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SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION - SEASONAL REPORT FOR CONTEMPORARY-MANCHESTER, MANCHESTER, NEW HAMPSHIRE

Prepared by

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George C. Marshall Space Flight Center, Alabama 35812

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16. ABSTRACT
This report 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. It is one of a series of reports describing the operational and thermal performance of a variety of solar systems installed in Operational Test Sites under this program. The analysis used is based on instrumented system data monitored and collected for at least one full season of operation. The objective of the analysis is to report the long-term field performance of the installed system and to make technical contributions to the definition of techniques and requirements for solar energy system design.

The Solar Energy System, Contemporary-Manchester, was designed by Contemporary Systems Incorporated (CSI), Jeffrey, New Hampshire to provide space heating and domestic hot water (DHW) preheating for a three-story dwelling located on the New Hampshire Vocational Technical College campus, Manchester, New Hampshire. The systems consist of twenty double glazed flat plate roof mounted warm air, CSI Series V, collectors (area 805 square feet) mounted with a tilt angle of 60 degrees from the horizontal, a 720 cubic foot horizontal rock bin for thermal storage, a central air handler, an 80 gallon DHW preheat tank, pumps, controls, plumbing and associated air ducting. Hot water pre-heating is accomplished by an air-to-water heat exchanger with auxiliary energy provided by conventional electric 80 gallon hot water tank. Auxiliary space heating is provided by a 112,000 BTU per hour, 1200 cubic feet per minute oil fired furnace.

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1. FOREWORD

The Solar Energy System Performance Evaluation - Seasonal Report 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 season. 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
- Performance Assessment
- Operating Energy
- Energy Savings
- Maintenance
- Summary and Conclusions

Data used for the seasonal analyses of the Operational Test Site described 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 instrumentation system design in April 1976. The Final Report emphasizes the economic analysis of solar systems performance and 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], [2] and [3]*.

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*Numbers in brackets designate references found in Section 8.

2. SYSTEM DESCRIPTION

The Contemporary Manchester Solar Energy System is installed in a three-story dwelling located on the campus of the New Hampshire Vocational Technical College in Manchester, New Hampshire. The system was designed by Contemporary Systems Incorporated (CSI) of Jeffrey, New Hampshire. System integration and installation were accomplished by CSI and by students and faculty of the Vocational Technical College. The Solar Energy System is designed to provide space heating and domestic hot water (DHW) preheating for the residence.

Solar energy collection is performed by twenty double glazed flat plate collectors, connected in parallel, with a total area of 805 square feet. The collectors are roof mounted on the dwelling and face 15 degrees west of south with a tilt angle of 60 degrees from the horizontal. Air is the heat transfer medium and the collectors are designated "Contemporary Systems, Series V, Warm Air".

Thermal storage is provided by a horizontal rock bin containing approximately 720 cubic feet of 1 inch to 1 1/2 inch stones of a type referred to as "trap rock" in the New England area and commonly used in septic system fields and foundation drainage. Air movement for solar heat transfer is accomplished by a central air handler with integral blower and damper controls for distribution of solar heated air to the heated space or to and from the rock storage bin.

Hot water pre-heating is accomplished by an air-to-water heat exchanger, with separate blower and fan coil unit, mounted near the collector outlet. Auxiliary space heating is provided by a 112,000 Btu per hour, 1200 cubic feet per minute oil fired furnace. Auxiliary energy for the domestic hot water system is provided by an electric resistance heating element in a conventional 80-gallon hot water tank.

The system is shown schematically in Figure 2-1. The sensor designations in Figure 2-1 are in accordance with NBSIR-76-1137 [5]. The measurement symbol prefixes: W, T, EP, I and F represent respectively: flow rate, temperature, electric power. solar insolation and fossil fuel usage. Figure 2-2 is a pictorial view of the Contemporary Manchester installation.

Based on data provided by Contemporary Systems in the performance design specification, the Solar Energy System should provide 92% of the average total heating load, during the heating season, of 8.5 million Btu per month. The system is designed to provide a peak heating capability of 35,000 Btu per hour. The system is also designed to provide 58 percent of the hot water heating requirements, based on a predicted average hot water load of 1.1 million Btu per month. The hot water heating requirements include a usage of 50 gallons per day delivered at a rate of not less than 1.25 gallons per minute at a minimum temperature of 130°F.

The Solar Energy System has six operational modes which are described as follows:

Mode 1 - Heating From Collectors: When the conditioned space thermostat calls for heat and the collector outlet temperature is sufficiently high, generally 85°F minimum, the main air handler blower is turned on and dampers positioned to allow delivery of solar heated air to the house.

Mode 2 - Storing Heat: When there is no demand for heat to the conditioned space and the collector outlet temperature is greater than that of the cold side of rock storage by a pre-set amount, the air handler blower and control dampers cause solar heated air to be delivered to the rock bin.

Mode 3 - Heating From Storage: A demand for heat from the house thermostat, when there is insufficient heat from the collectors, causes the system to enter this mode. A "storage minimum" temperature is pre-set in the system controller and the heating from storage mode is only entered when the hot side of storage is 5°F above this minimum setting. Operation in this mode is terminated when the hot side of storage falls below the "storage minimum" value.

