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SOLAR-ENERGY-SYSTEM PERFORMANCE EVALUATION

SOLAR/2011--79/14

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TERRELL D. MOSELEY OFFICE BUILDING, LYNCHBURG, VIRGINIA

OCTOBER 1978 THROUGH MARCH 1979

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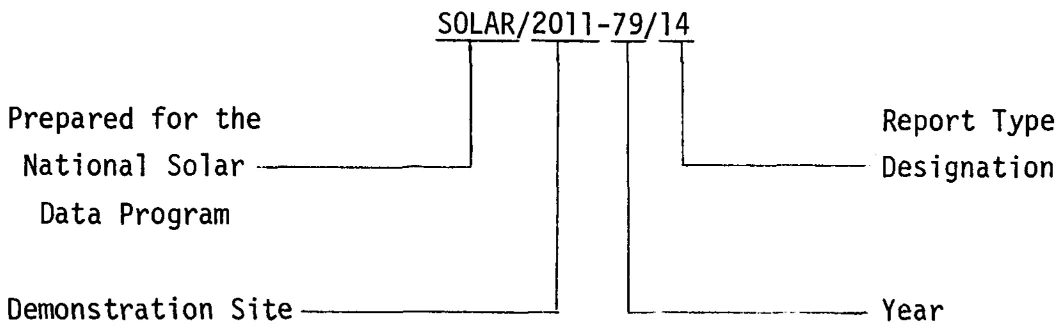
NATIONAL SOLAR DATA PROGRAM REPORTS

Reports prepared for the National Solar Data Program are numbered under a specific format. For example, this report for the Terrell D. Moseley project site is designated as SOLAR/2011-79/14. The elements of this designation are explained in the following illustration.



- Demonstration Site Number:

  Each Project site has its own discrete number - 1000 through 1999 for residential sites and 2000 through 2999 for commercial sites.

- Report Type Designation:

  This number identifies the type of report, e.g.,

  - Monthly Performance Reports are designated by the numbers 01 (for January) through 12 (for December).

  - Solar Energy System Performance Evaluations are designated by the number 14.

  - Solar Project Descriptions are designated by the number 50.

  - Solar Project Cost Reports are designated by the number 60.

These reports are disseminated through the U. S. Department of Energy, Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830.

1. FOREWORD

The National Program for Solar Heating and Cooling is being conducted by the Department of Energy under the Solar Heating and Cooling Demonstration Act of 1974. The overall goal of this activity is to accelerate the establishment of a viable solar energy industry and to stimulate its growth in order to achieve a substantial reduction in non-renewable energy resource consumption through widespread applications of solar heating and cooling technology.

Information gathered through the Demonstration Program is disseminated in a series of site-specific reports. These reports are issued as appropriate and may include such topics as:

- Solar Project Description
- Design/Construction Report
- Project Costs
- Maintenance and Reliability
- Operational Experience
- Monthly Performance
- System Performance Evaluation

The International Business Machines Corporation is contributing to the overall goal of the Demonstration Act by monitoring, analyzing, and reporting the thermal performance of solar energy systems through analysis of measurements obtained by the National Solar Data Program.

The System Performance Evaluation Report is a product of the National Solar Data Program. Reports are issued periodically to document the results of analysis of specific solar energy system operational performance. This report includes system description, operational characteristics and capabilities, and an evaluation of actual versus expected performance. The Monthly Performance Report, which is the basis for the System Performance Evaluation Report, is published on a regular basis. Each parameter presented in these reports as characteristic of system performance represents over 8,000 discrete measurements obtained each month by the National Solar Data Network.

All reports issued by the National Solar Data Program for the Terrell D. Moseley solar energy system are listed in Section 6, References.

This Solar Energy System Performance Evaluation Report presents the results of a thermal performance analysis of the Terrell D. Moseley solar energy system. The analysis covers operation of the system from October 1978 through March 1979. The Terrell D. Moseley solar energy system provides space heating to an office building located in Lynchburg, Virginia. A more detailed system description is contained in Section 3. Analysis of the system performance was accomplished using a system energy balance technique described in Section 4. Section 2 presents a summary of the results and conclusions obtained while Section 5 presents a detailed assessment of the system thermal performance.

Acknowledgements are extended to Mr. Terrell D. Moseley, the system designer and owner of the Terrell D. Moseley solar energy system. His insight and cooperation in the resolution of various on-site problems during the reporting period were invaluable.

2. SUMMARY AND CONCLUSIONS

This System Performance Evaluation report provides an operational summary of the solar energy system installed at the Terrell D. Moseley office building located in Lynchburg, Virginia. This analysis is conducted by evaluation of measured system performance and by comparison of measured weather data with long-term average climatic conditions. The performance of major subsystems is also presented.

The measurement data were collected [Reference 8]* by the National Solar Data Network (NSDN) [1] for the period October 1978 through March 1979. System performance data are provided through the NSDN via an IBM-developed Central Data Processing System (CDPS) [2]. The CDPS supports the collection and analysis of solar data acquired from instrumented systems located throughout the country. This data is processed daily and summarized into monthly performance reports. These monthly reports form a common basis for system evaluation and are the source of the performance data used in this report.

Features of this report include: a system description, a review of actual system performance during the report period, analysis of performance based on evaluation of meteorological load and operational conditions, and an overall discussion of results.

Monthly values of average daily insolation and average outdoor ambient temperature measured at the Terrell D. Moseley site are presented in Table 5.1-1. Also presented in the table are the long-term, average monthly values for these climatic parameters.

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*Numbers in brackets designate References found in Section 6.

