SERI/MR-632-714

MONTHLY REPORTING REQUIREMENTS FOR SOLAR INDUSTRIAL PROCESS HEAT FIELD TESTS

C. F. KUTSCHER
R. L. DAVENPORT

SEPTEMBER 1980

PREPARED UNDER TASK NO. 3472.01

Solar Energy Research Institute
A Division of Midwest Research Institute

1617 Cole Boulevard
Golden, Colorado 80401

Prepared for the
U.S. Department of Energy
Contract No. EG-77-C-01-4042

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PREFACE

Since 1976, the U.S. Department of Energy has funded a number of field tests intended to study the application of solar energy to various industrial processes. In each case, it has been the contractor's responsibility to collect data and report on performance. Evaluating performance of these systems based on the contractor's monthly reports has been difficult since the reports vary greatly in format, type of data reported, and detail. It is the purpose of this document to provide contractors with a uniform set of reporting requirements, which will allow for straightforward comparison between projects and provide a better understanding of how systems perform in the field.

The authors would like to thank Frances Arnold, Jim Castle, and Allan Lewandowski of SERI who provided much useful input to the draft version of this document. We are also grateful to Jerry Greyerbiehl of DOE headquarters and Bill Nettleton of the DOE San Francisco Operations Office who supported this effort. Finally, a special thanks to Ken Bergeron of Sandia National Laboratories, Albuquerque, for his lively discussion of the various imperfect alternatives for defining system efficiency.

Charles F. Kutscher

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Approved for

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SUMMARY

As a part of the Solar Industrial Process Heat program of the Department of Energy, a variety of field tests have been constructed. The purpose of this report is to detail the requirements for the monthly reports generated by these field tests, in order that the performance data, costs, and operating experiences of each project may be analyzed and compared to the others on an equal basis.

As detailed in this document, the monthly reports produced by each of the field test contractors are to be divided into six sections: Title Page, Project Description, Operating Experience, Performance, Operating and Maintenance Costs, and Planned Activities. Detailed hourly performance on a selected single day must be presented, as well as daily performance for the entire month. System operating experiences are to be described and details of costs and maintenance required must be presented. Results must be presented in tabular and graphical form in a consistent system of units. To aid contractors in interpreting these requirements, a complete example Monthly Report is included as an appendix.

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SECTION 1.0

OBJECTIVES

The projects in the program are intended to provide design and operating experience for solar IPH systems, including quantitative measures of

- how well solar is/can be integrated in specific industries;
- system performance with respect to converting solar energy into useful thermal energy on a daily, monthly, and annual or seasonal basis;
- thermal performance of major components (collectors, storage);
- operating and maintenance costs; and
- total fossil fuel saved.

The monthly report shall provide details of system problems and measures taken to correct them and present specific data for the evaluation of performance, cost, and energy savings. Data and analyses are to be presented in a format that will allow straightforward comparison among projects.

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SECTION 2.0

FORMAT OF THE MONTHLY REPORT

The following six sections detail the format requirements for the monthly report. Definitions of parameters are given in Appendix A. An example of a complete monthly report is given in Appendix B. In general, SI units are to be used except where both English and SI units are required as specified herein.

I. Title Page

The first page shall contain the following information:

- the date (including the year) and period covered by the report;
- the report number;
- the DOE contract number and title;
- the contractor's name and address and the name and telephone number of the responsible party; and
- the site industry's name and address and the name and telephone number of the responsible party.

II. Project Description

This section shall contain a short description of the system and of the industrial process to which solar is applied. This section shall be repeated each month. The following information shall be included:

- description of the application;
- site latitude, longitude, and elevation;
- process schedule;
- process load profile;
- auxiliary fuel(s) used and efficiency of auxiliary heat source;
- collectors used--including brand, model number, and collector type; number of collectors; total aperture area; total gross area; mounting location; tilt angle and azimuth; and packing factor (i.e., the ratio of total collector array aperture area to the total land area enclosed by the perimeter of the collector array);
- fluid type and flow rate(s);
- storage size (if applicable);
- design energy delivery (in GJ/yr); and
- design and construction costs.

A system diagram shall be included in which all major components of the solar energy system are labeled and the locations of all instrumentation are given. Also, a paragraph describing system operation shall be included, as shown in the example of Appendix B.

III. Operating Experience

A daily log of events shall be kept on-site describing all problems in the solar system and data acquisition equipment as well as the suspected origins of these problems and corrective actions taken. The log shall also include the operational status code and weather code for each day (see Appendix A) and contain information necessary for calculating the operation and maintenance costs.

Descriptive Paragraph. Significant events from the log shall be reported in Section III along with explanations and actions taken or planned. Explanations of any lack of data shall be provided here. Changes in instrumentation and any calibrations performed shall also be described.

Operation Summary Table. A system operation summary table shall be presented. This table shall contain the following items for each day of the month: Julian day, date, operational status code, weather code, and remarks from the daily log. The correct format is shown in Table B-1 in Appendix B.

IV. Performance

The performance section is divided into three subsections: (A) Monthly Summary, which contains a summary of thermal performance parameters; (B) Clear Day Performance, which provides data on how the system performed on a good day; and (C) Monthly Storage Performance, which details the thermal performance of the storage subsystem (when applicable). These three subsections of the performance report are further explained below. Definitions of major parameters can be found in Appendix A. For other definitions, the reader is referred to Ref. 1.

A. Monthly Summary

Descriptive Paragraph. The section shall contain a paragraph describing overall system thermal performance for the month. The performance should be compared to that which was predicted, and any deviations should be explained. Values of the monthly availability and utilization should be included. General comments on system operation should also be contained in this section.

Monthly Summary Table. A monthly summary table shall be presented. This table shall contain the following items for each day of the month: Julian day, date, incident solar energy on a horizontal surface and in the collector plane, energy collected, collector array efficiency based on total horizontal irradiation, collector array efficiency based on irradiation in the collector plane, energy delivered, operational and nonoperational piping losses, losses from storage, system thermal efficiency, and parasitic energy used. The totals of energy values for the month shall be shown (in both SI and English units) as well as monthly averages of the efficiencies. The proper format for the table is shown in Table B-2 in Appendix B.

Monthly Summary Graph. A graph showing the incident solar energy on a horizontal surface and in the collector plane, energy collected, and energy delivered versus day of the month shall be presented. (See Appendix B, Fig. B-2.)

B. Clear Day Performance

Descriptive Paragraph. A paragraph describing the system performance on a "clear day" during the month shall be provided. By "clear day" is meant that day of the month with maximum energy delivery during which the industrial plant, solar system, and data acquisition system operated normally. Any discrepancies between expected and actual performance shall be explained. Any factors influencing collector efficiency (e.g., washing, adjustment, etc.) shall be discussed as well as observations pertaining to collector degradation.