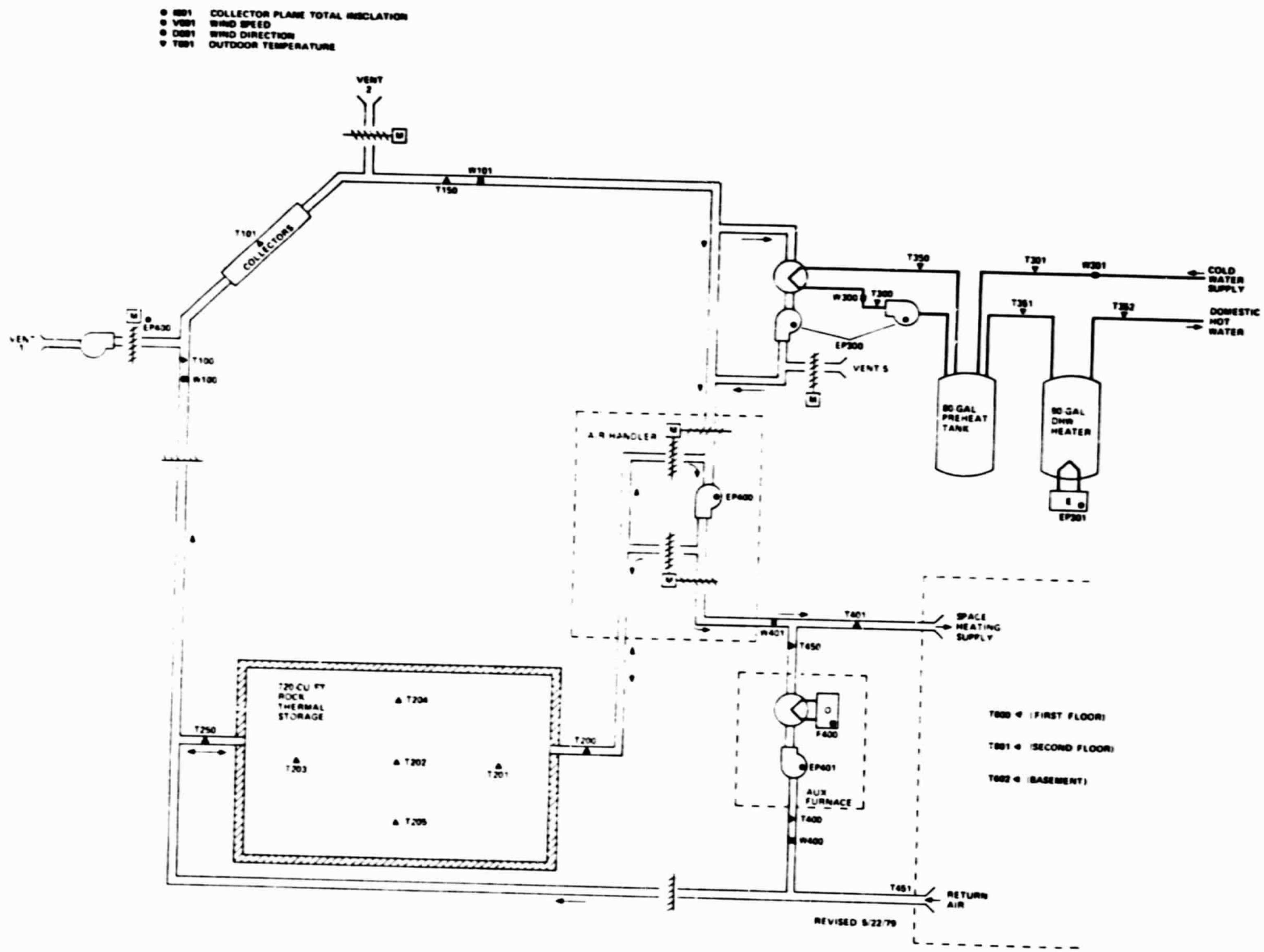
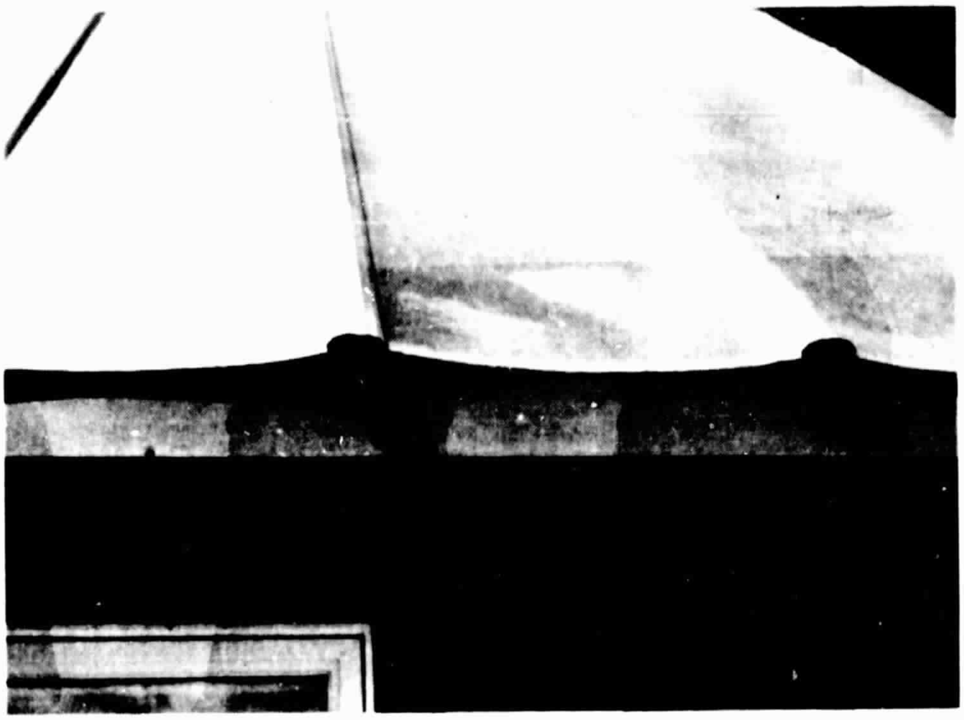


Figure 2-1. CONTEMPORARY SYSTEM NO. 2, MANCHESTER, SOLAR ENERGY SYSTEM SCHEMATIC



Close-up of Roof Mounted Air Collectors

Residence on Campus of New Hampshire Vocational Technical College

Figure 2-2. Contemporary Manchester Pictorial

Mode 4 - Auxiliary Heating: The auxiliary heating mode is entered when a heating demand exists and both collector outlet and storage temperatures are insufficient. When operating in this mode, the air handler dampers are positioned to prevent reverse flow into the solar storage and collector loops and heat is supplied to the conditioned space from the oil-fired furnace.

Mode 5 - Summer Venting: For warm weather or summer operation the system enters a thermal siphon venting mode through the use of damper controlled vents at the inlet side (vents 1 and 3) and outlet side (vents 2 and 4) of the collectors. Operation in this mode prevents excessive collector temperatures during periods of high insolation when no space heating demand exists.

Mode 6 - Hot Water Preheating: Hot water preheating can be utilized when the system is in the Heating From Collector or Storing Heat modes. Preheating can also be accomplished during summer operation provided that the collector outlet temperature is sufficiently above the preheat tank temperature and that venting control dampers are positioned to permit air flow through the domestic hot water heat exchanger.

2.1 Typical System Operation

Operation of the Contemporary Manchester Solar Energy System is controlled by a Contemporary System Logic Control Unit, designated LCU-110. The unit contains temperature comparison circuits which compare system input temperature with preselected temperature settings of the controller. The LCU-110 also contains a Solar Mode Selector which compares the signals generated by the comparison circuits with the room thermostat's request for heat and determines which mode the solar system should operate in to make the best use of available solar energy. The output of the Solar Mode Selector is routed to a Mode Implementor circuit which initiates the appropriate control actions to the air handler fan and control dampers to place the system in the proper operating mode.

Temperature settings which apply to the various operating modes are as follows:

Heating From Collectors - when the collector outlet temperature is 100°F, or higher, and the thermostat calls for heat, the system will be placed in this mode. Operation in this mode will cease when the outlet temperature falls below 85°F.

Heating From Storage - when heat is not available from the collectors and the thermostat calls for heat, this mode will be entered if the hot side of storage is 85°F, or more. Operation in this mode will cease if the temperature at the hot side of storage falls below 85°F.

Storing Heat - when the collector outlet temperature is 100°F or higher and is at least 15°F above the hot side storage temperature, the system will operate in this mode, if the room thermostat is not calling for heat.

Heating From Auxiliary - the auxiliary heating mode is entered when a heating demand exists and solar energy is unavailable either from the collectors or from storage. When operating in this mode, the air handler dampers are positioned to prevent reverse flow of auxiliary heat into the storage and collector loops. A signal from the second stage of the room thermostat moves the dampers to the position and turns on the oil-fired furnace and its associated fan to supply heat to the conditioned space.

December 14, 1979, has been selected to illustrate typical operation of the Contemporary Manchester system. On this particular day, there was no direct heating from the collectors but operation in the other three primary modes; heating from storage, storing heat and heating from the auxiliary source, were observed. Direct heating from the collectors is very infrequent because of low thermostat settings and passive heating during the day. Consequently, direct heating is not considered typical operation. Figure 2.1-1 is a plot of selected system parameters on this data which shows the interaction of the solar energy and auxiliary subsystem throughout the day.

Heating from storage occurred during two brief intervals between midnight and 2:00 AM, at which time storage temperatures fell below the 85°F minimum. Auxiliary heat was supplied, at the indicated intervals, between midnight and about 10:45 AM. Collector loop turn-on occurred at 10:35 AM and solar energy was supplied to rock storage until the collector turned off at 3:02 PM. During this period, the temperature at the hot side of storage increased from approximately 80°F to 120°F, as shown by the plot of temperature T201. The 120°F level of storage temperature was maintained until just after 8:00 PM when heating from storage was again required, as indicated by the eight cycles of heating from storage observed between 8:00 PM and midnight. This demand for heating from storage occurred when the first floor temperature of the house had declined to approximately 60°F.

Collector loop turn-on occurred when the solar insolation had reached a value of 311 Btu/Ft^2-Hr and was terminated at an insolation value of 147 Btu/Ft^2-Hr. Collector outlet temperature at collector turn-on was 147°F and had decreased to 96°F when turn-off occurred at 3:02 PM. Collector absorber surface temperatures at turn-on and turn-off were 159°F and 101°F, respectively.