The Terrell D. Moseley solar energy system performance evaluation began in February 1978. The performance of the solar energy system from February 1978 through May 1978 is described in a previous report [Reference 7]. That performance evaluation is summarized below. For the period June 1978 through September 1978, the solar energy system was operated as necessary to provide a small amount of solar preheating to the domestic hot water (DHW) tank supply water. Since the DHW consumption for the office building was predicted to be low (15 gallons per day), the DHW subsystem was not monitored for performance evaluation. Prior to the start of the current reporting period, October 1978 through March 1979, a modification was made to the operation of the Terrell D. Moseley solar energy system which caused signficant changes in the system performance from the previous reporting period.

During the reporting period, February 1978 through May 1978, the system operated differently than described in Section 3 in the following way:

- Previously, the natural gas-fired heater operated to provide auxiliary thermal energy to storage whenever the sensed storage tank middle temperature fell below a nominal 50°F control temperature setting. In the current mode of operation, the storage tank temperature is maintained above a nominal 105°F by the combination of the solar energy collection system and the natural gas-fired heater.

The change was made in order to compare the energy savings produced by each method of operation.

For the previous four-month reporting period (February 1978 through May 1978), the measured average outdoor ambient temperature was 49°F. A total of 1,962 heating degree-days were accumulated during that period. The measured average daily insolation in the plane of the collector array was 1,330 Btu/ft^2-day.

During the four-month period, total system savings were 22.72 million Btu of fossil energy at an expense of 5.54 million Btu of electrical energy for operating the circulating pumps, the heat pump compressor and the air distribution system blower. The savings were calculated based on an assumed conventional natural gas-fired heater supplying thermal energy directly to the load via a water-to-air heat exchanger located in the air distribution system duct.

A total of 63.86 million Btu of incident solar energy was measured in the plane of the collector array during that period. The solar energy system collected 17.47 million Btu of the 54.57 million Btu of incident solar energy when the collector pump was operating. The operational collector array efficiency was 32 percent.

A total of 19.52 million Btu was delivered to storage during that period, and 15.67 million Btu were removed from storage for support of the space heating load. The increase in storage energy amounted to 0.91 million Btu. The average effective storage heat loss coefficient for the period was computed to be 20.0 Btu/Hr-°F. This low heat loss coefficient suggests both a well insulated storage tank and an efficiently designed system.

The space heating load for that period was 18.3 million Btu. Solar energy supplied 13.6 million Btu of this load, for a solar utilization of 74 percent. During the February 1978 through May 1978 period, the Terrell D. Moseley solar energy system matched or exceeded all expected performance parameters with the exception of system savings, which were far below expectations.

For the six-month period from October 1978 through March 1979, the measured average outdoor ambient temperature was 43°F. This was one degree below the long-term average, and, as a result, a total of 4,032 heating degree-days were accumulated, as opposed to the long-term total of 3,855. The measured average daily insolation in the plane of the collector array was 1,210 Btu/ft^2, which is three percent below the long-term daily average of 1,248 Btu/ft^2 for the six-month reporting period. The collector array at the Terrell D. Moseley site is installed at an angle of 50 degrees from the horizontal, which is approximately 13 degrees greater than the site latitude. This was done to maximize the amount of available insolation during the heating season.

During the six-month period covered by this report, the system achieved a space heating fossil energy savings of 24.65 million Btu, at the expense of 4.51 million Btu of electrical energy required to operate the system.

A total of 88.39 million Btu of incident solar energy was measured in the plane of the collector array during the current reporting period. When the collector array was operating, there were 74.74 million Btu of incident insolation on the array. The system collected 19.64 million Btu, which represents an operational collector array efficiency of 26 percent.

A total of 55.74 million Btu was delivered to storage during the current reporting period, and 44.23 million Btu were removed from storage for support of the space heating load. The average storage heat loss coefficient was 34.30 Btu/Hr-°F for the October 1978 through March 1979 period.

The space heating load for this reporting period was 44.41 million Btu. Solar energy supplied 14.79 million Btu of this load, and the remaining 29.62 million Btu were supplied primarily by the natural gas-fired heater. This resulted in a solar fraction of 33 percent, and a net savings of 24.65 million Btu of fossil energy at the expense of 2.65 million Btu of electrical energy to operate the space heating system.

The Terrell D. Moseley solar energy system operated continuously during the current reporting period. There were only two system problems of any significance: 1) for several days in November, the heat pump compressor was used to support the space heating demand because the differential controller associated with the natural gas-fired heater failed to start the circulating pump P3, and 2) for several days in December, the natural gas-fired heater failed to supply heat to the water circulating between the heat exchanger in the gas heater and the storage heat exchanger because the pilot light was out. The performance impacts due to these factors are: a 38 percent increase in space heating electrical energy expense for November, and a 28 percent increase in electrical energy expense for December.

Comparison of the February 1978 through May 1978 performance to the current reporting period performance shows that the current mode of operation has increased the ratio of fossil fuel savings to electrical fuel expense by 33 percent. However, the performance of most other factors was significantly degraded: the solar fraction of the space heating load decreased 55 percent, the operational collector array efficiency decreased 32 percent, and the average storage heat loss coefficient increased by 82 percent.

3. SYSTEM DESCRIPTION

The Terrell D. Moseley Co. site is a 1,780-square foot, single story, commercial office building with attached warehouse in Lynchburg, Virginia. The solar energy system is designed to provide approximately 70 percent of the space heating and hot water energy requirements of the office building. Because the hot water consumption is very low, only the space heating system is monitored for performance evaluation. The site has a collector array of 24 flat-plate collector panels built by T. D. Moseley. The collector array has a gross area of 400 square feet, and faces south at a tilt angle of 50 degrees from the horizontal. Water is the heat transfer medium throughout the solar energy system. Collected solar energy is delivered to the 2,000-gallon storage tank, which is in an unheated attached warehouse building. The insulation on the tank is four inches of fiberglass.

