SOLAR/2078-81/14
(DE82003759)

# SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION



**SPEARFISH HIGH SCHOOL**
**Spearfish, South Dakota**
**September 1980 through June 1981**
**DHW SH**

**U.S. DEPARTMENT OF ENERGY**
**NATIONAL SOLAR DATA PROGRAM**

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Distribution Category UC-59

# SPEARFISH HIGH SCHOOL

# SPEARFISH, SOUTH DAKOTA

# SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

# SEPTEMBER 1980 THROUGH JUNE 1981

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G. A. McGinnis, Project Manager

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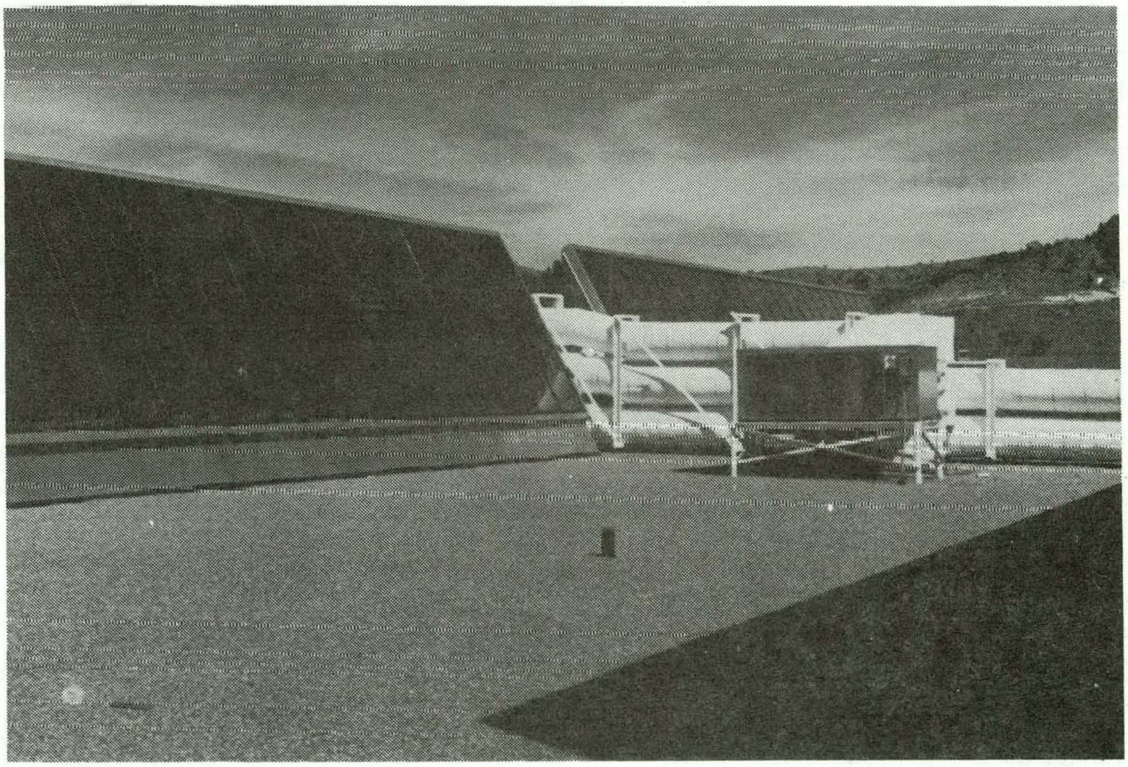
FOREWORD

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.



SPEARFISH HIGH SCHOOL

# SPEARFISH HIGH SCHOOL

Spearfish High School is a 43,000 square foot conditioned space institution building located in Spearfish, South Dakota. The active solar energy system is designed to supply the following:

Annual Design Factors
(Million BTU)

| | Total Load | Solar Contribution | % Solar |
|---|---|---|---|
| Heating | 1,304 | 743 | 57 |
| Hot Water | 1,348 | 674 | 50 |

It is equipped with:

| | |
|---|---|
| Collector | 8,034 square feet; SOLARON Series 2000 |
| Storage | 4,017 cubic feet with 3:1 aspect ratio, fitted in the basement mechanical area of the structure below the faculty work area |
| Auxiliary: | Eight heat pumps are used as distribution-air handlers of which six are solar supplied and instrumented, and summer air conditioning units with internal fans to augment distribution. Auxiliary natural-gas-fired boilers furnish thermal energy to coils in each of the air handlers. These boilers also supply backup heat to the DHW subsystem. |

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## SOLAR SYSTEM PERFORMANCE

### SPEARFISH HIGH SCHOOL
### SEPTEMBER 1980 THROUGH JUNE 1981

| | |
|---|---|
| Solar Fraction[1] | 54% |
| Solar Savings Ratio[2] | 0.44 |
| Conventional Fuel Savings[3] | 804,474 cubic feet of natural gas |
| System Performance Factor[4] | 0.38 |
| Solar System COP[5] | 4.47 |

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

| | Total Load | Solar Contribution | % Solar |
|---|---|---|---|
| Heating | 991.40 | 539.47 | 54 |
| Hot Water | * | 22.43 | * |

Environmental Data

| | Measured Average | Long-Term Average |
|---|---|---|
| Outdoor temperature | 46°F | 43°F |
| Heating degree-days (Total) | 5,887 | 7,294 |
| Cooling degree-days (Total) | * | 190 |
| Daily incident solar energy | 1,359 BTU/ft$^2$ | 1,404 BTU/ft$^2$ |

*Denotes unavailable data.

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

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

3. $$\text{Conventional Fuel Savings} = \text{Savings in BTU} \times 979.40 \times 10^{-6} \text{ cubic feet/BTU}$$

4. Ratio of system load to the total equivalent fossil energy (TEFE) expended or required to support the system load. (TEFE = 2586.62 million BTU based upon 0.6 equipment efficiency)

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

## 1.1 SUMMARY AND CONCLUSIONS

A solar energy system was installed at the Spearfish High School in Spearfish, South Dakota due to a reduced initial natural gas allocation of 40,000 cubic feet of natural gas per day. This allocation was not expected to meet the fuel requirements for the building if it had not been solar equipped.

The cost of the solar heating system was $392,886 for 8,034 square feet of SOLARON high volume collectors. There are seven arrays distributed on the roof of the school building. The cost of $8.44 per square foot is very reasonable for a solar system of this magnitude. Due to the use of natural gas at the site, the net dollar value of solar savings was small, $1,210 for the period of monitoring. The system would have fared better in terms of the dollar value of savings had the site been equipped with electrical or fuel oil as auxiliary fuel source.

The system thermal performance, shown in Table 1 and in Figures 1 and 2, was close to that expected for the site, but thermal loads were lower than expected. The design heating load, 1,304 million BTU, was 1.32 times the system load for the period of analysis. The solar fraction obtained at the site was 54% compared to an expected design solar fraction of 57%. The net collected solar energy was 805.41 BTU or 81% of the total heating load. High losses due to air leakage and

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

SPEARFISH HIGH SCHOOL
SEPTEMBER 1980 THROUGH JUNE 1981

(All values in million BTU, unless otherwise indicated)

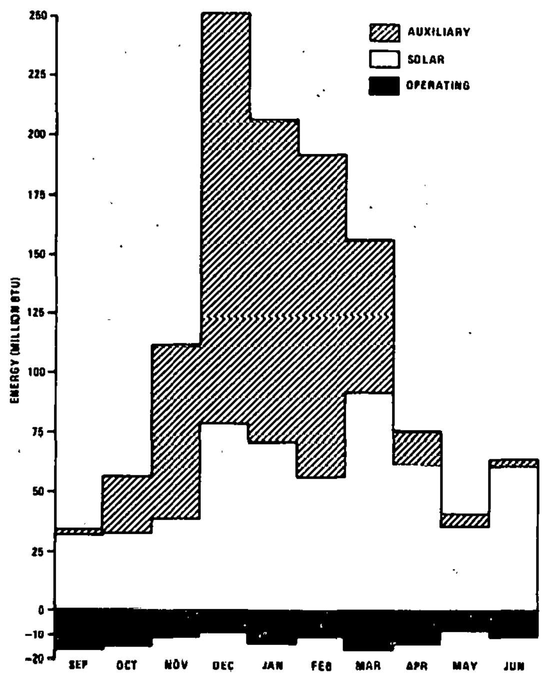
| | | | SOLAR ENERGY USED | | AUXILIARY ENERGY | | ENERGY SAVINGS | | SOLAR FRACTION (PERCENT) |
|---|---|---|---|---|---|---|---|---|---|
| MONTH | SOLAR ENERGY COLLECTED | SYSTEM LOAD | MEASURED | TOTAL INCLUDING LOSSES | FOSSIL | TOTAL OPERATING ENERGY | FOSSIL | ELECTRICAL | BASED ON TOTAL UTILIZED SOLAR THERMAL ENERGY(1) |
| SEP | 48.12 | 35.85 | 7.40 | 32.06 | 2.84 | 48.12 | 49.32 | -16.50 | 85 |
| OCT | 52.34 | 48.48 | 12.79 | 32.82 | 22.78 | 39.11 | 50.49 | -15.27 | 64 |
| NOV | 83.56 | 80.55 | 21.66 | 39.20 E | 71.94 | 26.20 | 60.31 E | -11.46 | 46 E |
| DEC | 74.76 | 182.79 | 27.79 | 79.26 | 172.38 | 26.34 | 114.15 | -9.26 | 43 |
| JAN | 101.84 | 162.03 | 37.03 | 70.15 | 136.18 | 30.95 | 93.46 | -14.20 | 42 |
| FEB | 86.11 | 147.67 | 29.71 | 56.86 | 135.28 | 28.10 | 76.12 | -11.18 | 37 |
| MAR | 121.72 | 139.08 | 30.89 | 92.27 | 64.53 | 30.63 | 135.24 | -15.85 | 64 |
| APR | 100.70 | 79.86 | 17.52 | 62.45 | 12.93 | 33.82 | 94.07 | -14.30 | 75 |
| MAY | 58.15 | 47.91 | 8.42 | 35.95 | 6.91 | 28.00 | 55.92 | -7.89 | 70 |
| JUN | 78.11 | 67.18 | 19.87 | 61.44 | 2.52 | 33.08 | 92.29 | -11.69 | 80 |
| TOTAL | 805.41 | 991.40 | 213.08 | 562.46 | 628.29 | 324.35 | 821.37 | -127.60 | - |
| AVERAGE | 80.54 | 99.14 | 21.31 | 56.25 | 62.83 | 32.44 | 82.14 | -12.76 | 54 |

E DENOTES ESTIMATED VALUE.
(1) SOLAR FRACTION HSE/SYSL.

heat loss from ducting and storage reduced the measured solar energy delivered at the space heating and DHW subsystems to 213.08 million BTU or 26% of what was collected. Solar energy losses from duct work to the conditioned space are calculated for solar energy delivered to the space heating load. Total losses contributing solar thermal energy to the conditioned space were 349.38 million BTU or 35% of the total load. These losses are thought to represent the significant solar energy which must be accounted for at air-type sites.

A total of 628.29 million BTU of fossil energy was supplied to the auxiliary subsystems for the space heating load. A total of 376.98 million BTU (at 0.6 efficiency) was the auxiliary thermal requirement to augment the 213.08 million BTU of controlled delivered solar energy and the 349.38 million BTU of solar losses contributed to the load. An expense of 127.60 million BTU of solar unique operating energy, or 39% of the total electric operating energy for the site, was incurred.

A building temperature of 74°F on the average was maintained for the 10-month period at an overall weighted Coefficient of Performance (COP) of 4.41. The ratio of solar energy delivered to the loads from available insolation resources was 0.17, for the 10-month average. The ratio ranged from a high of 0.35 in December to a low of 0.08 that previous October. Following the very good performance of December, solar system utilizability stabilized while the DHW subsystem COP and the overall solar COP showed gradual performance improvement. December was the month of overall best performance, with the exception of the DHW subsystem. The DHW subsystem had plumbing and control problems which were later rectified as shown by the improved COP since January.




OPERATING ENERGY FOR THE SYSTEM IS CONSIDERED A SYSTEM PENALTY AND IS PLOTTED AS A NEGATIVE VALUE BELOW THE ORIGIN.

Figure 1. System Thermal Performance
Spearfish High School
September 1980 through June 1981

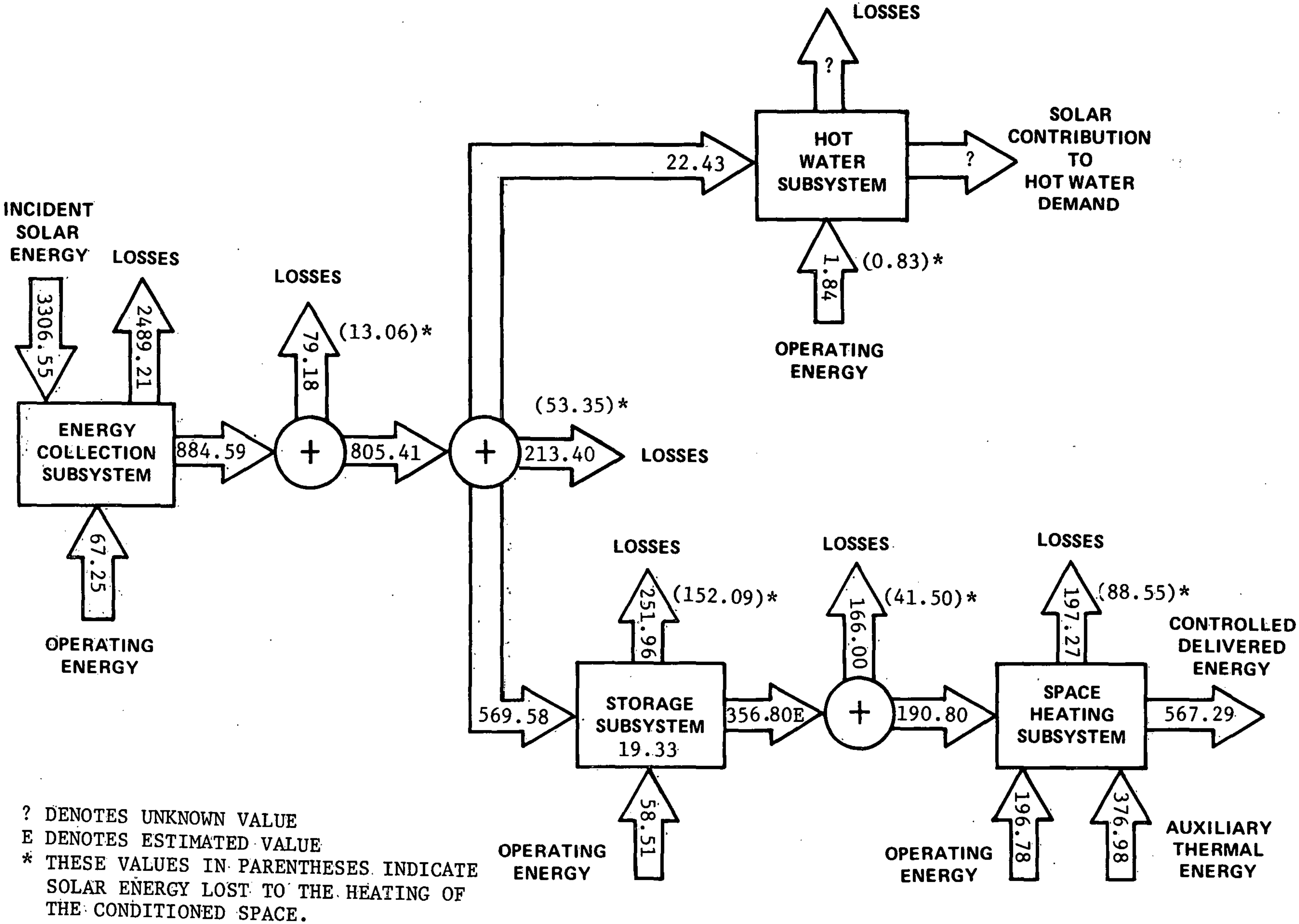



Figure 2. Energy Flow Diagram for Spearfish High School
September 1980 through June 1981
(Figures in million BTU)

All computed, calculated and estimated energy flows at the site are shown in the Energy Flow Diagram (Figure 2). Slightly over 75% of the 3,306.55 million BTU of available solar radiation was lost or uncollected from the collector subsystem. The subsystem gross gains were 884.59 million BTU of which 79.18 million BTU were lost in distribution to and from the inlet plenum to storage. The ducting for this transfer runs (15%) inside the conditioned space so 13.06 million BTU were calculated as contributing to heating of the conditioned space, although it was lost from the monitored energy flow. As collected solar energy was distributed to the DHW subsystem and the storage subsystem, 213.40 million BTU were lost. Of these losses, 53.35 million BTU contributed to the heating of the conditioned space. The supply of energy to storage had to be estimated due to abnormal control configurations and operation in October and November which indicated that more energy was being made available to storage than was collected by the system. The values were calculated on the basis of later computer runs which utilized improved performance working software for storage energy balance.

The solar energy coefficient of performance (COP) is indicated in Table 2. The COP provides a numerical value for the relationship of solar energy used or collected and the energy required to collect or deliver it. The greater the COP value, the more efficient the subsystem. The solar energy system at Spearfish High School functioned at a reporting period weighted average COP value of 4.41 for the period September 1980 through June 1981.

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

SPEARFISH HIGH SCHOOL
SEPTEMBER 1980 THROUGH JUNE 1981

| MONTH | SOLAR ENERGY SYSTEM | COLLECTOR SUBSYSTEM | DOMESTIC HOT WATER SOLAR | SPACE HEATING SOLAR | SOLAR TO LOADS / AVAILABLE INSOLATION |
|---|---|---|---|---|---|
| SEP | 1.94 | 4.09 | 4.81 | 3.68 | 0.09 |
| OCT | 2.15 | 8.04 | 5.34 | 2.57 | 0.08 |
| NOV | 3.42 | 18.43 | 12.70 | 2.92 | 0.14 |
| DEC | 8.56 | 26.10 | 10.71 | 4.27 | 0.35 |
| JAN | 4.94 | 23.28 | 15.54 | 3.63 | 0.21 |
| FEB | 5.09 | 22.65 | 16.43 | 3.84 | 0.18 |
| MAR | 5.82 | 20.97 | 19.30 | 2.81 | 0.22 |
| APR | 4.37 | 14.70 | 13.24 | 2.07 | 0.17 |
| MAY | 4.56 | 10.97 | 16.70 | 2.46 | 0.13 |
| JUN | 5.26 | 9.19 | 20.43 | 5.13 | 0.18 |
| WEIGHTED AVERAGE | 4.41 | 11.98 | 12.26 | 3.26 | 0.17 |

The COP of the collector subsystem had the greatest variance during the monitoring period. This is to be expected as the system presents various loads to the solar collector subsystem under differing periods of day length. September, October, May, and June show lower than average COP due to overheated absorber plates causing the run-on of the solar collector air handler (PCF1) after insolation was reduced below collectible levels. This problem was less severe in May and June than in the early part of the monitoring period. The set point collector control approach can reduce the savings of the system while not significantly improving overheat protection of the collector array.

