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REPORT

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SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION - SEASONAL
REPORT FOR IBM SYSTEM 3, GLENDO, WYOMING

Prepared by

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For the U. S. Department of Energy

U.S. Department of Energy

Solar Energy

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1. FOREWORD

The <u>Solar Energy System Performance Evaluation - Seasonal Report</u> has
been developed for the George C. Marshall Space Flight Center as a
part of the Solar Heating and Cooling Development Program Funded by
the Department of Energy. The analysis contained in this document
describes the technical performance of an Operational Test Site (OTS)
functioning throughout a specified period of time which is typically
one year. The objective of the analysis is to report the long-term
performance of the installed system and to make technical contributions
to the definition of techniques and requirements for solar energy system
design.

The contents of this document have been divided into the following topics
of discussion:

- System Description
- Summary and Conclusions
- Performance Evaluation Techniques
- Performance Assessment
- Maintenance

Data used for the seasonal analyses of the Operational Test Site de-
scribed in this document have been collected, processed and maintained
under the OTS Development Program and have provided the major inputs
used to perform the long-term technical assessment. This data is archived
by MSFC for DOE.

The Seasonal Report document in conjunction with the Final Report for
each Operational Test Site in the Development Program culminates the
technical activities which began with the site selection and instrument-
ation system design in April 1976. The Final Report emphasizes the
economic analysis of solar systems performance. The Final Report features
the payback performance based on life cycle costs for the same solar
system in various geographic regions. Other documents specifically related
to this system are References [1] through [3].*

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*Numbers in brackets designate references found in Section 7.

2. SYSTEM DESCRIPTION

The Glendo Reservoir Ranger Station is owned by the state of Wyoming. The building occupies 1078 square feet and is used as the residence for a Glendo Reservoir State Park Ranger. Figure 2-1 is an illustration of the IBM System 3 Glendo Solar Energy System Installation.

The solar energy installation, which was retrofitted to the existing building, includes 294 square feet of flat plate collectors, a 1,000 gallon hot water storage tank, a 65 gallon domestic hot water tank, together with pumps and heat exchangers to transfer solar energy on command from the controller.

Water is the only heat transfer medium used in this closed volume, passive drain down system designed for space and domestic hot water (DHW) heating. The collector array faces south with a tilt of 35 degrees to the horizontal.

The collected solar energy enters storage for distribution on load demand to the respective space heating or domestic hot water circuits.

If solar energy does not meet the full space heat load demand, a gas furnace is activated to make up the shortage. Similar energy shortage for the domestic hot water is made up by electric elements within the DHW tank. The system, shown schematically in Figure 2-2, utilizes the independent, nonexclusive operation of each of the three liquid pumps to accomplish a desired heat transfer function. Two differential thermostats, a low temperature sensor and a standard two stage room thermostat provide the controller input signals.
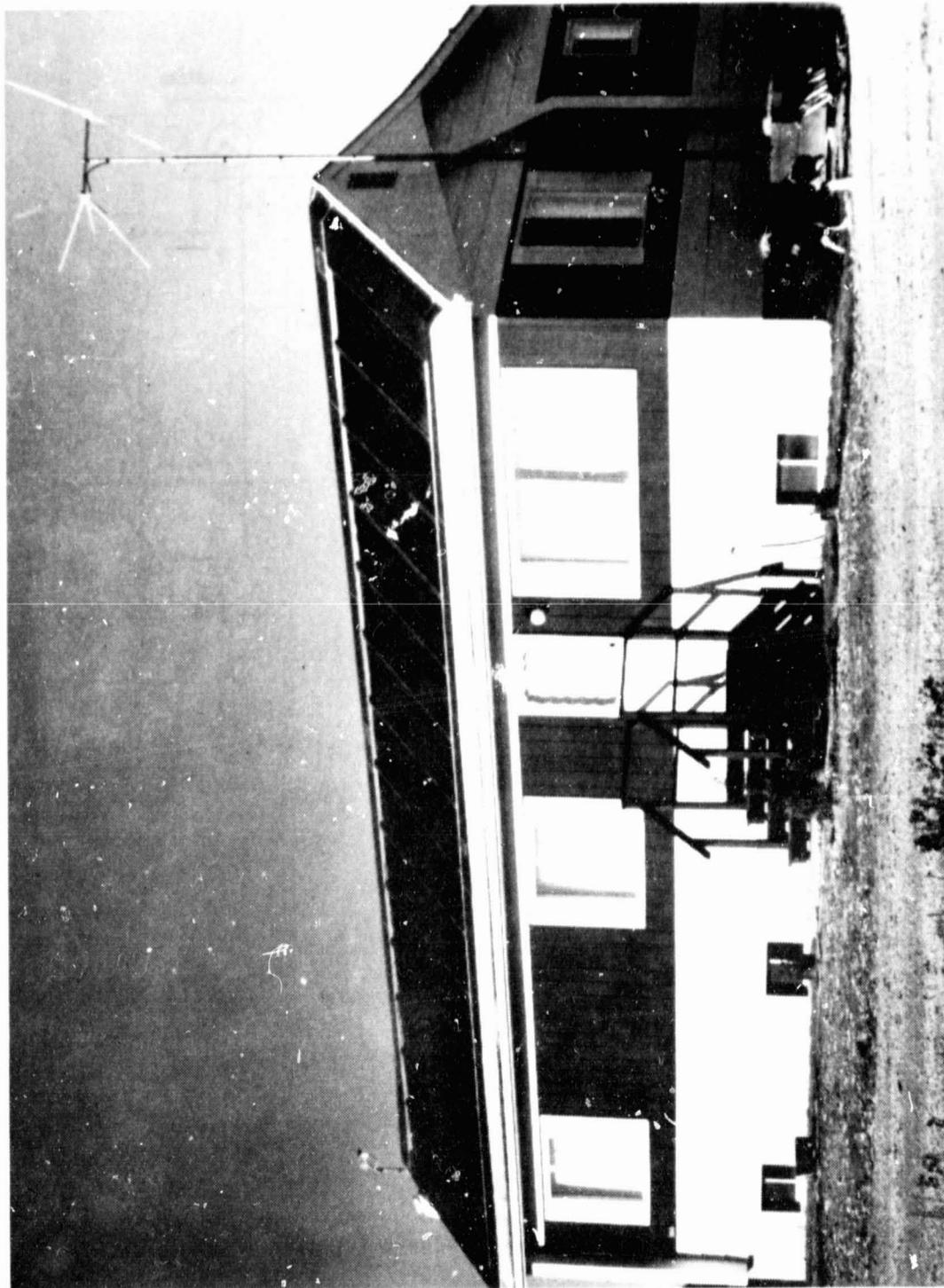
Figure 2-1 IBM System 3 Glendo Solar Energy System Installation

3

DOMESTIC
HOT
WATER

TEMPERING
VALVE

T903

SPACE
HEATING
SUPPLY

W401

T404

HX2

AUX HEATER

F400

T301

W301

T302

EXP
TANK

P3

EP301

HX3

T403

COLD
WATER
SUPPLY

W400

T400

T300

W300

T401

EP402

EP401

P2

T402

RETURN
AIR

HX1

SOLAR
THERMAL
STORAGE

T200

T201

T202

● I001   COLLECTOR PLANE TOTAL INSOLATION
▲ T001   OUTDOOR TEMPERATURE
▲ T600   INDOOR TEMPERATURE

T101

T103

T107
T106
T105
T104

COLLECTORS

T100

W100

T102

EP101

P1

E

EP300

REVISED 7/9/79
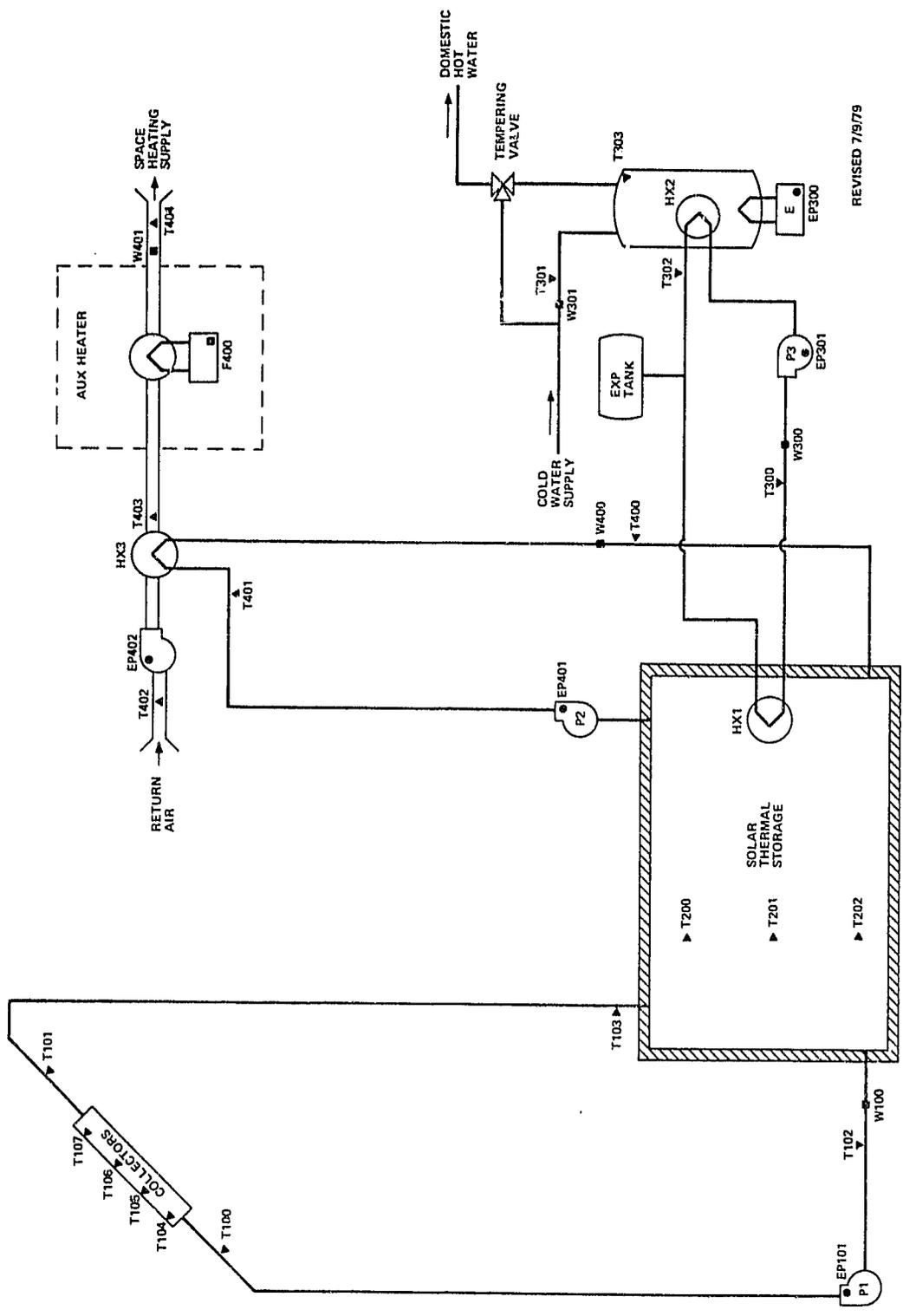
Figure 2-2 IBM System 3 Glendo Solar Energy System Schematic

<u>Mode 1 - Collector-to-Storage</u>: This mode is initiated when the collector
probe S1 is 20°F or more higher than the bottom of storage temperature (S3).
The solar collection pump (P1) circulates the transfer fluid through the
collectors and back into the top of solar storage tank. When the collector
probe is 4°F or less higher than storage probe temperature, the pump turns
off.

<u>Mode 2 - Storage-to-Space Heating</u>: In this mode, when the room temperature
drops to the setting of the thermostat, and the storage temperature is greater
than the low temperature limit, then pump, P2, turns on. When the room tempera-
ture equals the thermostat setting, then the pump turns off.

<u>Mode 3 - Domestic Water Preheat</u>: The DHW pump, P3, begins to transfer heat
energy from solar storage to domestic hot water storage anytime the solar
storage temperature is 20°F greater than the temperature at the bottom of the
DHW tank. Energy transfer continues until the control differential is reduced
to 4°F.

<u>Mode 4 - Auxiliary Space Heating Mode</u>: This mode is initiated when there is
a demand for space heating and the storage water temperature is below the
minimum thermostat set point. (If the minimum storage temperature test fails,
the heat request is routed to the auxiliary heat equipment.)

<u>Mode 5 - Auxiliary DHW Heating Mode</u>: When there is a demand for domestic
hot water heating, heat will be transferred from storage to the DHW tank
anytime storage temperature satisfies the 20°F/4°F differential thermostat
parameters. When main storage temperature is below the DHW temperature
set point, the electric heater in the top of the tank makes up the required
difference.

The basic collector module is the Sunworks liquid solar collector, Model LA1001A, which is a 7'x 3' rectangular unit housed in an aluminum frame weighing 114 lbs. Each module has a single 3/16" thick tempered safety glass cover for the 18.7 ft^2 selective surface absorber area. The liquid system has a flow pattern designed to provide uniform flow through all tubes and to drain without water entrapment. Inlet and outlet fluid connections are 1" diameter copper pipe. The collector array consists of 14 of these modules roof mounted and oriented due south with a tilt angle of 35°.

The storage subsystem consists of an Adamson ASME 1000 gallon hot water storage tank and two internal distribution manifolds. The hot (top) and cold (bottom) distribution manifolds are designed to enhance stratification within storage. (The finned tube heat exchanger which provides heat to DHW is installed near the hot manifold.) In operation, the tank will contain approximately 900 gallons of solar heated water with the remaining volume functioning as an expansion tank and air separator. To reduce corrosion problems, the system is air tight; therefore, the internal pressure will vary with storage temperature. Pressure relief is provided at 30 psig.

The energy transport subsystem has three functional modes, with each function associated with one of the three circulating pumps. These modes are as follows:

- Collector to Storage Mode
- Storage to Space Heating Mode
- Domestic Water Preheat Mode

In the Collector to Storage Mode, pump P1 transfers heat energy from the collectors to solar storage. A Grundfos Model UP 26-64F pumps lift water from the bottom of solar storage, through the collector array (where it is heated) and over the brink of the free fall return line. Solar heated water entering the free fall return line "drops" into storage.

In the Storage to Space Heating Mode, pump P2 removes heat energy from solar storage and adds it to air being circulated from the heated space. A single Grundfos Model UP 26-64F pump is capable of providing 7 gpm design flow through the coils of an liquid-to-air heat exchanger against 14 Ft H_2O head. The Heat exchanger has been sized to supply 30,000 BTU/Hr from solar storage water at 120°.

In the Domestic Water Preheat Mode, the DHW pump begins to transfer heat energy from solar storage to domestic hot water storage anytime the solar storage temperature is 20°F greater than the temperature at the bottom of the DHW tank. The transfer circuit consists of a water filled loop connecting a finned tube heat exchanger in solar storage to a similar heat exchanger in DHW storage. The dual exchanger configuration provides double wall isolation between solar water and potable water. Energy transfer continues until the control differential is reduced to 4°F.

The solar control subsystem provides for the independent, non-exclusive operation of each of the three liquid pumps to accomplish a desired heat transfer function. Two differential thermostats, a low temperature sensor and a standard two stage room thermostat provide the controller input signals.

The collector differential thermostat will start pump P1 when probe S1 is 20°F hotter than probe S3. When the temperature of probe S3 becomes 4°F ± 2°F colder than S1, pump P1 will turn off. This decision logic is shown in Figure 2-3.

The DHW differential thermostat will start pump P3 when probe S2 is 20°F hotter than probe S4. When the temperature of probe S4 becomes 4°F ± 2°F colder than probe S2, pump P3 will turn off. This decision logic is shown in Figure 2-4.

Freeze Protect: The differential thermostat is factory equipped with a freeze protect feature that will close the N-O contacts when probe #1 (typically collector probe) shows a temperature of 40°F ± 5°F. Since the system is designed to use passive drain down of the collectors for freeze protection, this feature must be disabled per vendor instructions from the collector control unit.

Boil Protect: The differential thermostat is factory equipped with a boil protect feature that will turn the controller off when a temperature of 180°F is reached at the collector. This feature must be disabled per vendor instructions for the unit used to control collector operation.

Figures 2-3, 2-4, and 2-5 show the decision logic for the Collect and Store, Heat Domestic Water and Space Heat control modes. A wiring diagram for the control subsystem is shown in Figure 2-6.