Clear Day Table. Hourly totals/averages of measured quantities and performance results shall be reported in tabular form. This table shall contain the following items for each hour of the day: hour, ambient temperature, wind speed, incident solar energy on a horizontal surface and in the collector plane, collector array flow rate, collector array inlet temperature, collector array outlet temperature, energy collected, collector array efficiency based on total horizontal irradiation, collector array efficiency based on irradiation in the collector plane, energy delivered, piping losses (operational or nonoperational, as appropriate), average storage temperature, and parasitic energy. Total energy values and average temperatures and wind speed shall be given for the day in both SI and English units. (See Appendix B, Table B-3.)

Clear Day Graph. A graph showing incident solar energy on a horizontal surface and in the collector plane, energy collected, energy delivered, parasitic energy use, and average storage temperature (or collector outlet temperature, if there is no storage) versus hour of the day shall be included. (See Appendix B, Fig. B-3.)

C. Monthly Storage Performance (when applicable)*

Descriptive Paragraph. Storage performance for the month shall be discussed, and deviations from expected performance should be explained.

Monthly Storage Performance Table. This table shall contain the following items for each day of the month: Julian day, date, energy removed from storage, energy added to storage, energy lost from storage, and average storage temperature. Total energy values (in both SI and English units), extremes of storage temperature achieved, and average storage temperature for the month shall also be given. (See Appendix B, Table B-4.) No graph of storage performance is required, except as described for the Clear Day Graph, above.

*See Appendix A for the definition of storage.

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V. Operating and Maintenance Costs

Descriptive Paragraph. This shall give the net monetary savings due to the solar system for the month and explain the operating and maintenance costs that were incurred.

Operating and Maintenance Cost Table. This table shall contain details of all costs (maintenance, operation, and fixed) and fossil fuel savings as well as the difference between these (i.e., net savings). Actual prices of parasitic energy and fossil fuel displaced shall be used. The proper format for this table is shown in Appendix B, Table B-5.

VI. Planned Activities

Activities planned for the next month shall be described in this section. Planned system modifications, collector washing, repairs, anticipated shutdowns, etc., shall be described here.

SECTION 3.0

REFERENCES

1. National Bureau of Standards. 1976 (Aug.). Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program. NBSIR 76-1137.

NOMENCLATURE

Symbols

C	Specific heat capacity [GJ/kg-°C]
M	Mass [kg]
Q	Energy [GJ]
Q_{COLL}	Energy collected by collectors
Q_{DEL}	Energy delivered to process
$Q_{NON-OP\ LOSS}$	Non-operational thermal piping loss
$Q_{OP\ LOSS}$	Operational thermal piping loss
Q_{PUMP}	Energy added by pumps
Q_{S-IN}	Energy added to storage
Q_{S-LOST}	Energy lost from storage
Q_{S-OUT}	Energy removed from storage
t	Time [s]
T	Temperature [°C]
w	Mass flow rate [kg/s]

Greek Symbols

Δx	Finite change in variable x [x]
η	Efficiency [%]
η_c	Collector array efficiency
η_f	Thermal efficiency of fossil fuel conversion process
η_T	System thermal efficiency

Superscripts

$\bar{x}$	Average value of variable x

APPENDIX A

DEFINITIONS

Availability. The availability is meant to be a measure of the mechanical reliability of the solar system, that is, that portion of the time the solar energy system was available to collect energy for the process. (It does not take into account climatic conditions that might render the system unusable.) Specifically,

$$\text{availability (\%)} = \frac{\text{number of days solar system was not down for repairs}}{\text{total number of days in the period of calculation}} \times 100\% \;.$$

The information necessary to calculate system availability is given in the column labeled "Plant/System Operational Status" in the monthly performance table (Table B-1, Appendix B). The status codes obtained from the monthly summary table are used to define system availability as

$$\text{availability (\%)} = \frac{\text{sum of number of days with status codes 1,3,4, or 6}}{\text{total number of days}} \times 100\% .$$

Collector Array Efficiency. The efficiency of the collector array is defined by:

$$\eta_c = \frac{\text{energy collected during time t}}{\text{incident solar energy during time t}} \;.$$

When the collector array efficiency is calculated based on the irradiation in the collector plane, the time t shall include the entire day for nontracking collectors but only periods of collector tracker operation for tracking collectors.

Energy Added to Storage. Energy added to storage should be the energy actually transferred into storage by means of a heat exchanger or flow of liquid into storage. Preferably, the energy flow should be calculated directly from measurement of the flow rate and temperature change of the storage tank fluid. For the example system shown in Fig. A-1,

$$Q_{S-IN} = \int w_2 C_2 (T_{301} - T_{302})\, dt \;.$$

Energy Collected. The collected energy is the summation of the measurements of energy change of the collector fluid in passing through the collector array. The energy change in the collector fluid is calculated from measurements of the total flow rate of fluid and its temperature change across the array. For the example system shown in Fig. A-1,

