance is presented in Table 3. The total incident solar radiation on the collector array for the period June 1980 through April 1981 was 907.24 million BTU. During the period in which the collector loop was operating, the total insolation was 600.64 million BTU or 66% of the total incident. The total collected solar energy for the period was 202.31 million BTU, resulting in a collector subsystem efficiency of 22% based on total incident solar radiation. Operating energy required by the collector subsystem (pump P1 and heat rejection cooling tower) was 10.62 million BTU. A control system problem in June resulted in a very high operating energy expense. The collector subsystem efficiencies for the summer mode months June through September 1980 are lower than the winter mode efficiencies due to the high temperature set point requirement of 180°F absorber plate temperature to initiate pump operation. This reduces collector efficiency by both the effect of higher collector inlet temperatures which increase heat loss, and also by increasing threshold losses by beginning collection later in the day.

Figure 3 shows the performance of the collector array for April 1981. The collector array efficiency is compared to the ASHRAE 93-77 test collector efficiency curve for a single collector panel. The hourly average collector efficiency for hours during which there was continuous flow through the collector array are plotted against the collector operating point. The operating point is defined as the temperature difference between the collector inlet temperature and the ambient temperature, divided by the insolation per square foot collector area. The first hour of each day is filtered to reduce the scatter. Transient effects related to startup of operation often result in higher and/or lower efficiencies than subsequent hours at the same operating point. In Figure 3, the least squares fit to the array data actually intersects the ASHRAE line, with one hour having an array efficiency higher than the ASHRAE testing. This high efficiency is due to a lower temperature difference between inlet and ambient temperature and a much lower solar radiation level than ASHRAE testing. Thus, in the array the efficiency at high values of $(T_{in} - T_a)/I$ is higher due to lower heat losses.

For nearly all the data points in Figure 3, the single-panel lab test results are significantly higher than the efficiencies of the collector array.

The reason for the difference in efficiencies is unknown for the South Dakota School of Mines site array, but there are many operational considerations for

Table 3. COLLECTOR SUBSYSTEM PERFORMANCE

SOUTH DAKOTA SCHOOL OF MINES
JUNE 1980 THROUGH APRIL 1981

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR SUBSYSTEM EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY	COLLECTOR ARRAY OPERATIONAL EFFICIENCY (%)	ECSS OPERATING ENERGY	SOLAR ENERGY DIRECTLY TO LOADS	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE (°F)
JUN	86.50	16.62	19	77.72	21	2.62	7.41	6.00	76
JUL	92.42	14.66	16	52.44	28	0.41	10.76	2.37 E	84
AUG	97.21	21.48	22	64.02	34	0.43	11.54	3.68 E	74
SEP	98.70	11.70	12	33.58	35	0.18	6.99	1.81 E	71
OCT	91.90	17.29	19	44.64	49	0.84	2.29	15.56	55
NOV	60.40	16.72	28	44.96	37	0.88	3.25	13.36	45
DEC	52.67	14.11	27	36.39	39	0.78	3.31	9.87	39
JAN	76.43	24.57	32	63.60	39	1.23	5.29	16.63	41
FEB	80.29	21.73	27	61.37	35	1.11	5.59	14.02	37
MAR	85.73	22.31	26	62.88	36	1.10	4.27	16.90	47
APR	84.99	21.12	25	59.04	36	1.04	1.87	18.00	58
TOTAL	907.24	202.31	-	600.64	-	10.62	62.57	118.20	-
AVERAGE	82.48	18.39	22	54.60	34	0.97	5.69	10.75	57

E Denotes estimated data.

Figure 3. Average Collector Efficiency
South Dakota School of Mines
April 1981

collector arrays which can lead to differences from single-panel lab test results. Some of these factors are: (1) unbalances in fluid flow distribution in large arrays, (2) corrosion of collector materials and fluid scaling, (3) larger incidence angle variations, (4) higher fraction of diffuse radiation, (5) different ranges of outdoor ambient temperatures and fluid temperatures in the collectors, (6) higher wind speeds, (7) different fluid and flow rate per panel than tested with, and (8) dust on collector covers.

Collector subsystem efficiency has been computed from two bases. The first assumes that the efficiency is based upon all available solar energy. This approach makes the operation of the control system part of array efficiency. For example, energy may be available at the collector, but the collector fluid temperature is below the control minimum; thus, the energy is not collected. In this approach, collector array performance is described by comparing the net amount of collected solar energy to the incident solar energy. Energy that is deliberately or inadvertently rejected or lost from the collector subsystem is subtracted from the collected energy in computing the net value. The ratio of these two energies represents the collector array efficiency which may be expressed as

$$\eta_c = Q_s / Q_i \times 100$$

where: η_c = collector array efficiency

Q_s = collected solar energy

Q_i = incident solar energy

The monthly efficiency computed by this method is listed in the column entitled "Collector Subsystem Efficiency" in Table 3.

The second approach assumes the efficiency is based upon the incident solar energy only during the periods of collection.

Evaluation of collector efficiency using operational incident energy yields operational collector efficiency. Operational collector efficiency, η_{co} , is computed as follows:

$$\eta_{co} = Q_s / Q_{oi} \times 100$$

where: Q_s = collected solar energy

Q_{oi} = incident solar energy while the collector pumps operated

The monthly efficiency computed by this method is listed in the column entitled "Collector Array Operational Efficiency" in Table 3. This latter efficiency term is not the same collector efficiency as represented by the ASHRAE Standard 93-77. Both operational collector efficiency and the ASHRAE collector efficiency are defined as the ratio of actual useful energy collected to solar energy incident upon the collector, and both use the same definition of collector area. However, the ASHRAE efficiency is determined from instantaneous evaluation under tightly controlled, steady-state test conditions, while the operational collector efficiency is determined from the actual conditions of daily solar energy system operation. Measured monthly values of operational incident energy and computed values of operational collector efficiency are presented in Table 3.

Storage performance data for the site for the reporting period are shown in Table 4. Thermal storage is provided by a 3,000-gallon storage tank located in the first floor equipment room. The thermal losses from the storage tank are not considered to contribute to the building heating load.

During the reporting period, total solar energy delivered to storage was 118.20 million BTU. There were 102.17 million BTU delivered from storage to the space heating subsystem. The change in stored energy (0.38 million BTU) was calculated from the change in storage temperature which occurred from the first hour of June 1, 1980 to the last hour of April 30, 1981. The difference between this value and the sum of the individual months arises due to methods of interpolation utilized in the site specific software. Energy loss from storage was 15.65 million BTU. This loss represented 13% of the energy delivered to storage. The storage efficiency was 87%. The heat loss coefficient of the storage tank was 0.12 BTU/hr°F·ft². (See Footnote 1.)

The high amounts of energy delivered to and drawn from storage during June were due to the control system failure which caused nonstop operation of the collector subsystem pumps until June 18. During this period, solar energy was collected and delivered to storage during daylight hours and then returned to the collectors and unintentionally rejected from the collectors again at night.

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:

$$c = (\text{STEI} - \text{STEO} - \text{STECH}) / [(T_s - T_a) \times A \times t] \frac{\text{BTU}}{\text{hr}^\circ\text{F} \cdot \text{ft}^2}$$

Where: c = effective storage heat loss coefficient

T_s = average storage temperature

T_a = average ambient temperature in the vicinity of storage

A = surface area of the storage tank

t = number of hours in the month

Table 4. STORAGE PERFORMANCE

SOUTH DAKOTA SCHOOL OF MINES
JUNE 1980 THROUGH APRIL 1981

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY TO STORAGE	ENERGY FROM STORAGE	CHANGE IN STORED ENERGY	STORAGE EFFICIENCY (%)	AVERAGE STORAGE TEMPERATURE (°F)	EFFECTIVE HEAT LOSS COEFFICIENT (BTU/hr°F·FT ²)	LOSS FROM STORAGE
JUN	6.00	3.84	1.86	95	123	-	0.30
JUL	2.37 E	1.96	-0.28	71 E	115	-	0.69 E
AUG	3.68 E	2.46	0.43	78 E	119	-	0.80 E
SEP	1.81 E	1.29	-1.16	7 E	110	0.18	1.68 E
OCT	15.56	10.20	1.42	75	105	0.35	3.83
NOV	13.36	13.53	-1.22	92	107	0.14	1.05
DEC	9.87	8.53	0.27	89	95	0.16	1.07
JAN	16.63	16.14	-0.22	96	101	0.12	0.71
FEB	14.02	10.80	2.12	92	108	0.11	1.10
MAR	16.90	18.77	-1.75	*	131	*	*
APR	18.00	14.65	0.99	87	138	0.10	2.36
TOTAL	118.20	102.17	0.38 ⁽¹⁾	-	-	-	15.65 ⁽¹⁾
AVERAGE	10.75	9.30	0.03	87	114	0.12	1.56

E Denotes estimated values.

* Denotes unavailable data.

(1) See text.

Values obtained for energy added to storage in July, August, and September on the basis of measured flows and temperature changes in the main heat transfer loop have been considered invalid. This is because for several extended periods during these months, storage temperatures gradually increased despite the fact that neither operation of pump P2, flow in the main heat transfer loop, nor disturbance of storage tank thermal stratification were measured. Possible reasons for this may have been:

- o Energy flow to storage from the main loop by conduction heat transfer;
- o Very low flow in the main loop due to thermosiphoning;
- o Insensitivity of flow sensor W101 to low flow rates in the main loop.

Values obtained for energy removed from storage, on the basis of main heat transfer loop flow and temperature measurements, were considered to be valid. During periods of energy removal from storage, the main loop pump P2 did operate, flow in the loop was measured, flow was confirmed by storage temperature destratification, and measured energy flow from storage was confirmed by measured energy decrease in storage.

Monthly values of energy lost from storage for July, August, and September were estimated on the basis of the design thermal conductivity of the tank, and the amounts of energy delivered to storage for the months were estimated using these values worked through energy balances for the solar storage tank.

The space heating performance for the South Dakota School of Mines site for the reporting period is shown in Table 5.