SYSTEM DIAGRAM

COLD IN

TEMPERING
VALVE

DOMESTIC
HOT WATER
TANK WITH
HEAT EXCHANGER

HOT
OUT

P3

(S4)

AIR TO
LOAD

WATER-TO-AIR
HEAT
EXCHANGER

AUX.
FAN

EXPANSION
TANK

LOW TEMP.
SENSOR

P2

(S1)

COLLECTORS

SOLAR STORAGE

(S3)

(S2)

P1

NO ← COLLECTOR 20°F G. T. STORAGE → YES → TURN PUMP P1 ON → COLLECTOR 4°F G. T. STORAGE → NO → TURN PUMP P1 OFF

YES
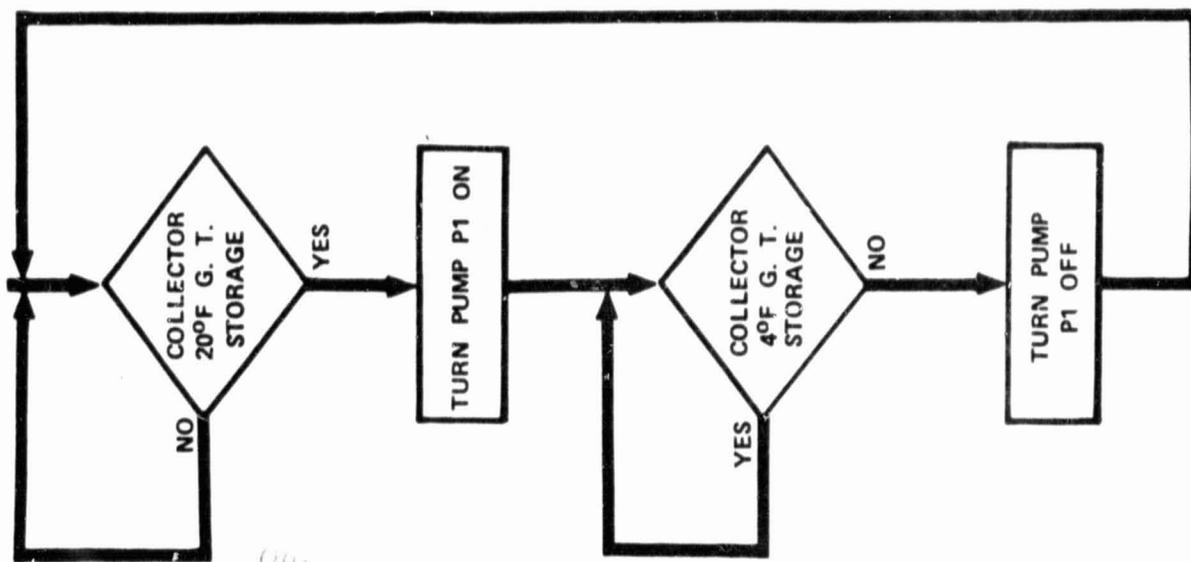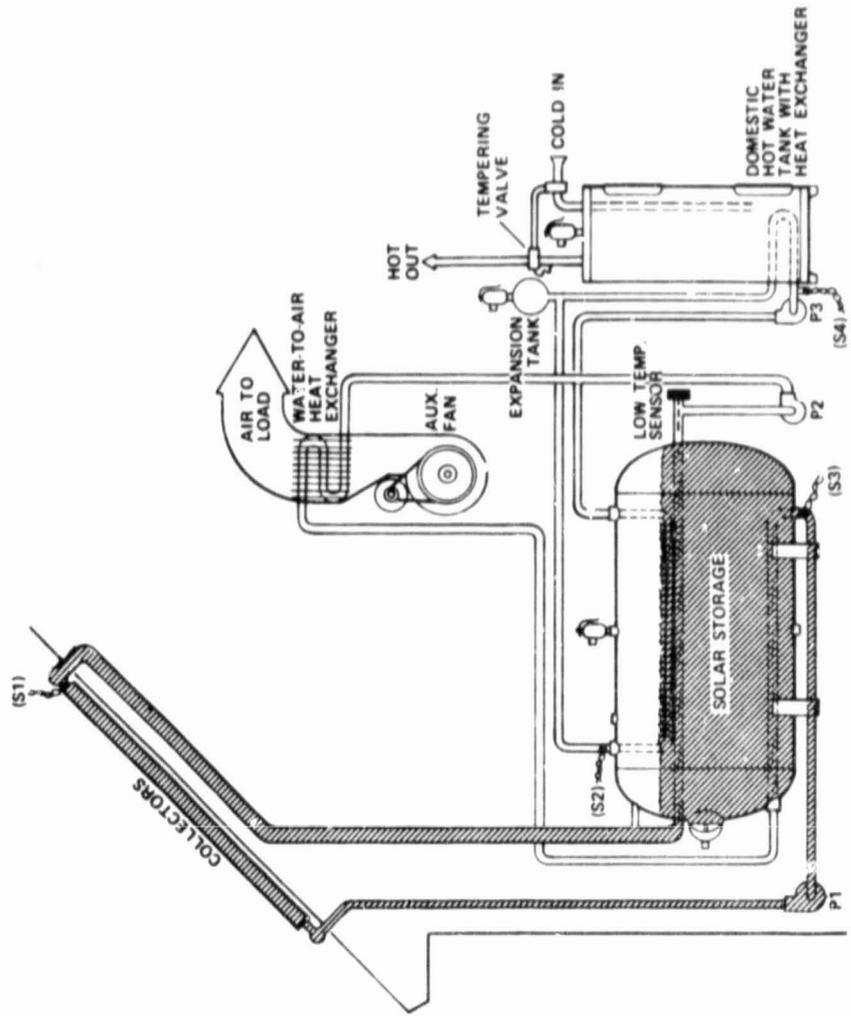
Figure 2-3 Collect and Store

9
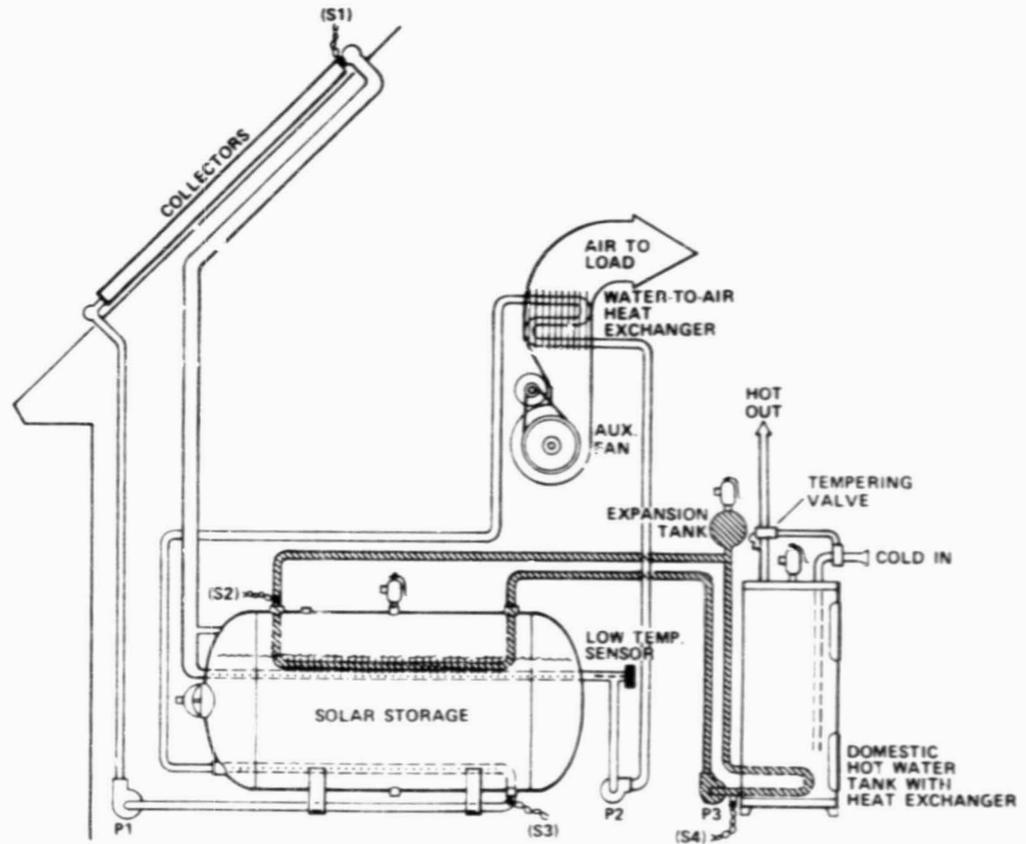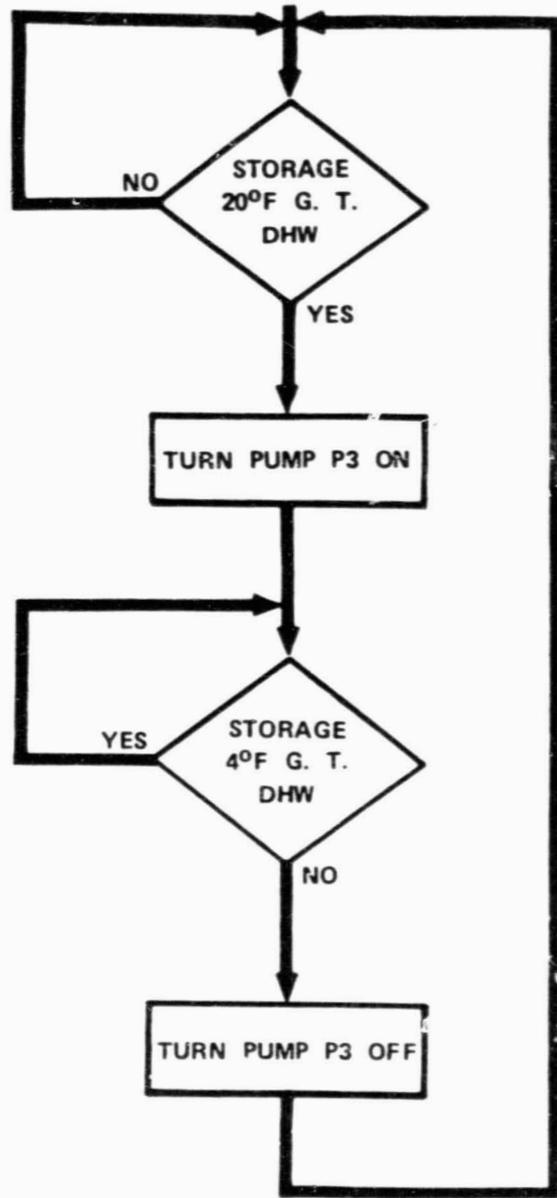
Figure 2-4   Heat Domestic Hot Water

SYSTEM DIAGRAM

COLLECTORS

(S1)

AIR TO LOAD

WATER-TO-AIR HEAT EXCHANGER

AUX. FAN

EXPANSION TANK

LOW TEMP. SENSOR

P2

SOLAR STORAGE

(S3)

(S2)

P1

TEMPERING VALVE

COLD IN

HOT OUT

DOMESTIC HOT WATER TANK WITH HEAT EXCHANGER

P3

(S4)

ROOM (DEG)°F G. T. SET POINT

YES

NO

STORAGE G. T. LOW TEMP LIMIT

YES

NO

TURN PUMP P2 ON

TURN AUXILIARY HEAT ON
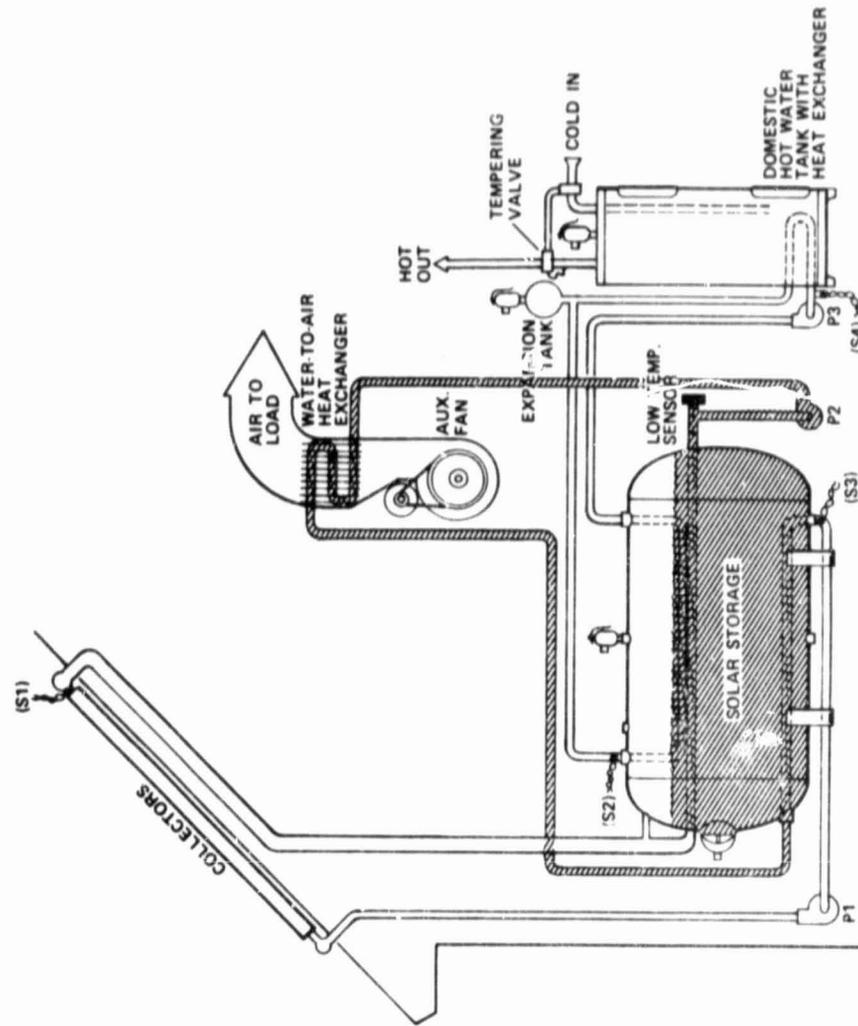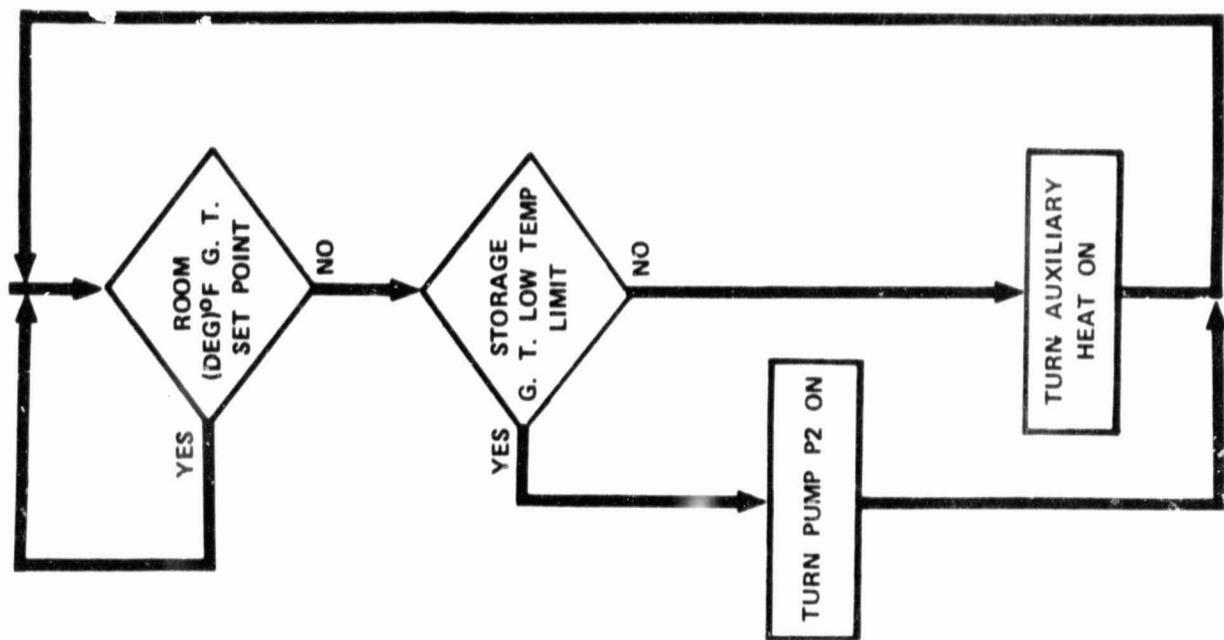
Figure 2-5 Space Heat

11
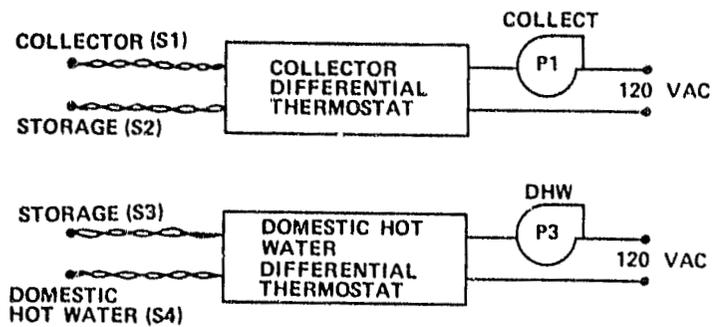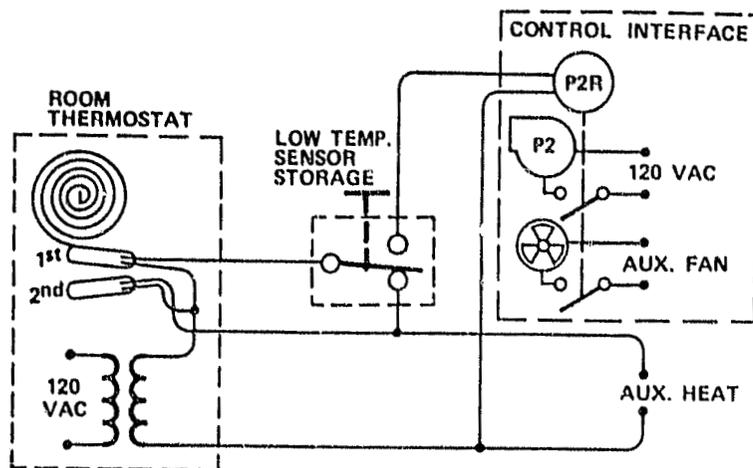
CONTROL DIAGRAM

Figure 2-6 Control Wiring

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The sensor designations in Figure 2-2 are in accordance with NBS-IR-76-1137 [5]. The measurement symbol prefixes, W, T, EP and I represent respectively: flow rate, temperature, electric power, and insolation.