Examination of Figure 2.1-1 shows that, on the typical day selected, the control system operated generally in accordance with design goals. The lack of direct solar heating from the collectors is believed to be due to a significant amount of passive solar energy input to the house which satisfied the interior heating demand during daylight hours and caused the available solar energy to be routed to rock storage rather than to the heated space.

CONTEMPORARY MANCHESTER DATA FOR DEC. 14, 1979

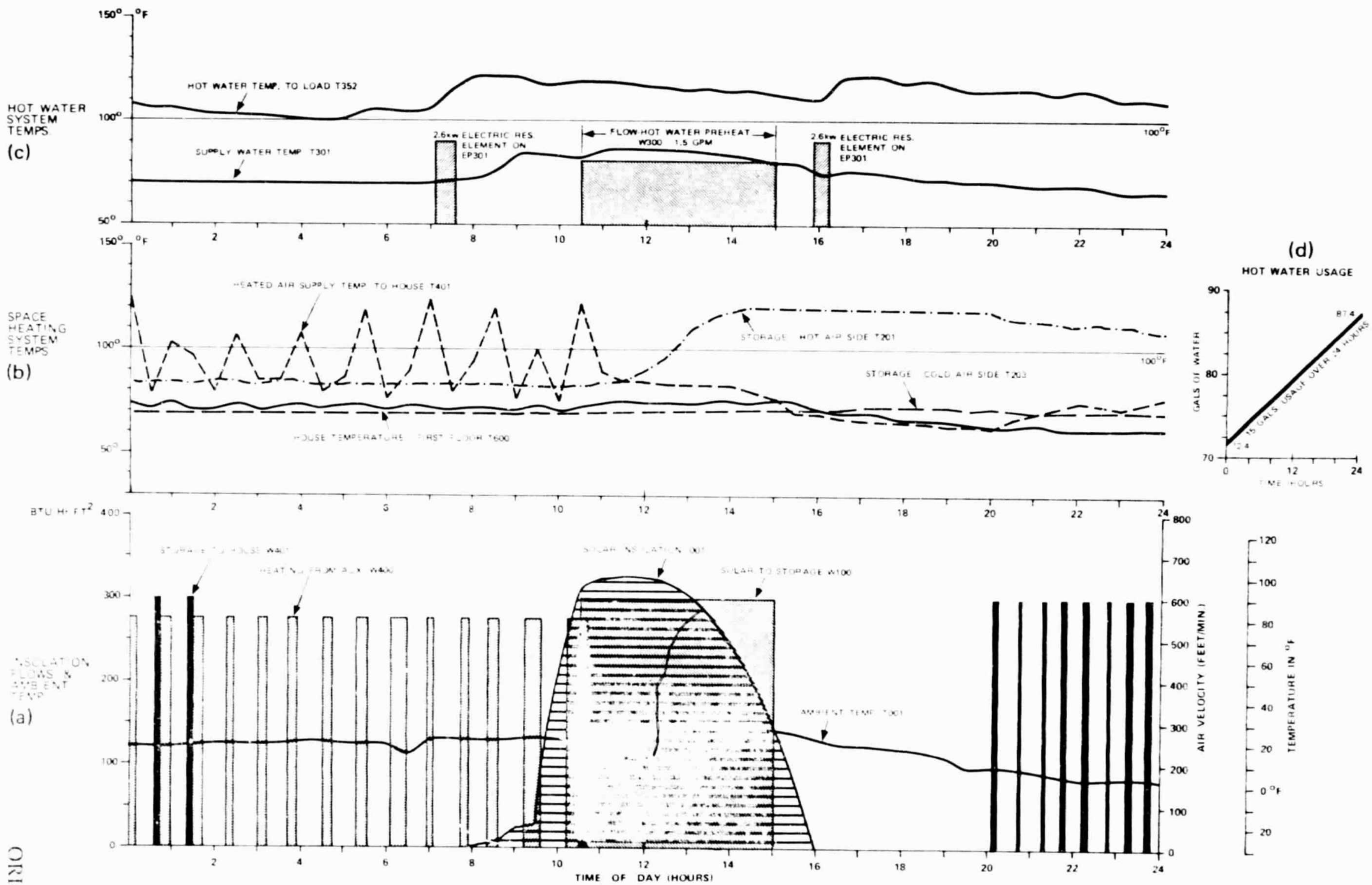


Figure 2.1-1. Typical System Operating Parameters and Operating Sequence

2.2 System Operating Sequence

The operating sequence of the Contemporary Manchester system is illustrated by further reference to Figure 2.1-1. System air flows in the various operating modes are plotted as a function of time and referenced to the incident solar energy in the lower graph, Figure 2.1-1(a).

The effects of operating cycles in the solar and auxiliary modes on the temperatures in the space heating subsystem can be seen in the concurrent center graph, Figure 2.1-1(b). Note that the variations in the hot air supply temperature, T401 are in time phase with heating cycles from storage and from the auxiliary source. Temperature T201 at the hot side of storage, and to a lesser extent, T203 at the cold side of storage, can be seen to be in phase with the storage of heat in Figure 2.1-1(a). Indoor first floor temperature T600 is maintained in the range of 73°F in the earl morning hours to 65°F in the late evening hours, despite an outdoor ambient temperature range of 20°F to 3°F over the twenty four hour period.

Response of the domesti hot water subsystem temperatures and flows are shown in the upper graph, Figure 2.1-(c). Activation of the electric resistance heating element first occurs from about 7:00 to 7:30 AM when the hot water outlet temperature T352 has decreased to approximately 100°F and is reflected in a rapid increase in T352 to 120°F. Flow W300 in the DHW preheat loop is exactly concurrent with collector loop flow (10:35 AM to 3:02 PM) maintaining the DHW output temperature above the 110°F level until about 4:00 PM when a second cycle of auxiliary DHW heat is required. It should be noted that the hot water usage, as plotted in Figure 2.1-1(d), was very low for December 14, totalling only 15 gallons. This usage is typical for the system because of the unoccupied status of the house throughout the performance period, and is attributed to a manual draw of hot water by students or faculty members from the New Hampshire Vocational Technical College.

3. PERFORMANCE ASSESSMENT

The performance of the Contemporary Manchester Solar Energy System has been evaluated for the March 1979 through February 1980 time period from two perspectives. The first was the overall system view in which the performance values of system solar fraction and net energy savings were evaluated against the prevailing and long-term average climatic conditions and system loads. The second view presents a more in depth look at the performance of the individual subsystems. Details relating to the performance of the system are presented first in Section 3.1 followed by the subsystem assessment in Section 3.2.

3.1 System Performance

This Seasonal Report provides a system performance evaluation summary of the operation of the Contemporary Manchester Solar Energy System located in Manchester, New Hampshire. 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 subsystem is also evaluated in subsequent section of this report.