The space heating subsystem maintained similar COPs from month to month in the study. The space heating subsystem was most efficient during December, January, and February while space heating loads were high.

The DHW subsystem COP was the only subsystem which showed a general trend of improved performance. This was due to implementation of some plumbing and controls refurbishment by the grantee. During and following January 1981, DHW system performance increased dramatically.

A utilizability factor was computed as the ratio of the solar energy which was delivered to the loads to the available insolation resource at the collector subsystem. This is the most gross system level performance figure of merit, and averaged 0.17, with a range of 0.08 to 0.35. System loads were similar in October and May, yet the solar utilizability factor improved from 0.08 to 0.13, a net improvement of 39% from the start to the conclusion of the heating system. This improvement is due to the efforts of on-site personnel to fine tune their system. While the system began the heating season performing poorly, the system completed the heating season in upgraded condition.

## 1.2 SYSTEM OPERATION

### 1.2.1 TYPICAL SYSTEM OPERATION

Curves depicting typical operation of the solar energy system at Spearfish High School on a mild mid-January day (January 12, 1981) are presented in Figures 3a, 3b, and 3c. In Figure 3a, the operation of the collector subsystem is depicted. The relationship between insolation and the activation of PCF1, the collector subsystem air handler, is indicated. The collector array began operation at 0934 hours (local time) and continued to collect solar energy until 1615 hours when the temperature of the absorber plate dropped below the set point for activation of PCF1. This temperature is about 85°F according to the data, and allows continued removal of heat from the collector array after insolation drops to zero. This effect is due to the large mass of the absorber plates in the 8,034 square feet of collectors which retains heat from previously collected insolation resources. Also included on this set of curves is the monitored operation of the storage air handler (PCF2), which delivers stored solar energy to the space heating subsystem via roof-mounted air handler units. The operation of the storage air handler shows two distinct stages typical of the operation of this variable volume delivery subsystem. Under low heating demand, PCF2 utilizes 5.2 kw to deliver solar heated air to the roof air handlers, while under greater demand for heat, 6.4 kw is utilized providing increased delivery air volume. On this day, energy was delivered both to storage and to the conditioned space from the collector subsystem. All solar heated air must pass either through or by the storage rock bin (see schematic in Appendix A, System Description). As shown in Figure 3b, only the top layer of storage (monitored by sensor T200) is storing solar energy while the rest of storage is quite cool at this time in the heating season. Delivery of solar energy through storage to the load is an efficient method of utilizing solar energy when the storage subsystem is drawn down. The storage temperatures recovered later in the season as heating loads moderated and controls were adjusted to recharge storage.

Figure 3b also shows the temperature profiles of the input and output sides of storage. It is readily observed that the storage is not highly integrated with the flow of new collected solar energy which is being routed directly to the load via insulated duct work and the roof-mounted air handlers. The air returning from the collectors reaches 151°F and the top level of storage reaches 134°F. The lower layers of storage remain isothermal until the following day, January 13, 1981, when the thermal wave reaches the second level, sensed by probe T201 after another excellent day of solar collection. The period January 6 through 14 obtained near optimal insolation values combined with mild temperatures at the site. Subsequently, the storage began to recharge with solar energy following its depletion during December 1980.

Figure 3c shows typical operation of one of seven collector subsystem arrays instrumented for inlet and outlet airflow and temperature.

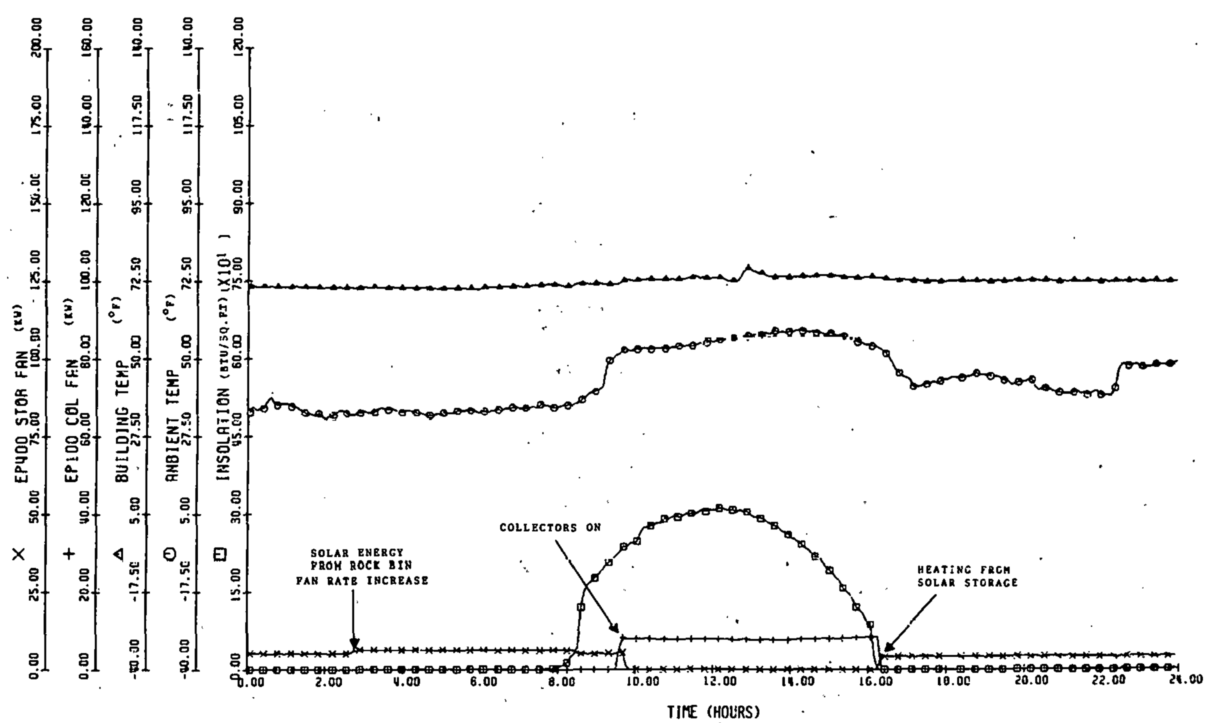



Figure 3a. Typical Insolation and Air Handler Operations Data
Spearfish High School
January 12, 1981

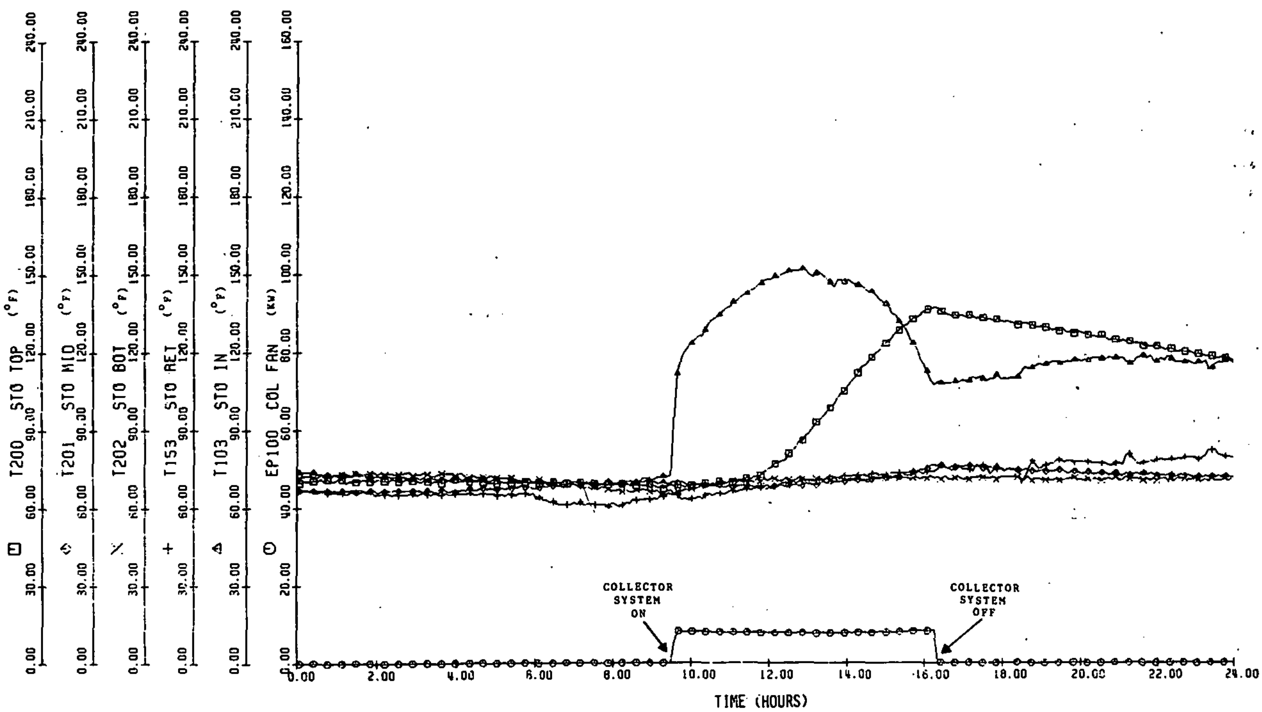



**Figure 3b. Typical Storage Temperatures**
**Spearfish High School**
**January 12, 1981**

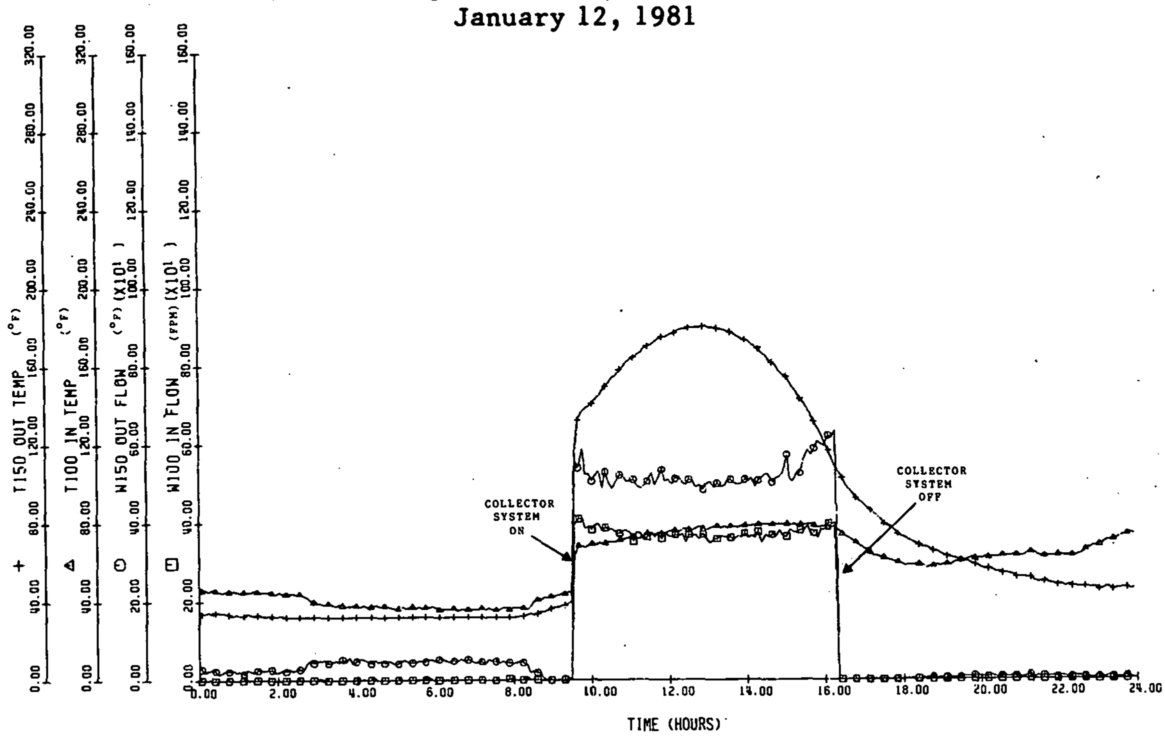



**Figure 3c. Typical Collector Array Temperatures, Inlet/Outlet**
**Spearfish High School**
**January 12, 1981**

The outlet flow is about 24% greater than inlet flow due to infiltration through the EPDM (ethylene-propylene-diene-monomer) grometting of the absorber plates and glazings. The PCF1 draws a high volume of air through the collector subsystem from return air made up from the conditioned space and the lower leg of the storage rock bin plenum. Inlet temperatures are typically 100°F lower than the outlet temperatures under this volumetric flow rate. This delta T is 20°F lower than the manufacturer's recommended delta T of 120°F. One reason for this reduction in delta T could be above optimal aspiration rates of the collector subsystem. The other four arrays which comprise the collector subsystem show very similar characteristics of elevated outlet flow rate and delta T. Some collector aspiration can be seen when PCF2 operates and produces a pressure drop across the inoperative collector subsystem. These low leakage rates (40-50 fpm) are typical of operations of solar air systems where damper leak rates can have a significant effect upon energy loss rates and the energy balance of the solar air system.

### 1.2.2 SYSTEM OPERATING SEQUENCE

Figure 4 presents a bar chart showing typical system operating sequences for January 12, 1981. This data correlates with the curves presented in Figures 3a, 3b, and 3c and provides some additional insight into those curves.

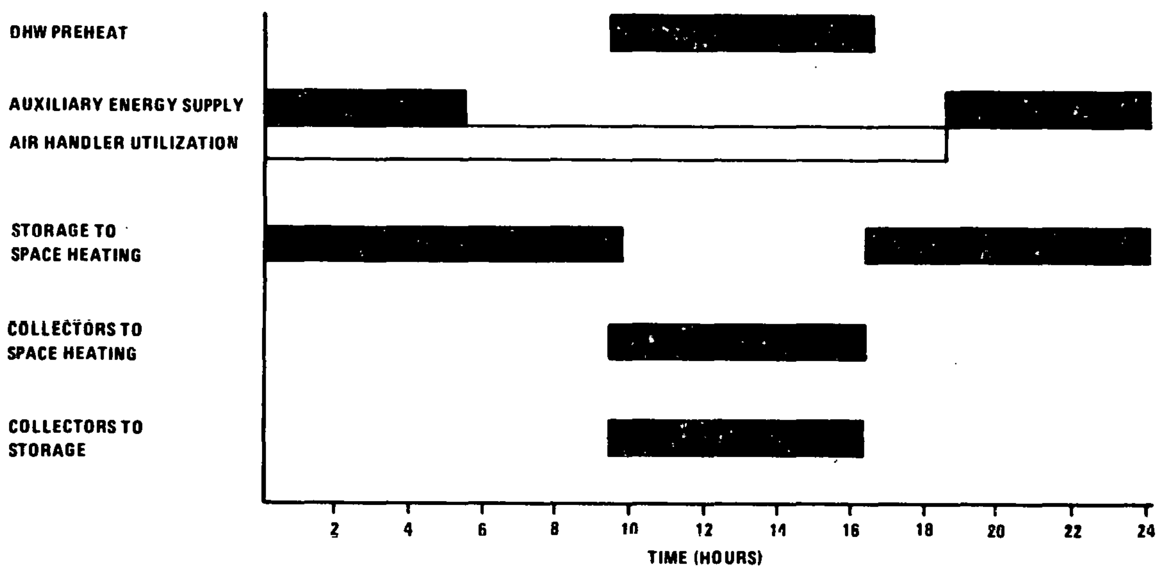



Figure 4. Typical System Operating Sequence
Spearfish High School
January 12, 1981

The operation of the two main system air handlers, PCF1 (collector subsystem) and PCF2 (storage delivery to loads), is independently controlled but interlocks under typical load conditions shown in Figure 4. On January 12, 1981, auxiliary energy was supplied to the conditioned space via the roof-mounted air handlers which are equipped with hot water liquid-to-air heat exchangers. Energy is supplied to these six air handlers from packaged natural-gas-fired boilers. This auxiliary energy supply was required until 0550 hours in the morning and from 1830 to the end of the day. The auxiliary hot water backup energy is supplied to the roof-mounted air handlers where the auxiliary is available upon demand. The energy is utilized only if the heating demand is called for in the specific zone. The air handlers move solar preheated air past the auxiliary space heat, heat exchangers upon demand. Throughout this day's operation, the air handlers ran continuously, providing heated air from the roof air handlers to the load under demand until 1834 hours. During this time period, solar energy was available to the air handlers on a continuous basis while auxiliary energy was only required in the morning hours until 0530 hours and was provided to the air handlers, but not utilized from 1834 hours until the following morning. Supplying auxiliary energy to the air handlers when solar energy is available is a wasteful use of auxiliary energy since 100% of the load was satisfied by solar via the rock storage bin. The auxiliary system should shut down until about 0500 hours on the following day. Shutdown of the auxiliary system would provide about eight hours of reduced auxiliary fuel consumption, presently delivered to the nonutilized air handlers at night.

The air handlers are also used to ventilate the conditioned space and provide fresh makeup air to the solar system.

The operating of the DHW subsystem is interlocked with PCF1 and has a differential thermostatic control. Some operational problems were solved in April 1981, improving performance and reducing the operating energy requirements.

## 1.3 SOLAR ENERGY UTILIZATION

Figure 5 shows the use of solar energy and the percentage of losses.

The losses of solar energy at the different stages through the system, from incident radiation to the load, are also presented in Table 3.

The largest source of losses from the Spearfish High School solar energy system is the collector subsystem. The collector subsystem shows only a nine percent threshold loss but collects an average of only 25% of the available insolation resource. One reason for these large losses is the large amount of exposed duct work on the school roof for the transport of collected solar energy. The solar heated air is moved to the storage subsystem, contained in a mechanical room below a vertical shaft containing the ducting runs for both solar collection-distribution and space heating supply air.

The collector subsystem controls are one area which requires attention. There are numerous hours of operation of the collector subsystem outside of the utilizability level of the collectors. The set point temperature could be elevated by 10% to 15% to partially eliminate this problem. Also, a photocell interlock for collector operation could be employed to further reduce nonoptimal collector array fan (PCF1) operation.