When solar energy is insufficient to maintain 105°F storage temperatures, a gas-fired boiler (auxiliary heater) provides additional energy to storage. Space heating is provided by circulating storage water through a heat exchanger located in the air distribution system of the building. Since the collector fluid automatically drains into storage after each solar energy collection operation, additional collector freeze protection measures are not required.

The system, shown schematically in Figure 3-1, has three modes of solar operation, which are described below.

<u>Mode 1 - Collector-to-Storage</u>: This mode is entered when the sensed collector absorber plate temperature exceeds the middle storage temperature by 20°F. The transfer fluid is pumped from storage through the collectors and back to storage until this temperature differential drops to less than 3°F.

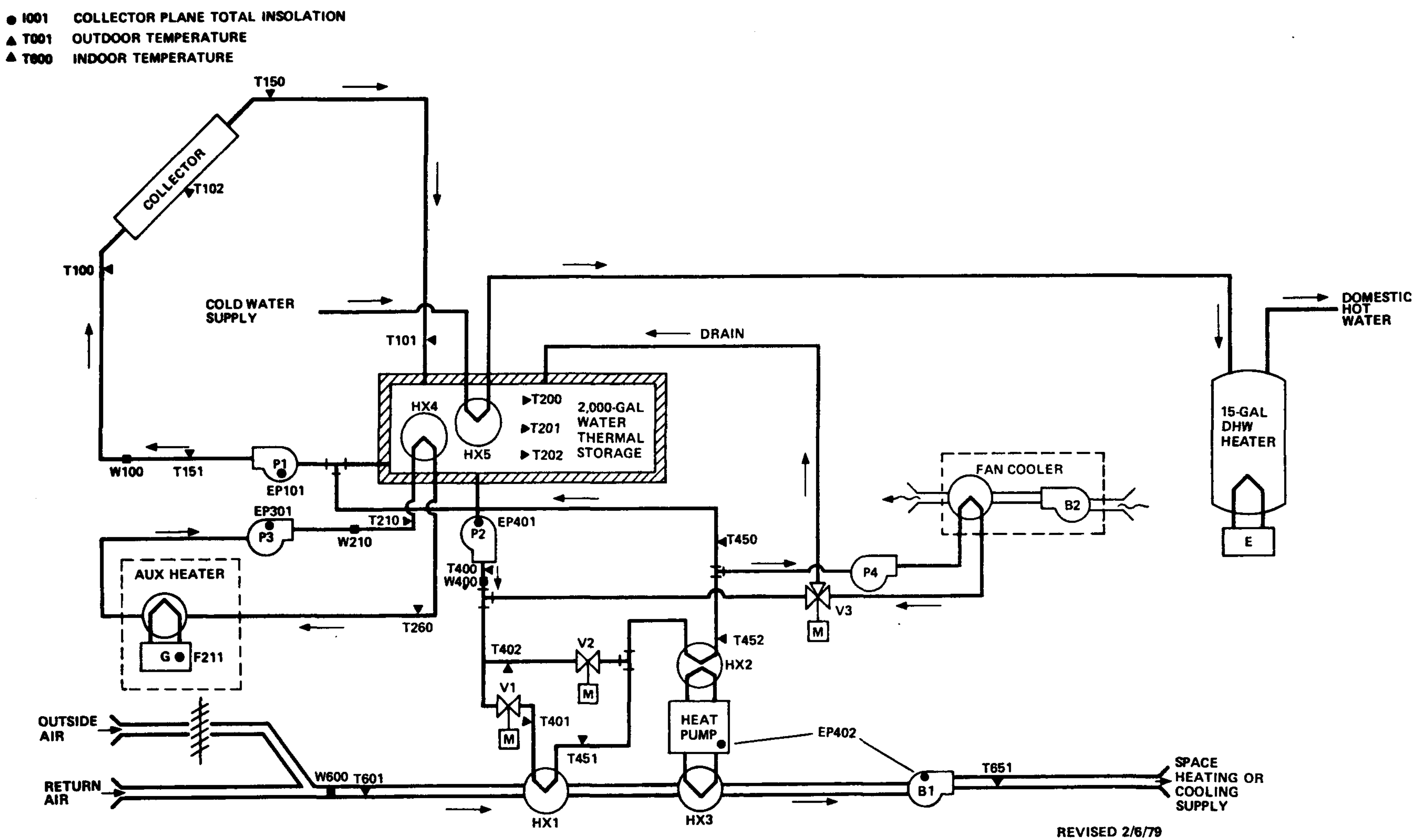

FIGURE 3-1 TERRELL D. MOSELEY SOLAR ENERGY SYSTEM SCHEMATIC

Mode 2 - Storage-to-Space Heating: This mode is entered when there is a demand for space heating and the sensed temperature of the storage water is greater than a nominal 85°F. Water is circulated between storage and liquid-to-air heat exchanger HX1 in the air-handling unit distribution duct until the space heating demand is satisfied, or the sensed storage temperature drops below 85°F.

Mode 3 - Storage-to-Heat Pump: This mode of operation will provide space heating when Mode 2 operation is not available. This mode is entered when there is a demand for space heating and the temperature of the storage water is below 85°F. Energy input to the heat pump is supplied by opening the normally closed valve V2, closing the normally open valve V1, and circulating storage water through heat pump evaporator HX2. This mode is terminated when either the sensed storage temperature rises above 90°F, or when no space heating demand exists.