The measurement data were collected for the period March, 1979, through February, 1980. 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 collection 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 contained 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:

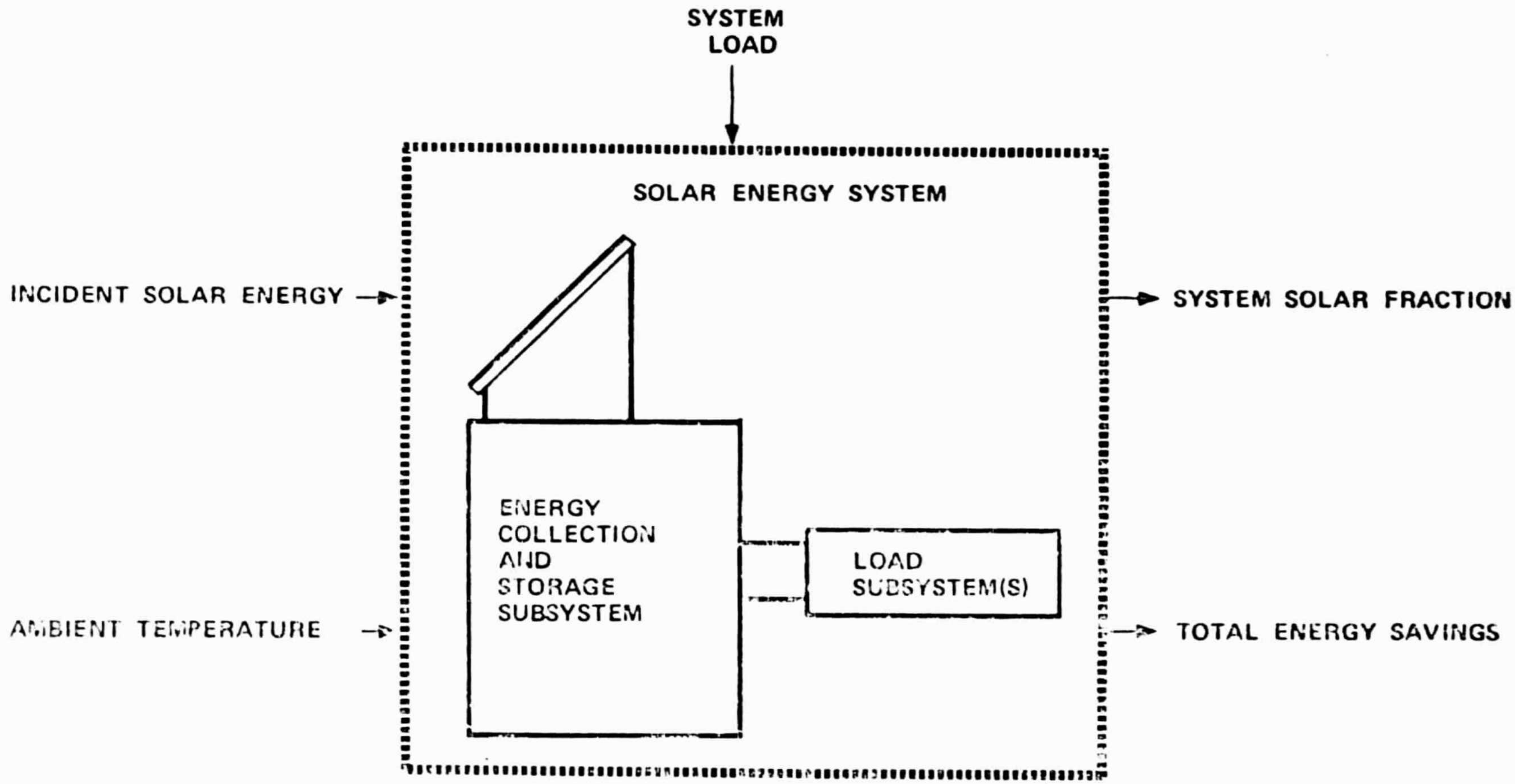


Figure 3.1.1 Solar Energy System Evaluation Block Diagram

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 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 temperature 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 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.

At the Contemporary Manchester site for the twelve month report period, the long-term average daily incident solar energy in the plane of the collector was 1089 Btu/ft^2. The average daily measured value was 1288 Btu/ft^2 which is about 18 percent above the long-term value. On a monthly basis, October of 1979 was the worst month with an average daily measured value of incident solar energy 18 percent below the long-term average daily value. February 1980 was the best month with an average daily measured value 54 percent above the long-term average daily value. On a long-term basis the measured value of incident solar energy was sufficiently above the long-term value to have a favorable influence on the performance of the solar energy system.

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 measured average daily ambient temperature was 53°F for the Contemporary Manchester site which is 7°F above the long-term value of 46°F. On a monthly basis January and February of 1980 were the worst months, temperaturewise, when the measured temperature was 1° to 6°F below the long-term daily average. This two month period of below average temperature has a slightly adverse impact on system performance. This resulted from an increased load and a decreased solar fraction which led to a decrease in the total net savings.

TABLE 3.1-1

SYSTEM PERFORMANCE SUMMARY

CONTEMPORARY MANCHESTER

Month	Daily Incident Solar Energy per Unit area @ 60° Tilt ($Btu/Ft^2 \cdot Day$)		Ambient Temperature °F		System Load-Measured	Solar Fraction (Percent)		Total Energy Savings
	Measured	Long-Term Average	Measured	Long-Term Average	(Million Btu)	Measured	Expected	(Million Btu)
Mar 79	1100	1137	45	32	3.32	33	47	1.66
Apr 79	1309	1225	52	44	3.17	52	59	2.51
May 79	1178	1243	67	55	0.59	74	61	0.48
Jun 79	1678	1243	77	65	0.11	6	3	-0.06
Jul 79	1565	1261	83	70	0.08	15	14	-0.06
Aug 79	1359	1260	78	67	0.06	18	20	-0.12
Sep 79	1702	1223	70	60	0.08	20	19	-0.26
Oct 79	935	1144	55	49	0.61	7	6	-0.16
Nov 79	891	774	46	38	2.65	63	58	2.57
Dec 79	1003	672	28	25	6.74	35	45	3.70
Jan 80	1165	850	20	21	8.95	12	23	1.62
Feb 80	1570	1022	17	23	8.53	20	47	-2.64
Total	15455	13054	-	-	34.89	-	-	14.52
Average	1288	1089	53	46	2.91	29*	41	1.21

*Average is weighted by the measured system load.

The effect of system load and ambient temperature on the performance of the Contemporary Manchester Solar Energy System can be seen by reference to Table 3.1-1. The maximum solar fraction of 74 percent was achieved in May, 1979, when system load was low and ambient temperature was 12°F above the long-term average value. Because of the extremely low and non-typical hot water loads which constituted the entire load during the summer months (June through September) the measured solar fraction during this period is not considered a valid index of system performance. The lowest solar fraction during the heating season was recorded in October, 1979, (7%) and, in this case, the poor performance is attributed to the fact that the incident solar energy was 18 percent below the long-term average, as cited earlier (worst month). The adverse effects of the combination of high load and low temperature can also be seen in January, 1980, when the ambient temperature was 1°F below the long-term average and the load was the highest in any month in the reporting period, resulting in a solar fraction of only 12 percent.

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 the 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 system [9]). The model used in the analysis is based on manufacturers' data and other known system parameters. The bases 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-Chart where 'f' is a designator for the system solar fraction. The output of the f-Chart procedure is the expected system solar fraction. 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.

The total energy saving is an important performance parameter for the solar energy system because the fundamental purpose of the system is to replace expensive conventional energy sources with less expensive 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 for the system. In terms of the technical analysis presented in this report the net total energy savings should be significant positive figure. The total net energy savings for the Contemporary Manchester Solar Energy System was 14.52 million Btu which is equivalent during the performance period. This is not considered to be normal savings for this system. The reason is that the house was unoccupied throughout the performance period. The loads were consequently light, and the system was not used in a manner as it was designed for.

3.2 Subsystem Performance

The Contemporary Manchester Solar Energy Installation may be divided into four subsystems:

1. Collector array
2. Storage
3. Hot water
4. Space Heating

Each subsystem has been evaluated by the techniques defined in Section 3 and is numerically analyzed each month for the monthly performance assessments. This section presents the results of integrating the monthly data available on the four subsystems for the period March, 1979, through February, 1980.

3.2.1 Collector Array Subsystem

The Contemporary Manchester collector array consists of twenty Contemporary Systems Incorporated, Series V, Warm Air collectors making up an array with a gross area of 805 square feet. The collectors are interconnected for parallel flow. Interconnection and flow details, as well as other pertinent operational characteristics are shown in Figure 3.2.1-1(a) and (b). 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:

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

where η_c = Collector array efficiency

Q_s = Collected solar energy

Q_i = 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 Efficiency" in Table 3.2.1-1.