Table 5. SPACE HEATING SUBSYSTEM

SOUTH DAKOTA SCHOOL OF MINES
JUNE 1980 THROUGH APRIL 1981

(All values in million BTU, unless otherwise indicated)

MONTH	SPACE HEATING LOAD	TOTAL SOLAR ENERGY USED	MEASURED SOLAR ENERGY USED	SOLAR ENERGY LOSSES TO LOAD	TOTAL OPERATING ENERGY	SOLAR SPECIFIC OPERATING ENERGY	AUXILIARY FOSSIL FUEL	SOLAR FRACTION (%)	BLDG TEMP (°F)	AMB TEMP (°F)	HEATING DEGREE- DAYS
JUN	6.17	4.17	3.84	0.33	0.10	0.09	3.71	68	70	66	96
JUL	3.35	2.05	2.00	0.05	0.04	0.03	2.18	61	76	73	17
AUG	5.37	2.62	2.55	0.07	0.08	0.06	4.57	49	73	66	84
SEP	8.25	1.30	1.26	0.04	0.54	0.02	8.20	16	68	60	194
OCT	31.23	12.49	12.37	0.12	2.79	0.28	26.74	40	68	47	537
NOV	42.05	16.78	16.67	0.11	3.60	0.33	36.14	40	65	38	760
DEC	43.19	11.84	11.80	0.04	4.27	0.30	45.26	27	65	34	946
JAN	51.68	21.43	21.26	0.17	4.48	0.49	42.95	41	65	34	913
FEB	44.38	16.39	16.27	0.12	4.26	0.42	39.48	37	64	29	967
MAR	42.61	23.04	22.53	0.51	4.41	1.14	25.26	54	65	38	757
APR	24.85	16.52	15.68	0.84	2.37	0.69	9.93	66	67	49	434
TOTAL	303.13	128.63	126.23	2.40	26.94	3.85	244.42	-	-	-	5,705
AVERAGE	27.56	11.69	11.48	0.22	2.45	0.35	22.22	42	68	49	519

The solar energy contribution to the heating load totaled 128.63 million BTU. The electrical operating energy (pump P2) that was required to deliver the solar thermal energy to the load was 3.85 million BTU. Losses of solar energy from the piping to and from the space heating heat exchanger, which contributed to the heating load, were 2.40 million BTU.

The average building temperature for the 11-month period was 68°F, and for the winter months December through March was 65°F.

The solar heating contribution was anomalously low in September due to the fact that the solar energy system was deactivated and drained for replacement of collector loop fluid on and after September 17. The solar space heating performance was also reduced in October since the system was not activated until October 9.

The solar specific operating energy during March and April was very high due to a control system problem which caused the storage/space heating pump (pump P2) to run almost continuously throughout March and much of April.

The performance factors for the cooling season June through September 1980 are presented in Table 6. The daily cooling load profile for three of the months in the cooling season is shown in Figure 4.

The total space cooling load of the Visitor's Center building for the four-month reporting period was 131.71 million BTU. Solar energy is used to supply space cooling to the Observation Room of the Visitor's Center. The portion of the total space cooling load incurred by the "single zone" cooling system serving the Observation Room was 25.27 million BTU. Of this Observation Room cooling load, 15.87 million BTU were carried by the absorption chillers of the solar space cooling subsystem. Thus, solar energy supplied 63% of the Observation Room cooling load, and thereby 12% of the total building cooling load, for the reporting period.

The solar space cooling equipment consists of three parallel plumbed three-ton ARKLA absorption chillers. Solar heated glycol solution is pumped directly to the chillers, which supply chilled water to the load directly. The auxiliary cooling equipment consists of two electric vapor compression air conditioners with an assumed coefficient of performance (COP) of 2.50.

Table 6. SPACE COOLING SUBSYSTEM

SOUTH DAKOTA SCHOOL OF MINES
JUNE 1980 THROUGH SEPTEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	COOLING LOAD	SOLAR FRACTION OF LOAD (%)	SOLAR ENERGY USED	OPERATING ENERGY	AUX THERMAL USED	AUX ELECT FUEL	BUILDING TEMP (°F)
JUN	34.80	7	7.08	3.95	32.25	12.90	70
JUL	40.83	14	10.67	4.46	35.28	14.11	76
AUG	38.44	12	11.38	4.52	33.88	13.55	73
SEP	17.64	18	6.98	2.27	14.43	5.77	68
TOTAL	131.71	-	36.11	15.20	115.84	46.33	-
AVERAGE	32.93	12	9.03	3.80	28.96	11.58	72

The thermal performance of the solar chiller is given in Table 7. The chillers supplied 15.87 million BTU of cooling at an operating expense of 4.18 million BTU of electrical energy. The solar thermal energy delivered to the absorption

Figure 4. Cooling Load vs Hour of Day
South Dakota School of Mines
June 1980 through August 1980

Table 7. SOLAR ABSORPTION CHILLER

SOUTH DAKOTA SCHOOL OF MINES
JUNE 1980 THROUGH SEPTEMBER 1980

(All values in million BTU)

MONTH	LOAD	SOLAR ENERGY USED	OPERATING ENERGY	REJECTED ENERGY	COEFFICIENT OF PERFORMANCE
JUN	2.55	7.08	0.85	7.80	0.36
JUL	5.55	10.67	1.31	15.84	0.52
AUG	4.56	11.38	1.30	16.39	0.40
SEP	3.21	6.98	0.72	10.31	0.46
TOTAL	15.87	36.11	4.18	50.34	-
AVERAGE	3.97	9.03	1.05	12.59	0.44

chiller was 36.11 million BTU. The average seasonal COP was 0.44 with a high of 0.52 in July and a low of 0.36 in June. The large range in COP is due to a problem in the automatic control systems which was more frequent in some months than others. This problem involved the deactivation of the solar absorption chillers during periods of high solar radiation levels. However, the pumps to circulate chilled water to the load (pump P3), to circulate water to the cooling tower (pump P4), and water to the chiller generator (pump P1) continued to operate while the chiller remained deactivated. Typically, this control anomaly would last from 15 to 30 minutes before the chiller would reactivate, and would occur sporadically throughout the day.

Hourly profiles of the South Dakota School of Mines absorption chiller generator inlet temperature and evaporator outlet temperatures versus cooling capacity in tons for June and August 1980 and average values for June, July, and August 1980 are shown in Figure 5. The slope of the South Dakota School of Mines generator curve is very low. Extrapolation of this curve would require a generator inlet temperature above 235°F to reach rated capacity. Since the chillers operate between 35°F and 42°F much of the time, this may be the cause of the poor chiller performance. The capacity appears to decrease as evaporator temperature increases. This unusual operation may be related to startup conditions also, since these chillers cycle on and off frequently. In addition, it was the designer's intent to operate at very low chilled water temperatures.

Figure 5. Absorption Chiller Generator Inlet and Evaporator
Outlet Temperatures vs Capacity
South Dakota School of Mines
June and August 1980
and
Seasonal Average for June, July and August 1980

Overall, the net energy savings during the cooling season are good due to excellent collector COP and very low chiller system power per ton. The site has a simple energy saving design because the collector pump also serves the generator of the absorption chiller. This accounts for the unusually low chiller subsystem power per ton at the site.

Measured monthly values of the South Dakota School of Mines solar energy system and subsystem operating energy for the report period are presented in Table 8. A total of 18.65 million BTU of operating energy was consumed by the solar system during the reporting period.

Table 8. SOLAR OPERATING ENERGY

SOUTH DAKOTA SCHOOL OF MINES
JUNE 1980 THROUGH APRIL 1981

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY	SHS OPERATING ENERGY	SCS OPERATING ENERGY	TOTAL SOLAR OPERATING ENERGY
JUN	2.62	0.09	0.85	3.56
JUL	0.41	0.03	1.31	1.75
AUG	0.43	0.06	1.30	1.79
SEP	0.18	0.02	0.72	0.92
OCT	0.84	0.28	0.00	1.12
NOV	0.88	0.33	0.00	1.21
DEC	0.78	0.30	0.00	1.08
JAN	1.23	0.49	0.00	1.72
FEB	1.11	0.42	0.00	1.53
MAR	1.10	1.14	0.00	2.24
APR	1.04	0.69	0.00	1.73
TOTAL	10.62	3.85	4.18	18.65
AVERAGE	0.97	0.35	1.05(1)	1.70

(1) Four-month cooling season average.

Total system operating energy for the South Dakota School of Mines site is the electrical energy required to support the space heating and space cooling subsystems without affecting their thermal states, exclusive of blower energy expended for ventilation during periods when neither space heating nor cooling is provided.

The solar energy collection and storage subsystem consumed a large amount of operating energy during June due to the control failure which caused the collector loop pump to run continuously. This failure occurred on May 23 and was not corrected until June 18.

Energy savings for this site for the reporting period are presented in Table 9. For this eleven-month period, the fossil fuel savings were 214.40 million BTU, for a monthly average of 19.49 million BTU. This is approximately 1,546 gallons of oil. A net electrical energy expense of 12.30 million BTU was incurred during the reporting period because the operation of solar energy components during the year required more energy than was saved during the solar cooling period.

Table 9. ENERGY SAVINGS

SOUTH DAKOTA SCHOOL OF MINES
JUNE 1980 THROUGH APRIL 1981

(All values in million BTU)

MONTH	SOLAR ENERGY USED	SPACE HEATING		SPACE COOLING		ECSS OPERATING ENERGY (SOLAR UNIQUE)	ENERGY SAVINGS	
		ELECTRICAL	FOSSIL FUEL	ELECTRICAL			ELECTRICAL	FOSSIL FUEL
JUN	11.25	-0.09	6.95	0.17		2.62	-2.54	6.67
JUL	12.72	-0.03	3.42	0.91		0.41	0.47	3.42
AUG	14.00	-0.06	4.37	0.52		0.43	0.03	4.37
SEP	8.28	-0.02	2.17	0.57		0.18	0.37	2.17
OCT	12.49	-0.28	20.82	0.00		0.84	-1.12	20.82
NOV	16.78	-0.33	27.97	0.00		0.88	-1.21	27.97
DEC	11.84	-0.30	19.73	0.00		0.78	-1.08	19.73
JAN	21.43	-0.49	35.72	0.00		1.23	-1.72	35.72
FEB	16.39	-0.42	27.32	0.00		1.11	-1.53	27.32
MAR	23.04	-1.14	38.40	0.00		1.10	-2.24	38.40
APR	16.52	-0.69	27.53	0.00		1.04	-1.73	27.53
TOTAL	164.74	-3.85	214.40	2.17		10.62	-12.30	214.40
AVERAGE	14.98	-0.35	19.49	0.54 ⁽¹⁾		0.97	-1.12	19.49

(1) Four-month average (June - September)

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

The auxiliary sources at the site consist of a fuel-oil-fired furnace which supplied the space heating load and two electric vapor compression air conditioner units which have an assumed coefficient of performance of 2.50. The oil-fired furnace is considered to be 60% efficient for computational purposes.

The solar energy used for space heating is divided by the boiler efficiency (0.60) to get the fossil fuel energy savings. The electrical energy expense is the operating energy required to collect and deliver solar energy to the space cooling and space heating subsystems and to operate the absorption chiller system.

On the cooling subsystem, the conventional backup is a vapor compression unit with an assumed COP of 2.50. This means that for every 2.50 BTU of solar cooling actually produced, one BTU of electrical energy can be saved minus the solar specific operating energy. The solar absorption chiller operated with a COP of 0.44, which means that, for each BTU of solar energy used, 0.44 BTU of cooling was produced. The electrical energy which would be required by the conventional air conditioners to supply the same amount of cooling as the solar absorption chiller minus the solar cooling operating energy represents the energy savings.