The problem of negative hourly values of collected solar energy exists in the warmer, transitional months of this study period. The collector subsystem is

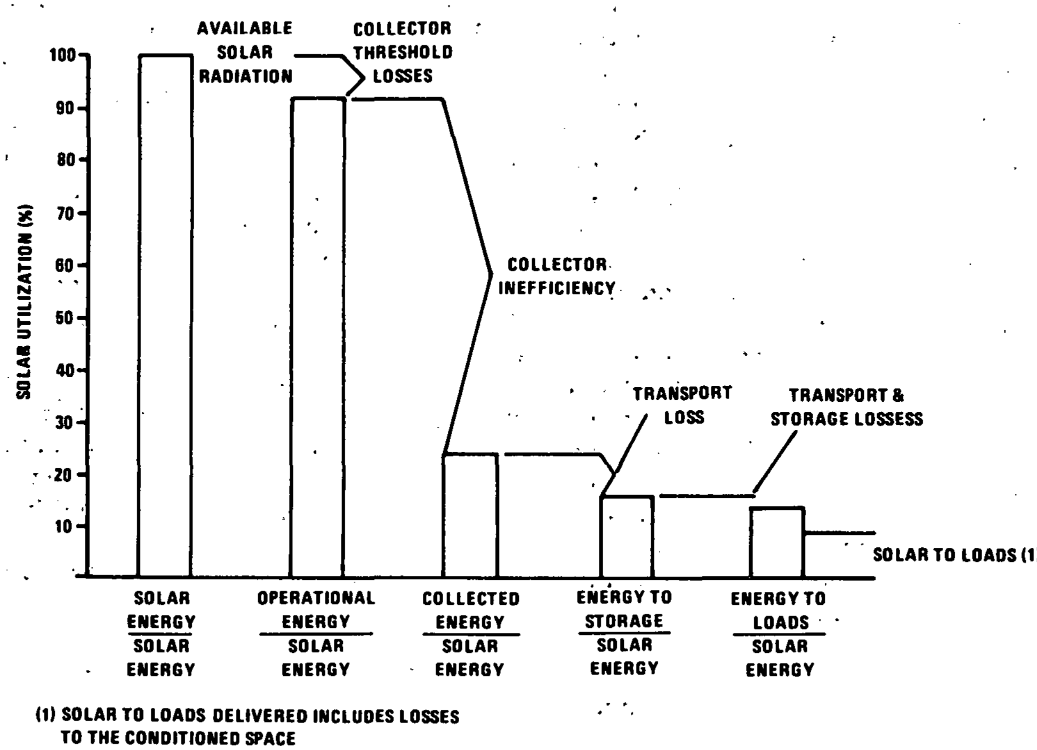



Figure 5. Solar Energy Use
Spearfish High School
September 1980 through June 1981

## Table 3. SOLAR ENERGY LOSSES

### SPEARFISH HIGH SCHOOL
### SEPTEMBER 1980 THROUGH JUNE 1981

| | MONTH | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SEP | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN |
| 1. COLLECTOR SUBSYSTEM SOLAR POSITIVE GAINS (million BTU) | 59.80 | 85.40 | 99.94 | 75.54 | 108.09 | 88.38 | 124.61 | 101.89 | 59.26 | 81.68 |
| 2. SOLAR ENERGY (SE) COLLECTED - SE LOST IN TRANSFER (million BTU) | 48.12 | 52.34 | 48.37 | 74.76 | 101.84 | 86.11 | 121.72 | 100.70 | 58.15 | 78.11 |
| 3. SE TO STORAGE (million BTU) | * | 50.75 | 46.53 | 55.04 | 61.37 | 55.04 | 116.09 E | 69.65 | 41.01 | 76.28 |
| 4. CHANGE IN STORED ENERGY (million BTU) | 0.04 | 0.66 | -1.58 | -0.06 | 3.86 | -0.18 | 1.38 | 14.92 | 1.34 | -1.17 |
| 5. HEATING SOLAR ENERGY (HSE) FROM STORAGE (million BTU) | 5.66 | 19.35 | 33.72 | 64.15 | 43.79 | * | 50.91 | 40.77 | 11.65 | 21.10 |
| 6. LOSS - STORAGE TO HSE (%) | * | 48 | 25 | 3 | 18 | * | 44 E | 16 | 68 | 74 |

*DENOTES UNAVAILABLE DATA.
E DENOTES ESTIMATED VALUE.

relatively efficient during periods of high space heat demand and reduced storage temperatures. The average operational collector subsystem efficiency during November through March, the most severe portion of the 1980-1981 heating season, was 32%. These months showed improvement above the average operational efficiency. These months also required the least collector subsystem operating energy, while still maintaining a small threshold collection loss factor.

The inefficient operation of the collector subsystem is partially tied to protection of the array from overheating. Unfortunately, this protection is obtained at a high cost, since expensive electrical power is used. As a result, the solar savings are significantly reduced.

Loss rates at other locations in the solar energy system are high but much of the lost energy is delivered and utilized for space heating as shown in the Energy Flow Diagram (Figure 2).

Another major area of concern is the high apparent losses from the storage to the distribution/space heating leg of the system. A total of about 615.23 million BTU is lost from storage and the space heat distribution system. Of these losses, a calculated total of 282.14 million BTU was lost to the conditioned space from this part of the system. An additional 67.24 million BTU were lost to the conditioned space from the solar collector subsystem duct work inside the building, and 0.83 million BTU were lost from operation of the DHW subsystem. These losses total 349.38 million BTU of additional solar thermal energy used in the structure. It would be very difficult and perhaps costly to reduce these losses. Increased insulation of the storage rock bin would improve the 60% long-term storage efficiency as well as reduce unnecessary overheating of localized interior spaces near storage. The low solar utilizability factor of 0.17 shows the net long-term effect of system inefficiency. Only 17% of available insolation resources was put to effective use at the structure, even when losses to the load are included.

## 1.4 SOLAR SYSTEM AVAILABILITY

The solar system was operational during the entire monitoring period. Several controls changes were made.

## SECTION 2

## SUBSYSTEM PERFORMANCE

### 2.1 COLLECTOR

Solar energy collection averaged 80.54 million BTU per month during the monitored period as shown in Table 4, from an average insolation resource of 330.66 million BTU per month for a long-term collector subsystem efficiency of 25%. The threshold collection loss was nine percent. This measurement consists of comparison of the total available insolation to the collector surface to the insolation available when the collector subsystem is activated. The low threshold collection loss signifies that the collector subsystem runs nearly continuously when there is available insolation. The threshold loss percentage is much lower than the typical 25% to 40% values seen at other instrumented sites. One reason for this difference is that this site employs a set point control system based upon the temperature monitored at the absorber plate by a control sensor. When, for any reason, this temperature is exceeded, the collector array fan is energized to handle air through the collector arrays.

Table 4. COLLECTOR SUBSYSTEM PERFORMANCE

SPEARFISH HIGH SCHOOL
SEPTEMBER 1980 THROUGH JUNE 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 (%) | RATIO OF OPERATIONAL INCIDENT TO TOTAL INCIDENT RADIATION | ECSS OPERATING ENERGY | SOLAR ENERGY TO LOADS | SOLAR ENERGY TO STORAGE | DAYTIME AMBIENT TEMPERATURE (°F) |
|---|---|---|---|---|---|---|---|---|---|---|
| SEP | 358.04 | 48.12 | 17 | 354.83 | 17 | 0.99 | 14.61 | 7.40 | 56.96 E | 70 |
| OCT | 393.51 | 52.34 | 22 | 375.35 | 23 | 0.95 | 10.62 | 12.79 | 50.75 | * |
| NOV | 268.38 | 83.56 | 31 | 248.63 | 34 | 0.93 | 4.54 | 21.66 | 46.53 | * |
| DEC | 227.73 | 74.76 | 33 | 212.37 | 35 | 0.93 | 2.86 | 27.79 | 55.04 | 38 |
| JAN | 335.19 | 101.84 | 30 | 315.98 | 32 | 0.94 | 4.37 | 37.03 | 61.37 | 39 |
| FEB | 313.02 | 86.11 | 28 | 294.22 | 29 | 0.94 | 3.80 | 29.71 | 55.04 | 35 |
| MAR | 417.55 | 121.71 | 29 | 407.16 | 30 | 0.97 | 5.80 | 30.89 | 56.96 E | 48 |
| APR | 373.46 | 100.70 | 27 | 322.78 | 31 | 0.86 | 6.85 | 17.51 | 69.65 | 60 |
| MAY | 272.94 | 50.15 | 21 | 201.41 | 29 | 0.74 | 5.30 | 8.42 | 41.01 | 61 |
| JUN | 346.73 | 78.11 | 23 | 305.11 | 26 | 0.88 | 8.50 | 19.87 | 76.28 | 71 |
| TOTAL | 3,306.55 | 805.41 | - | 3,037.84 | - | - | 67.25 | 213.07 | 569.58 E | - |
| AVERAGE | 330.66 | 80.54 | 25 | 303.78 | 27 | 0.91 | 6.73 | 21.31 | 56.96 E | 53 |

E DENOTES ESTIMATED VALUE.
* DENOTES UNAVAILABLE DATA.

Early in the heating season, the ratio was very high varying from 0.93 to 0.99 in September through March. In April, control system changes reduced the time of collector operation somewhat to an 0.86 ratio and further reduction was apparent in May, the month of greatest threshold collection loss, 26%. However, the ratio increased again in June to 0.88, which indicates the set point may still be somewhat lower than optimal. The most efficient collector subsystem operation would have the following attributes indicated from this and other air solar systems.

1. Balanced collector flow rates calibrated to produce a 120°F differential temperature across the arrays.

2. Collector subsystem activation at or above approximately 100 BTU/$ft^2$/hour insolation.

3. Reduced inefficient run-on of the collector subsystem air handler in the late afternoon when insolation drops below 100 BTU/$ft^2$/hour.

These parameters applied to control of the collector subsystem could significantly reduce the operating energy presently expended on collector operation. It is clear that some benefits were achieved in April which maintained lower ECSS operating energy than in similar fall months.

Figures 6, 7, and 8 show the performance of the collector subsystem during selected months, September, January, and June. The collector array efficiency curves are compared to the manufacturer's standard (ASHRAE 93-77/NBSIR 74-635) collector efficiency curve. The instantaneous collector efficiencies are plotted against the collector operating point, defined as the temperature difference between the collector inlet temperature and the ambient temperature, divided by insolation per unit collector area. The graph represents a least-squares curve fit of the various operating points, in the form of a linear equation with the collector transmission/absorption product ($F_R\tau\alpha$) indicated by the y-intercept and the effective collector heat loss coefficient ($F_RU_L$) indicated by the negative of the slope of the line. The correlation coefficient for the actual data was 0.81 in September, 0.58 in January 1981, and 0.89 in June 1981 (the months selected for analysis of collector subsystem efficiency).

An analysis of the performance of the instrumented collector subsystem is possible by comparing the all-day, monthly efficiency computations with manufacturers' single panel test data.

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.

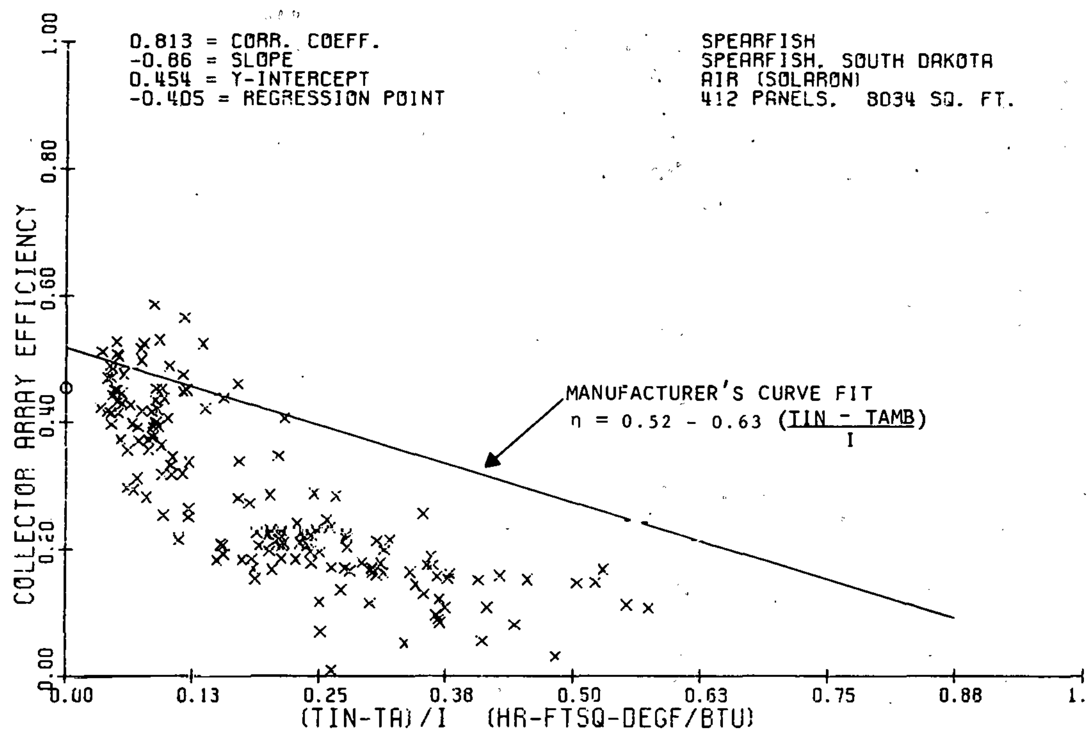



**Figure 6. Average Collector Efficiency Plot**
**Spearfish High School**
**September 1980**

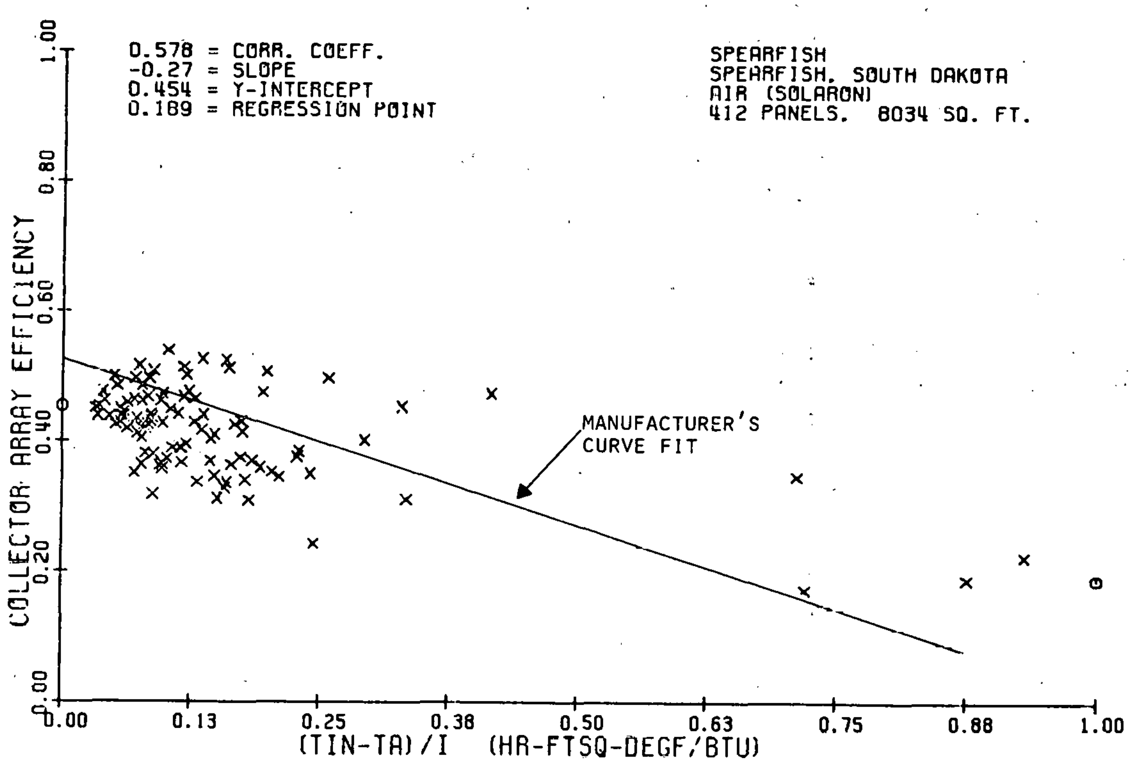



**Figure 7. Average Collector Efficiency Plot**
**Spearfish High School**
**January 1981**

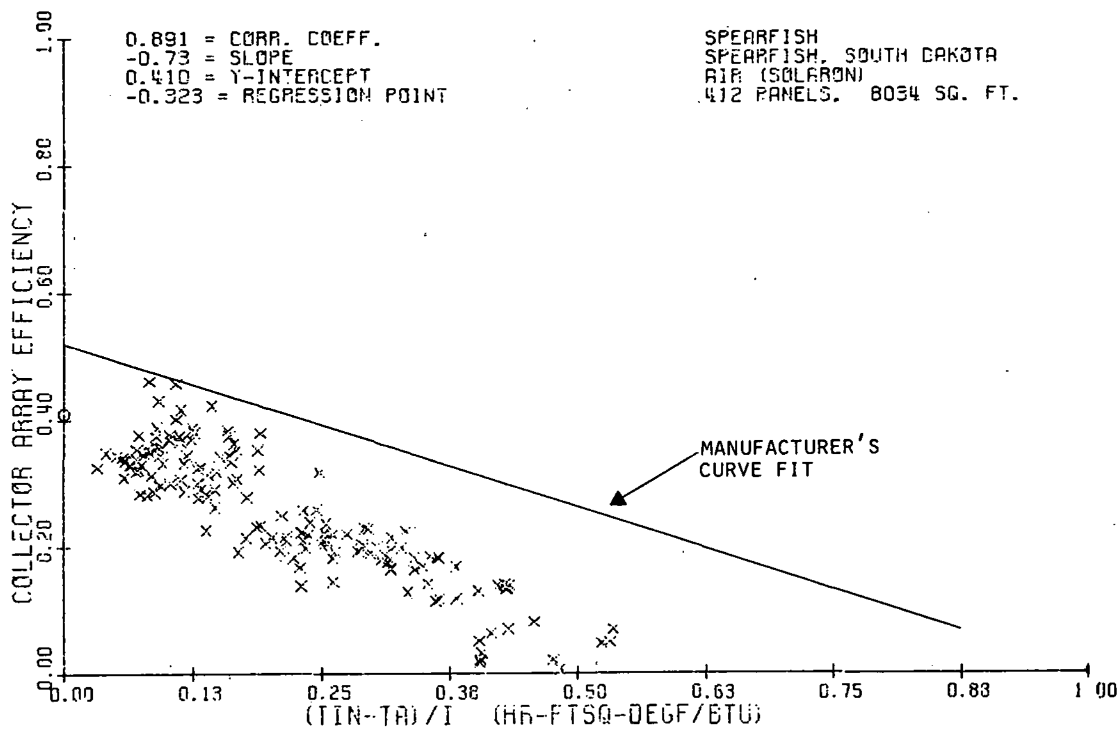



**Figure 8. Average Collector Efficiency Plot**
**Spearfish High School**
**June 1981**

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

$$n_c = Q_s/Q_i$$

where: $n_c$ = 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 4.

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, $n_{co}$, is computed as follows:

$$n_{co} = Q_s/Q_{oi}$$

where: $Q_s$ = collected solar energy

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

The monthly efficiency computed by this method is listed in the column entitled "Colletor Array Operational Efficiency" in Table 4. 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 4.