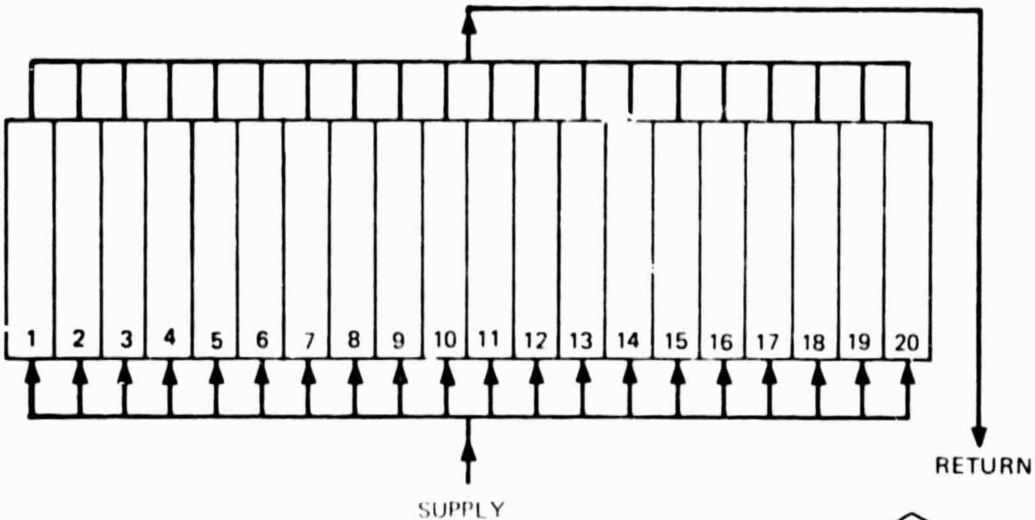


Figure 3.2.1-1(a). Collector Array Arrangement

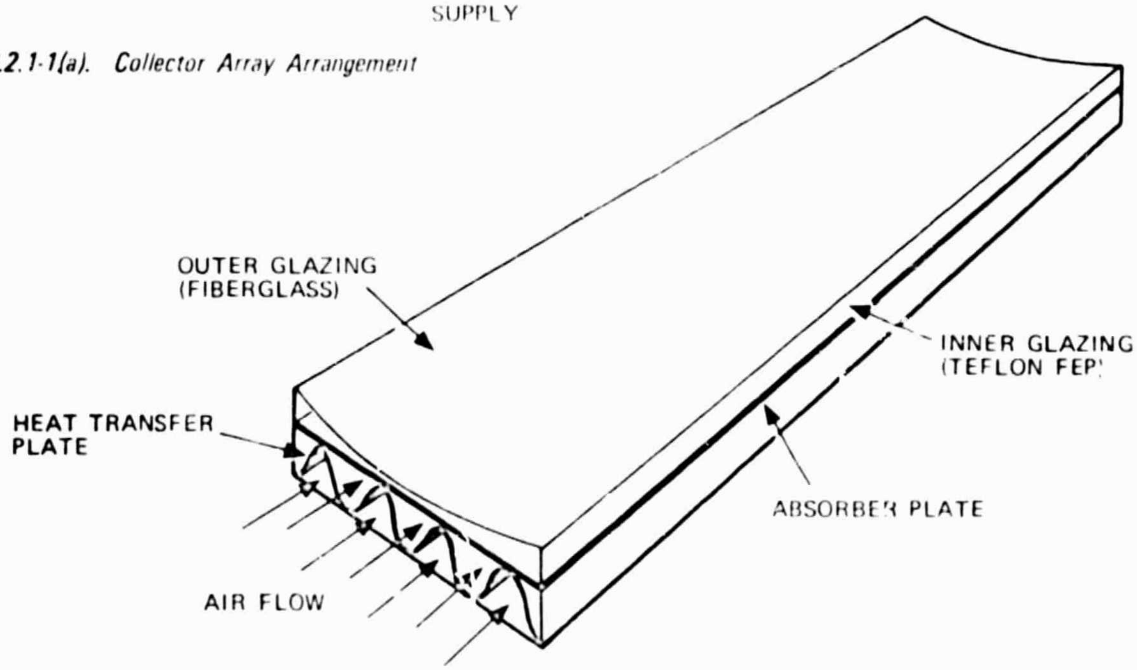


Figure 3.2.1-1(b). Collector Panel Air Flow Path

COLLECTOR DATA	
Manufacturer	– Contemporary Systems Inc.
Model	– Series V Warm Air
Type	– Air
Number of Collectors	– 20
Flow Paths	– 20

SITE DATA	
Location	New Hampshire Vocational Technical College Manchester, New Hampshire
Latitude	43.2°N
Longitude	71.5°W
Collector Tilt	– 60°
Azimuth	15° West of South

Figure 3.2.1-1. Collector Array Schematic

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:

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

where η_{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 collecto. 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.

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
Mar 79	27.44	3.40	0.12	8.75	0.39
Apr 79	31.62	5.14	0.16	13.96	0.37
May 79	29.40	4.06	0.14	13.17	0.31
Jun 79	40.53	2.10	0.05	3.70	0.57*
Jul 79	39.05	1.41	0.04	1.58	0.89*
Aug 79	33.91	1.40	0.04	25.52	0.05
Sep 79	41.10	6.07	0.15	34.72	0.17
Oct 79	23.33	4.20	0.18	18.97	0.22
Nov 79	21.51	5.20	0.24	16.96	0.31
Dec 79	25.03	4.92	0.20	19.53	0.25
Jan 80	29.07	3.63	0.13	22.56	0.16
Feb 80	36.65	4.17	0.11	30.25	0.14
Total	378.64	45.70	-	209.67	-
Average	31.55	3.81	0.12	17.47	0.22

*These efficiency values are computed for very brief periods of solar collection and are not considered to represent valid collector operation due to transient conditions.

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 a significant difference between laboratory calibrated single panel collector data and the collector data determined from long-term field measurements. There are two primary reasons for differences in the laboratory and field data:

- 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 distribution of the heat transfer fluid, insolation levels, aspect angle, wind conditions, leakage, 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 detailed 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:

(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 (η_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:

$$x_j = \frac{T_i - T_a}{I} \tag{3}$$

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

T_i = Collector inlet temperature

T_a = Outdoor ambient temperature

I = Rate of incident solar radiation

The data points (η_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:

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*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 in this analysis.

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

where η_j = Collector efficiency corresponding to the jth instant

b = Intercept on the efficiency axis

$(-)m$ = Slope

x_j = Collector operating point at jth 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 Hottell-Whillier-Bliss equation:

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

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

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 following set of relationships:

$$b = F_R \tau\alpha \quad \text{and} \quad m = F_R U_L \tag{6}$$

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 regression 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 two curves of Figure 3.2.1-2 show significant differences in overall performance. However, the crossover point of the two curves falls within the operating point range where most of the collector operation occurred, as can be seen from histograms of Figure 3.2.1-3. The long-term curve does show