The South Dakota School of Mines site is located in Keystone, South Dakota at 44 degrees N latitude and 104 degrees W longitude. Monthly values of the total solar energy incident in the plane of the collector array and the average outdoor temperature measured at the site during the reporting period are presented in Table 10. Also presented in the table are the corresponding long-term average monthly values of the measured weather parameters. These long-term average weather data were collected and estimated from nearby representative National Weather Service and SOLMET meteorological stations. The long-term average insolation values are estimated total global horizontal radiation converted to collector angle and azimuth orientation. These insolation values are estimated from opaque sky cover and sunshine duration data in conjunction with the relationship of these parameters to the measured global solar radiation at the closest representative SOLMET station.

Table 10. WEATHER CONDITIONS

SOUTH DAKOTA SCHOOL OF MINES
JUNE 1980 THROUGH APRIL 1981

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT ² -DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS		COOLING DEGREE-DAYS	
	MEASURED	LONG-TERM AVERAGE	MEASURED AVERAGE (1)	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
JUN	1,442	1,802	66 (66)	64	96	134	122	110
JUL	1,491	1,934	73 (74)	73	17	13	279	249
AUG	1,568	1,938	66 (66)	72	84	17	109	222
SEP	1,645	1,823	60 (60)	61	194	191	57	56
OCT	1,482	1,623	47 (48)	50	537	474	19	9
NOV	1,007	1,208	38 (40)	35	760	888	0	0
DEC	849	985	34 (34)	27	946	1,194	0	0
JAN	1,233	1,050	34 (36)	22	913	1,336	0	0
FEB	1,434	1,310	29 (30)	26	967	1,098	0	0
MAR	1,383	1,576	38 (41)	31	757	1,048	0	0
APR	1,416	1,658	49 (51)	45	434	612	5	0
TOTAL	-	-	-	-	5,705	7,005	591	646
AVERAGE	1,359	1,537	49 (50)	46	519	637	54	59

(1) Average temperatures in parentheses computed by averaging daily values of $(T_{min} + T_{max})/2$.

T_{min} = Minimum daily average temperature.

T_{max} = Maximum daily average temperature.

During the period from June 1980 through April 1981, the average daily total incident solar radiation on the collector array was 1,359 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 1,537 BTU per square foot per day for a plane facing 19 degrees West of South with a tilt of 46 degrees from the horizontal. The difference between measured insolation and the long-term average insolation during some months is due to the considerable shading of the collectors and pyranometer by tall pine trees to the east and mountains to the west.

During the reporting period, the highest monthly average insolation was 1,645 BTU per square foot per day during September. The average ambient temperature during the reporting period was 49°F as compared with the long-term average of 46°F. These are long-term average monthly temperatures from the period 1941-1970. The highest monthly average ambient temperature was 73°F during July, and the lowest monthly average ambient temperature was 29°F during February. The number of heating degree-days for the period (based on a 65°F reference) was 5,705, while the long-term average is 7,005 heating degree-days. The range of heating degree-days was from a high of 967 during February to a low of 17 during July. The number of cooling degree-days measured during the period was 591, while the long-term average is 646 cooling degree-days.

Measured average ambient temperature was computed by averaging all the data scans available in a given day to compute that day's average temperature (for a complete day's data - this is 270 scans). However, the National Weather Service computes average ambient temperature by averaging the daily maximum and minimum temperatures for each day and then averaging these daily temperatures to obtain the monthly average. Thus, some difference in average ambient temperatures, heating degree-days, and cooling degree-days can be attributed to the different calculation method for daily average temperature. The computation of heating and cooling degree-days, in both methods, is based on a 65°F reference temperature.

The values of average ambient temperature in parentheses in Table 1C were computed by averaging the daily maximum and minimum temperatures for each day and then averaging these daily temperatures to obtain the monthly average.

It is noted that the discrepancy between the average temperatures computed using the minimum and maximum temperatures and the true average temperatures (using 270 data points for each day) is due to the asymmetry of the temperature curve at this location.

1.2 SYSTEM OPERATION

1.2.1 TYPICAL SYSTEM OPERATION

January 20, 1981 represents a clear day of typical winter mode operation of the solar energy system. The variation of key system parameters for this day is presented in Figures 6a, 6b, and 6c. Figure 6a shows the insolation in the plane of the collector array, and the period of time that the array circulating pump was operating. The collector pump turned on at 0955 hours Mountain Standard Time and continued to operate until 1504 hours when it shut down for the day. A noise level signal from the pyranometer of three BTU/ft²hr is evident on the plot before sunrise and after sunset. Considerable shading in both the morning and afternoon is also obvious on this plot of the incident solar radiation. Shading in the morning is due to pine trees directly to the east of the array, and in the

afternoon due to the rock cliffs (Mount Rushmore) to the west of the collector array. During the collector pump operating period, the temperature difference between the collector heat exchanger inlet and outlet temperature sensors ranged from 14.0°F to a low of 4.6°F. The actual difference of temperature across the collector array was not known since collector inlet temperature sensor T100 was in error during this month, but the heat exchanger temperature differences are in close approximation.

Figure 6a. Typical Insolation Data, Winter Mode
South Dakota School of Mines
January 20, 1981

Figure 6b shows the temperature profile of the 3,000-gallon solar storage tank during the day. As can be seen in this plot, the tank is very well mixed with very little thermal stratification from top to bottom. The maximum difference in temperature between the top and the bottom of storage was 3.2°F at 1301 hours. As can be seen by the cycle of storage energy charging and discharging, the storage-to-load pump ran continuously except for one 45-minute period from 0907 to 0955 hours when storage top temperature dropped to 89°F. Storage temperature was raised from 89°F to 124°F by the solar collector subsystem in a period of approximately five hours.

Figure 6c shows the solar space heating fluid flow rate and temperatures along with an indication of times when the auxiliary oil furnace is activated. During the times when there is flow through the solar heating/storage loop, the temperature difference across the space heating heat exchanger ranged from 2.0°F to 3.5°F. A jump in the temperatures to the space heating heat exchanger occurred at 0955 hours when the collector pump activated. In this mode, higher fluid temperatures are transferred directly from the collector loop to the space heating loop by way of a heat exchanger. A drop in fluid temperatures is seen at 1509 hours when the collector pump turned off and the system was in the heating-from-storage mode again. From the trace of the fuel oil consumption meter, it is seen that the oil furnace operated during the night and morning hours until the collector pump activated. Then the system was heated exclusively by solar energy

Figure 6b. Typical Storage Fluid Temperatures, Winter Mode
South Dakota School of Mines
January 20, 1981

Figure 6c. Typical Heating System Operation
South Dakota School of Mines
January 20, 1981

for approximately 12 hours until the last two hours when oil consumption commenced again. It was not possible to measure the actual consumption of oil by the furnace since this is an oil recirculation loop system and only the supply oil flow is monitored, with the return oil flow not monitored.

July 16, 1980 represents a clear day of typical summer mode operation for the solar energy system. The variation of key system parameters for this day is presented in Figures 7a, 7b, 7c, and 7d. Figure 7a shows the insolation in the plane of the collector array, and the period of time when the array circulating pump was operating. On this day the collector pump turned on at 0955 hours Mountain Standard Time and continued to operate until 1729 hours when it shut down for the day. The collector pump does not activate until fairly late in the morning due to the controls in the summer mode requiring a collector plate temperature of 180°F or higher for turn-on. This high temperature set point is due to the high temperature set point for the operation of the absorption chillers. An apparent control system problem at the end of the day allowed the collector pump to run for one hour longer than the absorption chillers operated, without any energy being delivered to storage.

Figure 7a. Typical Insolation Data, Summer Mode
South Dakota School of Mines
July 16, 1980

Figure 7b shows typical collector array temperatures during the day. As the sun started to rise at approximately 0700 hours, the collector absorber plate temperature (T102) began to rise rapidly and reached 181°F when the collector array pump turned on. During the operational period, the absorber plate temperature roughly tracked the insolation, and leveled out at approximately 260°F, with several large drops in temperature coinciding with increases in collector flow from 31 gallon per minute to 41 gallons per minute. The high collector absorber plate temperatures are due to the low collector array flow rate (31 gallons per

Figure 7b. Typical Collector Array Temperatures, Inlet/Outlet
 Summer Mode
 South Dakota School of Mines
 July 16, 1980

minute) which is approximately 45% lower than ASHRAE 93-77 test flow rates. However, this is only one monitored panel out of an array of 112 panels and it is possible that this panel is receiving lower flow. During these periods of increased collector flow, the temperature difference between collector inlet and outlet dropped from a high of 15.6°F to a low of 1.0°F.

Figure 7c shows the variation in generator/collector flow and the resultant variation in generator inlet and outlet temperatures. Generator inlet temperatures ranged from a high of 197.4°F to a low of 171.3°F during absorption chiller operation. The temperature difference between generator inlet and outlet ranged from 3.6°F to 14.0°F, with the smallest temperature differences at the end of each day when the flow rate is high, ranging from 41 to 45 gallons per minute.

Figure 7d shows the variation in the absorption chiller evaporator inlet and outlet temperatures, and the flow rate in the evaporator loop showing times of pump operation. The extreme variations in temperatures during evaporator pump operation, causing two peaks in the temperature graphs, are due to times when the the absorption chiller shut down and the chiller pumps continued to operate. This control system failure occurred for two periods during the day, lasting approximately 20 minutes each time.

Figure 7c. Typical Generator/Collector Flow and Temperatures
Inlet/Outlet, Summer Mode
South Dakota School of Mines
July 16, 1980

Figure 7d. Typical Absorption Chiller Evaporator Temperatures
Inlet/Outlet
South Dakota School of Mines
July 16, 1980

1.2.2 SYSTEM OPERATING SEQUENCE

Figure 8 presents a bar chart showing typical system operating sequences for January 20, 1981. This data correlates with the curves in Figures 6a through 6c.

From this chart it can be seen that solar energy is used for space heating for nearly the whole day, both heating from storage and from the collectors to the main loop. It is also evident from the chart that both space heating from the collector loop to main loop, and storage charging can be accomplished simultaneously. Auxiliary oil furnace operation is seen to be very cyclic with very little oil consumed after 1000 hours. Solar and auxiliary heating are accomplished simultaneously in this system, with the solar energy preheating the air before it is heated by the oil furnace.

Figure 8. Typical System Operating Sequence, Winter Mode
South Dakota School of Mines
January 20, 1981

Figure 9 presents a bar chart showing typical system operating sequences for July 16, 1980. This data correlates with the curves in Figures 7a through 7d and provides some additional insight into those curves and the summer modes of operation.

There are a few observations to be made from Figure 9. First, it is seen that the solar cooling subsystem contributed significantly to the cooling load of the

Observation Room, enough for the auxiliary vapor compression air conditioner to shut off for approximately three hours. Secondly, it is seen that the solar chiller for space cooling is operated for the majority of the time that the collectors are delivering solar energy to the system. It is noted that the solar energy system does not supply cooling to the multizone air handler system, which cools a different part of the building.

Figure 9. Typical System Operating Sequence, Summer Mode
South Dakota School of Mines
July 16, 1980

1.3 SOLAR ENERGY UTILIZATION

Figure 10 shows the use of solar energy and the percentage of losses.