Analysis of the operational all-day collector subsystem plots computed from monitored values at appropriate sensors shows relatively good array subsystem performance compared with available data from the manufacturer, as show in Table 5. The ($F_RU_L$) heat loss, shown by the slope of the curve fit from operational data is in good agreement with the manufacturer's results. The ($F_R\tau\alpha$) intercept values are all lower than the manufacturer's expected values. This is due to the all-day computation of operational NSDN values as compared to the highly restricted panel testing, under optimal controlled conditions, which generates the manufacturer's curve.

There are many operational considerations when analyzing all-day efficiency and operational parameters of collector subsystems.

1. Unbalanced flow conditions.

2. Varying turbulent conditions inside collector panels due to assembly differences.

Table 5. COLLECTOR ARRAY SUBSYSTEM PERFORMANCE ANALYSIS (FOR SELECTED MONTHS)

SPEARFISH HIGH SCHOOL
SEPTEMBER 1980, JANUARY AND JUNE 1981

(All values in million BTU, unless otherwise indicated)

| MONTH | OPERATIONAL AVAILABLE INSOLATION | OPERATIONAL EFFICIENCY (%) | AMBIENT TEMPERATURE (°F) | STORAGE TEMPERATURE (°F) | DELTA TEMPERATURE (°F) | SLOPE ($F_RU_L$) | INTERCEPT ($F_R\tau\alpha$) | COLLECTED SOLAR ENERGY |
|---|---|---|---|---|---|---|---|---|
| SEP | 354.83 | 17 | 70 | 100 | 30 | -0.86 | 0.45 | 59.80 |
| JAN | 315.98 | 32 | 39 | 79 | 40 | -0.27 | 0.45 | 101.84 |
| JUN | 305.11 | 26 | 71 | 114 | 43 | -0.73 | 0.41 | 78.11 |
| MANUFACTURER | N.A. | 38 E | N.A. | N.A. | N.A. | -0.63 | 0.52 | N.A. |
| AVERAGE MONITORED NSDN | 325.31 | 25 | - | - | 38 | -0.62 | 0.44 | 79.92 |

E DENOTES ESTIMATED VALUE.
N.A. DENOTES NOT APPLICABLE.

3. Variations in incidence angles during the all-day analysis.

4. Regional differences and daily differences in diffuse solar radiation levels, e.g., cloud passage during normal operation of the subsystem.

5. Nonstandard, elevated, or gusting wind conditions.

6. Uncontrolled flow rate variations under operationally variable air makeup and distribution cycles at the structure (system integration to heat load and zone demands).

7. Different operational flow rates than the panel test flow rate.

8. Dust, condensation, or other degradation of glazings and absorber plates.

Comparisons between the months of September 1980 and June 1981 are relatively simple. In September, the ambient temperature to inlet temperature delta T was lower than in June. The reduced heat loss rate in September 1980 was due to the reduced storage temperature, hence gross collector inlet temperature to the collector subsystem was lower on the monthly level as compared to June 1981. The system operations had intentionally fully heated the rock storage subsystem at the site by June 1981, creating more inefficiencies but preparing the massive (4,300 cubic feet) storage to serve the space heating load in early winter. During January 1981, the storage temperature declined to 79°F while relatively moderate daytime conditions prevailed (average 39°F). Due to the much cooler air entering the collector subsystem in January 1981, there was a reduction in heat loss while the 0.45 intercept value was similar to September. Nearly twice as much solar energy was collected in January 1981 as in September 1980 and the operational subsystem efficiency increased to almost 30% better than the seasonal average.

The results from all-day computations on this air system show greatly improved efficiency in the cooler months of the season. During this time, storage temperatures are lower and return air to the collectors is made up from the conditioned space under direct heating via the storage plenum.

## 2.2 STORAGE

The storage subsystem is supplied with solar heated air from the collector subsystem via the collector array air handler (PCF1) to a plenum arrangement as shown in the system schematic. In certain damper configurations, air flows into and out of the storage subsystem cannot be computed directly and are calculated from system energy balance measurements. The energy to storage was estimated at 569.58 million BTU while the energy from storage was estimated at 356.80. There was a net 19.33 million BTU of thermal energy transferred to the storage subsystem and retained. Of this energy, 14.92 million BTU were obtained in April during a dramatic recharging of the storage rock bin. Minimum storage temperatures occurred in December, during which there was a net transfer of 9.17 million BTU from the conditioned space to the rock bin because the storage was cooler than the conditioned space. During December, most space heating from solar energy occurred by transfer through the top of the storage to the storage air handler.

The estimated effective heat loss rate for the storage subsystem was 1,385 BTU/hr°F. The estimated long-term R value for the subsystem is 2.0 based on the estimated loss rate. (The estimated surface area of the rock bin was calculated from construction drawings as 2,770 square feet.) The low resistance to heat loss is not surprising when considering that some air flow leakage, conduction through the lower storage section to the ground, and other unknowns may have influenced the effective heat loss rate. There seems to be no distinct trend in the values of the storage effective heat loss rate which may be due to covariations in many factors including the differential temperatures between storage and its environment as well as air handling strategies. The result of this heat loss, regardless of its mechanism, is reduced storage efficiency to 60% under average temperature conditions in storage of 92°F.

The total losses out of storage were 251.96 million BTU which were comprised of 193.45 million BTU from solar energy stored in the rock bin, and 58.51 million BTU utilized for operation of the storage air handler (PCF2).

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

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

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

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

Where: STEFF = storage efficiency

STECH = change in stored energy

STEO = energy removed from storage

STEI = energy added to storage

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

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

Where: c = effective storage heat loss coefficient

$T_s$ = average storage temperature

$T_a$ = average ambient temperature in the vicinity of storage

t = number of hours in the month

Table 6. STORAGE PERFORMANCE

SPEARFISH HIGH SCHOOL
SEPTEMBER 1980 THROUGH JUNE 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(1) HEAT LOSS COEFFICIENT (BTU/hr°F) | SOLAR THERMAL LOSSES FROM STORAGE |
|---|---|---|---|---|---|---|---|
| SEP | 56.96 E | 35.68 E | 0.04 | 64 | 100 | 1,283 | 21.24 E |
| OCT | 50.75 | 19.35 | 0.66 | 39 | 93 | 1,589 | 30.74 |
| NOV | 46.53 | 33.72 | -1.58 | 69 | 89 | 1,249 | 14.39 |
| DEC | 55.04 | 64.15(2) | 0.06 E | *(2) | 70 | *(2) | -9.17 |
| JAN | 61.37 | 43.79 | 3.86 | 78 | 79 | 2,634 | 13.72 |
| FEB | 55.04 | 35.68 E | -0.18 | 64 | 76 | * | 19.18 E |
| MAR | 56.96 E | 50.91 | 1.38 | 91 | 87 | 448 | 4.67 E |
| APR | 69.65 | 40.77 | 14.92 | 75 | 100 | 776 | 13.96 |
| MAY | 41.01 | 11.65 | 1.34 | 32 | 112 | 1,018 | 28.02 |
| JUN | 76.28 | 21.10 | -1.17 | 26 | 114 | 1,965 | 55.18 |
| TOTAL | 569.58 E | 356.80 E | 19.33 | - | - | - | 193.45 E |
| AVERAGE | 56.96 E | 35.68 | 1.93 | 60 | 92 | 1,385 E | 19.35 |

E DENOTES VALUE ESTIMATED FROM AVAILABLE DATA.
* DENOTES UNAVAILABLE DATA.
(1) TEMPERATURE OF THE STORAGE ENVIRONMENT IS BUILDING TEMPERATURE.
(2) TEMPERATURE OF STORAGE WAS BELOW THE TEMPERATURE OF THE CONDITIONED SPACE CAUSING NET TRANSFER OF ENERGY TO STORAGE.

## 2.3 DOMESTIC HOT WATER (DHW)

The DHW subsystem performance for the Spearfish High School site for the reporting period is shown in Table 7.

The DHW preheat subsystem consists of a 17-square-foot frontal area, air to-water heat exchanger employing a design face velocity of 705 fpm. This sizing is well matched to the monitored 12,000 cfm return rate from the collector subsystem. The exchanger consists of eight rows of exchanger tubing with 12 fins per inch of tube exposed to air flow.

The pump for circulating water in the solar preheat subsystem is a Bell and Gossett 1/6-Hp 1.5-inch bronze body pump which consumes about 0.2 kw per hour of operation. Control strategy integrates DHW preheat pump operation with operation of the collector array and appropriate damper positions are selected to route solar heated air to the heat exchanger prior to the rock-bed inlet. (See site schematic, Figure A-1.)

The DHW subsystem utilized 22.43 million BTU of solar energy and 1.84 million BTU of operating energy as shown in Table 7.

Table 7. DOMESTIC HOT WATER SUBSYSTEM PERFORMANCE

SPEARFISH HIGH SCHOOL
SEPTEMBER 1980 THROUGH JUNE 1981

(All values in million BTU)

| MONTH | SOLAR | OPERATING EXPENSE |
|---|---|---|
| SEP | 1.74 | 0.36 |
| OCT | 1.59 | 0.28 |
| NOV | 1.84 | 0.15 |
| DEC | 0.85 | 0.08 |
| JAN | 1.83 | 0.12 |
| FEB | 1.73 | 0.11 |
| MAR | 3.24 | 0.17 |
| APR | 2.49 | 0.19 |
| MAY | 2.42 | 0.15 |
| JUN | 4.70 | 0.23 |
| TOTAL | 22.43 | 1.84 |
| AVERAGE | 2.24 | 0.18 |

The load side of the DHW subsystem is not instrumented, therefore no load computations are available. Using an efficiency factor of 0.60 for fossil auxiliary consumed at the site, a total of 34.32 million BTU of fossil energy, or 36,791 cubic feet of natural gas, was saved through the operation of the solar DHW preheat subsystem. These savings represent a monetary saving of $155.00 from the use of solar energy for water heating.

Evidence of control strategy problems shows DHW preheat pump operation before suitable utilizable solar energy is available to the heat exchanger. Also, the system runs following termination of utilizable differential temperatures for collection of DHW solar preheat energy. The grantee was advised of the problem and provided with engineering recommendations for revising the system. Later data indicated more efficient operation toward the end of the monitoring period.

## 2.4 SPACE HEATING

The space heating subsystem performance for the Spearfish High School site for the reporting period is shown in Tables 8 and 9 and presented graphically in Figure 9.

The space heating load of 991.40 million BTU was satisfied by 539.85 million BTU of solar energy and 376.98 million BTU of auxiliary energy. The solar fraction of this load was 54% with a solar operating energy expense of 58.51 million BTU for distribution of stored solar energy and a total operating expense of 255.29 million BTU. From this large quantity of operating energy consumed inside the conditioned space, a total of 74.95 million BTU was computed to have been contributed to the satisfaction of the space heating load as thermal energy.

Table 8. SPACE HEATING SUBSYSTEM I

SPEARFISH HIGH SCHOOL
SEPTEMBER 1980 THROUGH JUNE 1981

(All values in million BTU, unless otherwise indicated)

| MONTH | SPACE HEATING LOAD | CONTROLLED DELIVERED ENERGY | TOTAL SOLAR ENERGY USED | TOTAL AUXILIARY THERMAL USED | SOLAR FRACTION OF LOAD (%) | BLDG TEMP (°F) | AMB TEMP (°F) |
|---|---|---|---|---|---|---|---|
| SEP | 35.85 | 7.26 | 30.32 | 1.70 | 85 | 77 | 62 |
| OCT | 48.48 | 24.85 | 31.23 | 13.67 | 64 | 74 | *(50) |
| NOV | 80.55 | 62.98 | 37.35 E | 43.16 | 46 | 73 | *(35) |
| DEC | 182.79 | 130.37 | 78.42 | 103.43 | 43 | 72 | 35 |
| JAN | 162.03 | 116.86 | 68.27 | 81.71 | 42 | 72 | 33 |
| FEB | 147.67 | 108.99 | 54.98 | 81.17 | 37 | 72 | 30 |
| MAR | 139.08 | 66.53 | 89.20 | 38.72 | 64 | 73 | 41 |
| APR | 79.86 | 22.77 | 59.95 | 7.76 | 75 | 75 | 53 |
| MAY | 47.91 | 10.14 | 33.52 | 4.15 | 70 | 75 | 55 |
| JUN | 67.18 | 16.54 | 56.23 | 1.51 | 80 | 75 | 65 |
| TOTAL | 991.40 | 567.29 | 539.85 | 376.98 | - | - | - |
| AVERAGE | 99.14 | 56.73 | 53.99 | 37.70 | 54 | 74 | 46 E |

E Denotes value estimated from available data.
* Denotes unavailable data.
() Indicates long-term value from NWS data used due to sensor failure.

The fossil fuel energy savings were 764.31 million BTU. The average building temperature for the season was 74°F.

The overall performance of the space heating subsystem was excellent. Very comfortable temperatures were maintained during the entire heating season. During the major load producing portion of the season, November through March, the temperature in the conditioned space was 72°F, while in transitional months solar losses caused some overheating. The average outdoor temperature was 46°F during the entire period of monitoring. These temperatures were elevated above the long-term NWS values. These elevated temperatures may have been the result of sensor placement near the collector subsystem, causing reradiation to the sensor. The sensor was relocated away from obvious sources of heat during repairs in early December.

Of the computed 539.85 million BTU of total solar energy used for space heating, 190.80 million BTU were delivered through the roof-mounted air handlers. Losses to the conditioned space totaled 349.38 million BTU from distribution and storage inside the conditioned space. These contribute to the space heating load of 991.40 million BTU. The controlled delivered energy at the site was 567.29 million BTU, which consists of monitored energy delivered by the HVAC equipment. The solar fraction of this controlled delivered energy is 34% while the solar fraction of the entire computed space heating load was 54% based on total solar energy.

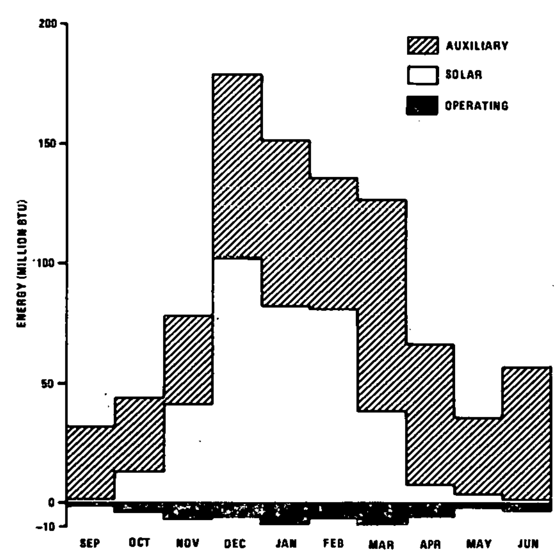
## Table 9. SPACE HEATING SUBSYSTEM II

### SPEARFISH HIGH SCHOOL
### SEPTEMBER 1980 THROUGH JUNE 1981

(All values in million BTU, unless otherwise indicated)

| MONTH | SPACE HEATING LOAD | MEASURED SOLAR ENERGY USED | SOLAR ENERGY LOSSES TO LOAD | TOTAL OPERATING ENERGY | SOLAR SPECIFIC OPERATING ENERGY | AUXILIARY FOSSIL FUEL | HEATING DEGREE-DAYS |
|---|---|---|---|---|---|---|---|
| SEP | 35.85 | 5.66 | 24.66 | 33.16 | 1.54 | 2.84 | 159 |
| OCT | 48.48 | 11.20 | 20.03 | 28.21 | 4.36 | 22.78 | (474)* |
| NOV | 80.55 | 19.81 | 17.54 E | 21.52 | 6.78 | 71.94 | (888)* |
| DEC | 182.79 | 26.94 | 51.48 | 23.39 | 6.31 | 172.38 | 937 |
| JAN | 162.03 | 35.20 | 33.12 | 26.46 | 9.70 | 136.18 | 971 |
| FEB | 147.67 | 27.98 | 27.16 | 24.20 | 7.28 | 135.28 | 940 |
| MAR | 139.08 | 27.82 | 61.38 | 24.66 | 9.88 | 64.53 | 745 |
| APR | 79.86 | 15.03 | 44.94 | 26.78 | 7.26 | 12.93 | 388 |
| MAY | 47.91 | 5.99 | 27.53 | 22.56 | 2.44 | 6.91 | 304 |
| JUN | 67.18 | 15.17 | 41.21 | 24.35 | 2.96 | 2.52 | 81 |
| TOTAL | 991.40 | 190.80 | 349.05 | 255.29 | 58.51 | 628.29 | 5,887 |
| AVERAGE | 99.14 | 19.08 | 34.91 | 25.53 | 5.85 | 62.83 | 589 |

E DENOTES ESTIMATED VALUE.
NOTE: VALUES IN PARENTHESES ARE LONG-TERM NWS HDD SUBSTITUTED FOR MISSING DATA.




OPERATING ENERGY FOR THE SYSTEM IS CONSIDERED A SYSTEM PENALTY AND IS PLOTTED AS A NEGATIVE VALUE BELOW THE ORIGIN.

Figure 9. Space Heating Subsystem Performance
Spearfish High School
September 1980 through June 1981

Insolation resources were at or above average for the months of highest space heating demand. The average insolation for the entire monitoring period was three percent lower than expected while the average ambient temperature monitored at the site was 3°F warmer than expected.

Of the 3,306.55 million BTU of insolation resources available to the collector subsystem, 190.80 million BTU (6%) were delivered by controlled HVAC equipment at the site. However, when the computed 349.38 (11%) million BTU of solar system losses inside the conditioned space are included, there were 539.47 million BTU of solar energy utilized at the site (17%) from available insolation.

The COP of the space heating subsystem was calculated on the basis of both controlled delivered energy and the equipment heating (total) load. The overall system COP was 3.88 based on the entire space heating load and the total operating energies required to provide the thermal energy. The system COP drops to 2.22 when solar losses to space heat demand are omitted. This COP is not realistic however, due to the unique configuration of this solar energy system. The COP of the solar energy portion of thermal energy delivered to the space heating load through controlled duct work distribution was 3.26. The space heating COP, reported in the COP table, is most valid on the seasonal level since the solar losses to the load show no distinct trend throughout the monitored period.

More efficient operation of the space heating subsystem might include:

1. Allowing the structure to cycle overnight using only solar energy to maintain a reduced thermostat set point.

2. Operation of the supply water pumps which provide auxiliary heated water at about 145°F to the air handler liquid to air heat exchangers (backup heating) only upon demand from the zone which is served by them. Several pumps ran continuously, wasting energy through heat loss at the roof-mounted air handlers. One alternative would be to enable the pumps on timers to reduce the overall time of operation by deactivation during periods when students are absent.

The role of internal gains in the school structure is offset by rapid ventilation rates of the fresh air makeup system. While this rate is not accurately known, the ratio of makeup air monitored at the inlets to the daily circulation of air in the heating system is about 1:5, with the collector outlet flow rate as reference. For example, intentional makeup air totaled 2.3 million pounds in January, while collector subsystem outlet flow totaled nearly 11 million pounds. This flow represents an intentional mass vent rate of about 53.5 pounds per square foot of conditioned space, per month. This vent rate represents about two air changes per hour, which is very low for a large multizone building.