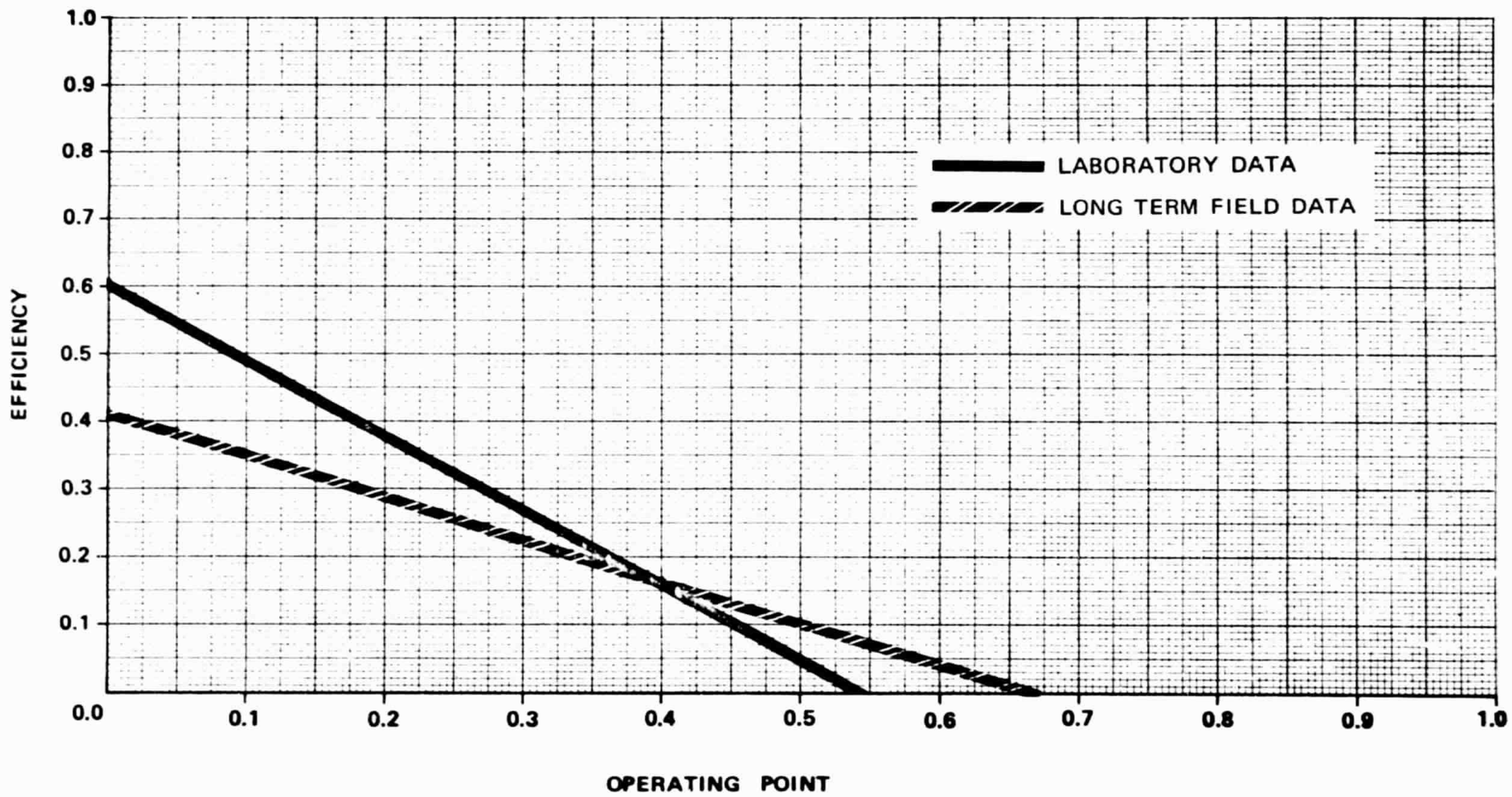


Figure 3.2.1-2. Contemporary Manchester Collector Efficiency Curves

a slightly less negative slope than the curve derived from single panel laboratory data. This may be attributable to the fact that the test flow rate for the single panel test was lower than the average flow rate of 61 cubic feet per minute per panel from field measurements.

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 predicted 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:

TABLE 3.2.1-2

ENERGY GAIN COMPARISON
(ANNUAL)

SITE: Contemporary Manchester — Manchester, New Hampshire

MONTH/YEAR	COLLECTED SOLAR ENERGY (MILLION BTU)	ERROR	
		FIELD DERIVED LONG-TERM	LAB PANEL
Mar 79	0.492	0.029	-0.332
Apr 79	4.255	-0.008	-0.364
May 79	3.670	-0.122	-0.376
Jun 79	0.671	-0.014	-0.313
Jul 79	0.101	0.214	-0.160
Aug 79	0.032	0.698	0.074
Sep 79	5.112	0.038	-0.302
Oct 79	4.066	0.105	-0.234
Nov 79	4.874	0.113	-0.220
Dec 79	4.597	0.178	-0.151
Jan 80	3.380	0.092	-0.194
Feb 80	3.826	0.011	-0.242
Average	2.923	0.054	-0.261

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

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 conditions in the field.

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.

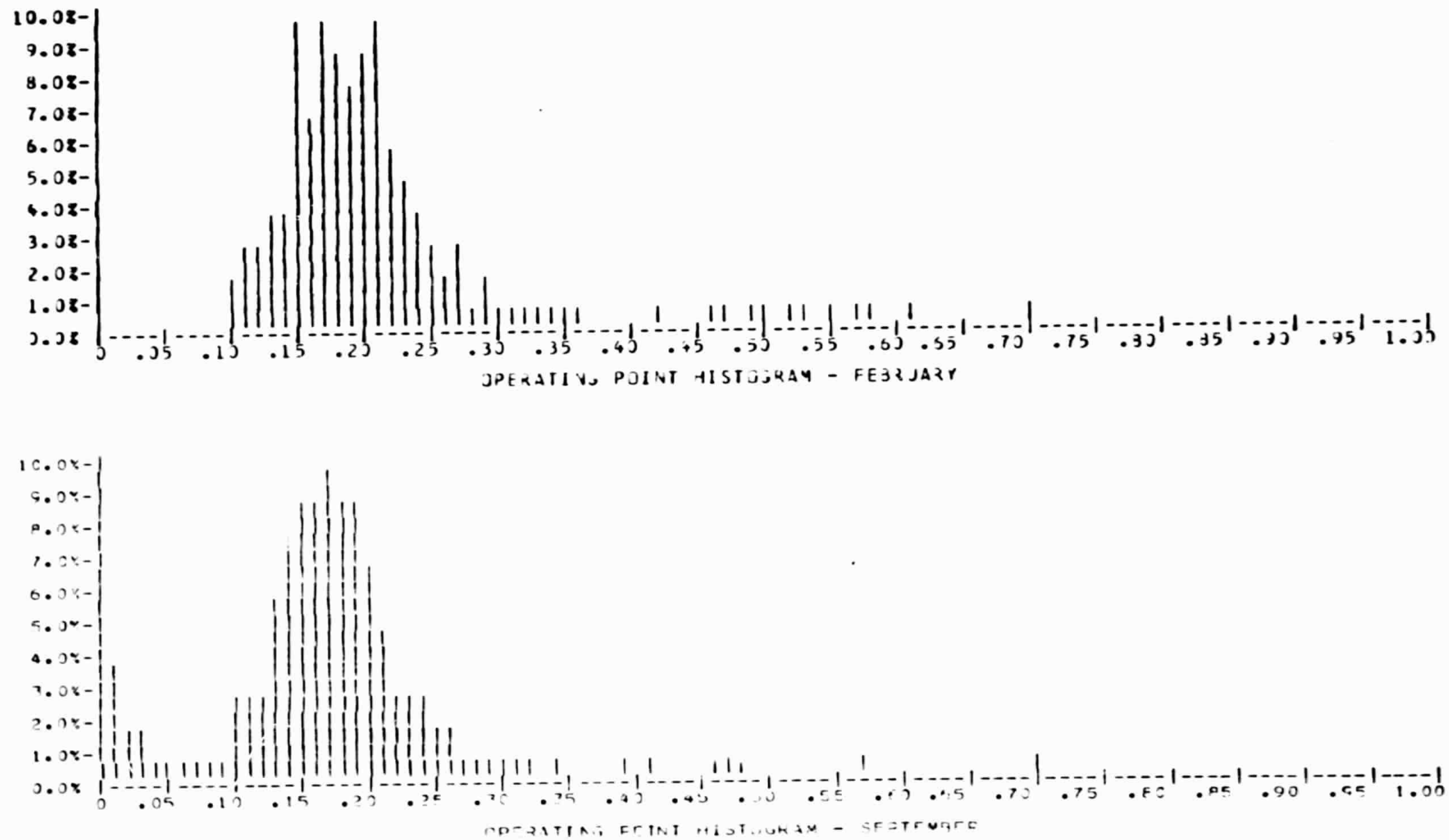
The data from Table 3.2.1-2 illustrates that for the Contemporary Manchester site the average error computed from the difference between the measured solar energy collected and the predicted solar energy collected based on the field derived long-term collector array efficiency curve was 5.4 percent. For the curve derived from the laboratory single panel data, the error was 26.1 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 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 (September) operation. The actual midpoint which represents the average operating point for February is at 0.18 and for September at 0.16. With a relatively constant collector inlet temperature, the operating point becomes dependent on outdoor ambient temperature and incident solar energy. From Equation (3) when the temperature difference becomes larger due to the lower T_a and the incident solar energy becomes smaller, as is typical in the winter, the operating point increases and collector operation shifts to the right on the operating point histogram. The opposite situation occurs in the summer. The important point to be made from this is that the average collector efficiency, which depends on the operating point, shifts from winter to summer, assuming the higher value in the summer. The behavior is further illustrated by considering the data in Table 3.2.1-1.