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

Thirty-four percent of the total incident solar energy was lost due to periods when insolation did not exceed the threshold level required to activate the collector pump. These threshold losses were larger in the summer due to the high temperature set point (absorber plate temperature $> 180^{\circ}\text{F}$) required for the collectors to operate the absorption chillers.

Twenty-two percent of the total incident energy was collected and 34% of the operational incident energy was collected. Eighty-one percent of the collected solar energy was delivered to the loads. This energy delivered to the loads was 18% of the total incident energy.

Figure 10. Solar Energy Use
South Dakota School of Mines
June 1980 through April 1981

SECTION 2

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- *6B. User's Guide to monthly Performance Reports, November 1981, SOLAR/0004-81/18, Vitro Laboratories, Silver Spring, Maryland.
- *6C. Instrumentation Installation Guidelines March 1981, Parts 1, 2, and 3, SOLAR/0001-81/15, Vitro Laboratories, Silver Spring, Maryland.
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- *9. Monthly Performance Report, South Dakota School of Mines, August 1980, SOLAR/2019-80/08, 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.

- *10. Monthly Performance Report, South Dakota School of Mines, September 1980, SOLAR/2019-80/09, Vitro Laboratories, Silver Spring, Maryland.
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- *13. Monthly Performance Report, South Dakota School of Mines, December 1980, SOLAR/2019-80/12, Vitro Laboratories, Silver Spring, Maryland.
- *14. Comparative Report: Performance of Active Solar Space Cooling Systems, 1980 Cooling Season, SOLAR/0023-81/40, 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

The South Dakota School of Mines solar energy system is installed in the Visitor's Center of the Mount Rushmore National Memorial at Keystone, South Dakota. The solar energy system is a retrofit to the original heating and cooling system, and is designed to provide 45% of the annual heating requirements for the entire building and 53% of the annual air conditioning requirements for the Observation Room.

Solar energy collection is performed by 112 double-glazed, flat-plate collectors manufactured by Lennox Industries, Inc., which have a gross area of 2,000 square feet. The collectors are mounted in six arrays on the roof of the building, and face 19 degrees West of South with a tilt of 46 degrees from the horizontal. The main system loop contains 150 gallons of 50% ethylene glycol and water solution, which is used to transfer energy, as required, from the collector to the collector-to-storage heat exchanger, the collector-to-space heating heat exchanger, and the absorption chillers. Thermal storage is provided by 3,000 gallons of water in a steel storage tank which is insulated with three inches of fiberglass. The tank is located in the first floor equipment room.

Heating demands are met by transferring energy from either the collector or storage to heating coils in the building multizone air handler. The multizone fan is energized continuously to circulate building air, and dampers in the multizone unit are positioned to allow flow across the solar heating coil when the system is in a solar heating mode. Auxiliary heating is provided by a two-stage fuel oil furnace.

Thermal energy from the collectors is used to operate the three ARKLA absorption chillers; chilled water from these chillers is circulated through a cooling coil in the Observation Room air handler. Thermal energy from storage is not used to operate the chillers because of the high temperatures required for ARKLA operation. Auxiliary cooling is provided to both the multizone and single-zone air handlers by vapor compression units.

The South Dakota School of Mines solar energy system is placed in one of two overall operational modes by manual operation of a "season selector" switch. If the heating season mode is selected, all cooling modes are prohibited. If the cooling season mode is selected, the operation of cooling or heating modes is allowed, depending primarily on whether the outside ambient temperature is above or below 65°F. The system, shown schematically in Figure A-1, has four unique modes of operation.

Mode 1 - Storage Charging - The storage charging mode is entered when the collector absorber plate temperature is 18°F higher than the temperature at the bottom of the storage tank. During storage charging, pumps P1 and P2 are energized, producing fluid flow in the collector loop and storage loop, respectively. Operation in this mode continues until the absorber plate to storage tank temperature difference falls to 3°F or below. A six-minute time delay circuit delays shutdown of pumps P1 and P2 to prevent short-cycling of the collection system. In the storage charging mode, pump P1 moves solar heated fluid from the collectors through valve V10, heat exchanger HX1, and valve V3.

Pump P2 draws water from the bottom of the storage tank through valve V2. The storage water flows through heat exchanger HX1, valve V8, and valve V7, and returns to the top of the tank via valve V1. Valve V8 is intended to prevent thermosiphon flow in the storage loop and is actuated to the open position concurrent with startup of pump P2. If a demand for heating occurs during storage charging, valve V7 proportions flow through heat exchanger HX2 and the heat exchanger bypass in order to maintain a 140°F hot deck air temperature in the multizone heating unit. Auxiliary oil heat is utilized to supplement solar heating in order to maintain the 140°F hot deck air temperature.

Mode 2 - Heating-from-Storage - This mode is entered when there is a heating demand and mode 1 is not in operation. This mode will be entered if the water temperature in the top of the storage tank is 120°F or higher. In this mode, valve V2 is positioned to allow pump P2 to draw water from the top of the storage tank until the temperature falls below 90°F. The storage water flows through heat exchanger HX1, valve V8, and is proportioned through heat exchanger HX2 and bypass valve V7 to maintain the multizone hot deck air temperature at 140°F. The storage water returns to the bottom of the tank through valve V1. Auxiliary oil heat is utilized to supplement solar heating in order to achieve the 140°F temperature when the storage temperature drops below this level.

Mode 3 - Cooling-from-Collectors - This mode is entered when there is a demand for cooling, as determined by a thermostat located in the Observation Room, and when the collector plate temperature is 180°F or higher. When this mode is initiated, pump P1 moves solar-heated fluid through valve V10, heat exchanger HX1, and valve V3 until the temperature of the fluid at the collector outlet is 180°F. Generator inlet temperatures of 180°F or above are required for effective operation of the absorption chillers.

When the collector loop fluid temperature reaches 180°F, chilled water pump P3, condenser water pump P4, and the cooling tower fan will be energized by cooling system controls. In addition, valve V10 is closed and valve V9 is opened to allow solar-heated fluid flow through the absorption chiller generator sections.

During operation in this mode, the storage charging mode is inhibited. Safety cutoff controls are provided to prevent overheating or excessive cooling of the chillers. Auxiliary cooling is provided by vapor compression air conditioning units in the Observation Room and multizone air handlers.

Mode 4 - Excess Heat Rejection - This mode is entered when the collector outlet fluid temperature exceeds 200°F. The excess heat rejection mode is available for simultaneous operation with all other operating modes. In this mode, valve V3 is positioned to allow flow through the heat rejection cooling tower. A fan in the cooling tower is controlled by an aquastat to keep the sump temperature below 195°F.

Figure A-1. South Dakota School of Mines Solar Energy System Schematic

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the South Dakota School of Mines 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 microprocessor 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 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 320 second interval, 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 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. The CDPS is also capable of transforming this data into plots, graphs, and processed reports.

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 data 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 scan interval. 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 computing 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 South Dakota School of Mines solar energy system from June 1980 through April 1981 was analyzed and Monthly Performance Reports were published through December 1980 for 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/2019-78/12
February 1979, SOLAR/2019-79/02
March 1979, SOLAR/2019-79/03
April 1979, SOLAR/2019-79/04
May 1979, SOLAR/2019-79/05
June 1979, SOLAR/2019-79/06
July 1979, SOLAR/2019-79/07
August 1979, SOLAR/2019-79/08
September 1979, SOLAR/2019-79/09
December 1979, SOLAR/2019-79/12
January 1980, SOLAR/2019-80/01
February 1980, SOLAR/2019-80/02
March 1980, SOLAR/2019-80/03
April 1980, SOLAR/2019-80/04
May 1980, SOLAR/2019-80/05
June 1980, SOLAR/2019-80/06
July 1980, SOLAR/2019-80/07
August 1980, SOLAR/2019-80/08
September 1980, SOLAR/2019-80/09
October 1980, SOLAR/2019-80/10
November 1980, SOLAR/2019-80/11
December 1980, SOLAR/2019-80/12

Solar Energy System Performance Evaluation: SOLAR/2019-80/14

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

APPENDIX C

PERFORMANCE FACTORS AND SOLAR TERMS

The performance factors identified in the site equations (Appendix D) by the use of acronyms or symbols are defined in this Appendix in Section 1. Section 1 includes the acronym, 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 general acronyms used in this report.

- Section 1. Performance Factor Definitions and Acronyms
- Section 2. Solar Terminology
- Section 3. General Acronyms

SECTION 1. PERFORMANCE FACTOR DEFINITIONS AND ACRONYMS

<u>ACRONYM</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.
CLAREA	Collector Array Area	The gross area of one collector panel multiplied by the number of panels in the array.
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.

* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
CSE	Solar Energy to SCS	Amount of solar energy delivered to the SCS.
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>ACRONYM</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	Amount of energy supplied to the HWS.
* HWDM	Hot Water Demand	Energy required to satisfy the temperature control demands of the building service hot water system.

*** Primary Performance Factors**

<u>ACRONYM</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>ACRONYM</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>ACRONYM</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>ACRONYM</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 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).

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	Incoming solar radiation.
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.
Microclimate	Highly localized weather features which may differ from long-term regional values due to the interaction of the local surface with the atmosphere.

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:
	$\frac{T_i - T_a}{I} \left(\frac{^{\circ}\text{F} \times \text{hr.} \times \text{sq. ft.}}{\text{BTU}} \right)$
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 which uses architectural components of the building to collect, distribute, and store solar energy.
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. GENERAL ACRONYMS

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

APPENDIX D

PERFORMANCE EQUATIONS

SOUTH DAKOTA SCHOOL OF MINES

INTRODUCTION

Solar energy system performance is evaluated by performing energy balance computations 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

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

where I001 is the solar radiation measurement provided by the pyranometer in BTU per square foot per hour, CLAREA 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 convert 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

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

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 or CP	=	Specific Heat
D	=	Direction or Position
EE	=	Electric Energy
EP	=	Electric Power
F	=	Fuel Flow Rate
HWD	=	Functional procedure to calculate the enthalpy change of water at the average of the inlet and outlet temperatures
H	=	Enthalpy
HR	=	Humidity Ratio
I	=	Incident Solar Flux (Insolation)
M	=	Mass Flow Rate
N	=	Performance Parameter
P	=	Pressure
PD	=	Differential Pressure
Q	=	Thermal Energy
RHO	=	Density
T	=	Temperature
TD	=	Differential Temperature
V	=	Velocity
W	=	Heat Transport Medium Volume Flow Rate
TI	=	Time
<u>P</u>	=	Appended to a function designator to signify the value of the function during the previous iteration

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

Initial Equations and Conditions

STOCAP = Storage volume = 3,000 gallons

CLAREA = Collector area = 2,000 ft²

FEFF = Furnace efficiency = 0.6

FCNST = Heating value of fuel = 0.14 million BTU/gallon

WCONST = 8.34 lb_m/gallon

C₁ = Specific heat 50% ethylene glycol solution

C₂ = Specific heat water

RHO₁ = Density 50% ethylene glycol solution

RHO₂ = Density water

} Temperature dependent

Mass Flow Rates

M100 = W100 x SQRT (WCONST x RHO₁) evaluated at T153

M101 = W101 x SQRT (WCONST x RHO₂) evaluated at T151

F400C = Cumulative fuel consumption in time interval (one hour)

PERFORMANCE EQUATIONS

(The symbol Σ in scan level equations indicates summation.)