# SECTION 3

# OPERATING ENERGY

The energy used for operation of the various subsystems at Spearfish High School is shown in Table 10.

Total solar-unique operating energy for this large high volume air system was 127.60 million BTU, or 39% of the total electrical power requirements for system operation. Solar-unique operating energy for space heating is monitored at the distribution air handler (PCF2 on site schematic) on the outlet side of storage. Solar operating energy required for space heating was 58.51 million BTU used to move stored solar energy from the rock bin to the air handlers.

Table 10. SOLAR OPERATING ENERGY

SPEARFISH HIGH SCHOOL
SEPTEMBER 1980 THROUGH JUNE 1981

(All values in million BTU)

| MONTH | ECSS OPERATING ENERGY | DHW OPERATING ENERGY | SHS OPERATING ENERGY | TOTAL SOLAR OPERATING ENERGY | TOTAL SYSTEM OPERATING ENERGY |
|---|---|---|---|---|---|
| SEP | 14.61 | 0.36 | 1.54 | 16.50 | 48.12 |
| OCT | 10.62 | 0.28 | 4.36 | 15.27 | 39.11 |
| NOV | 4.54 | 0.15 | 6.78 | 11.46 | 26.20 |
| DEC | 2.86 | 0.08 | 6.31 | 9.26 | 26.34 |
| JAN | 4.37 | 0.12 | 9.70 | 14.20 | 30.95 |
| FEB | 3.80 | 0.11 | 7.28 | 11.18 | 28.10 |
| MAR | 5.80 | 0.16 | 9.88 | 15.85 | 30.63 |
| APR | 6.85 | 0.19 | 7.26 | 14.30 | 33.82 |
| MAY | 5.30 | 0.15 | 2.44 | 7.89 | 28.00 |
| JUN | 8.50 | 0.23 | 2.96 | 11.69 | 22.08 |
| TOTAL | 67.25 | 1.84 | 58.51 | 127.60 | 324.35 |
| AVERAGE | 6.73 | 0.18 | 5.85 | 12.76 | 32.44 |

The operation of the solar collector subsystem required 67.25 million BTU or 21% of the total system operating energy. As shown in Table 10, the operating energy for September and October, as well as June, is elevated due to operating of the collector subsystem for protection from overheating. Due to the configuration of the system's solar controls, the operation of the collectors can be enabled when ambient temperature exceeds about 85°F and there is no insolation. The control sensor is affixed to the absorber plate, and no temperature differential with rock storage is employed for collection control. This simplified collection control strategy works well during months of ambient temperatures below 70-75°F but can elevate collection operating energy, as shown in the data, for warmer months. No damage would be done by elevation of the set point to 100-115°F during the summer. Overheat protection would be obtained at much lower operating costs.

## SECTION 4

## ENERGY SAVINGS

Energy savings for this site for the reporting period, September 1980 through June 1981, are presented in Table 11.

For this 10-month period, the total savings were 821.37 million BTU, for a monthly average of 82.14 million BTU. This is approximately 5,922 gallons of oil, or 804,474 cubic feet of natural gas, or 240,727 kwh of electricity. An electrical energy expense of 127.60 million BTU was incurred during the reporting period for the operation of solar energy components.

Table 11. ENERGY SAVINGS

SPEARFISH HIGH SCHOOL
SEPTEMBER 1980 THROUGH JUNE 1981

(All values in million BTU)

| MONTH | SOLAR ENERGY USED | SPACE HEATING ELECTRICAL | SPACE HEATING FOSSIL FUEL | DOMESTIC HOT WATER ELECTRICAL | DOMESTIC HOT WATER FOSSIL FUEL | ECSS OPERATING ENERGY | ENERGY SAVINGS ELECTRICAL | ENERGY SAVINGS FOSSIL FUEL |
|---|---|---|---|---|---|---|---|---|
| SEP | 32.06 | -1.54 | 40.63 | -0.36 | 2.89 | 14.61 | -16.50 | 49.32 |
| OCT | 32.82 | -4.36 | 41.85 | -0.28 | 2.65 | 10.62 | -15.27 | 50.49 |
| NOV | 39.20 E | -6.78 | 50.05 E | -0.15 | 3.07 | 4.54 | -11.46 | 60.31 |
| DEC | 79.26 | -6.31 | 112.74 | -0.08 | 1.41 | 2.86 | -9.26 | 114.15 |
| JAN | 70.15 | -9.70 | 90.35 | -0.12 | 3.06 | 4.37 | -14.20 | 93.46 |
| FEB | 56.86 | -7.28 | 73.08 | -0.11 | 2.88 | 3.80 | -11.18 | 76.12 |
| MAR | 92.27 | -9.88 | 130.12 | -0.16 | 5.12 | 5.80 | -15.85 | 135.24 |
| APR | 62.45 | -7.26 | 89.91 | -0.19 | 4.15 | 6.85 | -14.30 | 94.07 |
| MAY | 35.95 | -2.44 | 51.88 | -0.15 | 4.04 | 5.30 | -7.89 | 55.92 |
| JUN | 61.44 | -2.96 | 83.70 | -0.23 | 7.83 | 8.50 | -11.69 | 92.29 |
| TOTAL | 562.46 | -58.52 | 764.31 | -1.83 | 37.10 | 67.25 | -127.60 | 821.37 |
| AVERAGE | 56.25 | -5.85 | 76.43 | -0.18 | 3.71 | 6.73 | -12.76 | 82.14 |

E DENOTES ESTIMATED VALUE.

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

The auxiliary source at Spearfish High School consists of natural-gas-fired boilers. These units are considered to be 60% efficient for computational purposes.

When total solar energy savings are converted to monitary terms, a total of $3,379 was saved using natural gas as a comparison. The net savings due to solar energy are $1,210 when the operating energy expenses for the solar energy system are subtracted. A total of 37,397 kwh was utilized by the solar collection fan and storage distribution fan. This expense represents a cost of $2,169 for the solar operations at the site. Through more efficient control of the collector subsystem, the operating energy could be reduced. The control of PCF2, for solar space heating, has been fairly well optimized. The control of the collector subsystem could be improved to reduce electric power requirements in summer, thus increasing the net savings from solar energy. Had the building been heated by electric power, the net savings would have been $11,793 at 5.5 cents/kwh. Had the building been heated by fuel oil, the net savings would have been $5,234 based on $1.25/gallon fuel oil prices. Solar is not very competitive with natural-gas-fired equipment at this site due to elevated solar operating expenses. The solar energy system was obtained for the site to offset a projected shortfall in natural gas availability projected by the Federal Power Administration in the planning phase of the school. Had the school been heated electrically, the positive cash flow from solar savings would have been nearly ten times as great. Cost projections and accurate long-term pay-back estimates are not appropriate unless full life cycle analysis and evaluation of alternatives is undertaken. It is not advisable to utilize these net savings values to project system "pay back" because the costs of this system were elevated by its prototypical construction and collector subsystem control problems observed in the data for warmer months.

## SECTION 5

## WEATHER CONDITIONS

Spearfish High School is located in Spearfish, 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 12. Also presented in the table are the corresponding long-term average monthly values of the measured weather parameters. These long-term average weather data were obtained from nearby representative National Weather Service and SOLMET meteorological stations. The long-term insolation values are total global horizontal radiation converted to collector angle and azimuth orientation.

Table 12. WEATHER CONDITIONS

SPEARFISH HIGH SCHOOL
SEPTEMBER 1980 THROUGH JUNE 1981

| | DAILY INCIDENT SOLAR ENERGY PER UNIT AREA ($BTU/FT^2$-DAY) | | AMBIENT TEMPERATURE (°F) | | HEATING DEGREE-DAYS | | COOLING DEGREE-DAYS |
|---|---|---|---|---|---|---|---|
| MONTH | MEASURED | LONG-TERM AVERAGE | MEASURED | LONG-TERM AVERAGE | MEASURED | LONG-TERM AVERAGE | LONG-TERM AVERAGE |
| SEP | 1,486 | 1,719 | 62 | 61 | 159 | 191 | 56 |
| OCT | 1,580 | 1,591 | 50(1) | 50 | (474)(1) | 474 | 9 |
| NOV | 1,114 | 1,233 | 35(1) | 35 | (888)(1) | 888 | 0 |
| DEC | 914 | 1,024 | 35 | 27 | 937 | 1,194 | 0 |
| JAN | 1,346 | 1,080 | 34 | 22 | 971 | 1,336 | 0 |
| FEB | 1,391 | 1,309 | 30 | 25 | 940 | 1,098 | 0 |
| MAR | 1,677 | 1,507 | 41 | 31 | 745 | 1,048 | 0 |
| APR | 1,549 | 1,519 | 53 | 45 | 388 | 612 | 0 |
| MAY | 1,096 | 1,502 | 55 | 55 | 304 | 319 | 15 |
| JUN | 1,439 | 1,556 | 65 | 64 | 81 | 134 | 110 |
| TOTAL | - | - | - | - | 5,887(1) | 7,294 | 190 |
| AVERAGE | 1,359 | 1,404 | 46 E | 42 | 589 | 729 | 19 |

(1)LONG-TERM VALUES USED FOR MISSING VALUES.
E DENOTES ESTIMATED VALUE.

During the period from September 1980 through June 1981, the average daily total incident solar radiation on the collector array was 1,359 BTU per square foot per day. This radiation was slightly below the estimated average daily solar radiation for this geographical area during the reporting period of 1,404 BTU per square foot per day for a south-facing plane with a tilt of 62 degrees to the horizontal at a 26 degree West of South azimuth. During the period, the highest monthly average insolation was 1,677 BTU per square foot per day during March.

The average ambient temperature during the reporting period was 46°F as compared with the long-term annual average of 42°F. The highest monthly average ambient temperature was 65°F during June, and the lowest monthly average ambient temperature was 30°F during February. The number of heating degree-days for the period (based on a 65°F reference) was 5,887 as compared with the long-term average of 7,294. The range of heating degree-days was from a high of 971 during January to a low of 81 during June.

Extraterrestrial radiation values are computed (see Footnote 1) and given in the table below for each month. The ratio of total insolation on a tilted surface to extraterrestrial radiation on a similarly oriented surface is a type of solar-atmospheric transmission index (SAT).

This parameter quantifies the effects of cloudiness and atmospheric transmission on the insolation received at the earth's surface. The SAT index ranged from a high of 62% during June to a low of 31% during December.

| | SEP | OCT | NOV | DEC | JAN | FEB | MAR | APR | MAY | JUN |
|---|---|---|---|---|---|---|---|---|---|---|
| Extra-terrestrial Insolation | 3,120 | 3,255 | 3,108 | 2,970 | 3,066 | 3,260 | 3,249 | 2,908 | 2,534 | 2,341 |
| TTL INS / EXT INS (%) | 48 | 49 | 36 | 31 | 44 | 43 | 52 | 53 | 43 | 62 |

During the period of January through April, the insolation resource at the site was equal to or greater than expected while temperatures were above the long-term values. During the first four months of this study, September through December, the insolation to the site was below expected levels. November and December obtained elevated cloud cover as seen in the Daily Weather Maps (NOAA, Department of Commerce), while January was exceptionally clear compared to typical long-term values. At the end of the season, May was a month of increased cloud cover compared to long-term values, greatly reducing insolation. These deviations of short-term solar-meteorological conditions are to be expected and are reflected in the utilized solar energy collected at the site when compared to modeled long-term values.

The ambient temperature sensor failed in early October and was repaired in early December. During the months of October and November, the long-term average temperature values are substituted for the lost values for averaging purposes. Ambient temperature is monitored near the collector subsystem at this site and examination of the daily data revealed that a 6°F elevation of the temperature values during collection operation was common on sunny days. This accounts for the difference between the measured HDD values and the long-term values.

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

## SECTION 6

## REFERENCES


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

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

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

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

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

**6. ASHRAE Standard 94-77, Methods of Testing Thermal Storage Devices Based on Thermal Performance, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, NY, 1977.

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

*6B. Instrumentation Installation Guidelines March 1981, Parts 1, 2, and 3, SOLAR/0001-81/15, Vitro Laboratories, Silver Spring, Maryland.

*7. Monthly Performance Report, Spearfish, September 1980, SOLAR/2078-80/09, Vitro Laboratories, Silver Spring, Maryland.

*8. Monthly Performance Report, Spearfish, October 1980, SOLAR/2078-80/10, Vitro Laboratories, Silver Spring, Maryland.

*9. Monthly Performance Report, Spearfish, November 1980, SOLAR/2078-80/11, Vitro Laboratories, Silver Spring, Maryland.

*10. Monthly Performance Report, Spearfish, December 1980, SOLAR/2078-80/12, Vitro Laboratories, Silver Spring, Maryland.


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* 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.

## APPENDIX A

## SYSTEM DESCRIPTION

The Spearfish High School solar energy system consists of a high volume flat-plate (Solaron, Inc.) collector array of 8,034 square feet mounted at 62 degrees tilt facing 26 degrees West of South, operated by a circulating fan on the outlet duct return to the storage air handler. Upstream of the storage rock bin, capacity 4,150 cubic feet, is a damper system which selects solar heated air flow to a DHW preheat heat exchanger (36 inches x 68 inches) directly to the space heating load, or to the rock bin for storage. On about November 12, 1980, a mode was configured which allows simultaneous heating of the conditioned space and the storage rock bin with solar energy.

The ducting of the air transfer systems is resistant to air leakage and the installation of the collector array, air handlers, and distribution system is adequate for the region's severe winter climate. Auxiliary energy for space and hot water heating is provided by natural-gas-fired packaged boilers.

The system, shown schematically in Figure A-1, has three modes of operation for space heating.

Mode 1 - Collector-to-Storage - The solar energy is transferred to storage after the heating load is satisfied, by repositioning dampers so air flows from the top plenum of the rock box to the bottom plenum and back to the collector array.

Mode 2 - Collector-to-Space Heating - The solar collector air handler circulating fan is activated when the absorber plate temperature reaches 80°F. Solar heated air is moved to the air handler at the storage rock box where control logic, actuated by system demands for heat or DHW or both, determines damper positions. Mode 2 selects direct solar space heating in which solar heated air is provided to roof-mounted air handlers which make up the required thermal energy from conventional hot water boilers to satisfy the load.

Mode 3 - Collector-to-Space Heating and Storage - The collector circulating fan and the storage delivery fan can operate simultaneously in this new mode to provide both stored and direct heated solar energy to the load. This is accomplished by positioning the storage air handler dampers and opening the damper downstream of PCF2.

The DHW subsystem is enabled by operation of the main collector circulating fan. Appropriate damper positions are selected by control logic which senses hot water demand and routes water to be preheated into the air-to-water heat exchanger while damper positions are selected to route solar heated air to the heat exchanger.

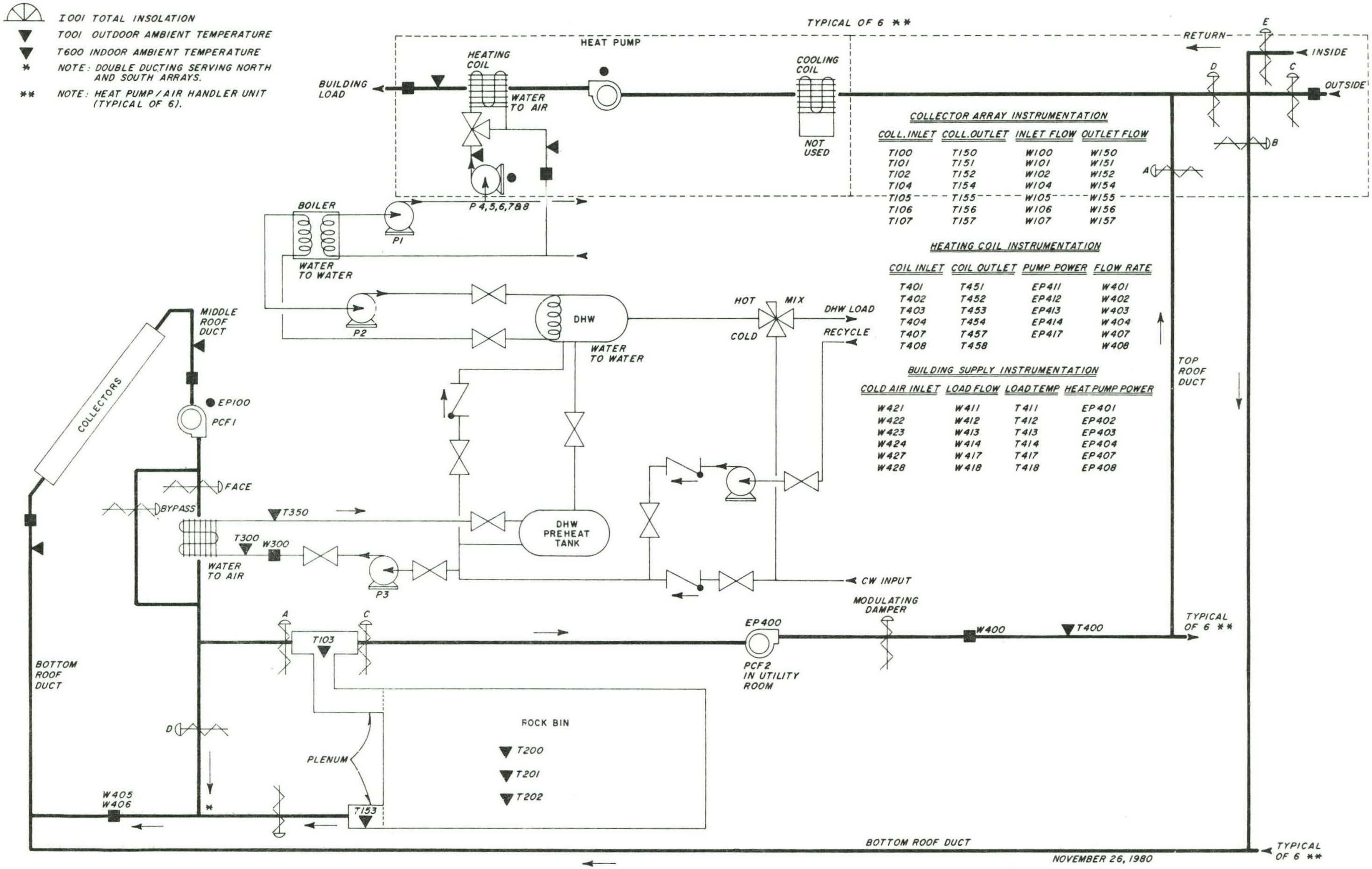


Figure A-1. Spearfish High School Solar Energy System Schematic

## APPENDIX B

## PERFORMANCE EVALUATION TECHNIQUES

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

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

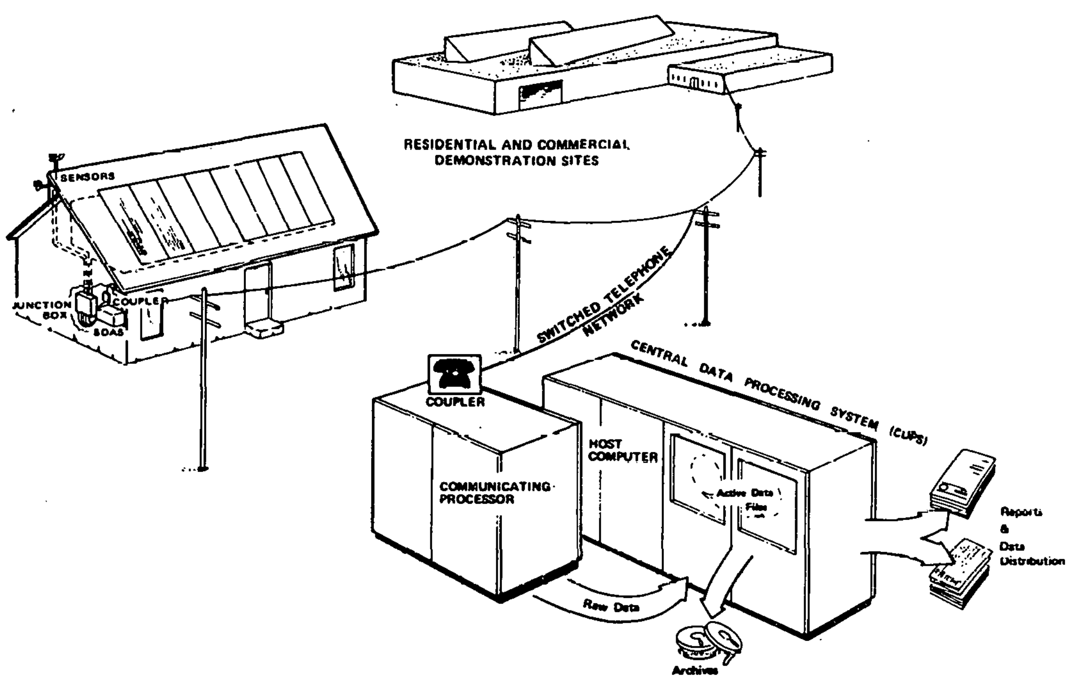


Figure B-1. The National Solar Data Network

## DATA COLLECTION AND PROCESSING

Each site contains standard industrial instrumentation modified for the particular site. Sensors measure temperatures, flows, insolation, electric power, fossil fuel usage, and other parameters. These sensors are all wired into a junction box (J-box), which is in turn connected to a 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 obviusly 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 Spearfish High School solar energy system from September 1980 through June 1981 was analyzed and Monthly Performance Reports were published through December 1980. See the following page for a list of these reports.