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 0.39 in March, 1979 to 0.14 in February, 1980. Transient values of efficiency for June and July, 1979, are not considered. On the average the operational collector array efficiency exceeded the collector array efficiency which included the effect of the control system by 10 percent.

CONTEMPORARY MANCHESTER   MANCHESTER, NH
COLLECTOR TYPE: CONTEMPORARY SYSTEMSCOLLECTOR MODEL: SERIES V WARM AIR



ABCISSA = (INLET TEMP - AMBIENT TEMP)/INSULATION   DEG F - HR - SQFT/BTU
ORDINATE = PERCENT OF TOTAL OCCURRENCES

Figure 3.2.1-3. Contemporary Manchester Operating Point Histograms for Typical Winter and Summer Months

At Contemporary Manchester, the incident solar energy totaled 378.64 million Btu and solar energy collected by the array totaled 45.70 million Btu for the report period (Table 3.2.1-1). The average collector array efficiency over the twelve month period was 12 percent and the operational collector efficiency averaged 22 percent. The operational efficiency is considered the best measure of solar system performance because it excludes such factors as control system anomolies and scheduled down time. It, therefore, reflects the true ability of the system to collect available solar energy when it is operating in the intended collection modes.

Additional information concerning collector array analysis is 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.

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, η_s. This relationship is expressed in the equation

$$\eta_s = (\Delta Q + Q_{so})/Q_{si} \tag{8}$$

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 system operation and weather conditions can be performed using the parameters defined above. The utility of these measured data in evaluation of the overall storage design are illustrated in the following discussion.

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
Mar 79	3.39	1 65	-0.08	0.46*	84*
Apr 79	4.96	2.32	0.41	0.55*	89*
May 79	3.73	0.02	-0.02	0.00	111
Jun 79	1.41	0.00	-0.03	-0.02	97
Jul 79	0.70	0.00	-0.14	-0.20	91
Aug 79	0.78	0.00	0.06	0.07	89
Sep 79	5.27	0.00	0.79	0.15	127
Oct 79	4.05	0.00	-0.19	-0.05	119
Nov 79	4.49	2.15	0.05	0.49*	99*
Dec 79	4.11	2.94	-0.48	0.60*	86*
Jan 80	2.82	1.10	0.24	0.47*	81*
Feb 80	2.95	1.16	-0.34	0.28*	91*
Total	38.66	11.34	0.27 (-0.20*)	-	-
Average	3.22	0.95	0.02 (-0.02*)	0.23 (0.49*)	97 (88*)

* Storage efficiency and temperature obtained by considering only the six months in which energy was drawn from storage to supply a significant heating load.

Table 3.2.2-1 summarizes the storage subsystem performance during the report period. However before discussing storage subsystem performance it is necessary to point out a minor difficulty relating to the monitoring instrumentation in the storage loop. Examination of Figure 2-1 will reveal that there is not flowmeter in the ducts leading directly in or out of the storage bin. Since there are air leaks in this air system, the computations for energy to and from storage will be slightly in error, even though an attempt was made to account for air leakage whenever possible.

During the twelve month period an approximate total of 38.66 million Btu was delivered to storage and 11.34 million Btu was extracted for support of the space heating load. It should be noted that little or no energy was drawn from storage from May, 1979 through October, 1979, due to the very small heating loads during these warm weather months. The net change in stored energy was 0.27 million Btu and the average storage efficiency over the report period was 0.23. A more meaningful storage efficiency of 0.49 is obtained by considering only the six months when energy was down from storage to supply a significant heating load. The average temperature of storage during the heating period was 88^{O}F, and for the full 12 months it was 97^{O}F.

Comparison of the "energy from storage" with the "energy to storage (Table 3.2.2-1) for the report period reveals a storage loss of 27.32 million Btu. It should be noted, however, that 15.94 million Btu of this loss occurred during the period from May, 1979, through October, 1979, during which there was little or no heating load with the result that all energy put into storage essentially became a loss. During the six colder months, when energy from storage was used to support a significant heating load, the losses, although still appreciable, (11.38 million Btu) were more typical of the expectations from a rock storage unit. Storage losses are attributed not only to thermal condition through the rock bin walls but also to leakage through imperfect control damper seals and ductwork joints.

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 consists of both solar energy and auxiliary thermal energy.

The performance of the Contemporary Manchester 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. In the case of Contemporary Manchester, where the hot water auxiliary energy is supplied by electric resistance elements, an efficiency of 100 percent is assumed, and the values of auxiliary energy and auxiliary thermal energy (energy delivered to the load) are the same. 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 thermal energy supplied shown in the Table.

For the 12 month period from March, 1979, through February, 1980, the solar energy system supplied a total of 2.33 million Btu to the hot water subsystem. Of this 2.33 million Btu contribution, 0.38 million Btu went into the load (hot water used), and 1.95 million Btu went into standby losses from the preheat tank. Auxiliary energy supplied over this period amounted to 3.76 million Btu yielding a total (solar plus auxiliary) input of 6.09 million Btu to the hot water subsystem. Since the hot water load for the report period was only 1.63 million Btu the thermal (standby) losses from the DHW tank amounted to 2.51 million Btu.

TABLE 3.2.3-1

HOT WATER SUBSYSTEM PERFORMANCE

Month	Energy Supplied (Million Btu)				Hot Water Parameters				Standby Losses	Weighted** Solar Fraction
	Auxiliary	Auxiliary Thermal	Solar	Total	Gallons Used	Temperature (°F) Supply	Temperature (°F) Delivery	Load (Million Btu)	(Million Btu)	(Percent)
Mar 79	0.538	0.538	0.036	0.574	347	74	159	0.249	0.325	0
Apr 79	0.543	0.543	0.129	0.672	387	80	160	0.257	0.415	1
May 79	0.351	0.351	0.156	0.507	358	77	131	0.179	0.328	14
Jun 79	0.315	0.315	-0.033	0.282	300	78	117	0.112	0.170	6
Jul 79	0.281	0.281	-0.001	0.280	269	84	112	0.078	0.202	15
Aug 79	0.306	0.306	0.499	0.805	222	84	116	0.057	0.748	18
Sep 79	0.283	0.283	0.409	0.692	321	86	115	0.084	0.608	20
Oct 79	0.237	0.237	0.252	0.489	443	81	120	0.141	0.348	8
Nov 79	0.215	0.215	0.141	0.356	369	75	115	0.125	0.231	8
Dec 79	0.252	0.252	0.173	0.425	398	71	115	0.142	0.283	4
Jan 80	0.238	0.238	0.245	0.483	372	74	112	0.115	0.368	9
Feb 80	0.201	0.201	0.321	0.522	292	76	111	0.086	0.436	11
Total	3.760	3.760	2.327	6.087	4078	-	-	1.625	4.462	-
Average	0.313	0.313	0.194	0.507	340	78	124	0.135	0.372	10

The weighted average monthly solar fraction of ten percent is very low for this site because of the low usage and the resulting small hot water load. Because of the unoccupied status of the house at the Contemporary Manchester site, the hot water flow averaged only 11.17 gallons per day over the entire report period and this flow is attributed to a leak in the pressure relief tank. This condition obviously prevented a realistic assessment of the performance of the hot water subsystem.