2.1 Typical System Operation

Curves depicting typical system operation on a cool clear day
(November 17, 1979) are presented in Figures 2.1-1 (a) through (c).
Figure 2.1-1 (a) shows the insolation (I001) on the collector array
and the period when the array was operating (shaded area). On this
particular day the array turned on for a short period at 0902 hours
and then started normal operation at 0924 hours. All collected energy
is provided to storage. The array continued to operate until 1516
hours and then shut down for the day.

Figure 2.1-1 (b) shows typical collector array temperatures during the
day. As the sun started to rise at approximately 0720 hours, the ab-
sorber plate temperature (T107) began to rise rapidly and reached 140°F
before the system began normal operation at 0924 hours. It should be
noted that the temperature of this sensor is not the control sensor that
governs system operation.

During the operational period the absorber plate temperature generally
tracked the insolation level and collector outlet temperature (T101)
showed some lag, as would be expected. Collector outlet temperature (T101)
closely tracked the inlet temperature (T100) with a slight lag.

Figure 2.1-1 (c) shows the temperature at the top, middle and bottom of
the storage. The solar energy from the collectors is supplied directly to
the storage tank. Prior to the collector array turn on (0924) the middle
of storage (T201) and bottom of storage (T202) were approximately 13°F
cooler than top of storage (T200). Upon turn on, T200 dropped while T201
and T202 increased due to the stratification perturbation taking place.
At about 1030 hours, T201 and T202 began tracking T200. When the collector
array turned off at 1516 hours, the three storage sensors were within a few
degrees of each other. Storage cool down was very slight until after 2200
hours when a slight demand was placed on the solar space heating subsystem.
At this time T202 exhibited a slight temperature decline as energy was
furnished to space heating.

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NOVEMBER 17, 1979
SITE: 039 IBM SYSTEM 3, GLENDO, WYOMING
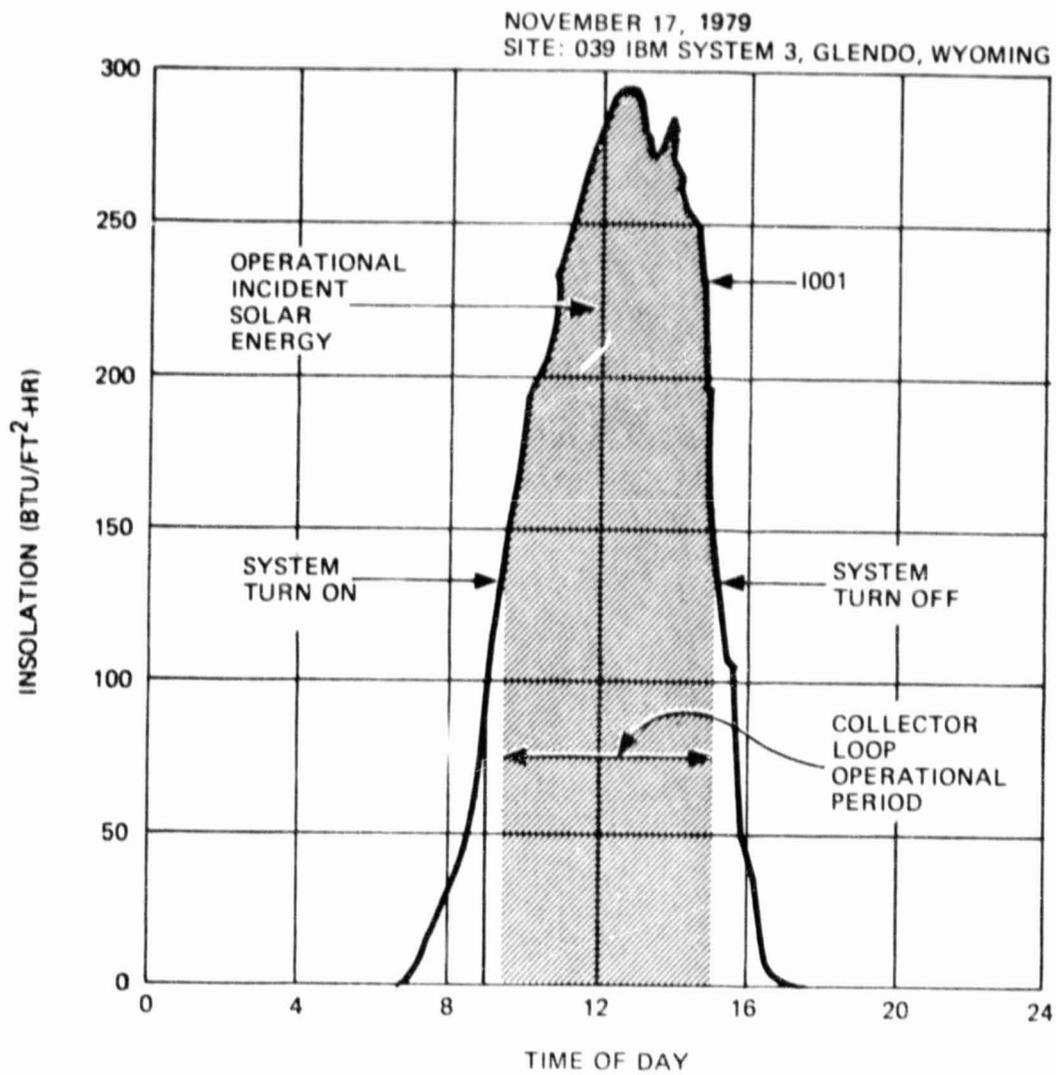
Figure 2.1-1(a) Solar Insolation Versus Time of Day

15
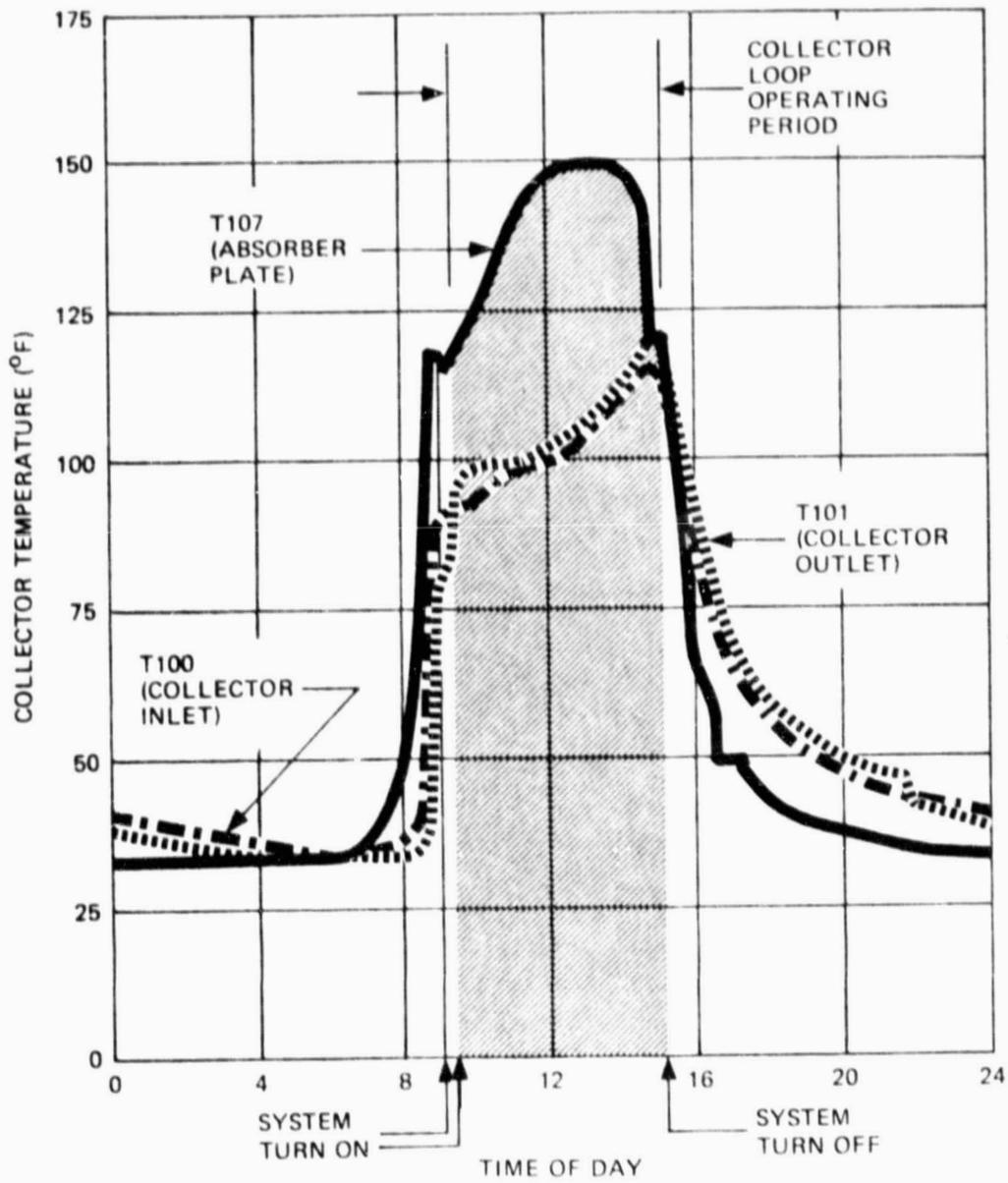
Figure 2.1-1(b) Collector Temperatures Versus Time

16
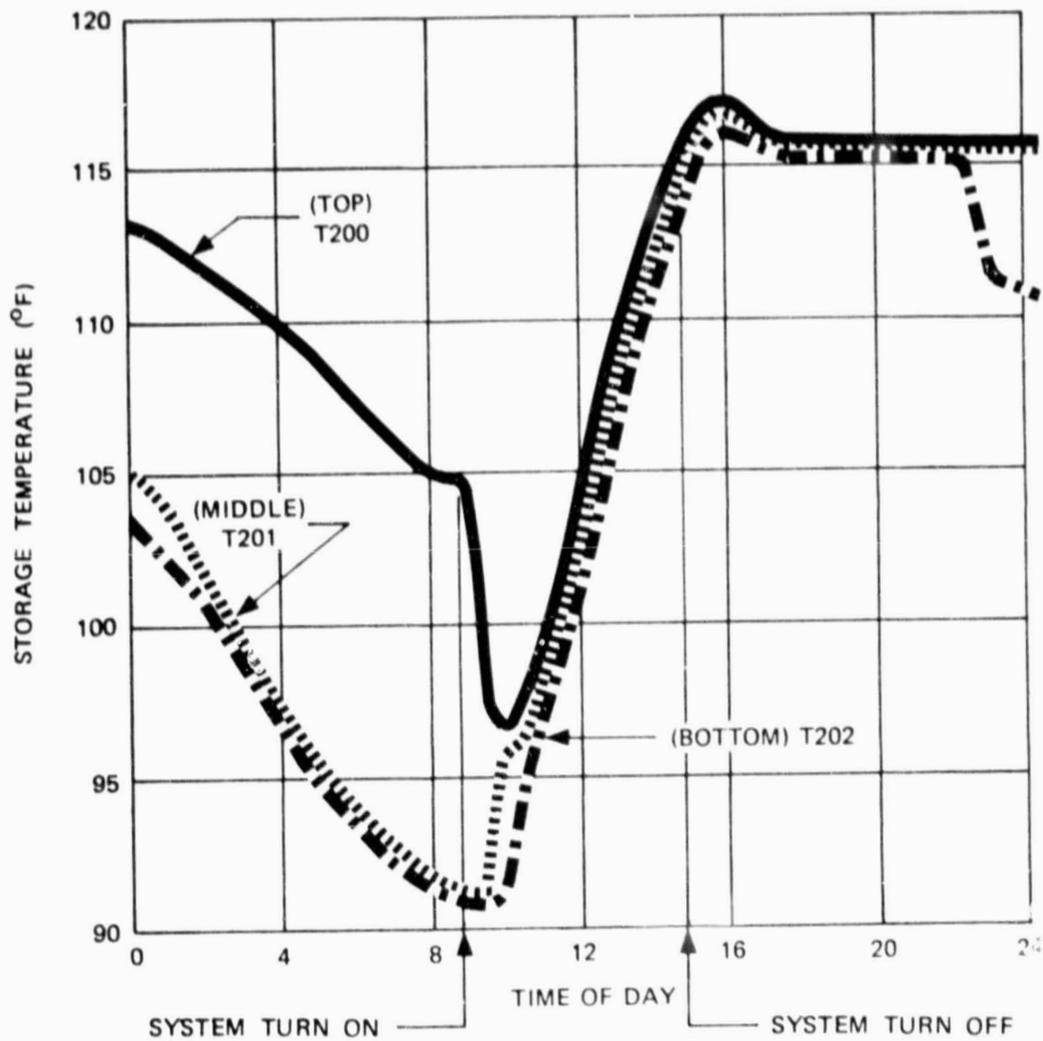
Figure 2.1-1(c) Storage Temperature Versus Time of Day

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2.2 Typical System Operating Sequence

Figure 2.2-1 presents bar charts showing typical system operating sequences for November 17, 1979. This data correlates with the curves presented in Figure 2.1-1 and provides some additional insight into those curves.

Solar space heating was utilized until 0804 hours, at which time it turned off and auxiliary space heat cycled on and off until 1006 hours. At 1022 hours solar space heating turned on briefly for five minutes and did not turn on again until 2237 hours from which time it cycled on and off through 2351 hours.

Solar energy was furnished to the domestic hot water tank for about a continuous three-hour period from 1121 hours through 1422 hours. Auxiliary electrical energy was supplied to the domestic hot water tank in six short turn-ons from 0830 hours til 1708 hours for a total time of approximately 45 minutes. Total hot water consumed on this day was nearly 40 gallons.