$$Q_{COLL} = \int w_1 C_1 (T_{102} - T_{101})\, dt \;.$$

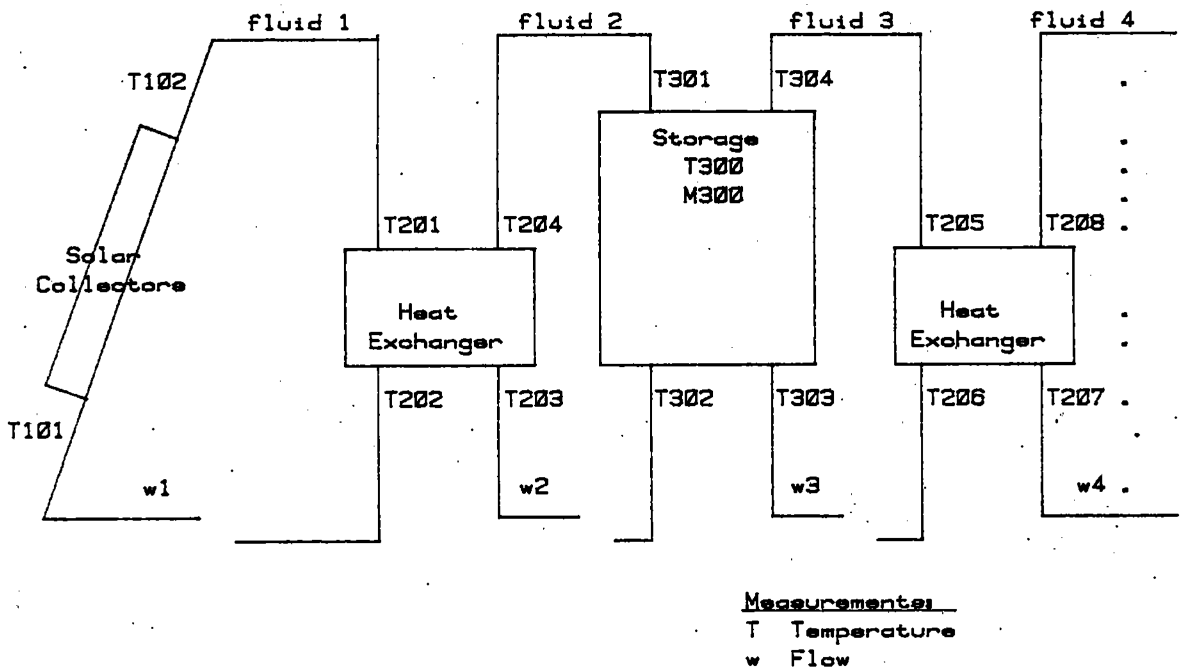

Figure A-1. Example Solar IPH System

Energy Delivered. The energy delivered is the actual amount of energy transferred from the solar system to the industrial process and used by the industrial process. It should be measured at the solar-to-load interface. For the example system shown in Fig. A-1,

$$Q_{DEL} = \int w_4 C_4 (T_{208} - T_{207}) dt \quad .$$

Energy Lost from Storage. The energy lost from storage is that energy lost due to thermal losses and leaks from the storage tank, not including heat exchanger losses accounted for under "piping losses." The value may be calculated from the difference between the net energy transferred into storage from the solar system (i.e., energy added to storage - energy removed from storage) and the net increase in energy stored as measured by the changes in volume and average temperature of the storage medium. For the example system shown in Fig. A-1, the energy lost from storage from time 1 to time 2 is

$$Q_{S-LOST} = Q_{S-IN} - Q_{S-OUT} - C_{300} (M_{300}\bar{T}_{300})_2 + C_{300} (M_{300} \bar{T}_{300})_1 \; ,$$

where M_{300} is the mass of storage material, C_{300} is its specific heat, and $\bar{T}_{300}$ is the average storage temperature.

Energy Removed from Storage. The energy removed from storage is that energy transferred via heat exchanger or flow of liquid from storage to the process (or to the collectors if storage is used for circulation freeze protection of the collectors). Where possible, the energy flow should be directly calculated from measurement of the flow rate and temperature change of the storage tank fluid. For the example system shown in Fig. A-1,

$$Q_{S-OUT} = \int w_3 C_3 (T_{304} - T_{303})\, dt \quad .$$

Fossil Fuel Displaced. Where possible, the amount of fossil fuel displaced should be measured from the actual fuel consumption. If this is impractical, fossil fuel displaced shall be calculated as a fuel equivalent of the energy delivered, which takes into account the conversion efficiency:

$$\text{fossil fuel displaced} = \frac{\text{energy delivered}}{\text{energy density of the fossil fuel}} \times \eta_f \quad ,$$

where η_f is the efficiency of the conversion process currently used at the plant. (If the exact efficiency is unknown, an estimated value should be used.) The value of η_f used is to be provided in the monthly report.

Incident Solar Energy. The incident solar energy is defined as either the total horizontal irradiation or the irradiation in the collector plane, as appropriate, multiplied by the collector array aperture area.

Irradiation in the Collector Plane. For nontracking collectors, total irradiance in the collector plane shall be used, integrated over the entire day. For tracking collectors, the time integral of the direct solar irradiance in the collector aperture plane shall be used. Direct irradiance is normally determined by mounting both a total and a shadow band pyranometer on a collector and taking the difference or by using a pyrheliometer and calculating the incident angle effects.

If a pyrheliometer is used, measurement of direct irradiance is not limited to hours of collector operation. While only the irradiation during collector operation shall be used to calculate collector array efficiency, irradiance for all hours of the day shall be reported in the Clear Day Table and the Clear Day Graph. In addition both irradiation during collector operation and during the entire day shall be reported in the Monthly Summary Table and Monthly Summary Graph.

Packing Factor. The packing factor for the collector array is defined as the ratio of the total collector array aperture area to the total land area enclosed by the perimeter of the collector array.

Parasitic Energy Used. This is to be the electrical energy used to operate the solar energy system, with no electrical conversion efficiency included (that is, one kWh of electricity equals 3,600,000 joules). If possible, the electricity used to operate the data acquisition system should be measured and presented separately from the energy used to operate the rest of the solar system, as in Tables B-1 and B-2 in Appendix B.

Piping Losses. Heat losses through the piping and components are of two types: operational and nonoperational. The former is that heat which is lost from all of the piping and components between the collector array and process interface during times of positive flow in the collector loop. Thus, in the example of Fig. A-1, the operational piping losses would be,

$$
\begin{aligned}
Q_{OP\ LOSS} = & \int w_1 C_1[(T_{102} - T_{201}) + (T_{202} - T_{101})]\, dt \\
& + \int [w_1 C_1 (T_{201} - T_{202}) - w_2 C_2 (T_{204} - T_{203})]\, dt \\
& + \int w_2 C_2[(T_{204} - T_{301}) + (T_{302} - T_{203})]\, dt \\
& + \int w_3 C_3[(T_{304} - T_{205}) + (T_{206} - T_{303})]\, dt \\
& + \int [w_3 C_3 (T_{205} - T_{206}) - w_4 C_4 (T_{208} - T_{207})]\, dt \quad ,
\end{aligned}
$$

where w_i and C_i are, respectively, the mass flow rate and the specific heat of a fluid i. The first, third, and fourth integrals represent pipe losses. The second and fifth terms represent heat exchanger losses, which in many cases will be negligible. (Storage losses are accounted for in the separate storage calculations.)

Nonoperational piping losses are those thermal losses that occur when the piping fluid inventory cools to ambient during shutdown. Since piping often runs both inside and outside buildings, measuring this loss explicitly can be difficult. While it is recommended that a direct measurement of cool-down losses be attempted, it is acceptable to calculate this as the difference between energy delivered and the energy collected plus operational piping losses (with storage losses and change in stored energy appppropriately accounted for).