OTHER DATA REPORTS ON THIS SITE*

Monthly Performance Reports:

September 1980, SOLAR/2078-80/09
October 1980, SOLAR/2078-80/10
November 1980, SOLAR/2078-80/11
December 1980, SOLAR/2078-80/12

* These reports can be obtained (free) by contracting: 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

| ACRONYM | NAME | DEFINITION |
|---|---|---|
| AXE | Auxiliary Electric Fuel Energy to Load Subsystem | Amount of electrical energy required as a fuel source for all load subsystems. |
| AXF | Auxiliary Fossil Fuel Energy to Load Subsystem | Amount of fossil energy required as a fuel source for all load subsystems. |
| * AXT | Auxiliary Thermal Energy to Load Subsystems | Thermal energy delivered to all load subsystems to support a portion of the subsystem loads, from all auxiliary sources. |
| CAE | SCS Auxiliary Electrical Fuel Energy | Amount of electrical energy provided to the SCS to be converted and applied to the SCS load. |
| CAF | SCS Auxiliary Fossil Fuel Energy | Amount of fossil energy provided to the SCS to be converted and applied to the SCS load. |
| CAREF | Collector Array Efficiency | Ratio of the collected solar energy to the incident solar energy. |
| CAT | SCS Auxiliary Thermal Energy | Amount of energy provided to the SCS by a BTU heat transfer fluid from an auxiliary source. |
| * CL | Space Cooling Subsystem Load | Energy required to satisfy the temperature control demands of the space cooling subsystem. |
| 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 | 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.

| ACRONYM | NAME | DEFINITION |
|---|---|---|
| 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

| ACRONYM | NAME | DEFINITION |
|---|---|---|
| HOPE | SHS Operating Energy | Amount of energy required to support the SHS operation (which is not intended to be applied directly to the SHS load). |
| HOURCT | Record Time | Count of hours elapsed from the start of 1977. |
| * HSFR | SHS Solar Fraction | Portion of the SHS load which is supported by solar energy. |
| HSE | Solar Energy to SHS | Amount of solar energy delivered to the SHS. |
| * HSVE | SHS Electrical Energy Savings | Difference in the electrical energy required to support an assumed similar conventional SHS and the actual electrical energy required to support the demonstration SHS, for identical SHS loads. |
| * HSVF | SHS Fossil Energy Savings | Differences in the fossil energy required to support an assumed similar conventional SHS and the actual fossil energy required to support the demonstration SHS, for identical SHS loads. |
| HWAE | HWS Auxiliary Electrical Fuel Energy | Amount of electrical energy provided to the HWS to be converted and applied to the HWS load. |
| HWAF | HWS Auxiliary Fossil Fuel Energy | Amount of fossil energy provided to the HWS to be converted and applied to the HWS load. |
| HWAT | HWS Auxiliary Thermal Energy | Amount of energy provided to the HWS by a heat transfer fluid from an auxiliary source. |
| HWCSM | Service Hot Water Consumption | Amount of heated water delivered to the load from the hot water subsystem. |
| * HWL | Hot Water Subsystem Load | Energy required to satisfy the temperature control demands of the building service hot water system. |

* Primary Performance Factors

| ACRONYM | NAME | DEFINITION |
|---|---|---|
| HWOPE | HWS Operating Energy | Amount of energy required to support the HWS operation which is not intended to be applied directly to the HWS load. |
| HWSE | Solar Energy to HWS | Amount of solar energy delivered to the HWS |
| * HWSFR | HWS Solar Fraction | Portion of the HWS load which is supported by solar energy. |
| * HWSVE | HWS Electrical Energy Savings | Difference in the eletrical enegy 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

| ACRONYM | NAME | DEFINITION |
|---|---|---|
| * SEL | Solar Energy to Load Subsystems | Amount of solar enregy 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 Performacne Factors

| ACRONYM | NAME | DEFINITION |
|---|---|---|
| TCEL | Thermodynamic Conversion Equipment Load | Controlled energy output of thermodynamic conversion equipment. |
| TCEOPE | TCE Operating Energy | Amount of energy required to support the operation of thermodynamic conversion equipment which is not intended to appear directly in the load. |
| TCERJE | TCE Reject Energy | Amount of energy intentionally rejected or dumped from thermodynamic conversion equipment as a by-product or consequence of its principal operation. |
| TDA | Daytime Average Ambient Temperature | Average temperature of the ambient air during the daytime (during normal collector operation period). |
| * TECSM | Total Energy Consumed by System | Amount of energy demand of the system from external sources; sum of all fuels, operating energies, and collected solar energy. |
| THW | Service Hot Water Temperature | Average temperature of the service hot water supplied by the system. |
| TST | ECSS Storage Temperature | Average temperature of the ECSS storage medium. |
| * TSVE | Total Electrical Energy Savings | Difference in the estimated electrical energy required to support an assumed similar conventional system and the actual electrical energy required to support the system, for identical loads; sum of electrical energy savings for all subsystems. |
| * TSVF | Total Fossil Energy Savings | Difference in the estimated fossil energy required to support an assumed similar conventional system and the actual fossil energy required to support the system, for identical loads; sum of fossil energy savings of all subsystems. |
| TSW | Supply Water Temperature | Average temperature of the supply water to the hot water subsystem. |

* Primary Performance Factors

| ACRONYM | NAME | DEFINITION |
| --- | --- | --- |
| WDIR | Wind Direction | Average wind direction at the site. |
| WIND | Wind Velocity | Average wind velocity at the site. |

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* 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 specific 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 enery output of the collector. |

**Energy Savings** — The estimated difference between the fossil and/or electrical energy requirements of an assumed conventional system (carrying the full measured load) and the actual electrical and/or fossil energy requirements of the installed solar-assisted system.

**Expansion Tank** — A tank with a confined volume of air (or gas) whose inlet port is open to the system heat transfer fluid. The pressure and volume of the confined air varies as to the system heat transfer fluid expands and contracts to prevent excessive pressure from developing and causing damage.

**F-Curve** — The collector instantaneous efficiency curve. Used in the "F-curve" procedure for collector analysis (see Instantaneous Efficiency).

**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 reradiated from the panel is trapped within the collector because it cannot pass through the cover. Glass is an effective cover material (see Selective Surface).

**Focusing Collector** — A concentrating type collector using parabolic mirrors or optical lenses to focus the energy from a large area onto a small absorbing area.

**Fossil Fuel** — Petroleum, coal, and natural gas derived fuels.

**Glazing** — In solar/energy technology, the transparent covers used to reduce energy losses from a collector panel.

**Heat Exchanger** — A device used to transfer energy from one heat transfer fluid to another while maintaining physical segregation of the fluids. Normally used in systems to provide an interface between two different heat transfer fluids.

| | |
|---|---|
| Heat Transfer Fluid | The fluid circulated through a heat source (solar collector) or heat exchanger that transports the thermal energy by virtue of its temperature. |
| Heating Degree-Days | The sum over a specified period of time of the number of degrees the average daily temperature is below 65°F. |
| Instantaneous Efficiency | The efficiency of a solar collector at one operating point, $\frac{Ti-Ta}{I}$ , under steady state conditions (see Operating Point). |
| Instantaneous Efficiency Curve | A plot of solar collector efficiency against operating point, $\frac{Ti-Ta}{I}$ (see Operating Point). |
| Incidence Angle | The angle between the line to a radiating source (the sun) and a line normal to the plane of the surface being irradiated. |
| Incident Solar Energy | The amount of solar energy irradiating a surface taking into account the angle of incidence. The effective area receiving energy is the product of the area of the surface times the cosine of the angle of incidence. |
| Insolation | 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. |
| 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 operated the solar and auxiliary equipments and to transport the thermal energy to the point of use, and which is not intended to directly affect the thermal state of the system. |

**Operating Point** — A solar energy system has a dynamic operating range due to changes in level of insolation (I), fluid input temperature (T), and outside ambient temperature (Ta). The operating point is defined as:

$$\frac{Ti-Ta}{I} \quad \frac{°F \times hr. \times sq.\ ft.}{BTU}$$

**Operational Collector Efficiency** — Ratio of collected solar energy to incident solar energy <u>only during the time the collector fluid is being circulated with the intention of delivering solar-source energy to the system</u>.

**Outgassing** — The emission of gas by materials and components, usually during exposure to elevated temperature, or reduced pressure.

**Passive Solar System** — A system 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 288,00 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 $2.932 \times 10^{-4}$ 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

SPEARFISH HIGH SCHOOL

## INTRODUCTION

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

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

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

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

where I001 is the solar radiation measurement provided by the pyranometer in BTU per square foot per hour, AREA is the area of the collector array in square feet, $\Delta\tau$ is the sampling interval in minutes, and the factor (1/60) is included to correct the solar radiation "rate" to the proper units of time.

Similarly, the energy flow within a system is given typically by

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

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

For a liquid system $\Delta H$ is generally given by

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

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

* See Appendix B.

For an air system $\Delta H$ is generally given by

$$\Delta H = H_a(T_{out}) - H_a(T_{in})$$

where $H_a(T)$ is the enthalpy, in $BTU/lb_m$, of the transport air evaluated at the inlet and outlet temperatures of the heat exchanging component.

$H_a(T)$ can have various forms, depending on whether or not the humidity ratio of the transport air remains constant as it passes through the heat exchanging component.

For electrical power, a general example is

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

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

<u>Letter Designations</u>

C or CP = Specific Heat

D = Direction or Position

EE = Electric Energy

EP = Electric Power

F = Fuel Flow Rate

H = Enthalpy

HR = Humidity Ratio

HWD = Functional procedure to calculate the specific heat of water at the average of the inlet and outlet temperatures

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

_P = 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

AVERAGE AMBIENT TEMPERATURE (°F)

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

AVERAGE BUILDING TEMPERATURE (°F)

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

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

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

for ± three hours from solar noon

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

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

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

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

when the collector loop is active

HUMIDITY RATIO FUNCTION (BTU/lb/°F)

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

where 0.24 is the specific heat of air and a calculation is made for the quantity of water vapor in the air

TEMPERATURE INTO COLLECTOR SUBSYSTEM (°F)

TEMPIN = (T100 + T101 + T102 + T104 + T105 + T106 + T107)/7

COLLECTOR SUBSYSTEM HOURLY AVERAGE OPERATING POINT ($°F/BTU/FT^2$)

if EP100 > 6.8 (full operation)
and if I001 > 85.0
then OPPNT = Σ d (TEMPIN - TA)/I001 (Δτ)
else OPPNT = 0

SOLAR ENERGY COLLECTED BY THE ARRAYS (BTU)

SECA1 = Σ M150 x HRF x (T150 - T100) x Δτ
SECA2 = Σ M151 x HRF x (T151 - T101) x Δτ
SECA3 = Σ M153 x HRF x (T152 - T102) x Δτ
SECA4 = Σ M154 x HRF x (T154 - T104) x Δτ
SECA5 = Σ M155 x HRF x (T155 - T105) x Δτ
SECA6 = Σ M156 x HRF x (T156 - T106) x Δτ
SECA7 = Σ M157 x HRF > (T157 - T107) x Δτ

TOTAL NET COLLECTED SOLAR ENERGY (BTU)

SECA = Σ SECA1 + SECA2 + SECA3 + SECA4 + SECA5 + SECA6 + SECA7

COLLECTOR SUBSYSTEM OPERATING ENERGY (BTU)

CSOPE = Σ (EP100 x EPCONST) x Δτ

where EPCONST converts kwh to BTU

SOLAR ENERGY TO STORAGE (BTU)

STEI = Σ MASSTOIN x HRF x (T103 - T153)

where MASSTOIN = Σ MASS AIR FLOW TO ROCK BIN

SOLAR ENERGY FROM STORAGE (BTU)

STEO = Σ M400 x HRF x (T400 - T153)

MASS FLOW OF PREHEAT WATER (LBS)

M300 = Σ W300 x SQRT [WCONST x RHO(T300)] x Δτ

where WCONST is the heat capacity of water at T300

SOLAR DHW PREHEAT (BTU)

HWSE = M300 x HWD x (T350 - T300) x Δτ

AVERAGE STORAGE TEMPERATURE (°F)

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

STORAGE HEAT LOSS COEFFICIENT INPUT VALUE ($FT^2/°F$)

$$STPER = \Sigma\ 2,769 \times (TST - TB) \times \Delta\tau$$

STORAGE PERFORMANCE INPUT VALUE (BTU/°F) (for STECH calculation)

$$STM\_CP = STOCAP \times RHOROCK \times CPROCK \times PACKING\ FACTOR \times TST$$

where packing factor is the reciprocal of the estimated voids

CHANGE IN STORED ENERGY (± BTU)

$$STECH = \Sigma\ STM\_CP \times (TST - TST\_PREVIOUS) \times \Delta\tau$$

STORAGE ENERGY THERMAL LOSS (BTU)

$$STLOSS = \Sigma\ (STEI - STECH) - STEO \times \Delta\tau$$

STORAGE EFFICIENCY (%)

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

SPACE HEATING BY SOLAR ENERGY (BTU) MEASURED

$$HSEM = \Sigma\ (M400 \times HRF \times T400 - T153) \times \Delta\tau$$

SPACE HEATING ENERGY COMPUTED FROM SOLAR LOSSES (BTU)

$$HSEL1 = \Sigma\ [SECA - (STEI + HWSE)] \times 0.25 \times \Delta\tau$$

$$HSEL2 = \Sigma\ (STEO - HSEM) \times 0.25 \times \Delta\tau$$

(because 25% of the duct length is run inside the conditioned space)

$$HSEL = HSEL1 + HSEL2 + (STLOSS \times 0.65)$$

(because 65% of the concrete rock bin is directly exposed to the conditioned space at TB°F)

SPACE HEATING AUXILIARY AND OPERATING ENERGY (BTU)

$$HAT1 = \Sigma\ M401 \times HWD(T401, T451) \times \Delta\tau$$

$$HOPE2A = \Sigma\ EPCONST \times EP411 \times \Delta\tau$$

$$HAT2 = \Sigma\ M402 \times HWD(T402, T452) \times \Delta\tau$$

$$HOPE2B = \Sigma\ EPCONST \times EP412 \times \Delta\tau$$

$HAT3 = \Sigma\ M403 \times HWD(T403, T453) \times \Delta\tau$

$HOPE2C = \Sigma\ EPCONST \times EP413 \times \Delta\tau$

$HAT\ 4 = \Sigma\ M404 \times HWD(T404, T454) \times \Delta\tau$

$HOPE2D = \Sigma\ EPCONST \times EP414 \times \Delta\tau$

$HAT7 = \Sigma\ M407 \times HWD(T407, T457) \times \Delta\tau$

$HOPE2E = \Sigma\ EPCONST \times (EP417/2) \times \Delta\tau$

$HAT8 = \Sigma\ M408 \times HWD(T408, T458) \times \Delta\tau$

$HOPE2F = \Sigma\ EPCONST \times (EP417/2) \times \Delta\tau$

MONITORED SPACE LOAD (BTU)

$HL1 = \Sigma\ M411 \times HRF \times (T411 - T600) \times \Delta\tau$

$HL2 = \Sigma\ M412 \times HRF \times (T412 - T600) \times \Delta\tau$

$HL3 = \Sigma\ M413 \times HRF \times (T413 - T600) \times \Delta\tau$

$HL4 = \Sigma\ M414 \times HRF \times (T414 - T600) \times \Delta\tau$

$HL7 = \Sigma\ M417 \times HRF \times (T417 - T600) \times \Delta\tau$

$HL8 = \Sigma\ M418 \times HRF \times (T418 - T600) \times \Delta\tau$

$HL = \Sigma\ (HL1 + HL2 + HL3 + HL4 + HL7 + HL8)$

HEATING AUXILIARY THERMAL (BTU)

$HAT = \Sigma\ (HAT1 + HAT2 + HAT3 + HAT4 + HAT7 + HAT8)$

TOTAL HEATING AUXILIARY OPERATING ENERGY (BTU)

$HOPE\ 2 = \Sigma\ (HOPE2A + HOPE2B + HOPE3C + HOPE2D + HOPE2E + HOPE2F)$

CONTROLLED DELIVERED ENERGY (BTU)

$CDE = HSEM + HAT$

SOLAR TO LOADS (BTU)

$CSEO = HSEM + HWSE$

TOTAL SOLAR ENERGY USED (BTU)