This day was characterized by freezing night temperatures with warming daytime temperatures. The design efficiency is indicated by its nearly exclusive use of solar energy with auxiliary providing only an occasional boost to both space and domestic hot water.
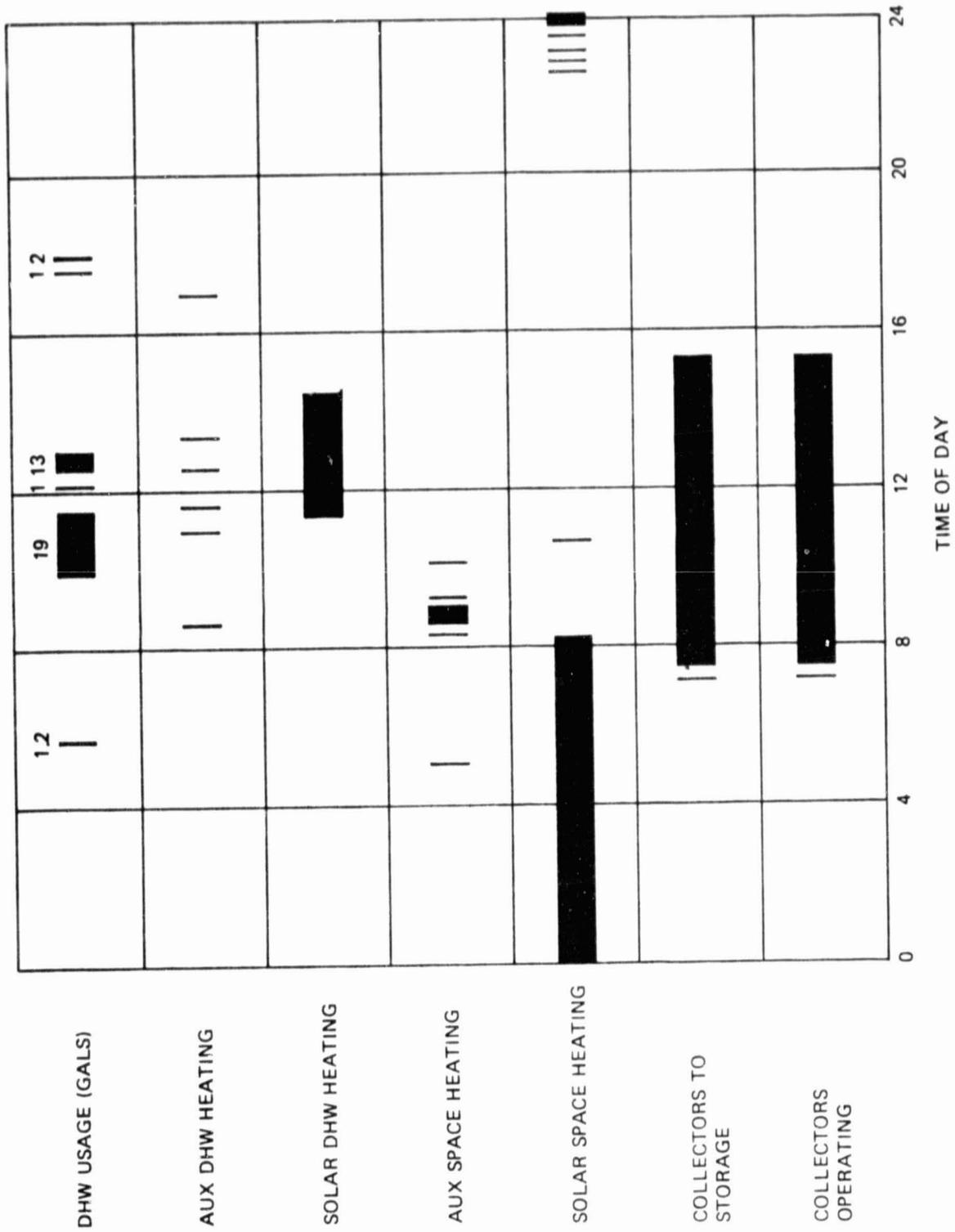
Figure 2.2-1 Typical System Operating Sequence

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3. PERFORMANCE ASSESSMENT

The performance of the IBM System 3 Solar Energy System has been evaluated for the January 1979 through December 1979 time period. Two perspectives have been taken in this assessment. The first looks at the overall system view in which the total solar energy collected, the system load, the measured values for solar energy used and the system solar fraction have been presented. Also presented, where applicable, are the expected values for solar energy used and system solar fraction. The expected values have been derived from a modified f-Chart analysis which uses measured weather and subsystem loads as inputs (f-Chart is the designation of an analytical procedure for designing solar heating systems that was developed by the Solar Energy Laboratory, University of Wisconsin-Madison). The model used in the analysis is based on manufacturers data and other known system parameters. The second view presents a more in-depth look at the performance of individual components. Details relating to the performance of the collector array and storage sub-systems are presented first, followed by details pertaining to the domestic hot water subsystem and the space heating subsystem. Included in this are all parameters pertinent to the operation of each individual subsystem.

The performance assessment of any solar energy system is highly dependent on the prevailing climatic conditions at the site during the period of performance. The original design of the system is generally based on the long-term averages for available insolation and temperature. Deviations from these long-term averages can significantly affect the performance of the system. Therefore, before beginning the discussion of actual system performance, a presentation of the measured and long-term averages for critical climatic parameters has been provided.

3.1 System Performance

This Seasonal Report provides a system performance evaluation summary
of the operation of the IBM-System 3 Solar Energy System located in
Glendo, Wyoming. This analysis was conducted by evaluation of
measured system performance against the expected performance with long-term
average climatic conditions. The performance of the system is evaluated by
calculating a set of primary performance factors which are based on those
proposed in the intergovernmental agency report, "Thermal Data Requirements
and Performance Evaluation Procedures for the National Solar Heating and
Cooling Demonstration Program" [5]. The performance of the major subsystems
is also evaluated in subsequent sections of this report.

The measurement data were collected for the period January 1979 through
December 1979. System performance data were provided through an IBM
developed Central Data Processing System (CDPS) [4] consisting of a remote
Site Data Acquisition System (SDAS), telephone data transmission lines
and couplers, an IBM System 7 computer for data management, and an IBM
System 370/145 computer for data processing. The CDPS supports the col-
lection and analysis of solar data acquired from instrumented systems
located throughout the country. These data are processed daily and
summarized into monthly performance formats which form a common basis
for comparative system evaluation. These monthly summaries are the basis
of the evaluation and data given in this report.

The solar energy system performance summarized in this section can be
viewed as the dependent response of the system to certain primary inputs.
This relationship is illustrated in Figure 3.1-1. The primary inputs are
the incident solar energy, the outdoor ambient temperature and the system
load. The dependent responses of the system are the system solar fraction
and the total energy savings. Both the input and output definitions are
as follows:

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SYSTEM
LOAD

SOLAR ENERGY SYSTEM

INCIDENT SOLAR ENERGY →

→ SYSTEM SOLAR FRACTION

ENERGY
COLLECTION
AND
STORAGE
SUBSYSTEM

LOAD
SUBSYSTEM(S)

AMBIENT TEMPERATURE →

→ TOTAL ENERGY SAVINGS

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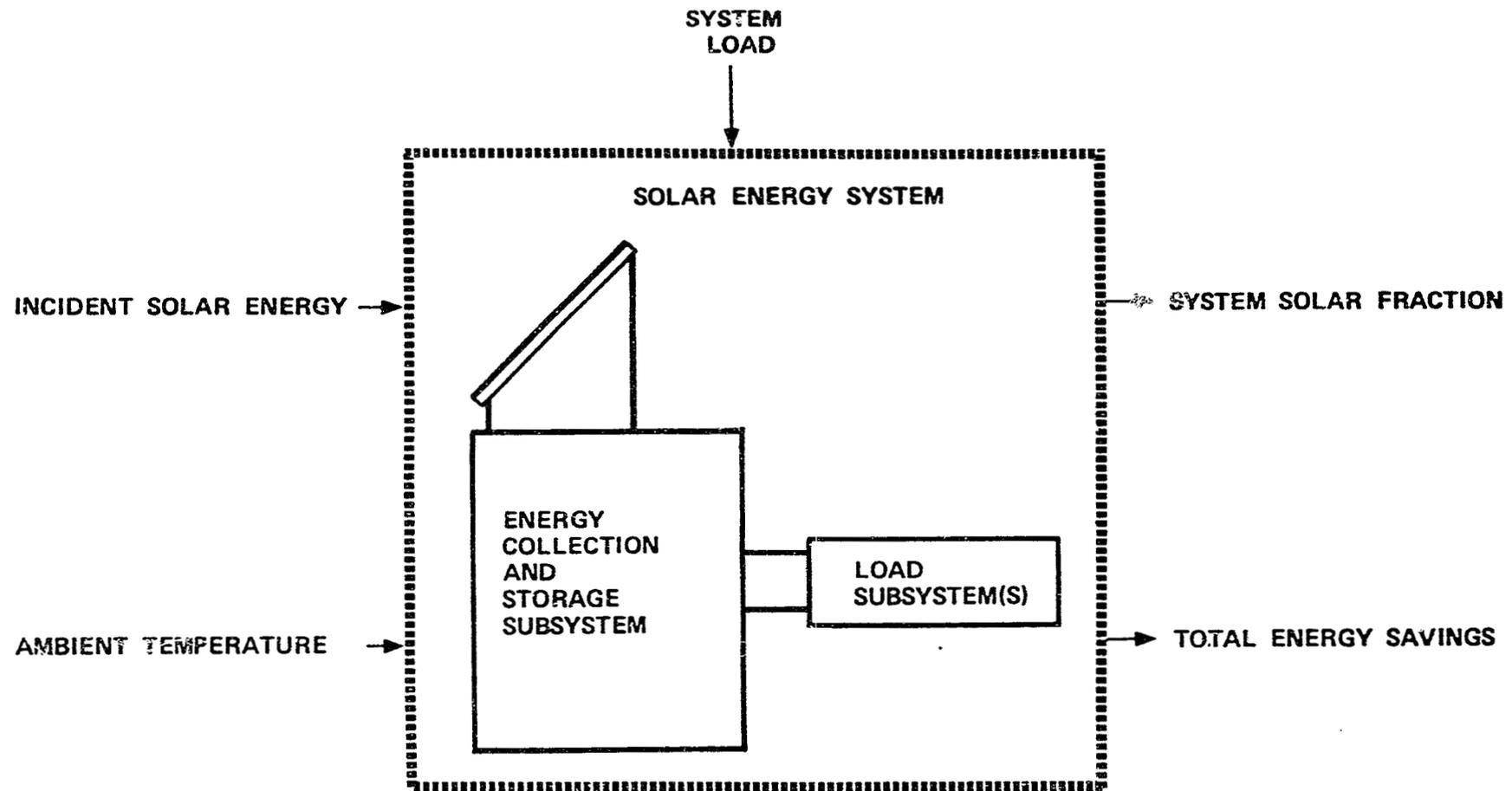
Figure 3.1-1 Solar Energy System Evaluation Block Diagram

Inputs

- Incident Solar Energy - The total solar energy incident on the collector array and available for collection.

- Ambient Temperature - The temperature of the external environment which affects both the energy that can be collected and the energy demand.

- System Load - The loads that the system is designed to meet, which are affected by the life style of the user (space heating/cooling, domestic hot water, etc., as applicable).

Outputs

- System Solar Fraction - The ratio of solar energy applied to the system loads to total energy (solar plus auxiliary energy) required by the loads.

- Total Energy Savings - The quantity of auxiliary energy (electrical or fossil) displaced by the solar energy.

The monthly values of the inputs and outputs for the total operational period are shown in Table 3.1-1, the System Performance Summary. Comparative long-term average values of daily incident solar energy, and outdoor ambient temperatture are given for reference purpose. The long-term data are taken from Reference 1 of Appendix C. Generally the solar energy system is designed to supply an amount of energy that results in a desired value of system solar fraction while operating under climatic conditions that are defined by the long-term average value of daily incident solar energy and

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Table 3.1-1

System Performance Summary

Month	Daily Incident Solar Energy per Unit Area @ 35° Tilt (Btu/ft²Day)		Ambient Temperature °F		System Load- Measured (Million Btu)	Solar Fraction (Percent)		Total Energy Savings (Million Btu)
	Measured	Long Term Average	Measured	Long Term Average		Measured	Expected	
Jan 79	691	1283	8	23	29.068	7	4	2.306
Feb 79	1275	1600	28	27	16.613	18	15	3.455
Mar 79	951	1870	39	31	12.248	26	16	3.669
Apr 79	1553	1985	47	43	3.714	61	38	2.535
May 79	1406	2089	51	53	4.114	70	68	3.313
Jun 79	1838	2239	65	62	2.248	89	73	2.337
Jul 79	2047	2327	72	71	0.246	66	88	0.726
Aug 79	1796	2281	68	70	0.099	37	98	0.815
Sep 79	1951	2134	65	59	0.923	93	98	1.928
Oct 79	1518	1833	50	48	5.457	61	64	3.906
Nov 79	1166	1379	29	34	14.169	17	18	2.730
Dec 79	1025	1177	32	26	13.448	16	14	2.358
Total	17,220	22,197	--	--	102.347	--	--	30.078
Average	1,435	1,850	46	46	8.529	24 *	22 *	2.507

* Averages are weighted values

outdoor ambient temperature. If the actual climatic conditions are close
to the long-term average values, there is little adverse impact on the
system's ability to meet design goals. This is an important factor in
evaluating system performance and is the reason the long-term average
values are given. The data reported in the following paragraphs are
taken from Table 3.1-1.

The outdoor ambient temperature influences the operation of the solar energy
system in two important ways. First the operating point of the collectors
and consequently the collector efficiency or energy gain is determined by
the difference in the outdoor ambient temperature and the collector inlet
temperature. This will be discussed in greater detail in Section 3.2.1.
Secondly the load is influenced by the outdoor ambient temperature. The
long-term average daily ambient temperature was 46°F for the IBM System 3
site which was exactly the measured value. On a monthly basis November,
December, January and February were the worst months temperaturewise.
January was an extremely cold month with measured temperature 15°F below
the long term average and insolation was only a little more than half the
long term average. Also, November was below the long term temperature and
insolation averages. Every month of the year showed lower insolation
than for the long term average. For the year measured insolation was only
about 78 percent of the expected long term average.

The system load was expected to vary in a manner roughly in inverse proportion
to the average monthly ambient temperature, other factors remaining constant.
During the twelve month reporting period, a total of 48.55 million Btu of
solar energy was collected and the total system load was 102.35 million Btu.
The measured amount of solar energy delivered to the load was 27.31 million
Btu.

Also presented in Table 3.1-1 are the measured and expected values of
system solar fraction where system solar fraction is the ratio of solar
energy applied to system loads to the total energy (solar plus auxiliary)
applied to the loads. The expected values have been derived from a
modified f-Chart analysis which uses measured weather and subsystem loads
as inputs (f-Chart is the designation of a procedure that was developed
by the Solar Energy Laboratory, University of Wisconsin-Madison, for modeling
and designing solar energy systems [8]). The model used in the analysis is
based on manufacturers' data and other known system parameters. The basis for
the model are empirical correlations developed for liquid and air solar
energy systems that are presented in graphical and equation form and referred
to as the f-Charts where 'f' is a designator for the system solar fraction.
The output of the f-Chart procedure is the expected system solar fraction.
This in turn is multiplied by the system load to derive the expected value
of solar energy used. The measured value of system solar fraction was computed
from measurements obtained through the instrumentation system of the energy
transfers that took place within the solar energy system. These represent the
actual performance of the system installed at the site.

Based on the original f-Chart analysis done during the design stage, the solar
energy system was expected to supply 46 percent of the estimated space
heating load of 94.44 million Btu. The estimated hot water heating load
was 20.6 million Btu based on 75 gallons per day at 140°F. The solar
energy system was expected to supply 80 percent of this load [10].

The original analysis was based on f-Chart with long-term average weather
conditions and estimated loads as inputs. In the f-Chart analysis done for
the Seasonal Report, actual weather and measured loads were used to give a
better estimate of expected performance. The small difference of 2 percentage
points between expected and actual system solar fraction indicates that this
technique was successful.

The average solar fraction for the space heating subsystem was 22 percent
based on a space heating load of 96.74 million Btu. The average solar fraction
for the hot water subsystem was 58 percent based on a load of 5.55 million Btu.

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Three factors account for the differences in the original estimates and the measured performance. These are:

1. Energy losses from the solar system

2. Differences in long-term average insolation and measured (actual) insolation

3. Differences in the estimated hot water load and the actual load.

The conclusions are that the solar energy system should be insulated to minimize the losses and designed for the actual loads to be encountered.

The total energy saving is the most important performance parameter for the solar energy system because the fundamental purpose of the system is to replace expensive conventional energy sources with inexpensive solar energy. In practical consideration, the system must save enough energy to cover both the cost of its own operation and to repay the initial investment of the system. In terms of the technical analysis presented in this report the net total energy savings should be a significant positive figure. The total energy savings for the IBM System 3 Solar Energy System was 30.08 million Btu or 8,813 kWh which is equivalent to 5 barrels of oil.