Thus,

$$Q_{DEL} = Q_{COLL} - Q_{OP\ LOSS} - Q_{NON\text{-}OP\ LOSS} + Q_{PUMP} - (Q_{S\text{-}IN} - Q_{S\text{-}OUT}) - Q_{S\text{-}LOSS}$$

or,

$$Q_{NON\text{-}OP\ LOSS} = Q_{COLL} - Q_{DEL} - Q_{OP\ LOSS} + Q_{PUMP} - (Q_{S\text{-}IN} - Q_{S\text{-}OUT}) - Q_{S\text{-}LOSS} \quad .$$

(The Q_{PUMP} term accounts for any heat that may have been added to the flow loop by pumps. In cases where this term is expected to be significant, it should be determined by measuring ΔT across each pump.) Measuring each term in the energy balance explicitly serves as a check on the measurements. The nonoperational losses can be measured as:

$$Q_{NON\text{-}OP\ LOSS} = \sum_i [M_i C_i \Delta T_i] \quad ,$$

where M_i is the mass of fluid in portion i of the system, C_i is the heat capacity of fluid i, and ΔT_i is the change in average bulk temperature of the fluid in portion i of the system during cooldown. (When significant, the mass of piping and components should also be taken into account.)

In the clear day table, the nonoperational piping losses will show up during nighttime hours if measured explicitly. If calculated from the energy balance, nonoperational piping losses will appear lumped together with operational losses during the morning hours when the collectors heat the working fluid from ambient up to the temperature needed for energy delivery.

Plant/System Operational Status Codes. The codes are defined as follows:

Daily Status Code	Solar Energy System	Industrial Plant	Comments
1	up	up	normal operation
2	down	up	solar energy system down
3	idle	up	solar energy system not turned on
4	up	down	solar energy collected but not delivered to process
5	down	down	both solar energy system and plant down
6	idle	down	plant down, solar system idled

For purposes of defining the operational status codes, partial days of system operation are accounted for as follows: The time period of collector pump operation on the one clear day, for which performance is given in the Clear Day Performance section of the monthly report, defines a normal daily period of operation. The solar system is then considered to be down if on a particular day the system could not be operated for more than half of that period due to mechanical or electrical problems or maintenance.

Storage. A solar energy system is considered to have a storage subsystem if any components of the system allow more energy to be delivered to the process than the collectors are collecting for a significant period of time. Examples of components that would be considered storage components are thermal storage tanks and buffer or flash tanks containing a significant fraction of the heated fluid inventory. Long pipe runs would not be considered a storage component.

System Thermal Efficiency. The thermal efficiency of the system is defined as

$$\eta_T \equiv \frac{\text{energy delivered during time t}}{\text{incident solar energy}} ,$$

where the incident solar energy is the total horizontal irradiation during time t multiplied by the collector array aperture area.

Total Horizontal Irradiation. This is the time integral of the total horizontal solar irradiance recorded during the entire day (not just during collector operation).

Utilization. Utilization is an indication of the extent to which the industrial process made use of the solar system when it was available.

Utilization is defined as:

$$\text{utilization (\%)} = \frac{\text{number of days of actual solar system operation}}{\text{number of days solar system was not down for repairs}} \times 100\% \ .$$

The plant/system operational status codes obtained from the monthly summary table yield a definition of utilization as

$$\text{utilization (\%)} = \frac{\text{sum of number of days with status codes 1 or 4}}{\text{sum of number of days with status codes 1,3,4, or 6}} \times 100\% \ .$$

Weather Codes. The following codes shall be used to describe the daily weather:

F = Fair
P = Partly Cloudy (sky less than 1/2 obscured)
C = Fog or Overcast (sky more than 1/2 obscured)
R = Rain
S = Snow

Wind Speed. The value presented for wind speed shall be the average value over the time period.

MONTHLY REPORT #7

5 March 1980
Report Period: 1 Feb. 1980 - 29 Feb. 1980

REPORT NO.:	SAN/1324-07
DOE CONTRACT NO.:	AB-CD12-34EF56789 (GH-80-I-00-1943)
CONTRACT TITLE:	Solar Energy Applied to the Widget Industry
CONTRACTOR:	ABC, Inc. 100 F Street Anywhere, CA 93001 contact: E. X. Jones, 213-889-1458, ext. 115
PROJECT SITE:	XYZ Corp. P.O. Box 007 Nowhere, TX 55007 contact: Mary Doe, 809-414-6201

II. Project Description

Application:	Preheat of plant process hot water for widget production
Site:	35° 22' N Latitude, 103° 02' W Longitude, Elevation = 240 m (780 ft)
Process Schedule:	8 a.m. to 12 midnight in two shifts, 7 days per week, 50 weeks per year
Process Load Profile:	4.4 GJ/shift (15,000 kg of water per shift at 90°C and 3.0 MPa; supply temperature, 20°C); 3077 GJ/yr
Auxiliary Fuel:	Natural gas, boiler efficiency = 70%
Collectors:	130 single-glazed (glass), selective-surface flat-plate collectors (Acme model #001) Total aperture area = 600 m^2 Total gross area = 648 m^2 Mounted on ground at 40° tilt, 15° east of south Packing factor = 0.510
Fluid Type, Flow Rate:	Water at constant flow rate of 10 kg s^{-1} in collector loop, 5 kg s^{-1} from storage to heat exchanger
Storage:	47.8 m^3 steel tank with R-12 insulation
Design Energy Delivery:	950 GJ/yr
Phase 1 Cost (Design):	$11,600
Phase 2 Cost (Construction):	$32,800 (excludes data acquisition)

Solar preheated water is supplied to the hot water heater of an industrial plant that produces widgets (1,200,000 per year) as shown in the system schematic, Fig. B-1. Measurement points for temperatures and flow rates are indicated on the schematic. Water is circulated at a constant flow rate between the collectors and storage tank. When needed, solar-heated water is circulated through a heat exchanger to preheat incoming process feedwater. Freeze protection in the collector loop is provided by automatic drainback to the vented storage tank whenever the pump shuts off. The solar system is sized to provide 31% of the energy used annually by the plant for heating water.