$SEL = HSEM + HSEL + HWSE$

AIR HANDLER OPERATING ENERGY (BTU)

$$HOPE1A = \Sigma\ EPCONST \times EP401 \times \Delta\tau$$

$$HOPE1B = \Sigma\ EPCONST \times EP402 \times \Delta\tau$$

$$HOPE1C = \Sigma\ EPCONST \times EP403 \times \Delta\tau$$

$$HOPE1D = \Sigma\ EPCONST \times EP404 \times \Delta\tau$$

$$HOPE1E = \Sigma\ EPCONST \times EP407 \times \Delta\tau$$

$$HOPE1F = \Sigma\ EPCONST \times EP408 \times \Delta\tau$$

$$HOPE\_AHS = HOPE1A + HOPE1B + HOPE1C + HOPE1D + HOPE1E + HOPE1F$$

ALL DAY COLLECTOR SUBSYSTEM EFFICIENCY (%)

$$CLEF = SECA/SEA$$

OPERATIONAL COLLECTOR SUBSYSTEM EFFICIENCY (%)

$$CLEFOP = SECA/SEOP$$

EQUIPMENT HEATING LOAD (BTU)

$$EHL = CDE + HSEL + (HOPE \times 0.45) + (HWOPE \times 0.45)$$

(because there are about 45% efficiency losses from these motors which heat the building conditioned space)

HEATING AUXILIARY FOSSIL (BTU)

$$HAF = HAT/0.60$$

HOT WATER PREHEAT FOSSIL SAVINGS (BTU)

$$HWSVF = HWSE/0.60$$

HEATING SOLAR SAVINGS (BTU)

$$HSVF = HSEM + HSEL/0.60$$

TOTAL SYSTEM OPERATING ENERGY (BTU)

$$SYSOPE = CSOPE + HOPE + HWOPE$$

SOLAR HEATING SPECIFIC OPERATING ENERGY (BTU)

$$HOPE1 = \Sigma\ (EP400 \times EPCONST) \times \Delta\tau$$

HOT WATER PREHEAT OPERATING ENERGY (BTU)

if M300 > 0

then EP300 = power required

HWOPE = $\Sigma$ (EP300 x EPCONST) x $\Delta\tau$

PERFORMANCE FACTORS

SYSTEM LOAD (BTU)

SYSL = EHL

TOTAL ENERGY CONSUMED (BTU)

TECSM = AXT + SYSOPE + SECA

HEATING SOLAR FRACTION (%)

HSFR = [(HSEM + HSEL)/EHL] x 100

SYSTEM SOLAR FRACTION (%)

SFR = HSFR

TOTAL ELECTRIC POWER CONSUMPTION (BTU)

TSVE = HSVE + HWSVE - CSOPE

OVERALL SOLAR SYSTEM EFFICIENCY (%)

CSCEF = SEL/SEA

SOLAR SAVINGS RATIO (%)

HSSR = [SEL - (CSOPE + HOPE1)]/SYSL

SSSR = HSSR

# APPENDIX E

# LONG-TERM WEATHER DATA

# SPEARFISH HIGH SCHOOL LONG-TERM WEATHER DATA

COLLECTOR TILT: 62 DEGREES
LATITUDE: 44 DEGREES

LOCATION: SPEARFISH, SOUTH DAKOTA
COLLECTOR AZIMUTH: 26W DEGREES

| MONTH | HOBAR | HBAR | KBAR | RBAR | SBAR | HDD | CDD | TBAR |
|---|---|---|---|---|---|---|---|---|
| SEP | 2,471 | 1,519 | 0.61479 | 1.131 | 1,719 | 191 | 56 | 61 |
| OCT | 1,769 | 1,062 | 0.60023 | 1.498 | 1,591 | 474 | 9 | 50 |
| NOV | 1,217 | 645 | 0.53030 | 1.912 | 1,233 | 888 | 0 | 35 |
| DEC | 979 | 476 | 0.48559 | 2.154 | 1,024 | 1,194 | 0 | 27 |
| JAN | 1,106 | 542 | 0.48994 | 1.992 | 1,080 | 1,336 | 0 | 22 |
| FEB | 1,584 | 830 | 0.52389 | 1.577 | 1,309 | 1,098 | 0 | 25 |
| MAR | 2,223 | 1,228 | 0.55228 | 1.227 | 1,507 | 1,048 | 0 | 31 |
| APR | 2,916 | 1,589 | 0.54493 | 0.956 | 1,519 | 612 | 0 | 45 |
| MAY | 3,426 | 1,888 | 0.55093 | 0.796 | 1,502 | 319 | 15 | 55 |
| JUN | 3,642 | 2,131 | 0.58511 | 0.730 | 1,556 | 134 | 110 | 64 |

LEGEND:

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

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

KBAR - Ratio of HBAR to HOBAR.

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

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

HDD - Number heating degree-days per month.

CDD - Number of cooling degree-days per month.

TBAR - Average ambient temperature in degrees Fahrenheit.

# APPENDIX F

## SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

Spearfish High School began reporting data during September 1980. The system had been operational since December 1979 but there were problems with the original control system. Damage to collectors was sustained in a violent hail storm and further discoloration of absorber plates was noted by Spearfish personnel, but data shows that the collectors are performing well.

Once the data system was activated, the site has reported continuously. One problem was corrected with the T001 outdoor ambient temperature sensor. The system has operated normally since monitoring began and performance improved during the period September 1980 through June 1981.

## APPENDIX G

## CONVERSION FACTORS

**Energy Conversion Factors**

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

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

[2]No. 5 and No. 6 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 conpensated 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 $\mu$ V/W/$\mu^2$ |
| 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<br>Body - Brass or stainless steel<br>Seals - Buna-N |
| Fluid Temperature: | -40°F to 250°F |
| Calibration Accuracy: | ± 1% (½" to 3½" line size)<br>± 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<br>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<br>± 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 |

FULL 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 are 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" |

# APPENDIX I

# TYPICAL MONTHLY DATA

MONTHLY REPORT: DECEMBER 1980
SITE SUMMARY: SPEARFISH HIGH SCHOOL

| | CONVENTIONAL UNITS |
|---|---|
| **GENERAL SITE DATA:** | |
| INCIDENT SOLAR ENERGY | 227.733 MILLION BTU |
| | 28346 BTU/SQ.FT. |
| COLLECTED SOLAR ENERGY | 74.759 MILLION BTU |
| | 9305 BTU/SQ.FT. |
| AVERAGE AMBIENT TEMPERATURE | 35 DEGREES F |
| AVERAGE BUILDING TEMPERATURE | 72 DEGREES F |
| ECSS SOLAR CONVERSION EFFICIENCY | 0.12 |
| ECSS OPERATING ENERGY | 2.864 MILLION BTU |
| STORAGE EFFICIENCY | 116.63 PERCENT |
| EFFECTIVE HEAT TRANSFER COEFFICIENT | 0.004 BTU/DEG F-SQ FT-HR |
| TOTAL SYSTEM OPERATING ENERGY | 26.335 MILLION BTU |
| TOTAL ENERGY CONSUMED | 204.524 MILLION BTU |

**SUBSYSTEM SUMMARY:**

| | HOT WATER | HEATING | COOLING | SYSTEM TOTAL |
|---|---|---|---|---|
| LOAD | N.A. | 182.265 | N.A. | 182.785 MILLION BTU |
| SOLAR FRACTION | N.A. | 43 | N.A. | 43 PERCENT |
| SOLAR ENERGY USED | 0.846 | 78.418 | N.A. | 79.264 MILLION BTU |
| OPERATING ENERGY | 0.079 | 23.392 | N.A. | 26.335 MILLION BTU |
| AUX. THERMAL ENERGY | N.A. | 103.430 | N.A. | 103.430 MILLION BTU |
| AUX. ELECTRIC FUEL | N.A. | N.A. | N.A. | N.A. MILLION BTU |
| AUX. FOSSIL FUEL | N.A. | 172.384 | N.A. | 172.384 MILLION BTU |
| ELECTRICAL SAVINGS | -0.079 | -6.312 | N.A. | -9.255 MILLION BTU |
| FOSSIL SAVINGS | 1.409 | 112.739 | N.A. | 114.148 MILLION BTU |

SYSTEM PERFORMANCE FACTOR: 0.70

INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS: 0.95

* = UNAVAILABLE; N.A. = NOT APPLICABLE; I = INVALID; E = ESTIMATED.

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

MONTHLY REPORT: DECEMBER 1980
SITE SUMMARY: SPEARFISH HIGH SCHOOL

| GENERAL SITE DATA: | SI UNITS |
|---|---|
| INCIDENT SOLAR ENERGY | 240.258 GIGA JOULES |
| | 321899 KJ/SQ.M. |
| COLLECTED SOLAR ENERGY | 78.870 GIGA JOULES |
| | 105670 KJ/SQ.M. |
| AVERAGE AMBIENT TEMPERATURE | 2 DEGREES C |
| AVERAGE BUILDING TEMPERATURE | 22 DEGREES C |
| ECSS SOLAR CONVERSION EFFICIENCY | 0.12 |
| ECSS OPERATING ENERGY | 3.021 GIGA JOULES |
| STORAGE EFFICIENCY | 116.63 PERCENT |
| EFFECTIVE HEAT TRANSFER COEFFFICIENT | 0.025 W/SQ M-DEG K |
| TOTAL SYSTEM OPERATING ENERGY | 27.783 GIGA JOULES |
| TOTAL ENERGY CONSUMED | 215.773 GIGA JOULES |

SUBSYSTEM SUMMARY:

| | HOT WATER | HEATING | COOLING | SYSTEM TOTAL |
|---|---|---|---|---|
| LOAD | N.A. | 192.290 | N.A. | 192.838 GIGA JOULES |
| SOLAR FRACTION | N.A. | 43 | N.A. | 43 PERCENT |
| SOLAR ENERGY USED | 0.892 | 82.732 | N.A. | 83.632 GIGA JOULES |
| OPERATING ENERGY | 0.083 | 24.679 | N.A. | 27.783 GIGA JOULES |
| AUX. THERMAL ENG | N.A. | 109.119 | N.A. | 109.119 GIGA JOULES |
| AUX. ELECTRIC FUEL | N.A. | N.A. | N.A. | N.A. GIGA JOULES |
| AUX. FOSSIL FUEL | N.A. | 181.865 | N.A. | 181.865 GIGA JOULES |
| ELECTRICAL SAVINGS | -0.083 | -6.660 | N.A. | -9.764 GIGA JOULES |
| FOSSIL SAVINGS | 1.487 | 118.939 | N.A. | 120.426 GIGA JOULES |

SYSTEM PERFORMANCE FACTOR: 0.70
INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS: 0.95

* = UNAVAILABLE; N.A. = NOT APPLICABLE; I = INVALID; E = ESTIMATED.

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

MONTHLY REPORT: SPEARFISH HIGH SCHOOL DECEMBER 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 | AUX THERMAL TO ECSS MILLION BTU | ECSS OPERATING ENERGY MILLION BTU (Q102) | ECSS ENERGY REJECTED MILLION BTU | ECSS SOLAR CONVERSION EFFICIENCY (N111) |
|---|---|---|---|---|---|---|---|
| 1 | 2.224 | * | 0.000 | N | 0.003 | N | 0.000 |
| 2 | 3.442 | * | 0.000 | O | 0.003 | O | 0.000 |
| 3 | 11.450 | * | 0.886 | T | 0.147 | T | 0.077 |
| 4 | 9.665 | * | 1.593 | | 0.152 | | 0.165 |
| 5 | 5.711 | 13 | 1.983 | A | 0.050 | A | 0.347 |
| 6 | 0.841 | 16 | 0.119 | P | 0.003 | P | 0.142 |
| 7 | 1.303 | 15 | 0.248 | P | 0.003 | P | 0.191 |
| 8 | 14.128 | 27 | 1.021 | L | 0.164 | L | 0.072 |
| 9 | 12.071 | 32 | 1.530 | I | 0.136 | I | 0.127 |
| 10 | 2.054 | 39 | 0.941 | C | 0.003 | C | 0.458 |
| 11 | 6.598 | 56 | 1.513 | A | 0.128 | A | 0.229 |
| 12 | 11.718 | 46 | 1.938 | B | 0.178 | B | 0.165 |
| 13 | 14.390 | 41 | 1.856 | L | 0.184 | L | 0.129 |
| 14 | 5.676 | 47 | 1.223 | E | 0.087 | E | 0.216 |
| 15 | 6.642 | 56 | 1.344 | | 0.114 | | 0.202 |
| 16 | 8.219 | 58 | 1.797 | | 0.140 | | 0.219 |
| 17 | 6.163 | 50 | 1.509 | | 0.135 | | 0.245 |
| 18 | 1.581 | 15 | 1.044 | | 0.003 | | 0.661 |
| 19 | 7.506 | 2 | 0.322 | | 0.030 | | 0.043 |
| 20 | 4.832 | 9 | 0.289 | | 0.026 | | 0.060 |
| 21 | 10.379 | 21 | 0.629 | | 0.138 | | 0.061 |
| 22 | 9.050 | 39 | 0.477 | | 0.123 | | 0.053 |
| 23 | 1.492 | 18 | 0.243 | | 0.003 | | 0.163 |
| 24 | 12.938 | 2 | 0.545 | | 0.046 | | 0.042 |
| 25 | 1.432 | 45 | 0.010 | | 0.003 | | 0.007 |
| 26 | 8.151 | 56 | 0.610 | | 0.121 | | 0.075 |
| 27 | 5.348 | 60 | 0.281 | | 0.111 | | 0.053 |
| 28 | 12.073 | 43 | 0.633 | | 0.171 | | 0.052 |
| 29 | 14.282 | 47 | 1.679 | | 0.184 | | 0.118 |
| 30 | 5.441 | 50 | 0.673 | | 0.089 | | 0.124 |
| 31 | 10.935 | 43 | 0.847 | | 0.186 | | 0.077 |
| SUM | 227.733 | - | 27.785 | N.A. | 2.864 | N.A. | - |
| AVG | 7.346 | 35 | 0.896 | N.A. | 0.092 | N.A. | 0.122 |
| PFRV | 1.0000 | 0.9086 | 1.0000 | N.A. | 1.0000 | N.A. | 0.4624 |

* = UNAVAILABLE; N.A. = NOT APPLICABLE; I = INVALID; E = ESTIMATED; PFRV = RELIABILITY VALUE.

MONTHLY REPORT: SPEARFISH HIGH SCHOOL DECEMBER 1980

COLLECTOR SUBSYSTEM PERFORMANCE

| DAY OF MONTH (NBSID) | INCIDENT SOLAR ENERGY MILLION BTU (Q001) | OPERATIONAL INCIDENT ENERGY MILLION BTU | COLLECTED SOLAR ENERGY MILLION BTU (Q100) | DAYTIME AMBIENT TEMP DEG F | COLLECTOR SUBSYSTEM EFFICIENCY (N100) | OPERATIONAL COLLECTOR SUBSYSTEM EFFICIENCY |
|---|---|---|---|---|---|---|
| 1 | 2.224 | 1.790 | -0.006 | * | -0.003 | -0.004 |
| 2 | 3.442 | 2.674 | -0.010 | * | -0.003 | -0.004 |
| 3 | 11.450 | 10.647 | 4.950 | * | 0.432 | 0.465 |
| 4 | 9.665 | 9.620 | 4.175 | * | 0.432 | 0.434 |
| 5 | 5.711 | 4.549 | 1.176 | 15 | 0.206 | 0.259 |
| 6 | 0.841 | 0.598 | -0.019 | 18 | -0.023 | -0.032 |
| 7 | 1.303 | 0.933 | -0.033 | 18 | -0.025 | -0.035 |
| 8 | 14.128 | 13.555 | 5.815 | 33 | 0.412 | 0.429 |
| 9 | 12.071 | 11.745 | 5.629 | 30 | 0.466 | 0.479 |
| 10 | 2.054 | 1.792 | -0.050 | 36 | -0.024 | -0.028 |
| 11 | 6.598 | 6.159 | 2.519 | 57 | 0.382 | 0.409 |
| 12 | 11.718 | 11.510 | 5.234 | 50 | 0.447 | 0.455 |
| 13 | 14.390 | 14.093 | 5.192 | 48 | 0.361 | 0.368 |
| 14 | 5.676 | 4.993 | 1.039 | 49 | 0.183 | 0.208 |
| 15 | 6.642 | 6.150 | 2.674 | 59 | 0.403 | 0.435 |
| 16 | 8.219 | 7.815 | 3.796 | 60 | 0.462 | 0.486 |
| 17 | 6.163 | 5.753 | 2.342 | 55 | 0.380 | 0.407 |
| 18 | 1.581 | 1.273 | -0.022 | 15 | -0.014 | -0.017 |
| 19 | 7.506 | 6.761 | 0.869 | 7 | 0.116 | 0.129 |
| 20 | 4.832 | 3.560 | 0.580 | 13 | 0.120 | 0.163 |
| 21 | 10.379 | 9.970 | 3.904 | 22 | 0.376 | 0.392 |
| 22 | 9.050 | 8.500 | 3.633 | 48 | 0.401 | 0.427 |
| 23 | 1.492 | 1.178 | -0.024 | 16 | -0.016 | -0.021 |
| 24 | 12.938 | 11.376 | 1.378 | 1 | 0.106 | 0.121 |
| 25 | 1.432 | 1.203 | -0.007 | 49 | -0.005 | -0.006 |
| 26 | 8.151 | 7.921 | 3.233 | 59 | 0.397 | 0.408 |
| 27 | 5.348 | 5.158 | 1.154 | 65 | 0.216 | 0.224 |
| 28 | 12.073 | 11.887 | 3.968 | 48 | 0.329 | 0.334 |
| 29 | 14.282 | 13.988 | 5.463 | 53 | 0.382 | 0.391 |
| 30 | 5.441 | 4.982 | 1.774 | 54 | 0.326 | 0.356 |
| 31 | 10.935 | 10.238 | 4.434 | 48 | 0.405 | 0.433 |
| SUM | 227.733 | 212.371 | 74.759 | - | - | |
| AVG | 7.346 | 6.851 | 2.412 | 38 | 0.328 | 0.352 |
| PFRV | 1.0000 | 1.0000 | 1.0000 | 0.9086 | 1.0000 | 1.0000 |

* = UNAVAILABLE; N.A. = NOT APPLICABLE; I = INVALID; E = ESTIMATED; PFRV = RELIABILITY VALUE.