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4. PERFORMANCE EVALUATION TECHNIQUES

The performance of the Terrell D. Moseley solar energy 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" [3]. These performance factors quantify the thermal performance of the system by measuring the amount of energies that are being transferred between the components of the system. The performance of the system can then be evaluated based on the efficiency of the system in transferring these energies.

Data from monitoring instrumentation located at key points within the solar energy system are collected by the National Solar Data Network. This data is first formed into factors showing the hourly performance of each system component, either by summation or averaging techniques, as appropriate. The hourly factors then serve as a basis for the calculation of the daily and monthly performance of each component subsystem.

Each month a summary of overall performance of the Terrell D. Moseley system and a detailed subsystem analysis are published. Monthly reports for the period covered by this System Performance Evaluation, October 1978 through March 1979, are available from the Technical Information Center, Oak Ridge, Tennessee 37830. The performance reports generated on the Terrell D. Moseley solar energy system for the period October 1978 through January 1979 contain values for the solar fraction, solar energy used and fossil savings parameters that are significantly lower than those tabulated in this report. This was the result of a change in the method of allocating tank losses between fossil and solar energy sources. Previously, all storage losses were charged against the solar energy in the storage tank and not shared proportionally by the fossil energy in the tank.

5. PERFORMANCE ASSESSMENT

The performance of the Terrell D. Moseley solar energy system has been evaluated for the October 1978 through March 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 and the measured values for solar energy used and system solar fraction are 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. The model used in the analysis is based on manufacturers' data and other known system parameters. In addition, the solar energy system coefficient of performance (COP) at both the system and subsystem level has been presented. 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 subsystems are presented first, followed by details pertaining to the space heating subsystem. Included in this area 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 weather 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 weather parameters has been provided.

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*f-chart is the designation of a procedure for designing solar heating systems. It was developed by the Solar Energy Laboratory, University of Wisconsin-Madison.

TABLE 5.2-2

SOLAR ENERGY SYSTEM COEFFICIENTS OF PERFORMANCE

Month	Solar Energy System COP	Collector Array Subsystem COP	Space Heating Subsystem Solar COP
Oct 78	1.98	9.05	14.50
Nov 78	4.64	10.32	8.15
Dec 78	4.89	12.79	8.12
Jan 79	4.59	10.50	8.86
Feb 79	4.38	8.96	9.38
Mar 79	3.83	11.30	8.77
Total Period	4.17	10.56	8.75

respectively. The values again relate the amount of solar energy associated with a particular subsystem to the amount of electrical energy required to operate the solar subsystem. As such, the COP serves as an indicator of the solar efficiency at both the system and subsystem level.

5.3 Subsystem Performance

The Terrell D. Moseley solar energy installation may be divided into three subsystems:

1) Collector array
2) Storage
3) Space heating.

Each subsystem is evaluated by the techniques defined in Section 4 and is numerically analyzed each month for the monthly performance reports. This section presents the results of integrating the monthly data available on the three subsystems for the period October 1978 through March 1979.

5.3.1 Collector Array Subsystem

Collector array performance is described by comparison of the collected solar energy to the incident solar energy. The ratio of these two energies represents the collector array efficiency which may be expressed as

$$\eta_c = Q_s/Q_i \qquad (1)$$

where: η_c = Collector Array Efficiency (CAREF)

Q_s = Collected Solar Energy (SECA)

Q_i = Incident Solar Energy (SEA).

The gross collector array area is 400 square feet. The measured monthly values of incident solar energy, collected solar energy, and collector array efficiency are presented in Table 5.3.1-1.

Evaluation of collector efficiency using operational incident energy and compensating for the difference between gross collector array area and the gross collector area yields operational collector efficiency. Operational collector efficiency, η_{co}, is computed as follows:

$$\eta_{co} = Q_s/\left(Q_{oi} \times \frac{A_p}{A_a}\right) \qquad (2)$$

where: Q_s = Collected Solar Energy (SECA)

Q_{oi} = Operational Incident Energy (SEOP)

Q_p = Gross Collector Area (product of the number of collectors and the total envelope area of one unit) (GCA)

A_a = Gross Collector Array Area (total area perpendicular to the solar flux vector including all mounting, connecting and transport hardware (GCAA).

Note: The ratio $\frac{A_p}{A_a}$ is typically 1.0 for most collector array configurations.

TABLE 5.3.1-1

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
Oct 78	19.55	3.44	0.18	16.28	0.21
Nov 78	11.35	2.58	0.23	9.38	0.28
Dec 78	14.83	4.22	0.28	13.40	0.31
Jan 79	12.97	2.74	0.21	10.84	0.25
Feb 79	11.75	2.15	0.18	9.36	0.23
Mar 79	17.94	4.51	0.25	15.48	0.29
Total	88.39	19.64	----	74.74	----
Average	14.73	3.27	0.22	12.46	0.26

This latter efficiency term is not the same as collector efficiency as represented by the ASHRAE Standard 93-77 [5]. Both operational collector efficiency and the ASHRAE collector efficiency are defined as the ratio of actual useful energy collected to solar energy incident upon the collector and both use the same definition of collector area. However, the ASHRAE efficiency is determined from instantaneous evaluation under tightly controlled, steady-state test conditions, while the operational collector efficiency is determined from the actual conditions of daily solar energy system operation. Measured monthly values of operational incident energy and computed values of operational collector efficiency are also presented in Table 5.3.1-1.

Collector array efficiency may be viewed from two perspectives. The first assumes that the efficiency be based upon all available solar energy; however, that point of view makes the operation of the control system a part of array efficiency. For example, energy may be available at the collector, but the collector fluid temperature is below the control minimum, thus the energy is not collected. The monthly efficiency computed by this method is listed in the column entitled "Collector Array Efficiency" in Table 5.3.1-1.