III. Operating Experience

The system ran without incident in an automatic mode for the first 12 days of the month. On 13 Feb., a leak developed and the system was shut down for two days while a replacement seal for the collector pump was installed. The cause of the leak was that the wrong size of seal was originally used. While the system was down, the insolation measuring devices were recalibrated. The measurements of total horizontal radiation were found to be 3% low, and those of the tilted total radiation were 5% high. Adjustments to the data reduction

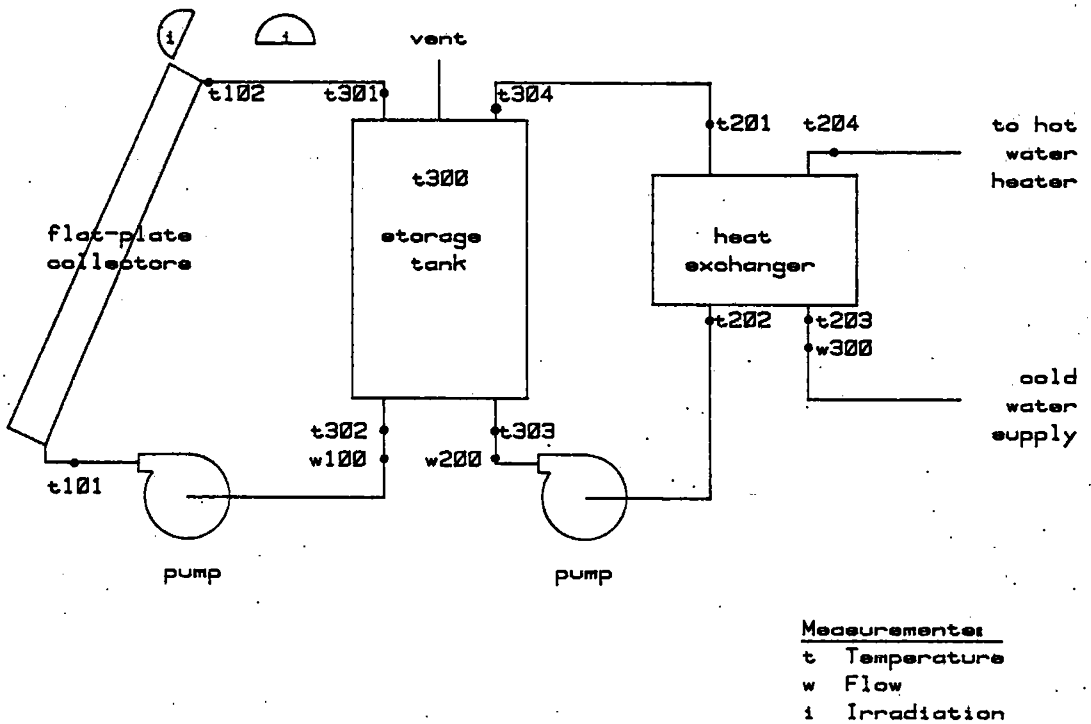

Figure B-1. XYZ Corporation Solar System Schematic

software were made to include the new calibration factors. The solar system operated normally from 15 Feb. to 29 Feb. On 21 Feb., the collectors were washed using the automatic washing system. The disk drive unit in the data acquisition system lost one day of data when a power failure occurred on 28 Feb. A plant holiday occurred on 23 Feb., and the system was idle for the day. System performance for the month is shown in Table B-1.

IV. Performance

A. Monthly Summary

The availability of the solar system was 93.5% for this month, and the utilization factor was 96.6%. Delivered energy was 6.5% less than predicted due primarily to greater than normal rainfall and the accompanying cloudiness and cold weather during this period. It is estimated that the system saved 1558 m^3, or 561 ccf, of natural gas this month, assuming a boiler efficiency of 0.70. Table B-2 presents a summary of the performance of the system for this period. The monthly summary plot is given in Fig. B-2.

Table B-1. XYZ CORP. - SYSTEM OPERATION SUMMARY TABLE - FEBRUARY 1980

Date	Julian Day	Status Code	Weather	Remarks
2/1	32	1	P	
2/2	33	1	F	Collector loop flowmeter calibrated
2/3	34	1	C	
2/4	35	1	C	
2/5	36	1	F	Collectors washed
2/6	37	1	P	
2/7	38	1	P	Two collector header fittings tightened
2/8	39	1	C	
2/9	40	1	C	DOE visitors given plant tour
2/10	41	1	P	
2/11	42	1	P	
2/12	43	1	P	
2/13	44	2	P	Collector pump leak discovered, solar system shut down
2/14	45	2	P	Collector pump seal replaced. Pyranometer recalibrated
2/15	46	1	R	Heavy rain in late afternoon
2/16	47	1	R	Heavy rain all day
2/17	48	1	F	
2/18	49	1	P	
2/19	50	1	P	
2/20	51	1	P	
2/21	52	1	P	
2/22	53	1	F	
2/23	54	6	P	Plant holiday
2/24	55	1	F	
2/25	56	1	P	
2/26	57	1	P	
2/27	58	1	P	
2/28	59	1	P	Data acquisition system power failure. Corrected by evening.
2/29	60	1	P	