MONTHLY REPORT: SPEARFISH HIGH SCHOOL — DECEMBER 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 | EFFECTIVE HEAT TRANSFER COEFFICIENT BTU/DEG F/ SQ FT/HR |
|---|---|---|---|---|---|
| 1 | 0.009 | 0.000 | I | 66 | 0.00 |
| 2 | 0.012 | 0.001 | | 67 | 0.00 |
| 3 | 3.213 | 1.814 | | 71 | 0.01 |
| 4 | 2.950 | 1.621 | | 84 | 0.01 |
| 5 | 0.835 | 5.246 | | 75 | 0.02 |
| 6 | 0.013 | 0.124 | | 65 | 0.00 |
| 7 | 0.017 | 0.303 | | 65 | 0.00 |
| 8 | 4.092 | 2.615 | | 63 | 0.01 |
| 9 | 3.798 | 2.039 | | 75 | 0.01 |
| 10 | 0.030 | 1.669 | | 76 | 0.01 |
| 11 | 1.991 | 1.696 | | 75 | 0.00 |
| 12 | 3.456 | 1.927 | | 80 | 0.01 |
| 13 | 4.306 | 5.754 | | 79 | 0.01 |
| 14 | 1.178 | 2.663 | | 76 | 0.01 |
| 15 | 1.940 | 1.638 | | 76 | 0.00 |
| 16 | 2.532 | 1.992 | | 79 | 0.00 |
| 17 | 1.682 | 2.542 | | 80 | 0.00 |
| 18 | 0.049 | 2.452 | | 69 | 0.01 |
| 19 | 0.545 | 0.845 | | 61 | 0.00 |
| 20 | 0.254 | 0.423 | | 60 | 0.00 |
| 21 | 3.290 | 3.379 | | 60 | 0.00 |
| 22 | 2.739 | 3.096 | | 61 | 0.00 |
| 23 | 0.024 | 0.440 | | 63 | 0.00 |
| 24 | 0.996 | 1.565 | | 62 | 0.00 |
| 25 | 0.006 | 0.017 | | 62 | 0.00 |
| 26 | 2.521 | 2.427 | | 63 | 0.00 |
| 27 | 1.680 | 1.691 | | 67 | 0.00 |
| 28 | 4.008 | 3.705 | | 69 | 0.00 |
| 29 | 3.730 | 7.303 | | 70 | 0.02 |
| 30 | 0.859 | 1.090 | | 70 | 0.00 |
| 31 | 2.283 | 2.081 | I | 68 | 0.00 |
| SUM | 55.036 | 64.153 | 0.06E | - | - |
| AVG | 1.775 | 2.069 | I | 70 | 0.00 |
| PFRV | 1.0000 | 1.0000 | N.A. | 1.0000 | 1.0000 |

* = UNAVAILABLE; N.A. = NOT APPLICABLE; I = INVALID; E = ESTIMATED; PFRV = RELIABILITY VALUE.

MONTHLY REPORT: SPEARFISH HIGH SCHCOL DECEMBER 1980

HOT WATER SUBSYSTEM

| DAY OF MONTH (NBS ID) | HOT WATER LOAD MILLION BTU (Q302) | SOLAR FR.OF LOAD PER. (N300) | SOLAR ENERGY USED MILLION BTU (Q300) | OPER ENERGY MILLION BTU (Q303) | AUX THERMAL USED MILLION BTU (Q301) | AUX ELECT FUEL MILLION BTU (Q305) | AUX FOSSIL FUEL MILLION BTU (Q306) | ELECT ENERGY SAVINGS MILLION BTU (Q311) | FOSSIL ENERGY SAVINGS MILLION BTU (Q313) | SUP. WAT. TEMP DEG F (N305) | HOT WAT. TEMP DEG F (N307) | HOT WATER USED GAL (N308) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | N | N | 0.000 | 0.000 | N | N | N | 0.000 | 0.000 | N | N | N |
| 2 | O | O | 0.000 | 0.000 | O | O | O | 0.000 | 0.000 | O | O | O |
| 3 | T | T | 0.071 | 0.004 | T | T | T | -0.004 | 0.118 | T | T | T |
| 4 | | | 0.022 | 0.004 | | | | -0.004 | 0.037 | | | |
| 5 | A | A | -0.025 | 0.001 | A | A | A | -0.001 | -0.042 | A | A | A |
| 6 | P | P | 0.000 | 0.000 | P | P | P | 0.000 | 0.000 | P | P | P |
| 7 | P | P | 0.000 | 0.000 | P | P | P | 0.000 | 0.000 | P | P | P |
| 8 | L | L | 0.078 | 0.004 | L | L | L | -0.004 | 0.130 | L | L | L |
| 9 | I | I | 0.104 | 0.003 | I | I | I | -0.003 | 0.173 | I | I | I |
| 10 | C | C | 0.000 | 0.000 | C | C | C | 0.000 | 0.000 | C | C | C |
| 11 | A | A | -0.053 | 0.003 | A | A | A | -0.003 | -0.089 | A | A | A |
| 12 | B | B | 0.065 | 0.004 | B | B | B | -0.004 | 0.109 | B | B | B |
| 13 | L | L | 0.312 | 0.005 | L | L | L | -0.005 | 0.521 | L | L | L |
| 14 | E | E | 0.048 | 0.002 | E | E | E | -0.002 | 0.080 | E | E | E |
| 15 | | | 0.008 | 0.002 | | | | -0.002 | 0.013 | | | |
| 16 | | | 0.051 | 0.003 | | | | -0.003 | 0.086 | | | |
| 17 | | | -0.041 | 0.003 | | | | -0.003 | -0.068 | | | |
| 18 | | | 0.000 | 0.000 | | | | 0.000 | 0.000 | | | |
| 19 | | | 0.011 | 0.000 | | | | 0.000 | 0.018 | | | |
| 20 | | | 0.014 | 0.000 | | | | 0.000 | 0.024 | | | |
| 21 | | | 0.048 | 0.003 | | | | -0.003 | 0.080 | | | |
| 22 | | | 0.033 | 0.003 | | | | -0.003 | 0.056 | | | |
| 23 | | | 0.000 | 0.000 | | | | 0.000 | 0.000 | | | |
| 24 | | | 0.015 | 0.001 | | | | -0.001 | 0.025 | | | |
| 25 | | | 0.000 | 0.000 | | | | 0.000 | 0.000 | | | |
| 26 | | | 0.013 | 0.003 | | | | -0.003 | 0.023 | | | |
| 27 | | | -0.028 | 0.002 | | | | -0.002 | -0.046 | | | |
| 28 | | | 0.066 | 0.004 | | | | -0.004 | 0.110 | | | |
| 29 | | | 0.063 | 0.004 | | | | -0.004 | 0.105 | | | |
| 30 | | | -0.011 | 0.002 | | | | -0.002 | -0.019 | | | |
| 31 | | | -0.024 | 0.004 | | | | -0.004 | -0.040 | | | |
| SUM | N.A. | - | 0.845 | 0.078 | N.A. | N.A. | N.A. | -0.078 | 1.409 | - | - | N.A. |
| AVG | N.A. | N.A. | 0.027 | 0.002 | N.A. | N.A. | N.A. | -0.002 | 0.045 | N.A. | N.A. | N.A. |
| PFRV | N.A. | N.A. | 1.0000 | 1.0000 | N.A. | N.A. | N.A. | 1.0000 | 1.0000 | 1.00 | 1.00 | N.A. |

* = UNAVAILABLE; N.A. = NOT APPLICABLE; I = INVALID; E = ESTIMATED; PFRV = RELIABILITY VALUE.

MONTHLY REPORT: SPEARFISH HIGH SCHOOL DECEMBER 1980

SPACE HEATING SUBSYSTEM I

| DAY OF MONTH (NBS ID) | SPACE HEATING LOAD MILLION BTU (Q402) | CONTROLLED DELIVERED ENERGY MILLION BTU | TOTAL SOLAR ENERGY USED MILLION BTU (Q400) | TOTAL AUXILIARY THERMAL USED MILLION BTU (Q401) | SOLAR FRACTION OF LOAD PCT (N400) | ELECT ENERGY SAVINGS MILLION BTU (Q415) | FOSSIL ENERGY SAVINGS MILLION BTU (Q417) | BLDG TEMP DEG F (N406) | AMB TEMP DEG F (N113) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 6.936 | 6.931 | 0.005 | 6.931 | 0 | -0.002 | 0.008 | 69 | * |
| 2 | 6.890 | 6.886 | 0.003 | 6.886 | 0 | -0.003 | 0.006 | 70 | * |
| 3 | 8.752 | 4.184 | 5.349 | 3.369 | 61 | -0.052 | 8.372 | 72 | * |
| 4 | 6.862 | 3.679 | 4.742 | 2.108 | 69 | -0.142 | 6.856 | 73 | * |
| 5 | 4.632 | 5.866 | 0.786 | 3.858 | 17 | -0.477 | -0.030 | 73 | 13 |
| 6 | 4.759 | 4.873 | 0.005 | 4.753 | 0 | -0.003 | -0.071 | 71 | 16 |
| 7 | 5.457 | 5.710 | -0.005 | 5.462 | I | -0.003 | -0.173 | 69 | 15 |
| 8 | 11.025 | 5.661 | 6.269 | 4.718 | 57 | -0.069 | 9.820 | 71 | 27 |
| 9 | 10.121 | 5.274 | 6.224 | 3.848 | 61 | -0.168 | 9.423 | 73 | 32 |
| 10 | 2.341 | 3.414 | -0.131 | 2.472 | I | -0.439 | -0.846 | 74 | 39 |
| 11 | 4.407 | 3.045 | 2.951 | 1.479 | 67 | -0.353 | 3.874 | 74 | 56 |
| 12 | 7.161 | 3.121 | 5.880 | 1.249 | 82 | -0.311 | 8.553 | 75 | 46 |
| 13 | 7.943 | 4.339 | 5.004 | 2.795 | 63 | -0.450 | 7.311 | 74 | 41 |
| 14 | 3.479 | 3.646 | 0.985 | 2.471 | 28 | -0.480 | -0.858 | 74 | 47 |
| 15 | 4.523 | 2.941 | 3.012 | 1.605 | 65 | -0.360 | 4.130 | 74 | 56 |
| 16 | 4.902 | 2.404 | 4.218 | 0.659 | 86 | -0.328 | 5.867 | 75 | 58 |
| 17 | 3.106 | 2.151 | 2.522 | 0.601 | 81 | -0.335 | 3.169 | 75 | 50 |
| 18 | 2.085 | 3.401 | -0.272 | 2.357 | I | -0.387 | -1.149 | 73 | 15 |
| 19 | 6.307 | 5.732 | 0.880 | 5.421 | 14 | -0.023 | 1.259 | 71 | 2 |
| 20 | 5.676 | 5.343 | 0.600 | 5.069 | 11 | -0.022 | 0.817 | 69 | 9 |
| 21 | 8.374 | 4.937 | 3.993 | 4.357 | 48 | -0.110 | 6.269 | 69 | 21 |
| 22 | 7.262 | 4.056 | 3.632 | 3.614 | 50 | -0.096 | 5.758 | 71 | 39 |
| 23 | 5.765 | 6.041 | -0.033 | 5.798 | I | -0.003 | -0.217 | 71 | 18 |
| 24 | 9.472 | 8.588 | 1.405 | 8.058 | 15 | -0.037 | 1.990 | 70 | 2 |
| 25 | 3.633 | 3.641 | 0.002 | 3.631 | 0 | -0.003 | -0.004 | 70 | 45 |
| 26 | 5.016 | 2.244 | 3.361 | 1.647 | 67 | -0.071 | 5.204 | 71 | 56 |
| 27 | 1.390 | 0.472 | 1.238 | 0.163 | 89 | -0.085 | 1.858 | 71 | 60 |
| 28 | 5.025 | 1.454 | 4.105 | 0.837 | 82 | -0.132 | 6.464 | 71 | 43 |
| 29 | 7.993 | 4.513 | 5.065 | 2.897 | 63 | -0.322 | 7.365 | 73 | 47 |
| 30 | 3.578 | 2.355 | 1.911 | 1.671 | 53 | -0.519 | 2.728 | 73 | 50 |
| 31 | 7.296 | 3.466 | 4.710 | 2.595 | 65 | -0.528 | 7.269 | 74 | 43 |
| SUM | 182.265 | 130.370 | 78.418 | 103.430 | - | -6.312 | 112.739 | - | - |
| AVG | 5.880 | 4.205 | 2.529 | 3.336 | 43 | -0.204 | 3.637 | 72 | 35 |
| PFRV | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9086 |

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MONTHLY REPORT: SPEARFISH HIGH SCHOOL DECEMBER 1980

SPACE HEATING SUBSYSTEM II

| DAY OF MONTH (NBS ID) | SPACE HEATING LOAD MILLION BTU (Q402) | MEASURED SOLAR ENERGY USED MILLION BTU | SOLAR ENERGY LOSSES TO LOAD MILLION BTU | TOTAL OPERATING ENERGY MILLION BTU (Q403) | SOLAR SPECIFIC OPERATING ENERGY MILLION BTU | AUX ELECT FUEL MILLION BTU | AUX FOSSIL FUEL MILLION BTU (Q410) | HEATING DEGREE DAYS |
|---|---|---|---|---|---|---|---|---|
| 1 | 6.936 | 0.000 | 0.005 | 0.625 | 0.002 | N | 11.552 | * |
| 2 | 6.890 | 0.000 | 0.003 | 0.672 | 0.003 | O | 11.477 | * |
| 3 | 8.752 | 0.815 | 4.534 | 0.671 | 0.052 | T | 5.615 | 18 |
| 4 | 6.862 | 1.571 | 3.171 | 0.735 | 0.142 | | 3.513 | 23 |
| 5 | 4.632 | 2.009 | -1.223 | 1.064 | 0.477 | A | 6.430 | 50 |
| 6 | 4.759 | 0.119 | -0.114 | 0.436 | 0.003 | P | 7.922 | 50 |
| 7 | 5.457 | 0.248 | -0.253 | 0.402 | 0.003 | P | 9.103 | 51 |
| 8 | 11.025 | 0.943 | 5.326 | 0.737 | 0.069 | L | 7.864 | 41 |
| 9 | 10.121 | 1.426 | 4.798 | 0.791 | 0.168 | I | 6.413 | 34 |
| 10 | 2.341 | 0.941 | -1.072 | 1.052 | 0.439 | C | 4.121 | 25 |
| 11 | 4.407 | 1.567 | 1.384 | 0.948 | 0.353 | A | 2.465 | 10 |
| 12 | 7.161 | 1.872 | 4.008 | 0.901 | 0.311 | B | 2.081 | 21 |
| 13 | 7.943 | 1.543 | 3.461 | 0.684 | 0.450 | L | 4.659 | 24 |
| 14 | 3.479 | 1.175 | -0.190 | 0.654 | 0.480 | E | 4.118 | 21 |
| 15 | 4.623 | 1.336 | 1.676 | 0.955 | 0.360 | | 2.676 | 9 |
| 16 | 4.902 | 1.745 | 2.473 | 0.980 | 0.328 | | 1.098 | 9 |
| 17 | 3.106 | 1.550 | 0.972 | 1.011 | 0.335 | | 1.002 | 17 |
| 18 | 2.085 | 1.044 | -1.316 | 0.999 | 0.387 | | 3.928 | 51 |
| 19 | 6.307 | 0.311 | 0.569 | 0.636 | 0.023 | | 9.036 | 63 |
| 20 | 5.676 | 0.274 | 0.326 | 0.465 | 0.022 | | 8.448 | 57 |
| 21 | 8.374 | 0.580 | 3.413 | 0.479 | 0.110 | | 7.261 | 40 |
| 22 | 7.262 | 0.443 | 3.189 | 0.764 | 0.096 | | 6.023 | 26 |
| 23 | 5.765 | 0.243 | -0.276 | 0.698 | 0.003 | | 9.663 | 44 |
| 24 | 9.472 | 0.529 | 0.876 | 0.775 | 0.037 | | 13.430 | 62 |
| 25 | 3.633 | 0.010 | -0.008 | 0.621 | 0.003 | | 6.052 | 32 |
| 26 | 5.016 | 0.596 | 2.765 | 0.670 | 0.071 | | 2.745 | 10 |
| 27 | 1.390 | 0.309 | 0.929 | 0.270 | 0.085 | | 0.272 | 9 |
| 28 | 5.025 | 0.567 | 3.538 | 0.318 | 0.132 | | 1.479 | 23 |
| 29 | 7.993 | 1.616 | 3.449 | 1.032 | 0.322 | | 4.829 | 19 |
| 30 | 3.578 | 0.684 | 1.227 | 1.151 | 0.519 | | 2.785 | 16 |
| 31 | 7.296 | 0.871 | 3.839 | 1.195 | 0.528 | | 4.325 | 23 |
| SUM | 182.265 | 26.939 | 51.479 | 23.392 | 6.312 | N.A. | 172.384 | 937 |
| AVG | 5.880 | 0.869 | 1.661 | 0.755 | 0.204 | N.A. | 5.561 | 30 |
| PFRV | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | N.A. | 1.0000 | N.A. |

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MONTHLY REPORT: SPEARFISH HIGH SCHOOL DECEMBER 1980

ENVIRONMENTAL SUMMARY

| DAY OF MONTH (NBS ID) | TOTAL INSOLATION BTU/SQ.FT (Q001) | DIFFUSE INSOLATION BTU/SQ.FT | AMBIENT TEMPERATURE DEG F (N113) | DAYTIME AMBIENT TEMP DEG F | RELATIVE HUMIDITY PERCENT | WIND DIRECTION DEGREES (N115) | WIND SPEED M.P.H. (N114) |
|---|---|---|---|---|---|---|---|
| 1 | 277 | N | * | * | N | N | N |
| 2 | 428 | O | * | * | O | O | O |
| 3 | 1425 | T | * | * | T | T | T |
| 4 | 1203 | | * | * | | | |
| 5 | 711 | A | 13 | 15 | A | A | A |
| 6 | 105 | P | 16 | 18 | P | P | P |
| 7 | 162 | P | 15 | 18 | P | P | P |
| 8 | 1759 | L | 27 | 33 | L | L | L |
| 9 | 1502 | I | 32 | 30 | I | I | I |
| 10 | 256 | C | 39 | 36 | C | C | C |
| 11 | 821 | A | 56 | 57 | A | A | A |
| 12 | 1459 | B | 46 | 50 | B | B | B |
| 13 | 1791 | L | 41 | 48 | L | L | L |
| 14 | 707 | E | 47 | 49 | E | E | E |
| 15 | 827 | | 56 | 59 | | | |
| 16 | 1023 | | 58 | 60 | | | |
| 17 | 767 | | 50 | 55 | | | |
| 18 | 197 | | 15 | 15 | | | |
| 19 | 934 | | 2 | 7 | | | |
| 20 | 601 | | 9 | 13 | | | |
| 21 | 1292 | | 21 | 22 | | | |
| 22 | 1126 | | 39 | 48 | | | |
| 23 | 186 | | 18 | 16 | | | |
| 24 | 1610 | | 2 | 1 | | | |
| 25 | 178 | | 45 | 49 | | | |
| 26 | 1015 | | 56 | 59 | | | |
| 27 | 666 | | 60 | 65 | | | |
| 28 | 1503 | | 43 | 48 | | | |
| 29 | 1778 | | 47 | 53 | | | |
| 30 | 677 | | 50 | 54 | | | |
| 31 | 1361 | | 43 | 48 | | | |
| SUM | 28346 | N.A. | - | - | - | - | - |
| AVG | 914 | N.A. | 35 | 38 | N.A. | N.A. | N.A. |
| PFRV | 1.0000 | N.A. | 0.9086 | 0.9086 | N.A. | N.A. | N.A. |

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