AVERAGE AMBIENT TEMPERATURE ($^{\circ}\text{F}$)

$$T_A = (1/60) \times \Sigma T_{001} \times \Delta\tau$$

AVERAGE BUILDING TEMPERATURE ($^{\circ}\text{F}$)

$$T_B = (1/60) \times \Sigma T_{601} \times \Delta\tau$$

DAYTIME AVERAGE AMBIENT TEMPERATURE ($^{\circ}\text{F}$)

$$T_{DA} = (1/360) \times \Sigma T_{001} \times \Delta\tau$$

for $\pm$ three hours from solar noon

INCIDENT SOLAR PER UNIT AREA (BTU/Ft^2)

$$S_E = (1/60) \times \Sigma I_{001} \times \Delta\tau$$

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

$$S_{EOP} = (1/60) \times CL_{AREA} \times \Sigma I_{001} \times \Delta\tau$$

if $M_{100} > 0$

COLLECTED SOLAR ENERGY (BTU)

$$S_{ECA} = \Sigma M_{100} \times C_1 \times (T_{150} - T_{100}) \times \Delta\tau$$

ECSS STORAGE TEMPERATURE ($^{\circ}\text{F}$)

$$T_{ST} = (1/60) \times \Sigma \{(T_{200} + T_{201} + T_{202})/3\} \times \Delta\tau$$

ENERGY DELIVERED TO ECSS STORAGE (BTU)

$$S_{TEI} = \Sigma M_{101} \times C_2 \times (T_{101} - T_{151}) \times \Delta\tau$$

ENERGY SUPPLIED BY ECSS STORAGE (BTU)

$$S_{TEO} = \Sigma M_{101} \times C_2 \times (T_{151} - T_{101}) \times \Delta\tau$$

SOLAR ENERGY TO SPACE HEATING SUBSYSTEM (BTU)

$$H_{SE} = \Sigma M_{101} \times C_2 \times (T_{450} - T_{101}) \times \Delta\tau$$

If $M_{101} > 0$
& $D_{003} < 0.5$
& $T_{450} > T_{101}$

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$$HOPE = \{ \Sigma (EP101/2) \times \Delta\tau + \Sigma EP201 + \Delta\tau + \Sigma EP601 \times \Delta\tau \} \times 56.8833$$

$$\begin{aligned} &\text{If } D003 < 0.5 \\ &\quad \& EP101 > 0 \end{aligned}$$

Otherwise,

$$\begin{aligned} &\text{If } D003 < 0.5 \\ &\quad \& EP101 = 0 \end{aligned}$$

Then,

$$HOPE = \{ \Sigma (EP101 + EP201 + EP601 + EP602) \times \Delta\tau \} \times 56.8833$$

ECSS REJECTED ENERGY (BTU)

$$\begin{aligned} CSRJE &= \Sigma M100 \times C_1 \times (T103 - T100) \times \Delta\tau \\ &\text{of } M100 > 0 \\ &\quad \& D004 < 0.5 \end{aligned}$$

INCIDENT SOLAR ENERGY ON ARRAY (BTU)

$$SEA = SE \times CLAREA$$

COLLECTED SOLAR ENERGY PER UNIT AREA (BTU/FT²)

$$SEC = SECA/CLAREA$$

COLLECTOR ARRAY EFFICIENCY (%)

$$CAREF = (SECA/SEA) \times 100$$

SPACE HEATING SUBSYSTEM AUXILIARY FUEL ENERGY (BTU)

$$HAF = FCONST \times F400C$$

SPACE HEATING SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$$HAT = FEFF \times HAF$$

SPACE HEATING SUBSYSTEM LOAD (BTU)

$$HL = HAT + HSE$$

SPACE HEATING SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

$$HSVE = - \{ \Sigma (EP101/2) \times \Delta\tau + \Sigma EP201 \times \Delta\tau \} \times 56.8833$$

$$\text{If } D003 < 0.5$$

SPACE HEATING SUBSYSTEM FOSSIL ENERGY SAVINGS (BTU)

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

SPACE HEATING SUBSYSTEM SOLAR FRACTION (%)

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

COLLECTOR SUBSYSTEM OPERATING ENERGY (BTU)

$$\text{CSOPE} = \{\sum (\text{EP101} + \text{EP201}/2)\} \times 56.8833$$

$$\begin{aligned} \text{if } \text{W502} &= 0 \\ &\& \text{EP201} > 0 \end{aligned}$$

$$= \{\sum \text{EP101}\} \times 56.8833$$

$$\begin{aligned} \text{if } \text{W502} &= 0 \\ &\& \text{EP201} = 0 \end{aligned}$$

$$= \{\sum (\text{EP101}/2 + \text{EP201}/2)\} \times 56.8833$$

$$\begin{aligned} \text{if } \text{W502} &> 0 \\ &\& \text{D003} < 0.5 \end{aligned}$$

$$= \{\sum (\text{EP101}/2)\} \times 56.8833$$

$$\begin{aligned} \text{if } \text{W502} &> 0 \\ &\& \text{D003} \geq 0.5 \end{aligned}$$

SINGLE ZONE COOLING AUXILIARY ELECTRIC FUEL (BTU)

$$\text{CAESZ} = \sum (\text{EP502} - 0.9) \times \Delta\tau \times 56.8833$$

$$\text{if } \text{EP502} > 2.5$$

EP502 > 2.5 indicates chiller operational

0.9 = blower power (kw)

MULTIZONE COOLING AUXILIARY ELECTRIC FUEL (BTU)

$$\text{CAEMZ} = \sum \text{EP504} \times \Delta\tau \times 56.8833$$

TOTAL COOLING AUXILIARY ELECTRIC FUEL (BTU)

$$\text{CAE} = \text{CAESZ} + \text{CAEMZ}$$

SOLAR COOLING LOAD (BTU)

$$\text{CLS} = \sum \text{M502} \times C_2 \times (\text{T552} - \text{T502}) \times \Delta\tau$$

$$\text{if } \text{M502} > 0$$

SINGLE ZONE AUXILIARY COOLING LOAD (BTU)

$$\text{CLAUSZ} = \text{CAESZ} \times 2.5$$

A COP of 2.5 is assumed for the vapor compression air conditioner.

MILTIZONE AUXILIARY COOLING LOAD (BTU)

$$\text{CLAUMZ} = \text{CAEMZ} \times 2.5$$

A COP of 2.5 is assumed for the vapor compression air conditioner.

TOTAL COOLING LOAD (BTU)

$$\text{CL} = \text{CLS} + \text{CLAUSZ} + \text{CLAUMZ}$$

COOLING AUXILIARY THERMAL ENERGY (BTU)

$$\text{CAT} = 2.5 \times \text{CAE}$$

COOLING SOLAR ENERGY (BTU)

$$\text{CSE} = \sum \text{M100} \times \text{C}_1 \times (\text{T550} - \text{T500}) \times \Delta\tau$$

$$\begin{aligned} &\text{if } \text{M100} > 0 \\ &\quad \& \text{W502} > 0 \end{aligned}$$

D002 > 0.5 used instead of W502 > 0, starting 8/80

COOLING SOLAR FRACTION (%)

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

SOLAR COOLING OPERATING ENERGY (BTU)

$$\text{COPE 1} = \sum (\text{EP501} + \text{EP_P3} + \text{EP_P4}) \times \Delta\tau \times 56.8833$$

$$+ \sum (\text{EP101}/2 + \text{EPSZBL}/2) \times \Delta\tau \times 56.8833$$

$$\begin{aligned} &\text{if } \text{M100} > 0 \\ &\quad \& \text{W502} > 0 \end{aligned}$$

$$+ \sum (\text{EPSZBL}/2) \times \Delta\tau \times 56.8833$$

$$\begin{aligned} &\text{if } \text{M100} > 0 \\ &\quad \& \text{W502} > 0 \\ &\quad \& \text{EP502} < 2.5 \end{aligned}$$

where

EP_P3 = pump P3 power (= 0.45 if W502 > 0)

EP_P4 = pump P4 power (= EP503)

EPSZBL = single zone blower power (= 0.9 if EP 502 > 2.5
or EP502 if EP502 $\leq$ 2.5)

M100 > 0 & W502 > 0 indicates solar cooling mode operational

EP502 $\leq$ 2.5 indicates single-zone auxiliary chiller not operational

SINGLE ZONE AUXILIARY COOLING OPERATING ENERGY (BTU)

$$\text{COPE 2} = \sum (0.9) \times \Delta\tau \times 56.8833$$

if EP502 > 2.5
& (W100 = 0 or W502 = 0)

$$= \sum (0.9/2) \times \Delta\tau \times 56.8833$$

if EP 502 > 2.5
& W100 > 0 & W502 > 0)

where

0.9 = single-zone blower power

EP502 > 2.5 indicates single-zone auxiliary chiller

(W100 = 0 or W502 = 0) indicates no solar cooling

(W100 > 0 & W502 > 0) indicates solar cooling

MILTIZONE COOLING OPERATING ENERGY (BTU)

$$\text{COPE 3} = \sum \text{EP602} \times \Delta\tau \times 56.8833$$

if EP504 > 0

TOTAL COOLING OPERATING ENERGY (BTU)

$$\text{COPE} = \text{COPE 1} + \text{COPE 2} + \text{COPE 3}$$

COOLING ELECTRICAL ENERGY SAVINGS (BTU)

$$\text{CSVE} = (\text{CLS}/\text{COPC}) - \text{TCEOPE}$$

COPC = alternative conventional chiller COP (=2.5)

TCEOPE = thermodynamic conversion equipment operating energy
(see below)

THERMODYNAMIC CONVERSION EQUIPMENT

(TCE: i.e., ABSORPTION CHILLER SUBSYSTEM)

TCE OPERATING ENERGY (BTU)

$$\text{TCEOPE} = \sum (\text{EP501} + \text{EP_P3} + \text{EP_P4}) \times \Delta\tau \times 56.8833$$

$$+ \sum (\text{EP101}/2) \times \Delta\tau \times 56.8833$$

if W100 > 0
& W502 > 0

TCE LOAD (BTU)

$$TCEL = CLS$$

TCE REJECTED ENERGY (BTU)

$$TCERJE = \sum M501 \times C_2 \times (T551 - T501) \times \Delta\tau$$

if $M501 > 0$

TCE ENERGY INPUT (BTU)