F: Fair

P: Partly Cloudy

C: Fog or Overcast

R: Rain

Table B-2. XYZ CORP. - MONTHLY PERFORMANCE SUMMARY TABLE - FEBRUARY 1980

Julian Day	(Date)	Incident Solar Energy[c]: On a Horizontal Surface (1) GJ	Incident Solar Energy[c]: In the Collector Plane (2) GJ	Energy Collected GJ	Collector Array Efficiency Based on (1) %	Collector Array Efficiency Based on (2) %	Energy Delivered GJ	Piping Losses: Operational GJ	Piping Losses: Non-Operational GJ	Losses from Storage GJ	System Thermal Efficiency %	Parasitic Energy Used GJ
032	(2/1)	11.5	13.0	4.0	34.8	30.8	3.6	0.05	0.05	0.2	31.3	0.150
033	(2/2)	14.0	16.5	5.0	35.7	30.3	4.2	0.10	0.20	0.1	30.0	0.170
034	(2/3)	0.8	1.0	0	—	—	0	0.00	0.05	0.1	—	0.014
035	(2/4)	0.2	0.3	0	—	—	0	0.00	0.05	0.1	—	0.014
036	(2/5)	15.2	16.3	5.0	32.9	30.7	3.0	0.05	0.05	0.1	19.7	0.105
037	(2/6)	8.0	10.2	3.0	37.5	29.4	3.2	0.20	0.20	0.1	40.0	0.123
038	(2/7)	10.8	12.7	4.0	37.0	31.5	2.5	0.20	0.30	0.2	23.1	0.065
039	(2/8)	0.8	1.0	0.2	25.0	20.0	2.1	0.05	0.05	0.1	262.5	0.060
040	(2/9)	0.9	1.1	0.3	33.3	27.3	0.5	0.05	0.05	0.0	55.6	0.045
041	(2/10)	10.0	11.5	3.8	38.0	33.0	1.5	0.30	0.30	0.2	15.0	0.082
042	(2/11)	4.8	6.2	2.0	41.7	32.3	2.0	0.10	0.10	0.1	41.7	0.075
043	(2/12)	12.1	14.0	4.0	33.0	28.6	3.0	0.20	0.30	0.1	24.8	0.116
044	(2/13)	10.5	12.0	PUMP SEAL FAILURE - SYSTEM DOWN				0.00	0.10	0.1		0.014
045	(2/14)	11.4	12.8	PUMP SEAL FAILURE - SYSTEM DOWN				0.00	0.05	0.1		0.013
046	(2/15)	2.2	3.1	0.9	40.9	29.0	1.5	0.05	0.10	0.1	68.2	0.075
047	(2/16)	0.3	0.3	0	—	—	3.0	0.00	0.00	0.1	1000.0	0.081
048	(2/17)	14.2	17.1	5.1	36.1	30.0	5.2	0.22	0.20	0.3	36.7	0.172
049	(2/18)	8.9	10.0	3.5	39.3	35.0	3.2	0.10	0.20	0.1	36.0	0.120
050	(2/19)	6.8	8.5	2.0	29.4	23.5	1.6	0.08	0.20	0.1	23.5	0.063
051	(2/20)	6.3	8.8	1.8	28.6	20.5	1.5	0.05	0.15	0.1	23.8	0.081
052	(2/21)	7.6	10.2	3.0	39.5	29.4	2.2	0.05	0.15	0.0	28.9	0.112
053	(2/22)	12.8	15.2	4.0	31.3	26.3	3.0	0.30	0.20	0.1	23.4	0.098
054	(2/23)	8.0	9.5	PLANT HOLIDAY, SYSTEM IDLED				0.00	0.20	0.2		0.013
055	(2/24)	13.5	16.0	5.0	37.0	31.3	4.5	0.30	0.30	0.1	33.3	0.143
056	(2/25)	6.0	8.8	2.0	33.3	22.7	1.5	0.10	0.20	0.1	25.0	0.085
057	(2/26)	5.9	8.5	1.8	30.5	21.2	2.0	0.20	0.20	0.1	33.9	0.110
058	(2/27)	8.8	11.1	3.0	34.1	27.3	2.6	0.30	0.20	0.3	29.5	0.121
059	(2/28)	NO DATA - DATA ACQUISITION SYSTEM FAILURE										
060	(2/29)	10.3	12.8	4.0	38.8	31.3	4.0	0.30	0.20	0.3	38.8	0.148
TOTALS/AVERAGES		222.6 GJ (211.2 MBtu)	268.4 GJ (254.6 MBtu)	67.4 GJ (63.9 MBtu)	35.0%[a]	28.9%[a]	61.4 GJ (58.3 MBtu)	3.35 GJ (3.22 MBtu)	4.25 GJ (4.08 MBtu)	3.4 GJ (3.2 MBtu)	31.9%[a]	2.468 GJ[b] (2.342 MBtu)[b]
		192.7 GJ[a] (182.8 MBtu)[a]	234.1 GJ[a] (222.1 MBtu)[a]									2.428 GJ[a] (2.304 MBtu)[a]

[a]Based on days for which operating status was 1 or 4 and data was taken.

[b]Includes 0.702 GJ (0.666 MBtu) required to operate the data acquisition system.

[c]Irradiation multiplied by collector array aperture area.

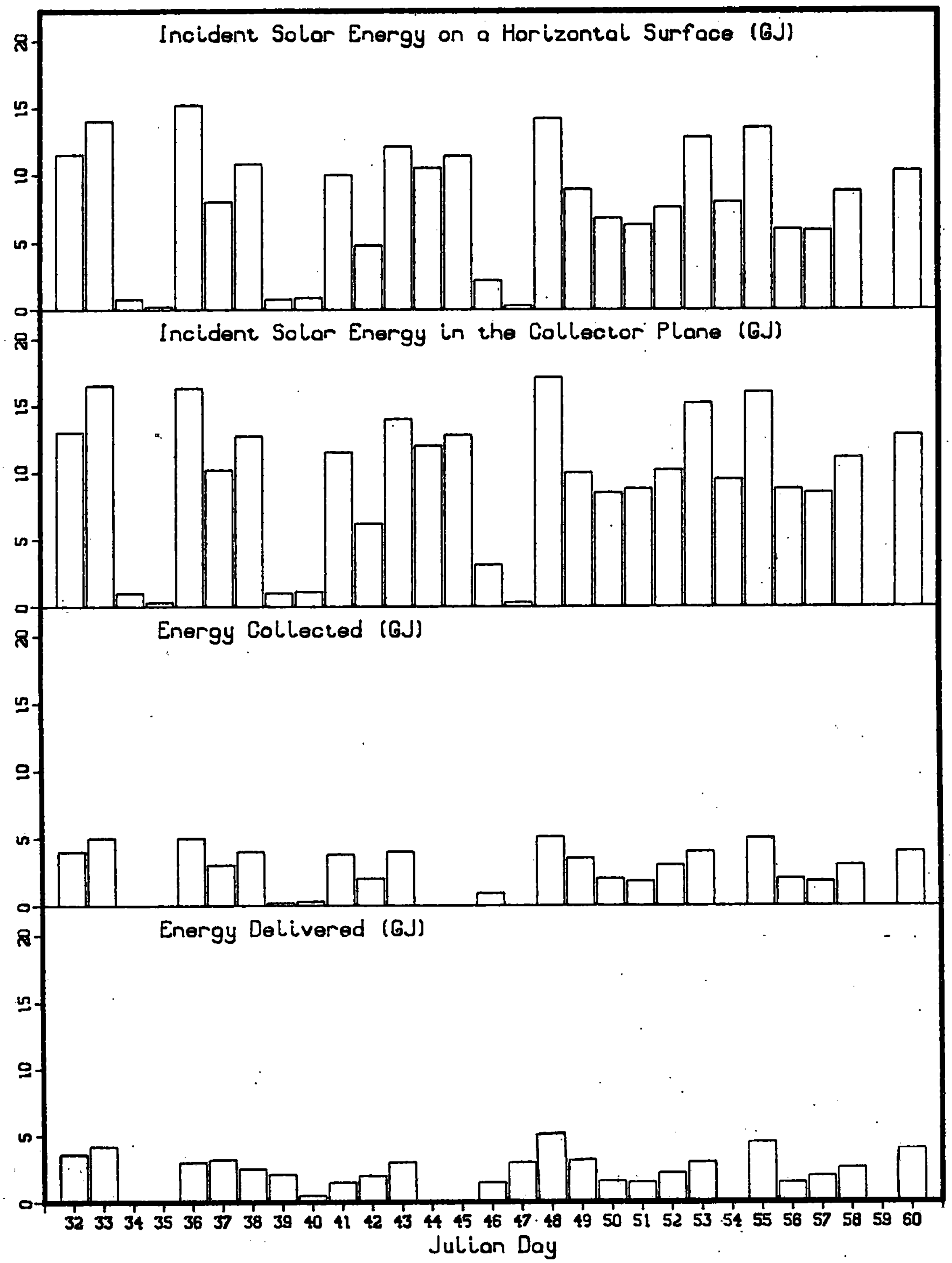

Figure B-2. XYZ Corporation Monthly Performance Summary Graph

B. Clear Day Performance

The performance of the solar system for 17 Feb. is presented in Table B-3, the clear day performance table, and Fig. B-3, the single day graph. Heavy rains on 15-16 Feb. left the collectors very clean, which contributed to good performance. Leakage of slight amounts of rainwater occurred around the covers of about 5% of the collectors, but quickly evaporated with no damage.