The second viewpoint assumes that the efficiency be based upon only the incident energy during periods of collection. The monthly efficiency computed by this method is listed in the column entitled "Operational Collector Array Efficiency." Efficiency computed by this method is used in the following discussion.

The Terrell D. Moseley collector array consists of 24 parallel flow flat plate collector panels. Table 5.3.1-2 presents a comparison of the actual performance of the collector array for the six-month report period against four predictions of performance which are based on instantaneous efficiency curves. Instantaneous efficiency curves are derived from laboratory test data supplied by the collector manufacturer and from three empirical sources: a linear regression line of field data obtained during March, a linear regression line fit through all field data in the base and a curvilinear (second order) regression line of all

TABLE 5.3.1-2

ENERGY GAIN COMPARISON
(ANNUAL)

SITE: TERRELL MOSELEY LYNCHBURG, VA

			ERROR			
			FIELD DERIVED			LAB
MONTH	YEAR	ACTUAL	MONTH	LONG TERM	2ND ORDER	PANEL
JANUARY	79	2.648E+06	0.050	0.031	0.036	-0.198
FEBRUARY	79	2.340E+06	0.092	0.099	0.118	-0.149
MARCH	79	4.491E+06	0.023	0.027	0.028	-0.194
APRIL		0.000E+00	0.000	0.000	0.000	0.000
MAY		0.000E+00	0.000	0.000	0.000	0.000
JUNE		0.000E+00	0.000	0.000	0.000	0.000
JULY		0.000E+00	0.000	0.000	0.000	0.000
AUGUST		0.000E+00	0.000	0.000	0.000	0.000
SEPTEMBER		0.000E+00	0.000	0.000	0.000	0.000
OCTOBER	78	3.656E+06	0.045	0.045	0.064	-0.197
NOVEMBER	78	2.684E+06	0.028	0.039	0.042	-0.188
DECEMBER	78	4.114E+06	0.027	0.037	0.042	-0.184
AVERAGE		3.356E+06	0.040	0.027	0.028	-0.187

CURVE	COEFFICIENTS			
	A0 (FRTA)	A1 (FRUL)	A2 (*)	R**2
PANEL	0.726	-1.265	N.A.	N.A.
MONTH	0.616	-1.164	N.A.	0.465
LT1ST	0.587	-1.056	N.A.	0.660
LT2ND	0.569	-0.920	-0.251	N.A.

field data in the base (the base data consists of all measurements relating to collector array performance mode from October 1978 through March 1979).

Each error value presented in the error field of Table 5.3.1-2 is computed by the equation

$$\text{error} = (A-P)/P \tag{3}$$

where:

A is the actual energy gain of the collector array shown in column one (million Btu/day).

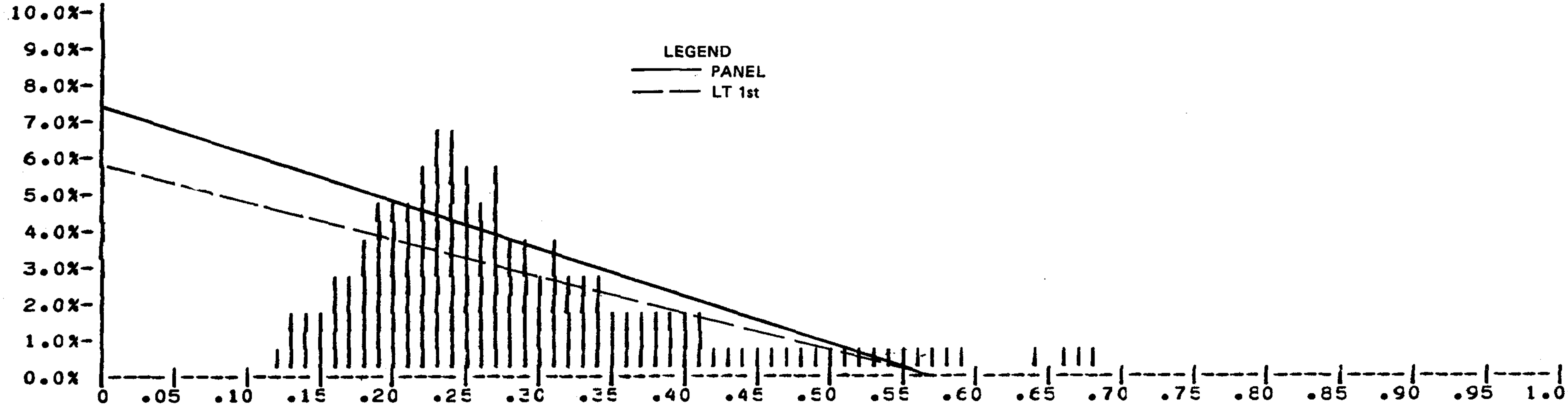
P is the predicted energy gain of the collector array based on projecting the measured operating point to the applicable instantaneous efficiency curve and multiplying by the measured insolation level and collector array area, and then summing over all the measured operating points (million Btu/day).

The computed error is then a measure of how well the particular prediction curve fits the reality of dynamic operating conditions in the field.

Figure 5.3.1-1 presents a histogram of the collector array operating points for December. Linear instantaneous efficiency curves based on controlled laboratory test data supplied by the collector manufacturer, field data for the month of December, and long-term field data for the base period are plotted on the histogram. The ordinate of the graph shown in Figure 5.3.1-1 has a printed range of 0 to 10 percent to display the distribution of collector array operating points. However, the value printed on the ordinate should be multiplied by 10 when the intercepts of the linear instantaneous efficiency curves are being evaluated (these values range from 0 to 100 percent).