3.2 Subsystem Performance

The IBM System 3 Solar Energy Installation may be divided into four
subsystems:

1. Collector array
2. Storage
3. Heating
4. Hot Water

Each subsystem has been evaluated by the techniques defined in Section 3 and
is numerically analyzed each month for the monthly performance assessment.
This section presents the results of integrating the monthly data available
on the four subsystems for the period January 1979 through December 1979.

3.2.1 Collector Array Subsystem

The IBM System 3 collector array consists of 14 Sunworks, Model LA1001A flat plate liquid collectors having a gross area of 294 square feet. Flow details and other pertinent operational characteristics are shown in Figure 3.2.1-1. The collector subsystem analysis and data are given in the following paragraphs.

Collector array performance is described by the collector array efficiency. This is the ratio of collected solar energy to incident solar energy, a value always less than unity because of collector losses. The incident solar energy may be viewed from two perspectives. The first assumes that all available solar energy incident on the collectors be used in determining collector array efficiency. The efficiency is then expressed by the equation:

$$\eta_c = Q_s/Q_i \tag{1}$$

where
$$\eta_c = \text{Collector array efficiency}$$

$$Q_s = \text{Collected solar energy}$$

$$Q_i = \text{Incident solar energy}$$

The efficiency determined in this manner includes the operation of the control system. For example, solar energy can be available at the collector, but the collector absorber plate temperature may be below the minimum control temperature set point for collector loop operation, thus the energy is not collected. The monthly efficiency by this method is listed in the column entitled "Collector Array Performance" in Table 3.2.1-1.

COLLECTOR ARRAY

(14 COLLECTORS IN PARALLEL)

SINGLE COLLECTOR
FLOW PATTERN

SITE DATA

LOCATION — GLENDO, WYOMING
LATITUDE — 42.91° N
LONGITUDE — 106.47° W
AZIMUTH   — DUE SOUTH
COLLECTOR TILT — 35°
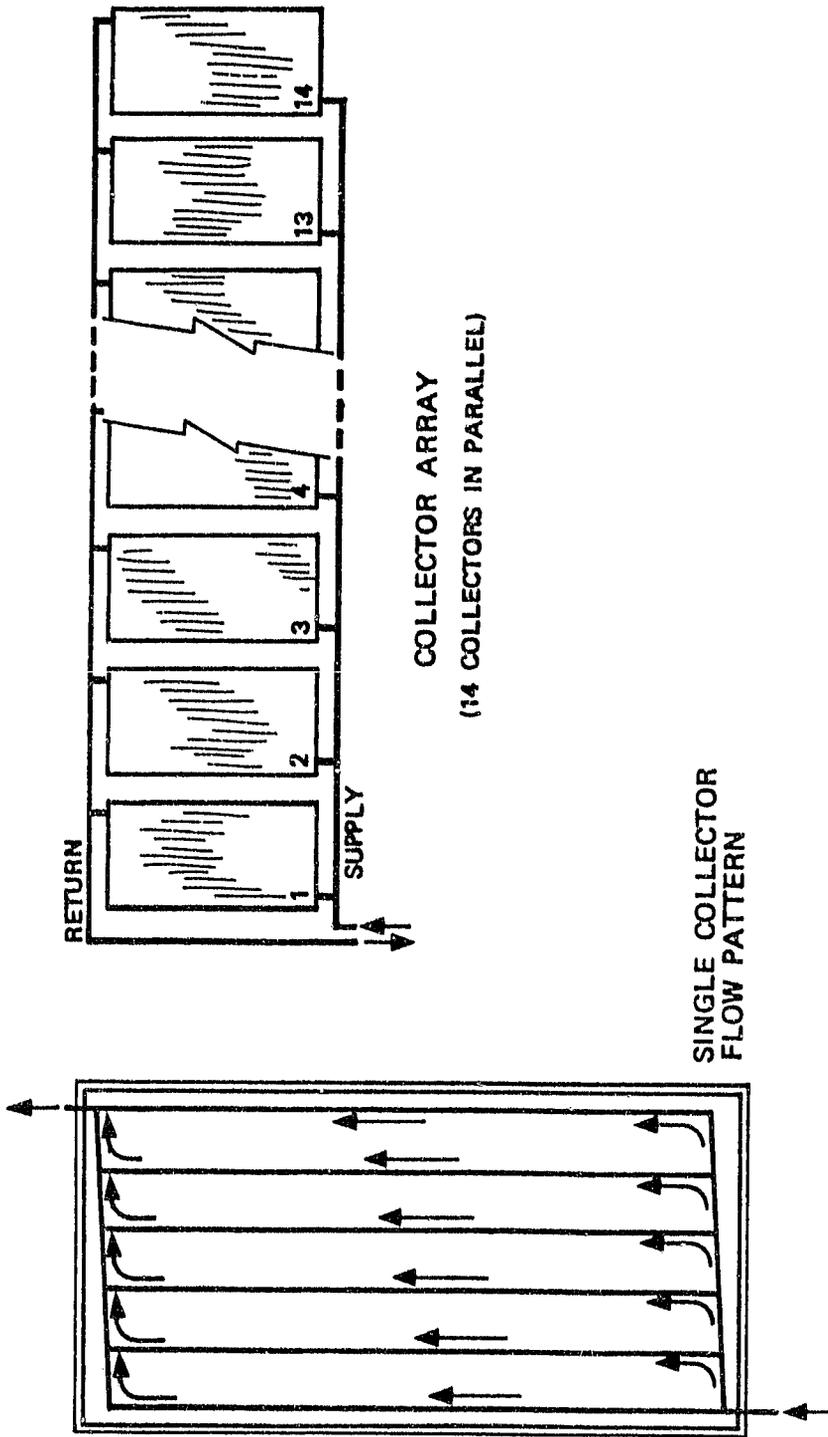
COLLECTOR DATA

MANUFACTURER — SUNWORKS
MODEL   — LA1001A
TYPE   — LIQUID (WATER)
NO. OF COLLECTORS — 14
FLOW PATHS   — 14
FLOW RATE   — 8 GPM

Figure 3.2.1-1 Collector Array Schematic

TABLE 3.2.1-1

COLLECTOR ARRAY PERFORMANCE

Month	Incident Solar Energy (Million Btu)	Collected Solar Energy (Million Btu)	Collector Array Efficiency	Operational Incident Energy (Million Btu)	Operational Collector Efficiency
Jan 79	6.295 *	2.846	0.452	4.464	0.64
Feb 79	10.493 *	4.330	0.413	9.504	0.46
Mar 79	8.669 *	4.503	0.519	7.969	0.57
Apr 79	13.695	5.394	0.394	11.974	0.45
May 79	12.812	4.454	0.348	9.997	0.45
Jun 79	16.213	4.508	0.278	12.206	0.37
Jul 79	18.656	3.736	0.200	13.058	0.29
Aug 79	16.368	3.342	0.204	11.548	0.29
Sept 79	17.204	4.367	0.254	13.297	0.33
Oct 79	13.834	4.566	0.330	11.460	0.40
Nov. 79	10.285 *	3.193	0.310	7.458	0.43
Dec 79	9.342 *	3.311	0.354	7.476	0.44
Total	153.866	48.550	---	120.411	--
Average	12.822	4.046	0.338	10.034	0.43

* Collector array tilt angle is 35° which provides lower than desired incident solar energy for winter months and higher in summer when system load is lowest.

The second viewpoint assumes that only the solar energy incident on the collector when the collector loop is operational be used in determining the collector array efficiency. The value of the operational incident solar energy used is multiplied by the ratio of the gross collector area to the gross collector array area to compensate for the difference between the two areas caused by installation spacing. The efficiency is then expressed by the equation:

$$n_{co} = Q_s/(Q_{oi} \times A_p/A_a) \qquad (2)$$

where n_{co} =   Operational collector array efficiency

Q_s =   Collected solar energy

Q_{oi} =   Operational incident solar energy

A_p =   Gross collector area (the product of the number of collectors and the envelope area of one collector)

A_a =   Gross collector array area (total area including all mounting and connecting hardware and spacing of units)

The monthly efficiency computed by this method is listed in the column entitled "Operational Collector Array Efficiency" in Table 3.2.1-1.

In the ASHRAE Standard 93-77 [6] a collector efficiency is defined in the same terminology as the operational collector array efficiency. However, the ASHRAE efficiency is determined from instantaneous evaluation under tightly controlled, steady state test conditions, while the operational collector array efficiency is determined from actual dynamic conditions of daily solar energy system operation in the field.

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The second viewpoint assumes that only the solar energy incident on the collector when the collector loop is operational be used in determining the collector array efficiency. The value of the operational incident solar energy used is multiplied by the ratio of the gross collector area to the gross collector array area to compensate for the difference between the two areas caused by installation spacing. The efficiency is then expressed by the equation:

$$n_{co} = Q_s/(Q_{oi} \times A_p/A_a)$$ (2)

where n_{co} = Operational collector array efficiency

Q_s = Collected solar energy

Q_{oi} = Operational incident solar energy

A_p = Gross collector area (the product of the number of collectors and the envelope area of one collector)

A_a = Gross collector array area (total area including all mounting and connecting hardware and spacing of units)

The monthly efficiency computed by this method is listed in the column entitled "Operational Collector Array Efficiency" in Table 3.2.1-1.

In the ASHRAE Standard 93-77 [6] a collector efficiency is defined in the same terminology as the operational collector array efficiency. However, the ASHRAE efficiency is determined from instantaneous evaluation under tightly controlled, steady state test conditions, while the operational collector array efficiency is determined from actual dynamic conditions of daily solar energy system operation in the field.

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The ASHRAE Standard 93-77 definitions and methods often are adopted
by collector manufacturers and independent testing laboratories in
evaluating collectors. The collector evaluation performed for this
report using the field data indicates that there was an insignificant
difference between the laboratory single panel collector data and the
collector data determined from long term field measurements. This is
not always the case, and there are two primary reasons for differences
when they exist:

- Test conditions are not the same as conditions
  in the field, nor do they represent the wide
  dynamic range of field operation (i.e. inlet and
  outlet temperature, flow rates and flow distri-
  bution of the heat transfer fluid, insolation
  levels, aspect angle, wind conditions, etc.)

- Collector tests are not generally conducted with
  units that have undergone the effects of aging
  (i.e. changes in the characteristics of the glazing
  material, collection of dust, soot, pollen or other
  foreign material on the glazing, deterioration of the
  absorber plate surface treatment, etc.)

Consequently field data collected over an extended period will generally
provide an improved source of collector performance characteristics for
use in long-term system performance definition.

The operational collector array efficiency data given in Table 3.2.1-1
are monthly averages based on instantaneous efficiency computations
over the total performance period using all available data. For de-
tailed collector analysis it was desirable to use a limited subset
of the available data that characterized collector operation under
"steady state" conditions. This subset was defined by applying the
following restrictions:

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(1) The measurement period was restricted to collector
     operation when the sun angle was within 30 degrees
     of the collector normal.

(2) Only measurements associated with positive energy gain
     from the collectors were used, i.e., outlet temperatures
     must have exceeded inlet temperatures.

(3) The sets of measured parameters were restricted to
     those where the rate of change of all parameters of
     interest during two regular data system intervals* was
     limited to a maximum of 5 percent.

Instantaneous efficiencies (n_j) computed from the "steady state"
operation measurements of incident solar energy and collected solar
energy by Equation (2)** were correlated with an operating point
determined by the equation:

$$x_j = \frac{T_i - T_a}{I} \qquad\qquad (3)$$

where x_j =   Collector operating point at the jth
                    instant

         T_i =   Collector inlet temperature

         T_a =   Outdoor ambient temperature

         I =   Rate of incident solar radiation

The data points (n_j, x_j) were then plotted on a graph of efficiency
versus operating point and a first order curve described by the slope-
intercept formula was fitted to the data through linear regression
techniques. The form of this fitted efficiency curve is:

---

*The data system interval was 5-1/3 minutes in duration. Values of
 all measured parameters were continuously sampled at this rate
 throughout the performance period.
**The ratio A_p/A_a was assumed to be unity for this analysis.

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$$\eta_j = b - mx_j \tag{4}$$

where η_j = Collector efficiency corresponding to the jth instant

b = Intercept on the efficiency axis

$(-)m$ = Slope

x_j = Collector operating point at j^{th} instant

The relationship between the empirically determined efficiency curve and the analytically developed curve will be established in subsequent paragraphs.

The analytically developed collector efficiency curve is based on the Hottel-Whillier-Bliss equation

$$\eta = F_R (\tau\alpha) - F_R U_L \frac{(T_i - T_a)}{I} \tag{5}$$

where η = Collector efficiency

F_R = Collector heat removal factor

τ = Transmissivity of collector glazing

α = Absorptance of collector plate

U_L = Overall collector energy loss coefficient

T_i = Collector inlet fluid temperature

T_a = Outdoor ambient temperature

I = Rate of incident solar radiation

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The correspondence between equations (4) and (5) can be readily seen.
Therefore by determining the slope-intercept efficiency equation from
measurement data, the collector performance parameters corresponding to
the laboratory single panel data can be derived according to the follow-
ing set of relationships:

$$b = F_R \tau \alpha$$
$$\text{and}$$
$$m = F_R U_L$$

(6)

where the terms are as previously defined

The discussion of the collector array efficiency curves in subsequent
paragraphs is based upon the relationships expressed by Equation (6).

In deriving the collector array efficiency curves by the linear re-
gression technique, measurement data over the entire performance period
yields higher confidence in the results than similar analysis over shorter
periods. Over the longer periods the collector array is forced to operate
over a wider dynamic range. This eliminates the tendency shown by some
types of solar energy systems* to cluster efficiency values over a narrow
range of operating points. The clustering effect tends to make the
linear regression technique approach constructing a line through a single
data point. The use of data from the entire performance period results
in a collector array efficiency curve that is more accurate in long-term
solar system performance prediction. The long-term curve and the curve
derived from the laboratory single panel data are shown in Figure 3.2.1-2.

The long-term curve shown in Figure 3.2.1-2 has a much lower negative slope
than the curve derived from single panel laboratory data. This is attri-
butable to the shrouding around the collectors in the array configuration
which reduces edge and back side losses. The efficiency of the long-term
data was somewhat lower than the single panel laboratory data in the opera-
ting point range from 0 to 0.35. The reason for this is not known, but it
is suspected that the flow rate of water for the single panel laboratory
data was somewhat higher than the long-term data flow rate which was approxi-
mately 15.3 pounds per hour per square foot.

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*Single tank hot water systems show a marked tendency toward clustering
because the collector inlet temperature remains relatively constant and
the range of values of ambient temperature and incident solar energy during
collector operation are also relatively restricted on a short-term basis.