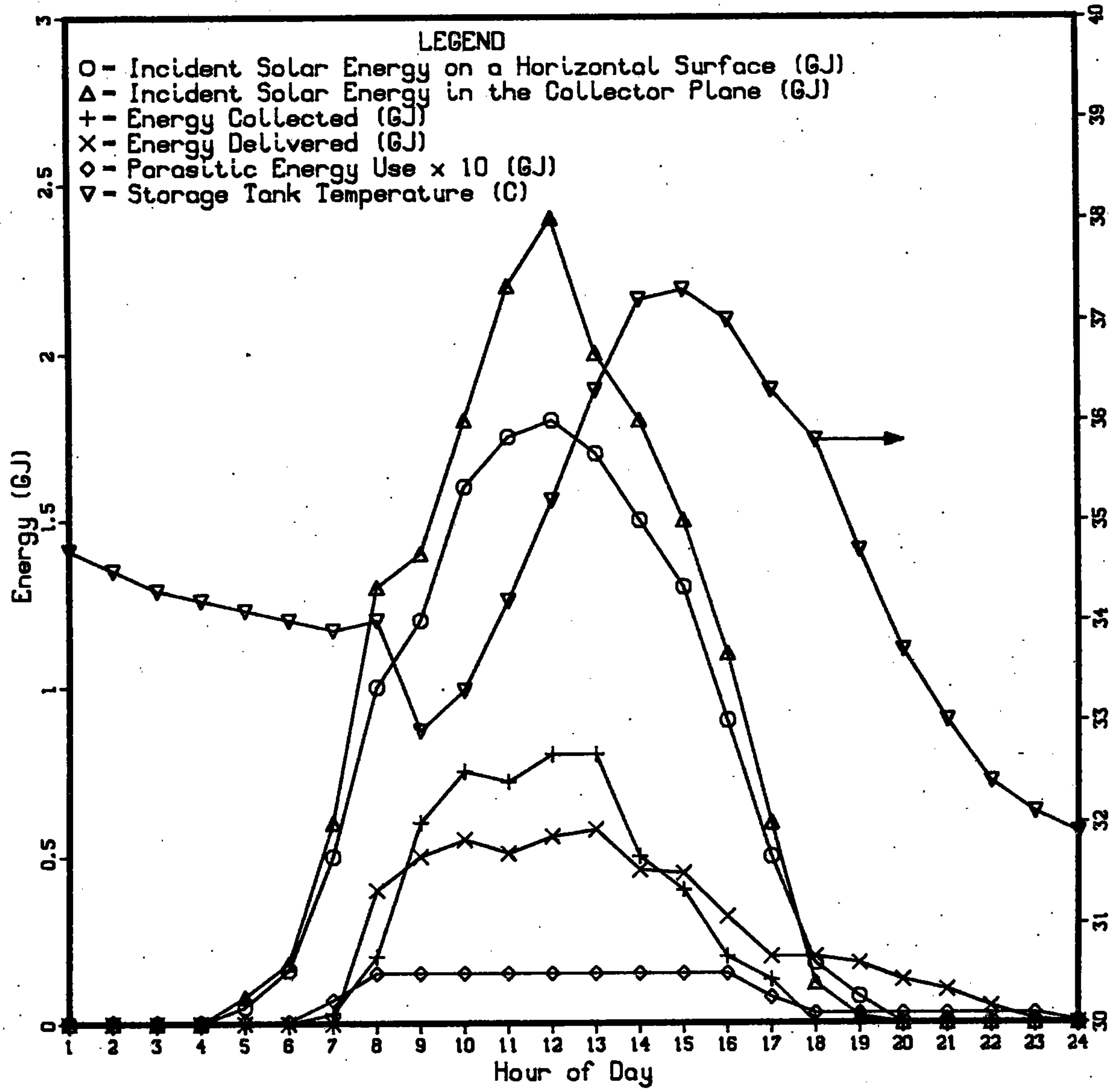

Figure B-3. XYZ Corporation Clear Day Graph

Table B-3. XYZ CORP. - CLEAR DAY PERFORMANCE TABLE - 17 FEBRUARY 1980 (JULIAN DAY 48)