TERRELL MOSELEY LYNCHBURG, VA

COLLECTOR TYPE: ON-SITE MFG COLLECTOR MODEL:



OPERATING POINT HISTOGRAM - DECEMBER

FLUID PROPERTIES - DECEMBER

WATER				
	COEFFICIENTS			
PROPERTY	A0	A1	A2	A3
SPECIFIC HEAT	1.011E+00	-2.348E-04	1.037E-06	
DENSITY	8.346E+00	4.129E-04	-9.961E-06	

ARRAY FLOW RATE 29.04 GPM

PANEL FLOW RATE 1.21 GPM

AVERAGE TEMPERATURE GAIN 2.22 DEGR FAHRENHEIT

LONG TERM CURVE FIT VALID FROM 0.116 TO 0.360 .

FIGURE 5.3.1-1 COLLECTOR ARRAY OPERATING POINT HISTOGRAM AND INSTANTANEOUS EFFICIENCY CURVES

The collector array operating points, X, are calculated each measurement scan by the equation:

$$X = (T_{f,i} - T_a)/I \qquad (4)$$

where:

$T_{f,i}$ is the inlet tempe, ature of the collector array transport fluid (°F)

T_a is the temperature of the ambient air (°F)

I is the insolation rate (Btu/Ft^2-Hr).

Examination of the operating point histogram indicates that the predominant region of collector array operation occurred for operating points between 0.16 and 0.34 (54 percent of the time). Therefore, the operational collector array efficiency would typically be on the order of 0.25. This was obtained by projecting upwards from the abscissa to the linear instantaneous collector array efficiency curve (LTIST), and then projecting horizontally to the ordinate to obtain the average efficiency values. This efficiency value is in close agreement with the average operational collector array efficiency as presented in Table 5.3.1-1.

From the instantaneous collector efficiency curves shown in Figure 5.3.1-1 and from the energy gain comparisons presented in Table 5.3.1-2, it can be concluded that the actual collector performance was consistently lower than the panel performance by about 19 percent. This difference may be attributable to higher array losses than those present in the collector panel efficiency tests.

Additional information concerning collector array analysis in general may be found in a forthcoming paper [9] that describes collector array analysis procedures in detail and presents the results of analysis performed on numerous collector array installations across the United States.

5.3.2 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, η_s. This relationship is expressed in the equation

$$\eta_s = (\Delta Q + Q_{so})/Q_{si} \quad (5)$$

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) (STECH).

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

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

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 storage average temperature (average storage temperature for the reporting period) and the ambient temperature in the vicinity of the storage tank.

An effective storage heat transfer coefficient (C) for the storage subsystem can be defined as follows:

$$C = (Q_{si}-Q_{so}-\Delta Q_s)/[(\bar{T}_s - \bar{T}_a) \times t] \frac{\text{Btu}}{\text{Hr-°F}} \quad (6)$$

where:

C = effective storage heat transfer coefficient

Q_{si} = energy to storage (STEI)

Q_{so} = energy from storage (STEO)

ΔQ_s = change in stored energy (STECH)

$\bar{T}_s$ = storage average temperature (TS)

$\bar{T}_a$ = average ambient temperature in the vicinity of storage (TE)

t = number of hours in the month (HM).

The effective storage heat transfer coefficient is comparable to the heat loss rate defined in ASHRAE Standard 94-77 [6]. It has been calculated for each month in this report period and included, along with Storage Average Temperature, in Table 5.3.2-1. The mean value of the storage heat loss coefficient was computed to be 34.3 Btu/Hr-°F.

The six-month period storage tank efficiency was computed to be 0.80. This figure may be slightly lower than the actual efficiency because an unmeasured amount of energy is removed from storage to preheat water for the DHW subsystem. Based on the site contractor's predicted 15 gallons per day DHW consumption, and an estimated ground water temperature of 55°F, the storage

TABLE 5.3.2-1

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 Transfer Coefficient (Btu/Hr-°F)
Oct 78	3.42	0.87	0.38	0.37	150	30.7
Nov 78	4.22	3.19	-0.66	0.60	119	33.5
Dec 78	9.95	8.75	-0.17	0.86	104	28.8
Jan 79	14.98	12.83	0.23	0.87	107	34.9
Feb 79	15.26	13.02	0.035	0.86	112	40.0
Mar 79	7.91	5.57	0.42	0.76	117	38.0
Total	55.74	44.23	0.24	----	---	----
Average	9.29	7.37	0.04	0.80	118	34.3

tank contribution to the DHW subsystem is estimated to be 0.60 million Btu. This amount will increase the six-month storage efficiency term by approximately one percent.

It should be noted that the "Energy to Storage" values in Table 5.3.2-1 do not agree with the "Collected Solar Energy" values shown in Table 5.3.1-1. This is because some thermal energy was added to storage by the auxiliary heater in each month for the November 1978 through March 1979 period.

5.3.3 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 Terrell D. Moseley space heating subsystem is presented in Table 5.3.3-1. For the six-month period from October 1978 through March 1979, the solar energy system supplied a total of 14.79 million Btu to the space heating load. The total heating load for this period was 44.41 million Btu, resulting in a solar fraction of 33 percent.

TABLE 5.3.3-1

HEATING SUBSYSTEM PERFORMANCE

Month	Space Heating Load (Million Btu)	Energy Consumed (Million Btu)			Measured Solar Fraction (Percent)
		Solar	Auxiliary Thermal	Auxiliary	
Oct 78	0.87	0.87	0.00	0.41	100
Nov 78	3.26	2.69	0.57	3.34	83
Dec 78	8.86	4.06	4.81	10.36	46
Jan 79	12.83	2.48	10.35	21.25	19
Feb 79	13.02	1.97	11.05	22.28	15
Mar 79	5.57	2.72	2.84	6.66	49
Total	44.41	14.79	29.62	64.3	--
Average	7.40	2.46	4.94	10.72	33

5.4 Operating Energy

Operating energy for the Terrell D. Moseley 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 energy collection and storage subsystem operating energy and space heating subsystem operating energy. 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 5.4-1.