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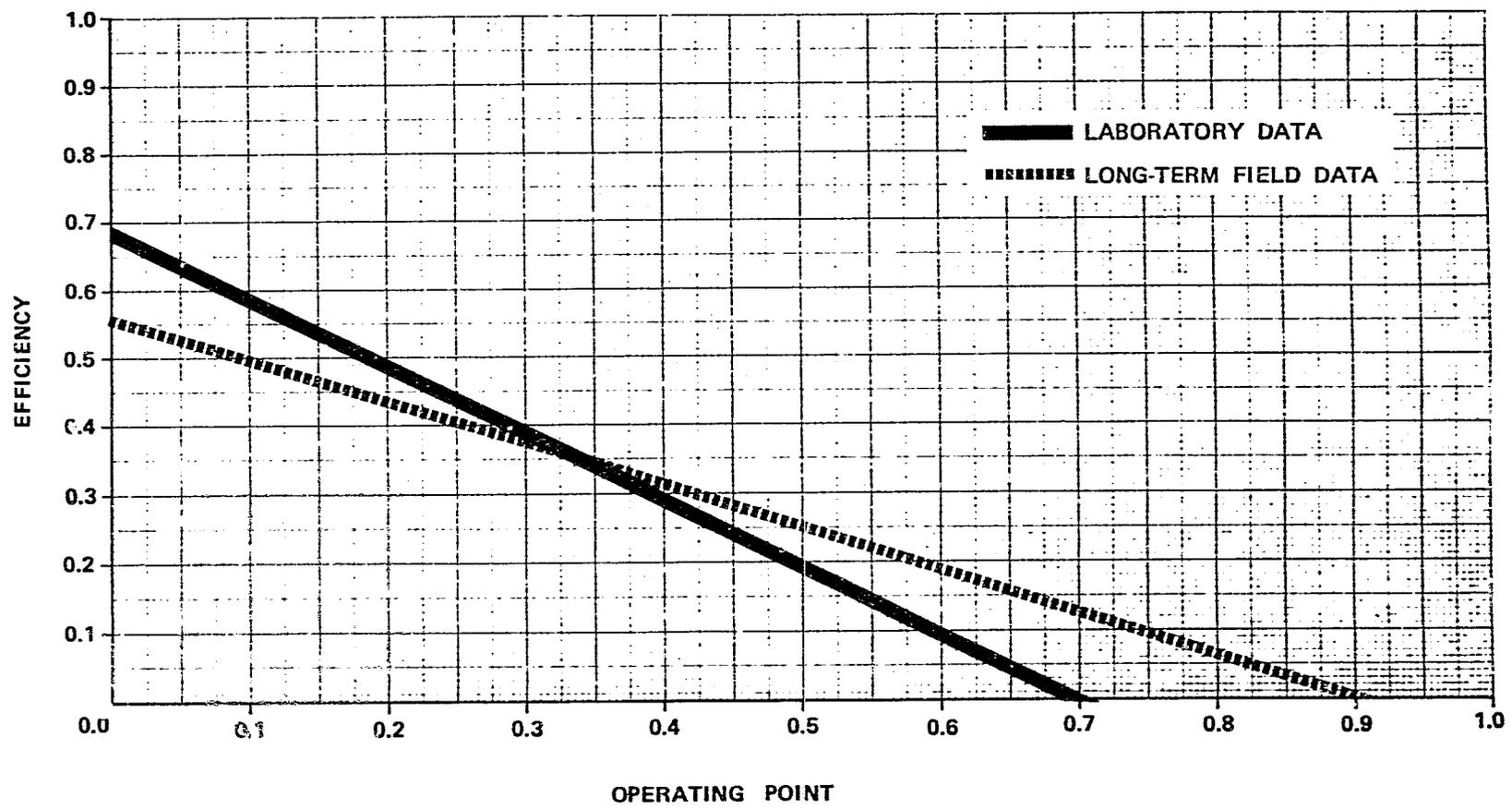
Figure 3.2.1-2 IBM System 3 Glendo Collector Efficiency Curve

Table 3.2.1-2 presents data comparing the monthly measured values of solar
energy collected with the predicted performance determined from the long-
term regression curve and the laboratory single panel efficiency curve.
The predictions were derived by the following procedure:

1. The instantaneous operating points were computed using
    Equation (3).

2. The instantaneous efficiency was computed using Equation
    (4) with the operating point computed in Step 1 above for:

    a. The long-term linear regression curve
        for collector array efficiency

    b. The laboratory single panel collector
        efficiency curve

3. The efficiencies computed in Steps 2a and 2b above
    were multiplied by the measured solar energy available
    when the collectors were operational to give two pre-
    dicted values of solar energy collected.

The error data in Table 3.2.1-2 were computed from the differences between
the measured and predicted values of solar energy collected according to
the equation:

$$\text{Error} = (A-P)/P \tag{7}$$

where   A   =   Measured solar energy collected

           P   =   Predicted solar energy collected

The computed error is then an indication of how well the particular prediction
curve fitted the reality of dynamic operating condition in the field.

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TABLE 3.2.1-2

ENERGY GAIN COMPARISON
(ANNUAL)

SITE: IBM 3 GLENDO   GLENDO, WYOMING

Month	Collected Solar Energy (Million Btu)	Error	
		Field Derived Long-Term	Laboratory Single Panel
Jan 79	1.505	-0.143	-0.070
Feb 79	3.459	0.012	-0.078
Mar 79	2.236	-0.028	-0.160
Apr 79	3.914	-0.026	-0.150
May 79	3.073	-0.011	-0.099
Jun 79	3.418	-0.008	-0.086
Jul 79	3.715	0.020	-0.010
Aug 79	3.419	0.034	-0.015
Sep 79	4.218	0.003	-0.057
Oct 79	4.057	0.000	-0.097
Nov 79	2.845	0.017	-0.084
Dec 79	2.806	0.060	-0.024
Average	3.222	0.001	-0.076

The values of "Collected Solar Energy" given in Table 3.2.1-2 are not necessarily identical with the values of "Collected Solar Energy" given in Table 3.2.1-1. Any variations are due to the differences in data processing between the software programs used to generate the monthly performance report data and the component level collector analysis program. These data are shown in Table 3.2.1-2 only because they form the references from which the error data given in the table are computed.

The data from Table 3.2.1-2 illustrates that for the IBM System 3 site the average error computed from the difference between the measured solar energy collected and the predicted solar energy collected based on the field derived long-term collector array efficiency curve was 0.1 percent. For the curve derived from the laboratory single panel data, the error was 7.6 percent. Thus the long-term collector array efficiency curve gives significantly better results than the manufacturer's laboratory single panel curve.

A histogram of collector array operating points illustrates the distribution of instantaneous values as determined by Equation (3) for the entire month. The histogram was constructed by computing the instantaneous operating point value from site instrumentation measurements at the regular data system intervals throughout the month, and counting the number of values within contiguous intervals of width 0.01 from zero to unity. The operating point histogram shows the dynamic range of collector operation during the month from which the midpoint can be ascertained. The average collector array efficiency for the month can be derived by projecting the midpoint value to the appropriate efficiency curve and reading the corresponding value of efficiency.

Another characteristic of the operating point histogram is the shifting of the distribution along the operating point axis. This can be explained in terms of the characteristics of the system and the climatic factors

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of the site, i.e., incident solar energy and ambient temperature. Figure
3.2.1-3 shows two histograms that illustrate a typical winter month
(February) and a typical summer month (July) operation. The actual
midpoint which represents the average operating point for February is
at 0.25 and for July at 0.32.

Table 3.2.1-1 presents the monthly values of incident solar energy,
operational incident solar energy, and collected solar energy from
the 12 month performance period. The collector array efficiency and
operational collector array efficiency were computed for each month
using Equations (1) and (2). The values of operational collector
efficiency range from a maximum of 0.64 in January 1979 to a minimum
of 0.29 in July and August of 1979. On the average the operational
collector array efficiency exceeded the collector array efficiency
which included the effect of the control system by 27 percent.

It is to be noted that the actual slope or tilt angle for these collectors
was 35° from the horizontal. The optimum tilt angle for a space heating
and hot water heating system is latitude plus 10° which is equal to 53°
for this site. The loss due to this non-optimum tilt angle is approximately
six percent.

Additional information concerning collector array analysis in general
may be found in Reference [8]. The material in the reference describes
the detailed collector array analysis procedures and presents the results
of analyses performed on numerous collector array installations across
the United States.

IBM GLENDO GLENDO, WYOMING

COLLECTOR TYPE: SUNWORK, INC. COLLECTOR MODEL: LA100lA

OPERATING POINT HISTOGRAM - FEBRUARY

OPERATING POINTS OVER 10%		
POINT		PERCENT
.31		10.058

OPERATING POINT HISTOGRAM - JULY
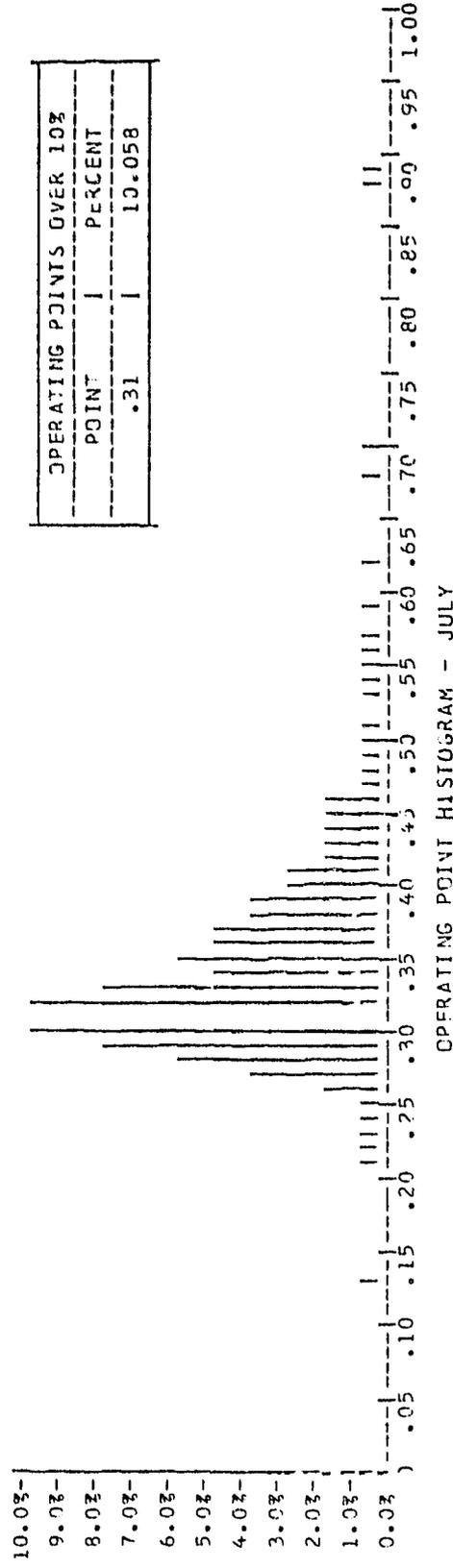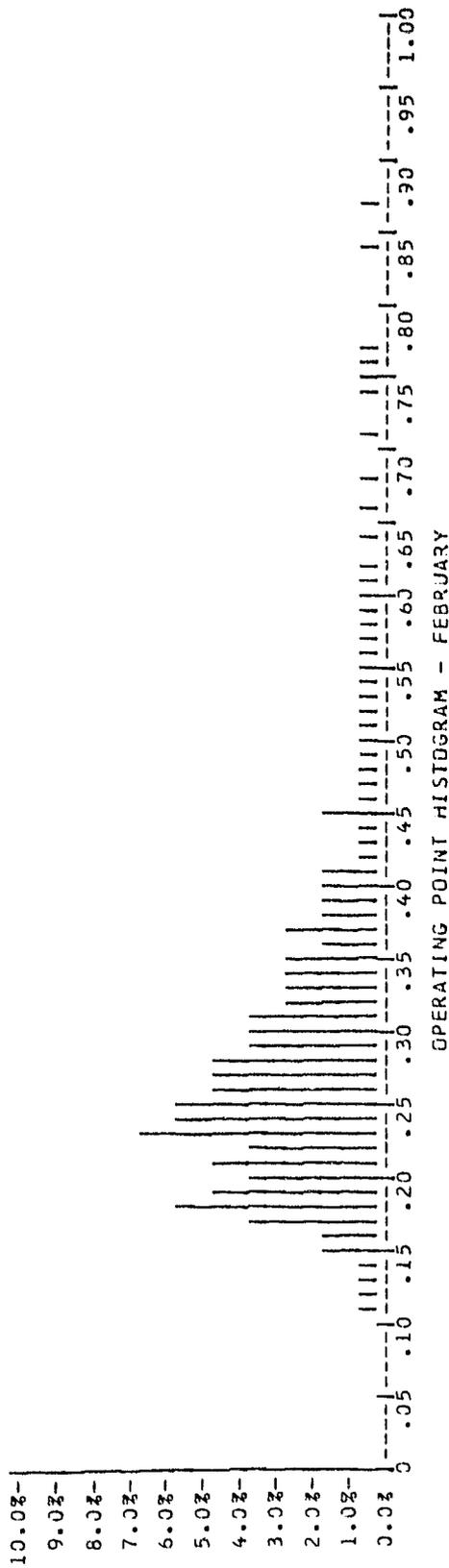
ABCISSA = (INLET TEMP - AMBIENT TEMP)/INSOLATION DEG F - HR - SQFT/BTJ
ORDINATE = PERCENT OF TOTAL OCCURRENCES

Figure 3.2.1-2 IBM System 3 Glendo Operating Point Histogram for Typical Winter and Summer Months

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3.2.2   Storage Subsystem

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

$$n_s = (\Delta Q + Q_{so})/Q_{si} \qquad (8)$$

where:

ΔQ =   Change in stored energy. This is the difference in the estimated stored energy during the specified reporting period, as indicated by the relative temperature of the storage medium (either positive or negative value)

Q_{so} =   Energy from storage. This is the amount of energy extracted by the load subsystem from the primary storage medium

Q_{si} =   Energy to storage. This is the amount of energy (both solar and auxiliary) delivered to the primary storage medium

Evaluation of the system storage performance under actual transient system operation and weather conditions can be performed using the parameters listed above. The utility of these measured data in evaluation of the overall storage design can be illustrated in the derivation presented below.

The overall thermal properties of the storage subsystem design can be derived empirically as a function of average storage temperature for the reporting period and the ambient temperature in the vicinity of the storage tank.

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An effective storage heat transfer coefficient for the storage sub-system can be defined as follows:

$$C = (Q_{si} - Q_{so} - \Delta Q)/[(\overline{T}_s - \overline{T}_a) \times t] \frac{Btu}{Hr-°F} \qquad (6)$$

where

C   =   Effective storage heat transfer coefficient

Q_{si} =   Energy to storage

Q_{so} =   Energy from storage

ΔQ =   Change in stored energy

$\overline{T}_s$ =   Storage average temperature

$\overline{T}_a$ =   Average ambient tempeature in the
                        vicinity of storage

t   =   Number of hours in the month

The effective storage heat transfer coefficient is comparable to the heat loss rate defined in ASHRAE Standard 94-77 [7]. It has been calculated for each month in this report period and included, along with Storage Average Temperature, in Table 3.2.2-1.

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TABLE 3.2.2-1

STORAGE SUBSYSTEM PERFORMANCE

Month	Energy To Storage (Million Btu)	Energy From Storage (Million Btu)	Change In Stored Energy (Million Btu)	Storage Efficiency	Storage Average Temperature (°F)	Effective Storage Heat Loss Coefficient (Btu/Hr°F)
Jan 79	2.846	2.066	0.002	0.727	92	33
Feb 79	4.330	3.070	0.020	0.714	95	53
Mar 79	4.503	3.205	- 0.174	0.673	98	52
Apr 79	5.394	2.254	0.459	0.503	138	34
May 79	4.454	2.959	- 0.675	0.513	138	40
Jun 79	4.508	2.201	0.433	0.584	157	30
Jul 79	3.736	0.838	0.070	0.243	181	36
Aug 79	3.342	0.914	- 0.057	0.256	173	34
Sep 79	4.367	1.834	- 0.057	0.407	170	36
Oct 79	4.566	3.389	- 0.521	0.628	125	35
Nov 79	3.193	2.372	- 0.004	0.742	96	32
Dec 79	3.311	2.208	0.028	0.675	96	40
Total	48.55	27.310	- 0.476	---	--	--
12 Month Average	4.046	2.276	- 0.040	0.555	130	38

The storage efficiency values are more closely related to usage than to the design and quality of the storage container. If the energy placed in storage is not used in a short period of time (hours), this energy escapes from storage to the lower temperature surroundings. The storage tank at the IBM System 3 site is located in a poured concrete walled room approximately 80 percent below ground level. The room is attached to the basement of the dwelling but separated by a door. The tank has steel feet set on concrete blocks on the concrete floor. The three partially buried exterior walls of the room tend to have a moderating effect on the room temperature.

The preferred use of storage is illustrated in Figure 2.1-1 (c) where most of the solar energy stored during the day was used that night. From Figure 2.1-1 (c), the typical temperature stratification in the storage can be seen. The close tracking of the middle of the storage with the bottom of storage is because the hot water to space heat is drawn from the bottom and returned to the middle.

3.2.3 Hot Water Subsystem

The performance of the hot water subsystem is described by comparing the amount of solar energy supplied to the subsystem with the energy required to satisfy the total hot water load. The energy required to satisfy the total load conists of both solar energy and auxiliary thermal energy.

The performance of the IBM System 3 hot water subsystem is presented in Table 3.2.3-1. The value for auxiliary energy supplied in Table 3.2.3-1 is the gross energy supplied to the auxiliary system. The value of auxiliary energy supplied multiplied by the auxiliary system efficiency gives the auxiliary thermal energy actually delivered to the load. The difference between the sum of auxiliary thermal energy plus solar energy and the hot water load is equal to the thermal (standby) losses from the hot water subsystem.

The measured solar fraction in Table 3.2.3-1 is an average weighted value for the month based on the ratio of solar energy in the hot water tank to the total energy in the hot water tank when a demand for hot water exists. This value is dependent on the daily profile of hot water usage. It does not represent the ratio of solar energy supplied to the sum of solar plus auxiliary energy supplied shown in the Table.