(i.e., SOLAR ENERGY TO ABSORPTION CHILLERS)

$$TCEI = CSE$$

TCE COEFFICIENT OF PERFORMANCE

$$TCECOP = TCEL/TCEI$$

SYSTEM LOAD (BTU)

$$SYSL = HL + CL$$

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

$$SEL = HSE + CSE$$

SYSTEM OPERATING ENERGY (BTU)

$$SYSOPE = HOPE + COPE + CSOPE$$

AUXILIARY THERMAL ENERGY TO LOAD (BTU)

$$AXT = HAT + CAT$$

AUXILIARY ELECTRICAL ENERGY TO LOAD (BTU)

$$AXE = CAE$$

AUXILIARY FOSSIL ENERGY TO LOAD (BTU)

$$AXF = HAF$$

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

$$TSVE = HSVE + CSVE - CSOPE$$

TOTAL FOSSIL ENERGY SAVINGS (BTU)

$$TSVF = HSVF$$

TOTAL ENERGY CONSUMED BY SYSTEM (BTU)

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

CHANGE IN ECSS STORED ENERGY (BTU)

$$\text{STECH} = \text{STOCAP} \times \left\{ (C_2 \times \text{RHO}_2 \times \text{TST})_{\text{end of time interval}} - (C_2 \times \text{RHO}_2 \times \text{TST})_{\text{beginning of interval}} \right\}$$

ECSS STORAGE EFFICIENCY (%)

$$\text{STEFF} = \{(\text{STECH} + \text{STEO})/\text{STEI}\} \times 100$$

ENERGY DELIVERED FROM ECSS (BTU)

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

ECSS SOLAR CONVERSION EFFICIENCY

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

SYSTEM PERFORMANCE FACTOR

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

SOUTH DAKOTA SCHOOL OF MINES LONG-TERM WEATHER DATA

COLLECTOR TILT: 46 DEGREES
LATITUDE: 44 DEGREES

LOCATION: MOUNT RUSHMORE, SOUTH DAKOTA
COLLECTOR AZIMUTH: 19 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JUN	3,642	2,131	0.58508	0.845	1,802	134	110	64
JUL	3,532	2,223	0.62948	0.870	1,934	13	249	73
AUG	3,115	1,961	0.62971	0.988	1,938	17	222	72
SEP	2,478	1,519	0.61296	1.200	1,823	191	56	61
OCT	1,779	1,066	0.59902	1.524	1,623	474	9	50
NOV	1,227	645	0.52571	1.873	1,208	888	0	35
DEC	990	476	0.48035	2.070	985	1,194	0	27
JAN	1,117	542	0.48523	1.937	1,050	1,336	0	22
FEB	1,594	826	0.51820	1.587	1,310	1,098	0	26
MAR	2,232	1,228	0.55017	1.284	1,576	1,048	0	31
APR	2,922	1,589	0.54393	1.043	1,658	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 heating degree-days per month.

CDD - Number of cooling degree-days per month.

TBAR - Average ambient temperature in degrees Fahrenheit.

APPENDIX F

FLUID SAMPLE ANALYSIS

The purpose of the chemical analysis of antifreeze solutions is to identify three characteristics of the liquid: (1) the thermal properties, (2) the freezing point, and (3) the occurrence or likelihood of corrosion. The percent and type of antifreeze affect the first two characteristics. In general, the glycol concentration should be somewhere in the range of 50% to give a freezing point of -37°F for ethylene glycol and -25°F for propylene glycol. This percentage of glycol also insures proper corrosion protection, because corrosion inhibitor concentrations are designed for this concentration.

The corrosivity of a liquid is hard to evaluate quantitatively. In general:

1. pH should be between 7.5 and 9.0.
2. Reserve alkalinity varies with each antifreeze manufacturer. The alkalinity might range from eight to 25 for fresh antifreezes. With time, the alkalinity tends to decrease and, if it reaches zero, then the liquid can rapidly turn acidic (i.e., pH less than seven). This is very undesirable.
3. Chloride concentration should be less than 50 ppm.

Presence of other components is indicative of type of antifreeze, type of water, and products of corrosion. Presence of silicon is generally indicative of automotive antifreeze, and a requirement to change the liquid at two-year intervals. Presence of ash, calcium, and magnesium indicates minerals in water and possibility of scaling. Copper, iron, or aluminum indicate that these metals in the system might be corroding.

The analysis of the fluid samples taken at South Dakota School of Mines is presented below. The first sample, which was a pale green color, is the fluid in the collector loop. The second sample was a dark green color, taken from the chiller-to-load loop. The samples were taken January 8, 1981.

	<u>Collector Loop</u>	<u>ARKLA to Load</u>
Water Content by K.F.	52.4	84.4
pH	8.30	9.19
Reserve Alkalinity	8.75	3.60
Specific Gravity	1.065	1.017
Ash	0.40	0.21
Sodium	2,480	1,050
Copper	1	1
Iron	2	2
Silicon	22	18
Aluminum	0	0
Zinc	0	0
Boron	1,076	419
Calcium	0	0

	<u>Collector Loop</u>	<u>ARKLA to Load</u>
Magnesium	1	1
Chlorides	3	0
Phosphate (P), Total	390	120
Phosphate (P), Ortho	170	120
Ethylene Glycol	45.6	16.4
Propylene Glycol	0	0

APPENDIX G
CONVERSION FACTORS

Energy Conversion Factors

<u>Fuel Type</u>	<u>Energy Content</u>	<u>Fuel Source Conversion Factor</u>
Distillate fuel oil ¹	138,690 BTU/gallon	7.21×10^{-6} gallon/BTU
Residual fuel oil ²	149,690 BTU/gallon	6.68×10^{-6} gallon/BTU
Kerosene	135,000 BTU/gallon	7.41×10^{-6} gallon/BTU
Propane	91,500 BTU/gallon	10.93×10^{-6} gallon/BTU
Natural gas	1,021 BTU/cubic feet	979.4×10^{-6} cubic feet/ BTU
Electricity	3,413 BTU/kilowatt-hour	292.8×10^{-6} kwh/BTU

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

²No. 5 and No. 6 fuel oils

APPENDIX H

SENSOR TECHNOLOGY

Temperature Sensors

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

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 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.

All temperature sensors are individually calibrated at the factory. In addition, the bridge circuit is calibrated in the field using a five-point check.

Nominal Resistance @ 25°C:	100 ohms
No. of Leads:	3
Electrical Connection:	Wheatstone Bridge
Time Constant	1.5 seconds max. in water at 3 fps
Self Heating:	27 mw/°F

WIND SENSOR

Wind speed and direction are measured by a WeatherMeasure W102-P-DC/540 or W101-P-DC/540 wind sensor. Wind speed is measured by means of a four-bladed propeller coupled to a DC generator.

Wind direction is sensed by means of a dual-wiper 1,000-ohm long-life conductive plastic potentiometer. It is attached to the stainless steel shaft which supports and rotates with the upper body assembly.

Size:	29-3/4"L X 30"H
Starting Speed:	1 mph
Complete Tracking:	3 mph
Maximum Speed:	200 mph
Distance Constant (30 mph):	6.2'
Accuracy:	± 1% below 25 mph ± 3% above 25 mph
Time Constant:	0.145 second

HUMIDITY SENSORS

The WeatherMeasure HMP-14U Solid State Relative Humidity Probe is used for the measurement of relative humidity. The operation of the sensor is based upon the capacitance of the 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.

Range:	0-100% R.H.
Response Time:	1 second to 90% humidity change at 20°C
Temperature Coefficient:	0.05% R.H./°C
Accuracy:	± 3% from 0-80% R.H. ± 5-6% 80-100% R.H.
Sensitivity:	0.2% R.H.

INSOLATION SENSORS

The Eppley Model PSP pyranometer is used for the measurement of insolation. The pyranometer consists of a circular multijunction thermopile of the plated, (copper-constantan) wirewound type which is temperature compensated to render the response essentially independent of ambient temperature. The receiver is coated with Parsons' black lacquer (non-wavelength-selective absorption). The instrument is supplied with a pair of precision-ground polished concentric hemispheres of Schott optical glass transparent to light between 285 and 2800 nm of wavelength. The instrument is provided with a dessicator which may be readily inspected. Pyranometers designated as shadowband pyranometers are equipped with a shadowband which may be adjusted to block out any direct solar radiation. These instruments are used for the measurement of diffuse insolation.

Sensitivity:	9 μ V/W/m ²
Temperature Dependence:	± 1% over ambient temperature range -20°C to 40°C
Linearity:	0.5% from 0 to 2,800 W/M ²
Response Time:	1 second
Cosine Error:	± 1% 0-70° zenith angle ± 3% 70-80° zenith angle

LIQUID FLOW SENSORS (NON-TOTALIZING)

The Ramapo Mark V strain gauge flow meters are used for the measurement of liquid flow. The flow meters sense the flow of the liquids by measuring the force exerted by the flow on a target suspended in the flow stream. This force is transmitted to a four active arm strain gauge bridge to provide a signal proportional to flow rate squared. The flow meters are available in a screwed end configuration, a flanged configuration, and a wafer configuration. Each flow meter is calibrated for the particular fluid being used in the application.

Materials:	Target - 17-PH stainless steel
	Body - Brass or stainless steel
	Seals - Buna-N
Fluid Temperature:	-40°F to 250°F
Calibration Accuracy:	± 1% ($\frac{1}{2}$ " to $3\frac{1}{2}$ " line size)
	± 2% (4" and greater line size)
Repeatability and Hysteresis:	0.25% of reading

LIQUID FLOW SENSORS (TOTALIZING)

Hersey Series 400 flow meters are used to measure totalized liquid flow. The meter is a nutating disk, positive displacement type meter. An R-15 register with an SPDT reed switch is used to provide an output to the data acquisition subsystem.

The output of the reed switch is input to a Martin DR-1 Digital Ramp which counts the number of pulses and produces a zero to five volt analog signal corresponding to the pulse count.

Materials:	Meter body	- bronze
	Measuring chamber	- plastic
Accuracy:	± 1.5%	

AIR FLOW SENSORS

The Kurz 430 Series of thermal anemometers is used for the measurement of air flow. The basic sensing element is a probe which consists of a velocity sensor and a temperature sensor. The velocity sensor is heated and operated as a constant temperature thermal anemometer which responds to a "standard" velocity (referenced to 25°C and 760 mm Hg) or mass flow by sensing the cooling effect of the air as it passes over the heated sensor. The temperature sensor compensates for variations in ambient temperature.

Since the probe measures air velocity at only one point in the cross section of the duct, it is necessary to perform a careful duct mapping to relate the probe reading to the amount of air flowing through the entire duct. This is done by dividing the duct into small areas and taking a reading at the center of each area using a portable probe. The readings are then averaged to determine the overall duct velocity. The reading at the permanently installed probe is then ratioed to this reading. This duct mapping is done for each mode.

Accuracy:	± 2% of full scale over temperature range -20°C to 60°C
	± 5% of full scale over temperature range -60°C to 250°C
Response Time:	0.025 second
Repeatability:	0.25% full scale

FUEL OIL FLOW SENSOR

The Kent Mini-Major is used as a flow oil flow meter. The meter utilizes an oscillating piston as a positive displacement element. The oscillating piston is connected to a pulser which sends pulses to the Site Data Acquisition Subsystem for totalization.