Total system operating energy for the Terrell D. Moseley site is that electrical energy required to operate the blower in the air-handling unit, the auxiliary energy circulating pump P3, the space heating circulating pump P2, and the solar energy pump P1.

For the period covered by this report, a total of 6.93 million Btu of operating energy was consumed. During the same period, a total of 14.79 million Btu of solar energy was supplied to the space heating load. Therefore, for every one million Btu of solar energy delivered to the load, 0.47 million Btu (or 137.7 kwh) of electrical operating energy was expended. The magnitude of this fraction is due in part to the fact that two pumps (P1 and P2) are oversized for their applications. This was done for increased reliability considerations. The high electrical operating cost had a significant effect on space heating system savings.

TABLE 5.4-1

OPERATING ENERGY

Month	ECSS Operating Energy (Million Btu)	Space Heating Operating Energy (Million Btu)	Total System Operating Energy (Million Btu)
Oct 78	0.38	0.06	0.44
Nov 78	0.25	0.40	0.65
Dec 78	0.33	1.09	1.42
Jan 79	0.26	1.48	1.74
Feb 79	0.24	1.40	1.64
Mar 79	0.40	0.64	1.04
Total	1.86	5.07	6.93
Average	0.31	0.84	1.16

5.5 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.

Calculated monthly values of both fossil energy savings and electrical energy savings are presented in Table 5.5-1. The negative signs preceding the values for net electrical savings indicate an expense rather than a saving of energy.

Energy savings calculations for the Terrell D. Moseley site are based on the projected energy requirements using a natural-gas-fired boiler with an assumed efficiency of 60 percent, supplying heated water to an air-duct heat exchanger. Total system savings for the six-month report period are 24.65 million Btu of fossil energy at an expense of 4.51 million Btu of electrical energy. Since this comparison is made with different energy sources, a more meaningful way to represent the savings would be to convert metered fuel savings to raw fuel savings at the generating station. Assuming that the electric power was generated at a natural-gas-fired generating station, the electrical expense converted to natural gas expense is 15,033 cubic feet.

The conversion efficiency of 0.3 was used to convert metered savings to generating station savings in Btu. Then, the natural gas energy content factor of 1,000 Btu per cubic foot was applied to yield electrical energy savings in cubic feet. The total fossil energy savings are 24,650 cubic feet. Therefore, the net computed savings are roughly equivalent to 9,617 cubic feet of natural gas.

TABLE 5.5-1

ENERGY SAVINGS

	Space Heating Savings		Net Savings			
	Electrical	Fossil	Electrical		Fossil	
Month	Million Btu	Million Btu	Million Btu	kwh*	Million Btu	Cubic Feet**
Oct 78	-0.01	1.45	-0.39	-114.3	1.45	1,450
Nov 78	-0.29	4.48	-0.54	-158.2	4.48	4,480
Dec 78	-0.72	6.76	-1.05	-307.6	6.76	6,760
Jan 79	-0.71	4.13	-0.97	-284.2	4.13	4,130
Feb 79	-0.61	3.29	-0.85	-249.0	3.29	3,290
Mar 79	-0.31	4.54	-0.71	-208.0	4.54	4,540
Total	-2.65	24.65	-4.51	-1,321.4	24.65	24,650
Average	-0.44	4.11	-0.75	-220.2	4.11	4,108

*Based on 3,413 Btu per kilowatt hour.

**Based on 1,000 Btu per cubic foot of natural gas.

The major portion of the system electrical operating energy expense was attributed to the collector pump P1 and the space heating circulating pump P2. The heat pump was not used for a significant time in the six-month reporting period.

6. REFERENCES

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

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7. Solar Energy System Performance Evaluation, Terrell D. Moseley Office Building, SOLAR/2011-78/14, Department of Energy, Washington, February 1978 Through May 1978.

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9. McCumber, W. H. Jr., "Collector Array Performance for Instrumented Sites of the National Solar Heating and Cooling Demonstration Program", to be published and distributed at the 1979 Solar Update Conference.

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

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 collector 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 collected 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 collector array efficiency reported here.

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.

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.

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

- ELECTRICAL ENERGY SAVINGS (HSVE) 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.

- 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 program. It is tabulated in this data report for two purposes--as a measure of the conditions prevalent during the operation of the system at the site, and as an historical record of weather data for the vicinity of the site.

- TOTAL INSOLATION (SE) is 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.
- WIND DIRECTION (WDIR) is the average direction of the prevailing wind.
- WIND SPEED (WIND) is the average wind speed measured 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 THE TERRELL D. MOSELEY SOLAR ENERGY SYSTEM

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 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 3-1

AVERAGE AMBIENT TEMPERATURE (°F)

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

AVERAGE BUILDING TEMPERATURE (°F)

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

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

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

FOR ± 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

ENTHALPY FUNCTION (BTU/LBM)

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

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

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \Sigma\ [M100 \times HWD\ (T150,\ T100)] \times \Delta\tau$$

SOLAR ENERGY TO STORAGE (BTU)

$STEI = \Sigma\ [M100 \times HWD(T101,\ T151)] \times \Delta\tau$

AUXILIARY THERMAL ENERGY TO STORAGE (BTU)

$CSAUX = \Sigma\ [M210 \times HWD(T210,\ T260)] \times \Delta\tau$

SOLAR ENERGY FROM STORAGE (BTU)