For the 12-month period from January 1979 through December 1979, the solar energy system supplied total of 6.002 million Btu to the hot water load. The total hot water load this period was 5.551 million Btu, and the weighted average monthly solar fraction was 58 percent.

The monthly average hot water load during the reporting period was 0.463 million Btu. This is based on an average daily consumption of 21 gallons, delivered at an average temperature of 146°F and supplied to the system at an average temperature of 62°F. The temperature of the supply water ranged from a low of 58°F to a high of 65°F.

Each month an average of 0.500 million Btu of solar energy and 0.219 million Btu of auxiliary thermal electrical energy were supplied to the hot water

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TABLE 3.2.3-1

HOT WATER SUBSYSTEM PERFORMANCE

Month	Energy Supplied (Million Btu)				Hot Water Load (Million Btu)	Average Daily Usage (Gal.)	Hot Water Standby Losses (Million Btu)	Weighted** Solar Fraction (Percent)
	Auxiliary	Auxiliary Thermal*	Solar	Total				
Jan 79	0.470	0.470	0.141	0.611	0.549	22	0.062	23
Feb 79	0.246	0.246	0.097(a)	0.343	0.249	11	0.094	29
Mar 79	0.254	0.254	0.032(a)	0.286	0.324	13	-0.038	14
Apr 79	0.087	0.087	0.001(a)	0.088	0.006	0	0.082	24
May 79	0.096	0.096	0.484(a)	0.580	0.513	20	0.067	84
Jun 79	0.071	0.071	1.097	1.168	0.954	38	0.214	89
Jul 79	0.000	0.000	0.838	0.838	0.185	6(b)	0.653	87
Aug 79	0.014	0.014	0.911	0.925	0.035	1(b)	0.890	94
Sep 79	0.022	0.022	0.977	0.999	0.002	1(b)	0.997	93
Oct 79	0.159	0.159	0.663	0.822	0.765	42	0.057	81
Nov 79	0.577	0.577	0.330	0.907	0.912	50	-0.005	36
Dec 79	0.637	0.637	0.431	1.068	1.057	53	0.011	39
Total	2.633	2.633	6.002	8.635	5.551	--	3.084	--
Average	0.219	0.219	0.500	0.720	0.463	21	0.257	58

* Auxiliary Thermal (the thermal energy applied to the load) is the product of Auxiliary Energy and system efficiency.

** Weighted Solar Fraction is computed at the time hot water is actually used.

(a) Data system problem provided faulty measurements of solar energy supplied to hot water subsystem corrected 5/17/79.

(b) Intermittent water totalizer resulted in low measured flow. Problem was corrected 10/5/79.

subsystem. Since the average monthly hot water load was 0.463 million Btu, an average of 0.257 million Btu was lost from the hot water tanks each month. This dwelling was occupied by one person from January through the middle of March and was vacant til May at which time it became occupied by a family with higher demands on hot water. A malfunctioning of the totalizer occurred in July giving erroneous usage data until the totalizer was replaced on October 5, 1979. For that reason the measured hotwater consumption for July, August, and September was much lower than the actual consumption. Estimated consumption for these months is about 40 gallons per month.

The hot water usage at the IBM System 3 site averaged 21 gallons per day. This average is a composite of the three months in which the dwelling had only one user, a period of vacancy and the remainder (two-thirds of year) in which the family occupied the dwelling. The family used an estimated 45 gallons per day. The hot water solar function varied from 14 percent to 94 percent. The 94 percent solar fraction was for August 1979 and should be disregarded due to the totalizer problem. In September, the original 65 gallon hot water tank was replaced by a 120 gallon tank due to higher demands placed on hot water by the family occupants.

3.2.4 Space Heating Subsystem

The performance of the space heating subsystem is described by comparing the amount of solar energy supplied to the subsystem with the energy required to satisfy the total space heating load. The energy required to satisfy the total load consists of both solar energy and auxiliary thermal energy. The ratio of solar energy supplied to the load to the total load is defined as the heating solar fraction. The calculated heating solar fraction is the indicator of performance for the subsystem because it defines the percentage of the total space heating load supported by solar energy.

The performance of the IBM System 3 space heating subsystem is presented in Table 3.2.4-1. For the 12-month period under study, the solar energy system supplied a total of 21.31 million Btu to the space heating load. The total heating load for this period was 96.74 million Btu, and the weighted average monthly solar fraction was 22 percent.

The measured space heating subsystem performance was lower than expected during the reporting period. January and February were colder and more cloudy than expected. If these two months had been near normal, the weighted average solar fraction would have been considerably higher.

During the transition months (September, October, and May) the space heating subsystem provided the expected high percentage of small heating load. The solar fraction for September, October, and May were respectively 93, 58, and 69 percents. The total load for these three months was 9.22 million Btu and the weighted solar fraction was 66 percent.

A major contributing factor to the performance of this subsystem is energy to storage. This ultimately is a function of the collector array tilt angle which at 35° is very poor for winter months.

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TABLE 3.2.4-1

SPACE HEATING SUBSYSTEM PERFORMANCE

Month	Heating Parameters			Energy Supplied (Million Btu)			Measured Solar Fraction (Percent)
	Space Heating Load (Million Btu)	Temperature (°F)		Solar	Auxiliary Thermal	Auxiliary	
		Building	Outdoor				
Jan 79	28.55	70	8	1.93	26.62	32.08	7
Feb 79	16.36	70	28	2.97	13.39	16.74	18
Mar 79	11.91	69	39	3.17	8.74	10.92	27
Apr 79	3.68	65	47	2.25	1.42	1.78	62
May 79	3.60	70	51	2.48	1.13	1.41	69
Jun 79	1.23	76	65	1.10	0.13	0.16	90
Jul 79	0.06	79	72	0.00	0.06	0.08	0
Aug 79	0.06	77	68	0.00	0.06	0.08	5
Sep 79	0.92	77	65	0.86	0.06	0.08	93
Oct 79	4.69	74	50	2.73	1.97	2.46	58
Nov 79	13.26	73	29	2.04	11.22	14.02	15
Dec 79	12.42	72	32	1.78	10.64	13.30	14
Total	96.74	--	--	21.31	75.44	93.11	--
Average	8.06	73	46	1.78	6.29	7.76	22**

* System in "Summer Mode" these months.

** Weighted Solar Fraction: $\Sigma \dfrac{\text{Space Heating Load}}{\text{Total Load}}$ * Measured Solar Fraction

$$\frac{\sum\limits_{i=1}^{n} (\text{Space Heating Load})_i * (\text{Measured Solar Fraction})_i}{\text{Total Load}}$$

4. OPERATING ENERG.

Operating energy for the IBM System 3 Solar Energy System is defined as the energy required to transport solar energy to the point of use. Total operating energy for this system consists of the collector loop pump (P1), the space heating loop pump (P2), the domestic hot water preheat pump (P3) and the space heating air circulation blower power.

Operating energy is electrical energy that is used to support the subsystems without affecting their thermal state. Measured monthly values for subsystem operating energy are presented in Table 4.1.

For the January 1979 through December 1979 period covered by this report a total of 6.47 million Btu of operating energy was consumed. During the same time a total of 27.31 million Btu of solar energy was supplied to the total system load.

Therefore, for every one million Btu of solar energy delivered to the load, 0.237 million Btu (or 70.0 kWh) of electrical operating energy was expended.

TABLE 4-1

OPERATING ENERGY

Month	ECSS Operating Energy (Million Btu)	Hot Water Operating Energy (Million Btu)	Space Heating Operating Energy (Million Btu)	Total System Operating Energy (Million Btu)
Jan 79	0.130	0.011	0.944	1.085
Feb 79	0.184	0.008	0.847	1.039
Mar 79	0.173	0.008	0.673	0.854
Apr 79	0.200	0.021	0.225	0.446
May 79	0.166	0.031	0.250	0.447
Jun 79	0.092	0.031	0.099	0.222
Jul 79	0.083	0.029	0.000	0.112
Aug 79	0.074	0.026	0.000	0.100
Sep 79	0.089	0.025	0.042	0.156
Oct 79	0.099	0.017	0.331	0.447
Nov 79	0.077	0.011	0.643	0.731
Dec 79	0.157	0.027	0.643	0.827
Total	1.524	0.245	4.697	6.466
Average	0.127	0.020	0.391	0.539

5. ENERGY SAVINGS

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 provide solar energy to the load subsystems is subtracted from the solar energy contribution, and the resulting energy savings are adjusted to reflect the coefficient of performance (COP) of the auxiliary source being supplanted by solar energy.

Energy savings for January 1979 through December 1979 are presented in Table 5-1. For this time period, the average gross monthly savings were 2.633 million Btu. After the ECSS subsystem operating energy was deducted, the average net monthly electrical savings were 2.507 million Btu, or 732.9 kwh. For the overall time period covered by this report the total net savings were 30.078 million Btu, or 8813 kwh, which is equivalent to approximately 5 barrels of oil.

The solar energy system showed steady energy savings throughout the year. Reduced savings are noted, as expected, during the summer months of June, July, August, and September when the system was provided little or no solar energy to the space heating subsystem. Also, as previously noted, savings were not as great as would have been expected had the collector array tilt angle been set at an optimum for this latitude, which is approximately 53° for this installation.

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TABLE 5-1

ENERGY SAVINGS

Month	Electrical Energy Savings (Million Btu)		Fossil Energy Savings (Million Btu)		ECSS Operating Energy (Million Btu)	Total Net Savings	
	Hot Water	Space Heating	Hot Water	Space Heating		Million Btu	Kwh
Jan 79	0.130	-0.100	N/A	2.406	0.130	2.306	675.7
Feb 79	0.089	-0.166	N/A	3.716	0.184	3.455	1012.3
Mar 79	0.023	-0.147	N/A	3.966	0.173	3.669	1075.0
Apr 79	-0.023	-0.059	N/A	2.817	0.200	2.535	742.7
May 79	0.453	-0.068	N/A	3.094	0.166	3.313	970.7
Jun 79	1.066	-0.017	N/A	1.380	0.092	2.337	684.7
Jul 79	0.809	0.000	N/A	0.000	0.083	0.726	212.7
Aug 79	0.885	0.000	N/A	0.004	0.074	0.815	238.8
Sep 79	0.952	-0.007	N/A	1.072	0.089	1.928	564.9
Oct 79	0.646	-0.049	N/A	3.408	0.099	3.906	1144.4
Nov 79	0.319	-0.064	N/A	2.552	0.077	2.730	799.9
Dec 79	0.404	-0.110	N/A	2.221	0.157	2.358	609.9
Total	5.753	-0.787	---	26.636	1.524	30.078	8794.70
Average	0.479	-0.066	---	2.220	0.127	2.507	732.9

6. MAINTENANCE

The only maintenance required on the IBM 3 Glendo site during the
October, 1978 to April, 1980 reporting period was to seal pin holes in
the collector array. One collector developed a leak on March 12, 1979,
and was repaired on March 16, 1979. Another collector developed a small
leak in October. The leak was repaired in May, 1980. Both leaks devel-
oped in a copper nipple at the outlet of the collector. The nipple forms
the attachment point at which the upper manifold is soldered to the
collector. Both nipples exhibited evidence of clamping deformation
and burning from extreme heat that was applied when the collector
was manufactured.

The hot water capacity with the 65 gallon tank proved to be inadequate.
It was replaced with a Ford Product Company Model TC120E, 120 gallon tank
in September.

A solar override switch was added to the control system in mid March, 1980.
When in the solar override position the switch causes the dwelling heating
thermostat first stage contacts to activate the space heating furnace
instead of the solar circulation pump P2 and the furnace blower.

7. SUMMARY AND CONCLUSIONS

This System Performance Evaluation report provides an operational summary of the IBM System 3 solar energy system installed at the Glendo Reservoir Ranger Station owned by the state of Wyoming. This analysis was conducted by evaluation of measured system performance and by comparison of measured climatic data with long-term average climatic conditions. The performance of major subsystems is also presented.

Measured average daily insolation was low for the year, indicating an abnormally high number of cloudy days. A detail discussion of the insolation data is found in Section 3.1.

The yearly average ambient temperature was exactly the same as the long-term average. Measured heating degree days were 7694 compared to 7555 for the long-term average at the near by Casper Wyoming Weather Station. January, May, August, and November were colder than the average (by 15, 2, 2, and 5 percent respectively) but the other months were slightly warmer than the long-term average. With the exception of January there was negligible adverse impact on solar system performance due to weather conditions.

The system provided solar energy to the building space heat and hot water loads as expected for the year, providing 22 percent of the space heating and 58 percent of the hot water energy.

The occupants at the site complained that the space heating blower ran excessively and that at times the air from the registers felt cool. The control system is set to heat from stored solar energy when the dwelling heating thermostat first stage contacts call for heat if solar storage is above the mid 90°F range. When storage is in the mid 90°F range solar heated air will be in the low 80°F range which will feel cold to the skin if there is motion. This problem can be corrected by raising the temperature setting of the control thermostat in storage; however, this will increase storage losses and reduce the efficiency of the system.

For the period covered by this report the total net average savings were 30.078 million Btu, or 8813 kWh, which is equivalent to approximately 5 barrels of oil.

8. REFERENCES

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APPENDIX A

DEFINITION OF PERFORMANCE FACTORS

APPENDIX A

DEFINITION OF PERFORMANCE FACTORS AND SOLAR TERMS

COLLECTOR ARRAY PERFORMANCE

The collector array performance is characterized by the amount of solar energy
collected with respect to the energy available to be collected.

- INCIDENT SOLAR ENERGY (SEA) is the total insolation available on the
  gross collector array area. This is the area of the collector
  array energy-receiving aperture, including the framework which is
  an integral part of the collector structure.

- OPERATIONAL INCIDENT ENERGY (SEOP) is the amount of solar energy
  incident on the collector array during the time that the col-
  lector loop is active (attempting to collect energy).

- COLLECTED SOLAR ENERGY (SECA) is the thermal energy removed from
  the collector array by the energy transport medium.

- COLLECTOR ARRAY EFFICIENCY (CAREF) is the ratio of the energy col-
  lected to the total solar energy incident on the collector array.
  It should be emphasized that this efficiency factor is for the
  collector array, and available energy includes the energy incident
  on the array when the collector loop is inactive. This efficiency
  must not be confused with the more common collector efficiency
  figures which are determined from instantaneous test data obtained
  during steady state operation of a single collector unit. These
  efficiency figures are often provided by collector manufacturers
  or presented in technical journals to characterize the functional
  capability of a particular collector design. In general, the
  collector panel maximum efficiency factor will be significantly
  higher than the reported collector array efficiency.

STORAGE PERFORMANCE

The storage performance is characterized by the relationships among the energy delivered to storage, removed from storage, and the subsequent change in the amount of stored energy.

- ENERGY TO STORAGE (STEI) is the amount of energy, both solar and auxiliary, delivered to the primary storage medium.

- ENERGY FROM STORAGE (STEO) is the amount of energy extracted by the load subsystems from the primary storage medium.

- CHANGE IN STORED ENERGY (STECH) is the difference in the estimated stored energy during the specified reporting period, as indicated by the relative temperature of the storage medium (either positive or negative value).

- STORAGE AVERAGE TEMPERATURE (TST) is the mass-weighted average temperature of the primary storage medium.

- STORAGE EFFICIENCY (STEFF) is the ratio of the sum of the energy removed from storage and the change in stored energy to the energy delivered to storage.

ENERGY COLLECTION AND STORAGE SUBSYSTEM

The Energy Collection and Storage Subsystem (ECSS) is composed of the collector array, the primary storage medium, the transport loops between these, and other components in the system design which are necessary to mechanize the collector and storage equipment.

- INCIDENT SOLAR ENERGY (SEA) is the total insolation available on the gross collector array area. This is the area of the collector array energy-receiving aperture, including the framework which is an integral part of the collector structure.

- AMBIENT TEMPERATURE (TA) is the average temperature of the outdoor environment at the site.

- ENERGY TO LOADS (SEL) is the total thermal energy transported from the ECSS to all load subsystems.

- AUXILIARY THERMAL ENERGY TO ECSS (CSAUX) is the total auxiliary supplied to the ECSS, including auxiliary energy added to the storage tank, heating devices on the collectors for freeze-protection, etc.

- ECSS OPERATING ENERGY (CSOPE) is the critical operating energy required to support the ECSS heat transfer loops.