Operating Temperature:	100°C (max)
Flow Range:	0.6 to 48 gph
Accuracy:	± 1% of full scale

FUEL GAS FLOW SENSOR

The American AC-175 gas meter is used for the measurement of totalized fuel gas flow. The drop in pressure between the inlet and outlet of the meter is responsible for the action of the meter. The principle of measurement is positive displacement. Four chambers in the meter fill and empty in sequence. The exact volume of compartments is known, so by counting the number of displacements the volume is measured. Sliding control valves control the entrance and exit of the gas to the compartments. The meter is temperature compensated to reference all volumetric readings to 60°F.

Rated Capacity:	175 cubic ft/hr
Max Working Pressure:	5 psi

ELECTRIC POWER SENSORS

Ohio Semitronics Series PC5 wattmeters are used as electric power sensors. They utilize Hall effect devices as multipliers taking the product of the instantaneous voltage and current readings to determine the electrical power. This technique automatically takes power factor into consideration and produces a true power reading.

Power Factor Range:	1 to 0 (lead or lag)
Response Time:	250 ms
Temperature Effect:	1% of reading
Accuracy:	0.5% of full scale

HEAT FLUX SENSORS

The Hy-Cal Engineering Model BI-7X heat flow sensor is used for the measurement of heat flux. The sensor consists basically of an insulating wafer, with a series of thermocouples arranged such that consecutive thermoelectric junctions fall on opposite sides of the wafer. This assembly is bonded to a heat sink to assure heat flow through the sensor. Heat is received on the exposed surface of the wafer and conducted through the heat sink. A temperature drop across the wafer is thus developed and is measured directly by each junction combination embodied along the wafer. Since the differential thermocouples are connected electrically in series, the voltages produced by each set of junctions is additive, thereby amplifying the signal directly proportional to

the number of junctions. The temperature drop across the wafer, and thus the output signal, is directly proportional to the heating rate.

Operation Temperature:	-50° to 200°F
Response Time:	6 seconds
Linearity:	2%
Repeatability:	0.5%
Sensitivity:	2 mv/BTU/ft ² -hr
Size:	2" X 2"

MONTHLY REPORT: JULY 1980
SITE SUMMARY: SOUTH DAKOTA SCHOOL OF MINES

CONVENTIONAL UNITS

GENERAL SITE DATA:

INCIDENT SOLAR ENERGY.	92.422 MILLION BTU 46211 BTU/SQ.FT.
COLLECTED SOLAR ENERGY	14.659 MILLION BTU 7329 BTU/SQ.FT.
AVERAGE AMBIENT TEMPERATURE.	73 DEGREES F
AVERAGE BUILDING TEMPERATURE	76 DEGREES F
ECSS SOLAR CONVERSION EFFICIENCY	0.14
ECSS OPERATING ENERGY.	0.409 MILLION BTU
TOTAL SYSTEM OPERATING ENERGY.	4.917 MILLION BTU
TOTAL ENERGY CONSUMED.	35.869 MILLION BTU

SUBSYSTEM SUMMARY:

	HEATING	COOLING	SYSTEM TOTAL
LOAD	3.032	29.078	32.381 MILLION BTU
SOLAR FRACTION	60	19	23 PERCENT
SOLAR ENERGY USED	1.995	10.674	12.669 MILLION BTU
OPERATING ENERGY	0.042	4.464	4.917 MILLION BTU
AUX. THERMAL ENERGY	1.307	9.880	11.187 MILLION BTU
AUX. ELECTRIC FUEL	N.A.	14.114	14.114 MILLION BTU
AUX. FOSSIL FUEL	2.178	N.A.	2.178 MILLION BTU
ELECTRICAL SAVINGS	-0.033	1.062	0.618 MILLION BTU
FOSSIL SAVINGS	3.325	N.A.	3.325 MILLION BTU

SYSTEM PERFORMANCE FACTOR: 0.49

N.A. DENOTES NOT APPLICABLE DATA.

REFERENCE: USER'S GUIDE TO MONTHLY PERFORMANCE REPORTS, JUNE 1980, SOLAR/0004-80/18. READ THIS BEFORE TURNING PAGE.

MONTHLY REPORT: JULY 1980
SITE SUMMARY: SOUTH DAKOTA SCHOOL OF MINES

SI UNITS

GENERAL SITE DATA:

INCIDENT SOLAR ENERGY.	97.505	GIGA JOULES
	524774	KJ/SQ.M.
COLLECTED SOLAR ENERGY	15.466	GIGA JOULES
	83238	KJ/SQ.M.
AVERAGE AMBIENT TEMPERATURE.	23	DEGREES C
AVERAGE BUILDING TEMPERATURE	24	DEGREES F
ECSS SOLAR CONVERSION EFFICIENCY	0.14	
ECSS OPERATING ENERGY.	0.432	GIGA JOULES
TOTAL SYSTEM OPERATING ENERGY.	5.187	GIGA JOULES
TOTAL ENERGY CONSUMED.	37.842	GIGA JOULES

SUBSYSTEM SUMMARY:

	HOT WATER	HEATING	SYSTEM TOTAL
LOAD	3.483	30.678	34.161 GIGA JOULES
SOLAR FRACTION	60	19	23 PERCENT
SOLAR ENERGY USED	2.104	11.261	18.366 GIGA JOULES
OPERATING ENERGY	0.045	4.710	5.187 GIGA JOULES
AUX. THERMAL ENERGY	1.378	10.423	11.802 GIGA JOULES
AUX. ELECTRIC FUEL	N.A.	14.890	14.890 GIGA JOULES
AUX. FOSSIL FUEL	2.298	N.A.	2.298 GIGA JOULES
ELECTRICAL SAVINGS	-0.035	1.120	0.652 GIGA JOULES
FOSSIL SAVINGS	3.508	N.A.	3.508 GIGA JOULES

SYSTEM PERFORMANCE FACTOR: 0.49

N.A. DENOTES NOT APPLICABLE DATA.

REFERENCE: USER'S GUIDE TO MONTHLY PERFORMANCE REPORTS, JUNE 1980, SOLAR/0004-80/18. READ THIS BEFORE TURNING PAGE.

MONTHLY REPORT: SOUTH DAKOTA SCHOOL OF MINES, JULY 1980
ENERGY COLLECTION AND STORAGE SUBSYSTEM (ECSS)

DAY OF MONTH (NBS ID)	INCIDENT SOLAR ENERGY MILLION BTU (Q001)	AMBIENT TEMP DEG F (N113)	ENERGY TO LOADS MILLION BTU	ECSS OPERATING ENERGY MILLION BTU (Q102)	ECSS ENERGY REJECTED MILLION BTU	ECSS SOLAR CONVERSION EFFICIENCY (N111)
1	2.754	63	0.789	0.023	0.000	0.287
2	2.595	71	0.303	0.016	0.000	0.117
3	3.294	80	0.513	0.015	0.000	0.156
4	2.178	71	0.072	0.005	0.000	0.033
5	3.034	76	0.408	0.012	0.000	0.134
6	4.149	87	0.715	0.014	0.175	0.172
7	3.215	73	0.321	0.011	0.000	0.100
8	3.538	75	0.504	0.012	0.000	0.143
9	2.618	77	0.258	0.006	0.000	0.099
10	3.337	83	0.404	0.013	0.027	0.121
11	4.148	79	0.658	0.013	0.000	0.159
12	2.735	76	0.479	0.013	0.017	0.151
13	2.198	76	0.211	0.012	0.000	0.101
14	2.852	71	0.341	0.011	0.000	0.120
15	1.921	67	0.126	0.015	0.000	0.065
16	4.131	75	0.719	0.020	0.001	0.174
17	2.946	75	0.307	0.009	0.000	0.104
18	3.711	70	0.523	0.019	0.038	0.141
19	3.622	73	0.456	0.010	0.000	0.126
20	1.214	58	0.913	0.018	0.000	0.752
21	3.045	64	0.408	0.026	0.000	0.134
22	3.048	74	0.274	0.013	0.000	0.090
23	2.028	75	0.130	0.006	0.032	0.064
24	1.908	75	0.112	0.006	0.000	0.059
25	1.143	58	0.433	0.011	0.000	0.379
26	2.520	66	0.235	0.011	0.000	0.093
27	4.054	79	0.425	0.019	0.000	0.105
28	4.114	77	0.000	0.017	0.000	0.000
29	3.760	85	0.608	0.018	0.076	0.162
30	2.358	72	0.074	0.002	0.000	0.031
31	4.205	76	1.000	0.014	0.303	0.238
SUM	92.422	-	12.670	0.410	0.667	-
AVG	2.981	73	0.409	0.013	0.022	0.137

MONTHLY REPORT: SOUTH DAKOTA SCHOOL OF MINES, JULY 1980
COLLECTOR ARRAY PERFORMANCE

DAY OF MONTH (NBS ID)	INCIDENT SOLAR ENERGY MILLION BTU (Q001)	OPERATIONAL INCIDENT ENERGY MILLION BTU	COLLECTED SOLAR ENERGY MILLION BTU (Q100)	DAYTIME AMBIENT TEMP DEG F	COLLECTOR ARRAY EFFICIENCY (N100)
1	2.754	1.637	0.341	70	0.124
2	2.595	1.663	0.385	85	0.148
3	3.294	2.523	0.583	90	0.177
4	2.178	0.605	0.233	79	0.107
5	3.034	1.766	0.432	88	0.142
6	4.149	3.077	1.147	94	0.276
7	3.215	2.061	0.508	79	0.158
8	3.538	2.216	0.571	86	0.161
9	2.618	1.117	0.408	86	0.156
10	3.337	2.189	0.680	98	0.204
11	4.148	3.006	0.939	89	0.226
12	2.785	1.993	0.561	96	0.202
13	2.198	1.142	0.239	87	0.109
14	2.852	1.719	0.407	83	0.143
15	1.921	0.984	0.150	70	0.078
16	4.131	3.456	0.876	88	0.212
17	2.946	1.630	0.449	89	0.152
18	3.711	2.840	0.723	80	0.195
19	3.622	1.943	0.521	85	0.144
20	1.214	0.354	0.114	64	0.094
21	3.045	1.484	0.447	73	0.147
22	3.048	1.697	0.555	85	0.182
23	2.028	0.765	0.161	86	0.079
24	1.908	0.465	0.126	*	0.066
25	1.143	0.000	0.000	62	0.000
26	2.520	1.213	0.386	77	0.153
27	4.054	2.232	0.751	89	0.185
28	4.114	0.017	-0.001	88	0.000
29	3.760	3.028	0.907	99	0.241
30	2.358	0.440	0.067	78	0.028
31	4.205	3.174	0.994	86	0.236
SUM	92.422	52.435	14.660	-	-
AVG	2.981	1.691	0.473	84	0.159