$STEO = \Sigma\ [M400 \times HWD(T400,\ T450)] \times \Delta\tau$

AVERAGE TEMPERATURE OF STORAGE (°F)

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

ENERGY DELIVERED FROM ECSS TO SPACE HEATING SUBSYSTEM (BTU)

$CSEO = STEO$

ECSS OPERATING ENERGY (BTU)

$CSOPE = 56.8833 \times \Sigma\ EP101 \times \Delta\tau$

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$HOPE = 56.8833 \times \Sigma\ (EP301 + EP401 + BLPWR) \times \Delta\tau$

WHERE BLPWR = THE BLOWER ELECTRICAL OPERATING POWER (KW) REQUIRED FOR SPACE HEATING

SPACE HEATING SUBSYSTEM AUXILIARY ELECTRICAL FUEL ENERGY (BTU)

$HAE = 56.8833 \times \Sigma\ (EP402 - BLPWR) \times \Delta\tau$

WHEN THE SYSTEM IS IN STORAGE-TO-HEAT PUMP MODE

SPACE HEATING SUBSYSTEM AUXILIARY FOSSIL FUEL ENERGY (BTU)

$HAF = HVF \times \Delta F211$

WHERE HVF = HEATING CONTENT OF NATURAL GAS IN BTU/CF

ΔF211 = HOURLY CHANGE IN F211

STORAGE SOLAR FRACTION

$STORSFR = STEIST/(STEIST + STEIAT)$

WHERE STEIST = TOTAL SOLAR ENERGY IN THE STORAGE TANK AT THE END OF AN HOUR

STEIAT = TOTAL AUXILIARY THERMAL ENERGY IN THE STORAGE TANK AT THE END OF AN HOUR

SOLAR ENERGY TO SPACE HEATING SUBSYSTEM (BTU)

HSE = STEO x STORSFR

AUXILIARY THERMAL ENERGY TO SPACE HEATING SUBSYSTEM (BTU)

HAT = STEO x [1 - STORSFR] + HAE x HPCOMPF

WHERE HPCOMPF = HEAT PUMP COMPRESSOR EFFICIENCY (ASSUMED TO BE 0.7)

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

SEA = CLAREA x SE

COLLECTED SOLAR 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

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

SEL = CSEO

ECSS SOLAR CONVERSION EFFICIENCY

CSCEF = SEL/SEA

SPACE HEATING SUBSYSTEM SOLAR FRACTION (PERCENT)

HSFR = 100 x HSE/HL

SPACE HEATING SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

HSVE = CONV - HOPE

WHERE CONV IS THE ELECTRICAL ENERGY REQUIRED FOR THE CONVENTIONAL SYSTEM.

SPACE HEATING SUBSYSTEM FOSSIL ENERGY SAVINGS (BTU)

HSVF = HSE/BEFF

WHERE BEFF = 0.6, WHICH IS THE ASSUMED BURNING EFFICIENCY OF THE NATURAL GAS-FIRED HEATER

SYSTEM LOAD (BTU)

SYSL = HL

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

SFR = HSFR

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

AXE = HAE

AUXILIARY FOSSIL ENERGY SUPPLIED TO THE SYSTEM (BTU)

AXF = HAF

SYSTEM OPERATING ENERGY (BTU)

SYSOPE = HOPE + CSOPE

TOTAL ENERGY CONSUMED (BTU)

TECSM = SYSOPE + AXE + AXF + SECA

TOTAL ENERGY SAVINGS (BTU)

TSVE = HSVE - CSOPE

TOTAL FOSSIL ENERGY SAVINGS (BTU)

TSVF = HSVF

SYSTEM PERFORMANCE FACTOR

SYSPF = SYSL/[3.33 x (AXE + SYSOPE) + AXF]

APPENDIX C

LONG-TERM AVERAGE WEATHER CONDITIONS

SITE: T.D.MOSELEY 14.

LOCATION: LYNCHBURG VA

ANALYST: J. DWIGGINS

FDRIVE NO.: 40.

COLLECTOR TILT: 50.00 (DEGREES)

COLLECTOR AZIMUTH: 0.0 (DEGREES)

LATITUDE: 37.40 (DEGREES)

RUN DATE: 6/04/79

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JAN	1466.	649.	0.44275	1.678	1089.	880	0	37.
FEB	1919.	896.	0.46687	1.418	1270.	753	0	38.
MAR	2494.	1224.	0.49080	1.162	1422.	605	0	46.
APR	3078.	1582.	0.51393	0.945	1495.	260	8	57.
MAY	3477.	1799.	0.51750	0.813	1462.	85	91	65.
JUN	3635.	1928.	0.53055	0.759	1463.	0	232	73.
JUL	3549.	1844.	0.51938	0.783	1443.	0	335	76.
AUG	3226.	1659.	0.51431	0.885	1468.	0	291	74.
SEP	2701.	1383.	0.51198	1.072	1482.	33	126	68.
OCT	2084.	1077.	0.51649	1.355	1458.	234	17	58.
NOV	1570.	752.	0.47906	1.639	1233.	540	0	47.
DEC	1340.	579.	0.43199	1.758	1018.	843	0	38.

LEGEND:

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

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

KBAR ==> RATIO OF HBAR TO HOBAR.

RBAR ==> RATIO OF MONTHLY AVERAGE DAILY RADIATION ON TILTED SURFACE TO THAT ON A HORIZONTAL SURFACE FOR EACH MONTH (I.E., MULTIPLIER OBTAINED BY TILTING).

SBAR ==> MONTHLY AVERAGE DAILY RADIATION ON A TILTED SURFACE (I.E., RBAR * 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.