Hour	Ambient Temp. °C	Wind Speed m s⁻¹	Incident Solar Energy[c]: On a Horizontal Surface (1) GJ	Incident Solar Energy[c]: In the Collector Plane (2) GJ	Collector Array Flow Rate kg s⁻¹	Collector Array Temp.: Inlet °C	Collector Array Temp.: Outlet °C	Energy Collected GJ	Collector Array Effic. Based on (1) %	Collector Array Effic. Based on (2) %	Energy Delivered GJ	Piping Losses GJ	Average Storage Temperature °C	Parasitic Energy MJ
01	7.0	0.4	0	0	0	10.0	10.0	0			0	0.018	34.7	0.6
02	8.8	0.3	0	0	0	9.8	9.8	0			0	0.018	34.5	0.6
03	9.4	0.5	0	0	0	9.6	9.6	0			0	0.017	34.3	0.6
04	9.0	0.7	0	0	0	9.4	9.4	0			0	0.017	34.2	0.6
05	10.6	0.6	0.05	0.08	0	10.0	10.0	0			0	0.016	34.1	0.6
06	11.0	1.4	0.16	0.18	0	13.5	13.5	0			0	0.018	34.0	0.6
07	12.3	2.2	0.50	0.60	4.0	33.8	34.3	0.03	6.0	5.0	0	0.018[a]	33.9	7.0
08	13.5	3.5	1.00	1.30	10.0	33.0	34.3	0.20	20.0	15.4	0.40	0.019[a]	34.0	15.0
09	16.4	3.4	1.20	1.40	10.0	31.1	35.1	0.60	50.0	42.9	0.50	0.019[a]	32.9	15.0
10	19.3	1.2	1.60	1.80	10.0	31.3	36.3	0.75	46.9	41.7	0.55	0.020[a]	33.3	15.0
11	19.6	1.4	1.75	2.20	10.0	31.5	35.3	0.72	41.1	32.7	0.51	0.019[a]	34.2	15.0
12	22.0	1.0	1.80	2.40	10.0	32.5	37.8	0.80	44.4	33.3	0.56	0.019[a]	35.2	15.0
13	20.6	0.6	1.70	2.00	10.0	33.4	38.7	0.80	47.1	40.0	0.58	0.019[a]	36.3	15.0
14	20.8	0.4	1.50	1.80	10.0	35.6	38.9	0.50	33.3	27.8	0.46	0.018[a]	37.2	15.0
15	17.9	1.2	1.30	1.50	10.0	36.0	38.7	0.40	30.8	26.7	0.45	0.018[a]	37.3	15.0
16	17.5	1.1	0.90	1.10	10.0	36.3	37.6	0.20	22.2	18.2	0.32	0.017[a]	37.0	15.0
17	17.0	2.2	0.50	0.60	6.0	35.9	36.8	0.13	26.0	21.7	0.20	0.017[a]	36.3	7.8
18	16.5	2.4	0.18	0.12	0	30.2	32.3	0			0.20	0.017	35.8	3.0
19	16.3	1.8	0.08	0.02	0	22.9	24.5	0			0.18	0.017	34.7	3.0
20	15.9	1.2	0	0	0	21.0	21.9	0			0.13	0.016	33.7	3.0
21	15.2	0.8	0	0	0	19.5	20.0	0			0.10	0.016	33.0	3.0
22	14.3	0.4	0	0	0	18.5	18.7	0			0.05	0.016	32.4	3.0
23	13.5	0.1	0	0	0	16.4	16.4	0			0.01	0.016	32.1	3.0
24	12.8	0.0	0	0	0	15.5	15.5	0			0	0.015	31.9	0.6
TOT./ AVG.	14.9°C (58.8°F)	1.2m s⁻¹ (3.9ft s⁻¹)	14.22 GJ (13.49 MBtu)	17.10 GJ (16.22 MBtu)	—	—	—	5.13 GJ (4.87 MBtu)	36.1%	30.0%	5.20 GJ (4.93 MBtu)	0.420 GJ (0.398 MBtu) 0.217 GJ[a] (0.206 MBtu)[a]	34.5°C (94.1°F)	172.0 MJ[b] (0.163 MBtu)[b]

[a]Operational losses.

[b]Includes 24.2 MJ (23,000 Btu) required to operate the data acquisition system.

[c]Irradiation multiplied by collector array aperture area.

C. Monthly Storage Performance

Table B-4 summarizes the performance of the storage subsystem for the month. Generally, storage performed as expected, with an average temperature for the month of 46.6°C.

V. Operating and Maintenance Costs

The only maintenance performed in February was the replacement of the pump seal. Cleaning was necessary only once during the month due to the rains that occurred. The net savings for the month comes to $83.64. Table B-5 summarizes the costs and fossil fuel savings associated with the solar system for this month.

VI. Planned Activities

Scheduled maintenance activities for March are

- changing the oil in the collector circulating pump; and
- addition of anticorrosion agents to the water in the storage tank.

Table B-4. XYZ CORP. - MONTHLY STORAGE PERFORMANCE TABLE - FEBRUARY 1980

Day	(Date)	Energy Removed from Storage GJ	Energy Added to Storage GJ	Energy Lost from Storage GJ	Average Storage Temp. °C
32	(2/1)	3.6	3.9	0.2	53.2
33	(2/2)	4.2	4.7	0.1	55.0
34	(2/3)	0	0	0.1	54.4
35	(2/4)	0	0	0.1	54.1
36	(2/5)	3.0	4.8	0.1	62.3
37	(2/6)	3.2	2.6	0.1	59.0
38	(2/7)	2.5	3.5	0.2	62.9
39	(2/8)	2.1	0.1	0.1	52.6
40	(2/9)	0.5	0.2	0.0	51.3
41	(2/10)	1.5	3.2	0.2	58.5
42	(2/11)	2.0	1.8	0.1	56.8
43	(2/12)	3.0	3.5	0.1	58.9
44	(2/13)	0	0	0.1	58.5
45	(2/14)	0	0	0.1	57.9
46	(2/15)	1.5	0.6	0.1	53.2
47	(2/16)	3.0	0	0.1	37.4
48	(2/17)	5.2	4.9	0.3	34.5
49	(2/18)	3.2	3.2	0.1	34.0
50	(2/19)	1.6	1.8	0.1	34.6
51	(2/20)	1.5	1.6	0.1	34.5
52	(2/21)	2.2	2.8	0.0	37.3
53	(2/22)	3.0	3.5	0.1	39.6
54	(2/23)	0	0	0.2	38.5
55	(2/24)	4.5	4.2	0.1	36.7
56	(2/25)	1.5	1.7	0.1	37.0
57	(2/26)	2.0	1.4	0.1	33.4
58	(2/27)	2.6	2.6	0.3	32.0
59	(2/28)	—	—	—	—
60	(2/29)	4.0	3.5	0.3	27.9
TOTALS		61.4 GJ (58.3 MBtu)	60.1 GJ (57.0 MBtu)	3.6 GJ (3.4 MBtu)	62.9°C (145.2°F) max 46.6°C (115.9°F) avg 27.9°C (82.2°F) min

Table B-5. XYZ CORP. - MONTHLY COST SUMMARY TABLE - FEBRUARY 1980

Maintenance			
Cleaning	Hours	2	
	Avg $/h	10.00	
	Labor Cost ($)	20.00	
	Materials ($)	5.00	
	Total ($)	25.00	
Other	Hours	0.50	
	Avg $/h	10.00	
	Labor Cost ($)	5.00	
	Materials ($)	0.00	
	Parts ($)	5.00	
	Total ($)	10.00	
Total			$35.00
Operation and Fixed Cost			
Property Taxes ($)		1.00	
Insurance ($)		0.00	
Parasitic Energy	kWh Used	68.60	
	$/kWh	0.03	
	Total ($)	20.58	
Total			$21.58
TOTAL COST			$56.58
Fossil Fuel Savings			
	m^3 (natural gas)	1558[a]	
	$/$m^3$	0.09	
Total			$140.22
TOTAL SAVINGS			$140.22
NET SAVINGS			$83.64

[a]70% burner efficiency assumed.