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SOUTH DAKOTA SCHOOL OF MINES, JULY 1980
STORAGE PERFORMANCE

DAY OF MONTH (NBS ID)	ENERGY TO STORAGE MILLION BTU (Q200)	ENERGY FROM STORAGE MILLION BTU (Q201)	CHANGE IN STORED ENERGY MILLION BTU (Q202)	STORAGE AVERAGE TEMP DEG F	STORAGE EFFICIENCY (N108)
1	I	0.503	-0.546	108	I
2	I	0.000	-0.009	104	I
3	I	0.000	-0.006	103	I
4	I	0.000	-0.003	103	I
5	I	0.000	0.003	103	I
6	I	0.000	0.239	106	I
7	I	0.000	0.115	115	I
8	I	0.000	-0.038	117	I
9	I	0.000	0.055	117	I
10	I	0.000	0.166	122	I
11	I	0.000	0.143	128	I
12	I	0.000	0.052	132	I
13	I	0.000	-0.060	132	I
14	I	0.000	-0.032	130	I
15	I	0.000	-0.044	129	I
16	I	0.000	0.047	128	I
17	I	0.000	0.048	131	I
18	I	0.000	0.061	132	I
19	I	0.000	-0.050	133	I
20	I	0.796	-0.833	116	I
21	I	0.219	0.091	94	I
22	I	0.000	0.178	105	I
23	I	0.000	0.036	109	I
24	I	0.000	-0.027	110	I
25	I	0.428	-0.477	99	I
26	I	0.013	0.133	91	I
27	I	0.000	0.371	102	I
28	I	0.000	-0.064	109	I
29	I	0.000	0.201	111	I
30	I	0.000	-0.010	116	I
31	I	0.000	-0.021	115	I
SUM	2.370 E	1.959	-0.280	-	-
AVG	0.076 E	0.063	-0.009	115	0.710

I DENOTES INVALID DATA.
E DENOTES ESTIMATED DATA.

MONTHLY REPORT: SOUTH DAKOTA SCHOOL OF MINES, JULY 1980
SPACE HEATING SUBSYSTEM

DAY OF MON. (NBS)	SPACE HEATING LOAD MILLION BTU (Q402)	SOLAR FR. OF LOAD PER. (N400)	SOLAR ENERGY USED MILLION BTU (Q400)	OPER ENERGY MILLION BTU (Q403)	AUX THERMAL USED MILLION BTU (Q401)	AUX FOSSIL FUEL MILLION BTU (Q410)	ELECT ENERGY SAVINGS MILLION BTU (Q415)	FOSSIL ENERGY SAVINGS MILLION BTU (Q417)	BLDG TEMP DEG F (N406)	AMB TEMP DEG F (N113)
1	0.505	100	0.503	0.006	0.002	0.003	-0.006	0.839	76	63
2	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	76	71
3	0.001	0	0.000	0.000	0.001	0.002	0.000	0.000	76	80
4	0.001	0	0.000	0.000	0.001	0.001	0.000	0.000	76	71
5	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	77	76
6	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	78	87
7	0.001	0	0.000	0.000	0.001	0.001	0.000	0.000	77	73
8	0.001	0	0.000	0.000	0.001	0.002	0.000	0.000	77	75
9	0.001	0	0.000	0.000	0.001	0.002	0.000	0.000	77	77
10	0.001	0	0.000	0.000	0.001	0.001	0.000	0.000	78	83
11	0.001	0	0.000	0.000	0.001	0.001	0.000	0.000	76	79
12	0.148	0	0.000	0.000	0.143	0.247	0.000	0.000	75	76
13	0.002	0	0.000	0.000	0.002	0.003	0.000	0.000	74	76
14	0.001	0	0.000	0.000	0.001	0.001	0.000	0.000	73	71
15	0.001	0	0.000	0.000	0.001	0.001	0.000	0.000	73	67
16	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	75	75
17	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	76	75
18	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	74	70
19	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	74	73
20	0.864	93	0.805	0.013	0.059	0.098	-0.012	1.342	76	58
21	0.546	44	0.240	0.010	0.306	0.509	-0.006	0.401	76	64
22	0.001	0	0.000	0.000	0.001	0.001	0.000	0.000	74	74
23	0.043	0	0.000	0.000	0.043	0.071	0.000	0.000	75	75
24	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	75	75
25	0.779	56	0.433	0.012	0.346	0.576	-0.009	0.722	75	58
26	0.406	3	0.013	0.003	0.393	0.654	0.000	0.022	75	66
27	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	75	79
28	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	77	77
29	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	77	85
30	0.001	0	0.000	0.000	0.001	0.001	0.000	0.000	77	72
31	0.000	0	0.000	0.000	0.000	0.000	0.000	0.000	77	76
SUM	3.302	-	1.995	0.043	1.307	2.178	-0.033	3.325	-	-
AVG	0.107	60	0.064	0.001	0.042	0.070	-0.001	0.107	76	73

MONTHLY REPORT: SOUTH DAKOTA SCHOOL OF MINES, JULY 1980
SPACE COOLING SUBSYSTEM

DAY OF MON. (NBS)	SPACE COOLING LOAD MILLION BTU (Q502)	SOLAR FR. OF LOAD PCT (N500)	SOLAR ENERGY USED MILLION BTU (Q500)	OPER ENERGY MILLION BTU (Q503)	AUX THERMAL USED MILLION BTU (Q501)	AUX ELECT FUEL MILLION BTU	ELECT ENERGY SAVINGS MILLION BTU (Q512)	BLDG DRY BULB TEMP F (N406)	AMB TEMP DEG F (N113)
1	0.388	39	0.286	0.098	0.148	0.211	0.031	76	63
2	0.814	21	0.303	0.145	0.341	0.488	0.030	76	71
3	1.128	30	0.513	0.185	0.375	0.536	0.077	76	80
4	0.481	8	0.072	0.101	0.279	0.399	0.006	76	71
5	0.864	25	0.408	0.155	0.381	0.545	0.042	77	76
6	1.657	21	0.715	0.215	0.480	0.686	0.076	78	87
7	0.949	20	0.321	0.178	0.386	0.551	0.037	77	73
8	0.889	34	0.504	0.161	0.370	0.528	0.069	77	75
9	0.838	18	0.258	0.163	0.408	0.582	0.030	77	77
10	1.493	14	0.404	0.191	0.497	0.710	0.036	78	83
11	1.415	27	0.658	0.235	0.462	0.660	0.084	76	79
12	1.446	14	0.419	0.209	0.477	0.681	0.039	75	76
13	1.446	8	0.221	0.204	0.562	0.802	0.018	74	76
14	1.017	18	0.341	0.204	0.423	0.604	0.037	73	71
15	0.735	6	0.126	0.133	0.280	0.400	0.001	73	67
16	1.127	29	0.719	0.165	0.282	0.404	0.069	75	75
17	0.871	21	0.307	0.120	0.269	0.384	0.039	76	75
18	0.740	34	0.523	0.142	0.206	0.294	0.045	74	70
19	1.053	26	0.456	0.158	0.286	0.409	0.056	74	73
20	0.627	3	0.107	0.037	0.082	0.117	0.001	76	58
21	0.890	6	0.167	0.100	0.212	0.302	0.002	76	64
22	0.801	19	0.274	0.126	0.293	0.419	0.025	74	74
23	0.963	4	0.130	0.126	0.346	0.494	-0.002	75	75
24	0.632	12	0.112	0.097	0.240	0.343	0.014	75	75
25	0.277	0	0.000	0.023	0.048	0.068	0.000	75	58
26	0.593	21	0.222	0.092	0.185	0.265	0.027	75	66
27	0.912	26	0.425	0.146	0.290	0.414	0.048	75	79
28	0.759	26	0.000	0.120	0.267	0.382	0.038	77	77
29	1.613	16	0.608	0.181	0.450	0.643	0.043	77	85
30	0.579	7	0.074	0.095	0.252	0.360	0.002	77	72
31	1.063	25	1.000	0.162	0.304	0.435	0.041	77	76
SUM	29.079	-	10.674	4.465	9.880	14.114	1.062	-	-
AVG	0.938	19	0.344	0.144	0.318	0.455	0.034	76	73

MONTHLY REPORT: SOUTH DAKOTA SCHOOL OF MINES, JULY 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	1377	63	70
2	1298	71	85
3	1647	80	90
4	1089	71	79
5	1517	76	88
6	2074	87	94
7	1607	73	79
8	1769	75	86
9	1309	77	86
10	1668	83	98
11	2074	79	89
12	1392	76	96
13	1099	76	87
14	1426	71	83
15	960	67	70
16	2066	75	88
17	1473	75	89
18	1856	70	80
19	1811	73	85
20	607	58	64
21	1523	64	73
22	1524	74	85
23	1014	75	86
24	954	75	*
25	571	58	62
26	1260	66	77
27	2027	79	89
28	2057	77	88
29	1880	85	99
30	1179	72	78
31	2102	76	86
SUM	46211	-	-
AVG	1491	73	84

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SOUTH DAKOTA SCHOOL OF MINES, JULY 1980
THERMODYNAMIC CONVERSION EQUIPMENT

DAY OF MONTH	EQUIPMENT LOAD MILLION BTU	THERMAL ENERGY INPUT MILLION BTU	OPERATING ENERGY MILLION BTU	ENERGY REJECTED MILLION BTU	COEFFICIENT OF PERFORMANCE (SEE NOTE)
1	0.152	0.286	0.030	0.430	0.554
2	0.168	0.302	0.037	0.472	0.558
3	0.335	0.512	0.056	0.934	0.651
4	0.040	0.071	0.009	0.127	0.568
5	0.213	0.407	0.043	0.546	0.525
6	0.354	0.715	0.065	0.970	0.496
7	0.194	0.321	0.040	0.548	0.605
8	0.299	0.504	0.050	0.825	0.594
9	0.154	0.258	0.031	0.397	0.598
10	0.206	0.404	0.046	0.603	0.510
11	0.381	0.657	0.069	1.070	0.521
12	0.207	0.419	0.044	0.614	0.495
13	0.115	0.221	0.028	0.333	0.523
14	0.185	0.341	0.036	0.531	0.543
15	0.043	0.125	0.016	0.165	0.346
16	0.332	0.718	0.064	0.955	0.462
17	0.182	0.307	0.033	0.462	0.594
18	0.253	0.522	0.056	0.747	0.485
19	0.272	0.456	0.053	0.743	0.597
20	0.017	0.107	0.005	0.074	0.163
21	0.054	0.167	0.020	0.200	0.328
22	0.149	0.273	0.034	0.412	0.547
23	0.039	0.130	0.017	0.136	0.301
24	0.075	0.111	0.016	0.200	0.678
25	0.000	0.000	0.000	0.000	0.000
26	0.124	0.222	0.023	0.342	0.562
27	0.241	0.425	0.048	0.751	0.567
28	0.197	0.000	0.041	0.510	0.000
29	0.253	0.607	0.058	0.785	0.417
30	0.039	0.074	0.014	0.134	0.523
31	0.262	0.999	0.063	0.810	0.263
SUM	5.551	10.674	1.158	15.838	-
AVG	0.179	0.344	0.037	0.510	0.520