HOT WATER SUBSYSTEM

The hot water subsystem is characterized by a complete accounting of the energy flow to and from the subsystem, as well as an accounting of internal energy. The energy into the subsystem is composed of auxiliary fossil fuel, and electrical auxiliary thermal energy, and the operating energy for the subsystem. In addition, the solar energy supplied to the subsystem, along with solar fraction is tabulated. The load of the subsystem is tabulated and used to compute the estimated electrical and fossil fuel savings of the subsystem. The load of the subsystem is further identified by tabulating the supply water temperature, and the outlet hot water temperature, and the total hot water consumption.

- HOT WATER LOAD (HWL) is the amount of energy required to heat the amount of hot water demanded at the site from the incoming temperature to the desired outlet temperature.

- SOLAR FRACTION OF LOAD (HWSFR) is the percentage of the load demand which is supported by solar energy.

- SOLAR ENERGY USED (HWSE) is the amount of solar energy supplied to the hot water subsystem.

- OPERATING ENERGY (HWOPE) is the amount of electrical energy required to support the subsystem, (e.g., fans, pumps, etc.) and which is not intended to directly affect the thermal state of the subsystem.

- AUXILIARY THERMAL USED (HWAT) is the amount of energy supplied to the major components of the subsystem in the form of thermal energy in a heat transfer fluid, or its equivalent. This term also includes the converted electrical and fossil fuel energy supplied to the subsystem.

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- **AUXILIARY ELECTRICAL FUEL** (HWAE) is the amount of electrical energy supplied directly to the subsystem.

- **ELECTRICAL ENERGY SAVINGS** (HWSVE) is the estimated difference between the electrical energy requirements of an alternative conventional system (carrying the full load) and the actual electrical energy required by the subsystem.

- **SUPPLY WATER TEMPERATURE** (TSW) is the average inlet temperature of the water supplied to the subsystem.

- **AVERAGE HOT WATER TEMPERATURE** (THW) is the average temperature of the outlet water as it is supplied from the subsystem to the load.

- **HOT WATER USED** (HWCSM) is the volume of water used.

SPACE HEATING SUBSYSTEM

The space heating subsystem is characterized by performance factors accounting for the complete energy flow to and from the subsystem. The average building temperature and the average ambient temperature are tabulated to indicate the relative performance of the subsystem in satisfying the space heating load and in controlling the temperature of the conditioned space.

- SPACE HEATING LOAD (HL) is the sensible energy added to the air in the building.

- SOLAR FRACTION OF LOAD (HSFR) is the fraction of the sensible energy added to the air in the building derived from the solar energy system.

- SOLAR ENERGY USED (HSE) is the amount of solar energy supplied to the space heating subsystem.

- OPERATING ENERGY (HOPE) is the amount of electrical energy required to support the subsystem, (e.g., fans, pumps, etc.) and which is not intended to affect directly the thermal state of the subsystem.

- AUXILIARY THERMAL USED (HAT) is the amount of energy supplied to the major components of the subsystem in the form of thermal energy in a heat transfer fluid or its equivalent. This term also includes the converted electrical and fossil fuel energy supplied to the subsystem.

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- **ELECTRICAL ENERGY SAVINGS** (HSVE) is the cost of the operating energy (HOPE) required to support the solar energy portion of the space heating subsystem.

- **BUILDING TEMPERATURE** (TB) is the average heated space dry bulb temperature.

- **AMBIENT TEMPERATURE** (TA) is the average ambient dry bulb temperature at the site.

ENVIRONMENTAL SUMMARY

The environmental summary is a collection of the weather data which is generally instrumented at each site in the Development Program. It is tabulated in this report for two purposes (1) as a measure of the conditions prevalent during the operation of the system at the site, and (2) as a historical record of weather data for the vicinity of the site.

- TOTAL INSOLATION (SE) is the accumulated total solar energy incident upon the gross collector array measured at the site.

- AMBIENT TEMPERATURE (TA) is the average temperature of the environment at the site.

- DAYTIME AMBIENT TEMPERATURE (TDA) is the temperature during the period from three hours before solar noon to three hours after solar noon.

APPENDIX B

SOLAR ENERGY SYSTEM PERFORMANCE EQUATIONS FOR

IBM GLENDO

APPENDIX B

SOLAR ENERGY SYSTEM PERFORMANCE EQUATIONS FOR
IBM SYSTEM 3

I.   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 subsystem every
320 seconds. This data is then numerically 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 evaluation.

Data samples from the system measurements are numerically integrated
to provide discrete approximations of the continuous functions which
characterize the system's dynamic behavior. This numerical 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 numerical 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/ft^2-hr, 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 ΔH is the enthalpy change, in Btu/lb_m, of the fluid as it passes through the heat exchanging component.

For a liquid system ΔH is generally given by

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

where $\overline{C}_p$ is the average specific heat, in Btu/(lb_m-°F), of the heat transfer fluid and ΔT, in °F, is the temperature differential across the heat exchanging component.

For an air system ΔH is generally given by

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

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

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

For electrical power, a general example is

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

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

These equations are comparable to those specified in "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program." This document, given in the list of references, was prepared by an inter-agency committee of the government, and presents guidelines for thermal performance evaluation.

Performance factors are computed for each hour of the day. Each numerical integration process, therefore, is performed over a period of one hour. Since long-term performance data is desired, it is necessary to build these hourly performance factors to daily values. This is accomplished, for energy parameters, by summing the 24 hourly values. For temperatures, the hourly values are averaged. Certain special factors, such as efficiencies, require appropriate handling to properly weight each hourly sample for the daily value computation. Similar procedures are required to convert daily values to monthly values.

EQUATIONS USED IN MONTHLY PERFORMANCE REPORT

NOTE: MEASUREMENT NUMBERS REFERENCE SYSTEM SCHEMATIC FIGURE 2-2

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)

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

FOR ± 3 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/LBM-°F)

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

WHERE 0.24 IS THE SPECIFIC HEAT AND HR IS THE HUMIDITY RATIO
OF THE TRANSPORT AIR. THIS FUNCTION IS USED WHENEVER THE
HUMIDITY RATIO WILL REMAIN CONSTANT AS THE TRANSPORT AIR FLOWS
THROUGH A HEAT EXCHANGING DEVICE

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \Sigma \; [M100 \times HRF \times (T150 - T100P)] \times \Delta\tau$$

WHEN THE COLLECTOR PUMP OPERATES FOR AT LEAST 90 PERCENT OF ONE SCAN TIME.
WHERE T100P IS THE PAST VALUE OF T100. THE PAST VALUE OF T100P
WAS USED TO CORRECT FOR ANALYTICAL ERRORS WHICH WOULD BE CAUSED BY
THE COLLECTOR FILL TIME.

ENTHALPY FUNCTION FOR WATER (BTU/LBM)

$$HWD(T_2, T_1) = \int_{T_1}^{T_2} Cp(T)dT$$

THIS FUNCTION COMPUTES THE ENTHALPY CHANGE OF WATER AS IT
PASSES THROUGH A HEAT EXCHANGING DEVICE.

SOLAR ENERGY TO STORAGE (BTU)

STEI = SECA

AVERAGE TEMPERATURE OF STORAGE (°F)

$TST = (1/60) \times \Sigma \; [(T200 + T20i + T202)/3] \times \Delta\tau$

SOLAR ENERGY FROM STORAGE TO DHW SUBSYSTEM

$STEO1 = \Sigma \; [M300 \times HWD \; (T302, T300)] \times \Delta\tau$

SOLAR ENERGY FROM STORAGE TO SPACE HEATING (BTU)

$STEO2 = \Sigma \; [M400 \; X \; HWD \; (T401, T400)]$

ECSS OPERATING ENERGY (BTU)

$CSOPE = 56.8833 \; X \; \Sigma \; EP101 \; X \; \Delta\tau$

DOMESTIC HOT WATER CONSUMPTION (GALLONS)

$HWCSM = \Sigma \; WD301 \; X \; \Delta\tau$

HOT WATER LOAD (BTU)

$HWL = \Sigma \; [M301 \times HWD \; (T303, T301)]$

HOT WATER OPERATING ENERGY

$HWOPE = 56.8833 \times \Sigma \; EP301 \times \Delta\tau$

HOT WATER SUBSYSTEM AUXILIARY ELECTRICAL FUEL ENERGY (BTU)

$$HWAE = 56.8833 \times \Sigma \text{ EP300} \times \Delta\tau$$

AUXILIARY ENERGY TO SPACE HEATING SUBSYSTEM (BTU)

$$HAT = \Sigma \text{ [M401} \times \text{HRF} \times \text{(T404} - \text{T403)]} \times \Delta\tau$$

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$$HOPE = 56.8833 \times \Sigma \text{ (EP401} + \text{EP402)} \times \Delta\tau$$

SOLAR ENERGY TO SPACE HEATING OPERATING ENERGY (BTU)

$$HOPE \text{ 1} = 56.8833 \times \Sigma \text{ EP401} \times \Delta\tau$$

SUPPLY WATER TEMPERATURE (°F)

$$TSW = T301$$

DOMESTIC HOT WATER TEMPERATURE (°F)

$$THW = T303$$

> BOTH TSW AND THW ARE COMPUTED ONLY WHEN FLOW EXISTS IN THE
> SUBSYSTEM, OTHERWISE THEY ARE SET EQUAL TO THE VALUES OBTAINED
> DURING THE PREVIOUS FLOW PERIOD.

TOTAL SOLAR ENERGY FROM STORAGE (BTU)

$$STEO = STEO1 + STEO2$$

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$$SEA = CLAREA \times SE$$

COLLECTED SOLARE ENERGY (BTU/FT^2)

$$SEC = SECA/CLAREA$$

COLLECTOR ARRAY EFFICIENCY

$$CAREF = SECA/SEA$$

CHANGE IN STORED ENERGY (BTU)

$$STECH = STECH1 - STECH1_p$$

WHERE THE SUBSCRIPT p REFERS TO A PRIOR REFERENCE VALUE

STORAGE EFFICIENCY

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

ENERGY DELIVERED FROM ECSS TO SUBSYSTEMS (BTU)

$$CSEO = STEO$$

TOTAL ENERGY USED BY HOT WATER SUBSYSTEM (BTU)

$$HWSE = STEO1$$

TOTAL ENERGY USED BY SPACE HEATING SUBSYSTEM (BTU)

$$HSE = STEO2$$

ECSS SOLAR CONVERSION EFFICIENCY

$$CSCEF = SEL/SEA$$

AUXILIARY THERMAL ENERGY TO HOT WATER SUBSYSTEM (BTU)

$$HWAT = HWAE$$

HOT WATER SOLAR FRACTION (PERCENT)

$$HWSFR = 100 \times HWTKSE/(HWTKSE + HWTKAUX)$$

WHERE HWTKSE AND HWTKAUX REPRESENT THE CURRENT SOLAR AND
AUXILIARY ENERGY CONTENT OF THE HOT WATER TANK

HOT WATER ELECTRICAL ENERGY SAVINGS (BTU)

$$HWSVE = HWSE - HWOPE$$

SPACE HEATING LOAD (BTU)

$$HL = HAT + HSE$$

SPACE HEATING SUBSYSTEM SOLAR FRACTION (PERCENT)

$$HSFR = 100 \times HSE/HL$$

SPACE HEATING SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

$$HSVE = -HOPE1$$

SPACE HEATING SUBSYSTEM FOSSIL ENERGY SAVINGS (BTU)

$$HSVF = HSE/.8$$

SPACE HEATING AUXILIARY FOSSIL

$$HAF = HAT/.8$$

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

$$SEL = HSE + HWSE$$

SYSTEM LOAD (BTU)

$$SYSL = HL + HWL$$

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

$$SFR = 100 \times [(HWSFR/100) \times HWL \times HSE]/(HWL + HL)$$

SYSTEM OPERATING ENERGY (BTU)

$$SYSOPE = CSOPE + HWOPE + HOPE$$

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

$$AXT = HWAT + HAT$$

AUXILIARY ELECTRICAL ENERGY TO LOADS (BTU)

$$AXE = HWAE$$

AUXILIARY FOSSIL ENERGY TO LOADS (BTU)

$$AXF = HAF$$

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

TSVE = HWSVE + HSVE - CSOPE

TOTAL FOSSIL ENERGY SAVINGS (BTU)

TSVF = HSVF

TOTAL ENERGY CONSUMED (BTU)

TECSM = SYSOPE + AXE + SECA + AXF

TOTAL FOSSIL ENERGY CONSUMED (BTU)

FOSSIL = AXF + 3.33 x (AXE + SYSOPE)

SYSTEM PERFORMANCE FACTOR

SYSPF = SYSL/FOSSIL

APPENDIX C

LONG-TERM AVERAGE WEATHER CONDITIONS

APPENDIX C

LONG-TERM AVERAGE WEATHER CONDITIONS

The environmental estimates given in this appendix provide a point of reference for evaluation of weather conditions as reported in the Monthly Performance Assessments and Solar Energy System Performance Evaluations issued by the National Solar Data Program. As such, the information presented can be useful in prediction of long-term system performance.

Environmental estimates for this site include the following monthly averages: extraterrestrial insolation, insolation on a horizontal plane at the site, insolation in the tilt plane of the collection surface, ambient temperature, heating degree-days, and cooling degree-days. Estimation procedures and data sources are detailed in the following paragraphs.

The preferred source of long-term temperature and insolation data is "Input Data for Solar Systems" (IDSS) [1] since this has been recognized as the solar standard. The IDSS data are used whenever possible in these environmental estimates for both insolation and temperature related sources; however, a secondary source used for insolation data is the Climatic Atlas of the United States [2], and for temperature related data, the secondary source is "Local Climatological Data" [3].

Since the available long-term insolation data are only given for a horizontal surface, solar collection subsystem orientation information is used in an algorithm [4] to calculate the insolation expected in the tilt plane of the collector. This calculation is made using a ground reflectance of 0.2.

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SITE: IBM GLEND   39.   LOCATION: CASPER WY

ANALYST: R. GIUNTINI   FDRIVE NO.:   49.

COLLECTOR TILT: 35.00 (DEGREES)   COLLECTOR AZIMUTH: 0.0 (DEGREES)

LATITUDE: 42.50 (DEGREES)   RUN DATE: 04/21/80

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JAN	1192.	682.	0.57214	1.881	1283.	1296	0	23.
FEB	1665.	1014.	0.60887	1.578	1600.	1070	0	27.
MAR	2291.	1442.	0.62934	1.297	1870.	1054	0	31.
APR	2958.	1847.	0.62443	1.075	1985.	669	0	43.
MAY	3442.	2205.	0.64062	0.947	2089.	388	6	53.
JUN	3643.	2503.	0.68717	0.894	2239.	147	54	62.
JUL	3538.	2537.	0.71691	0.917	2327.	13	199	71.
AUG	3142.	2227.	0.70881	1.024	2281.	17	159	70.
SEP	2529.	1751.	0.69253	1.218	2134.	229	40	59.
OCT	1846.	1220.	0.66093	1.502	1833.	536	0	48.
NOV	1302.	767.	0.58918	1.799	1379.	933	0	34.
DEC	1065.	594.	0.55729	1.983	1177.	1203	0	26.

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LEGEND:

    HOBAR -- MONTHLY AVERAGE DAILY EXTRATERRESTRIAL RADIATION (IDEAL) IN BTU/DAY-FT2.

    HBAR -- MONTHLY AVERAGE DAILY RADIATION (ACTUAL) IN BTU/DAY-FT2.

    KBAR -- RATIO OF HBAR TO HOBAR.

    RBAR -- RATIO OF MONTHLY AVERAGE DAILY RATIATION 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 * HBAR) IN BTU/DAY-FT2.

    HDD   -- NUMBER OF HEATING DEGREE DAYS PER MONTH

    CDD   -- NUMBER OF COOLING DEGREE DAYS PER MONTH

    TBAR -- AVERAGE AMBIENT TEMPERATURE IN DEGREES FAHRENHEIT.

REFERENCES

[1] Cinquemani, V., et al. "Input Data for Solar Systems." Prepared for the U.S. Department of Energy by the National Climatic Center, Asheville, NC, 1978.

[2] United States Department of Commerce, Climatic Atlas of the United States, Environmental Data Service, Reprinted by the National Oceanic and Atmospheric Administration, Washington, DC, 1977.

[3] United States Department of Commerce, "Local Climatological Data," Environmental Data Service, National Oceanic and Atmospheric Administration, Asheville, NC, 1977.

[4] Klein, S. A., "Calculation of Monthly Average Insolation on Tilted Surfaces," Joint Conference 1976 of the International Solar Energy Society and the Solar Energy Society of Canada, Inc., Winnipeg, August 15-20, 1976.