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 Contemporary Manchester space heating subsystem is presented in Table 3.2.4-1. For the 12 month period from March, 1979, through February, 1980, the solar energy system supplied a measured total of 9.93 million Btu to the space heating load. The total measured heating load for this period was 33.27 million Btu, and the average monthly solar fraction was 30 percent.

In assessing the performance of the space heating subsystem it should be noted that there are limitations on the instrumenation system which preclude the direct measurement of system losses. Measurement of space heating load, solar and auxiliary contributions and solar fraction are based on "delivered energy", therefore, losses must be computed from the difference between delivered energy and collected energy. The solar energy losses are significant, however, because the majority of such losses are added to the interior of the house and represent an uncontrolled contribution to the space heating load. At the Contemporary Manchester site the solar energy losses occur during energy transport between the various subsystems (primarily due to duct leakage), from the rock storage unit and, to a lesser extent, the hot water preheat tank. During the heating season (March, 1979 through May, 1979 and October, 1979 through February, 1980) a total of approximately 22.89 million Btu of solar

TABLE 3.2.4-1

HEATING SUBSYSTEM PERFORMANCE

Month	Heating Parameters			Energy Consumed (Million Btu)			Measured Solar Fraction (Percent)
	Load (Million Btu)	Temperatures (°F)		Solar	Auxiliary Thermal	Auxiliary	
		Building	Outdoor				
Mar 79	3.06	69	45	1.08	1.98	3.30	35
Apr 79	2.92	74	52	1.65	1.26	2.11	57
May 79	0.42	81	67	0.42	0.00	0.00	100
Jun 79	0.00	89	77	0.00	0.00	0.00	-
Jul 79	0.00	94	83	0.00	0.00	0.00	-
Aug 79	0.00	91	78	0.00	0.00	0.00	-
Sep 79	0.00	89	70	0.00	0.00	0.00	-
Oct 79	0.47	77	55	0.03	0.44	0.72	7
Nov 79	2.52	72	46	1.66	0.86	1.43	66
Dec 79	6.60	66	28	2.33	4.27	7.11	35
Jan 80	8.84	66	20	1.07	7.77	12.95	12
Feb 80	8.44	66	17	1.69	6.75	11.24	20
Total	33.27	-	-	9.93	23.33	38.86	-
Average	2.77	78	53	0.83	1.94	3.24	30*

* Average solar fraction is the ratio of Total Solar Energy to Total Load.

energy was added to the interior of the house through these losses. Thus, the energy added to the heated space due to solar system losses was approximately 230 percent greater than the measured amount of solar energy supplied during the primary heating season, in the intended operating modes.

A calculation, which treats these losses as a positive contribution to the space heating requirements, results in a higher solar fraction than that determined by the measured data. If solar losses are added to the space heating load and to the solar contribution, the heating solar fraction increases to 58 percent.

During the 12 month reporting period a total of 23.33 million Btu of auxiliary energy was supplied to the space heating load. Using an efficiency of sixty percent for the oil fired furnace, the energy input to the auxiliary source was 38.86 million Btu as shown in Table 3.2.4-1.

4. OPERATING ENERGY

Operating energy for the Contemporary Manchester 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 (ECSS) operating energy, hot water 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 4-1.

Total system operating energy for the Contemporary Manchester Solar Energy System is that electrical energy required to operate the blower in the main air handler unit and in the duct used for summer ventilation of the collectors, the pump and blower in the DHW subsystem and the blower in the auxiliary heating unit (oil fired furnace). These are shown as EP400, EP300 and EP401, respectively, in Figure 2-1. Although additional electrical energy is required to operate motor driven dampers and the control system for the installation, it is not included in this report. These devices are not monitored for power consumption and the power they consume is insignificant, when compared to the fan and pump motors.

During the 12 month reporting period, a total of 4.58 million Btu (1342 kWh) of operating energy was consumed. However, this energy includes that portion of the energy required by the blower in the main air handler unit when the blower is distributing air to the heated space (space heating operating energy) and that energy would be required whether or not the solar energy system was present. Therefore, this component of the operating energy is not considered "solar peculiar."

A total of 2.32 million Btu (680 kWh) of operating energy was required to support the blowers and fans when the solar collection and storage subsystems were active. Of this total, 1.32 million Btu were allocated to the Energy Collection and Storage Subsystem (ECSS) and 1.00 million Btu to the DHW subsystem . Since a measured 12.26 million Btu of solar energy was delivered to system loads during the reporting period, a total of 0.19 million Btu (56 kWh) of operating energy was required for each one million Btu of solar energy delivered to the system loads.

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)
Mar 79	0.10	0.02	0.24	0.36
Apr 79	0.17	0.06	0.34	0.57
May 79	0.16	0.11	0.24	0.51
Jun 79	0.04	0.03	0.16	0.23
Jul 79	0.02	0.09	0.17	0.28
Aug 79	0.02	0.15	0.15	0.32
Sep 79	0.18	0.14	0.29	0.61
Oct 79	0.13	0.09	0.01	0.23
Nov 79	0.16	0.06	0.10	0.32
Dec 79	0.14	0.07	0.07	0.28
Jan 80	0.10	0.08	0.25	0.43
Feb 80	0.10	0.10	0.24	0.44
Total	1.32	1.00	2.26	4.58
Average	0.11	0.08	0.19	0.38

5. ENERGY SAVINGS

Solar energy system savings are realized whenever energy provided by the solar energy system is used to meet demands which would otherwise be met by auxiliary energy sources. The operating energy required to provide solar energy to the load subsystem is subtracted from the solar energy contribution to obtain the net savings attributed to the use of solar energy.

Energy savings for the 12 month reporting period are presented in Table 5-1. The gross savings in fossil energy was 16.56 million Btu which, when adjusted to account for the 1.32 million Btu of ECSS operating energy, gave a net fossil energy savings of 15.24 million Btu. Because of the unoccupied status of the dwelling and resulting negligible hot water usage (actually leakage), as discussed in Section 3.2.3, solar energy usage was low, amounting to only 0.38 million Btu over the entire 12 month period. Operating energy for the solar hot water system was greater than the solar energy utilized by about a factor of three because of the requirement to operate both a blower and pump to transfer solar energy into the DHW preheat tank. Thus, a net loss, or penalty, of 0.69 million Btu was incurred in the DHW system over the report period. On an overall system basis the electrical penalty of 0.69 million Btu is subtracted from the net fossil savings giving a net system savings of 14.52 million Btu over the 12 month period.

It should be noted that all values relating to space heating savings are based only on the measured solar energy contribution to the space heating load. As discussed in the Space Heating Subsystem section, approximately 22.89 million Btu of solar energy were added to the interior of the house through various losses during the heating season. This uncontrolled addition of solar energy to the house, had it been included in the space heating subsystem computations, would have altered the space heating (and total system) savings significantly. This additional but unreported savings can be approximated by dividing the assumed furnace efficiency of 60 percent into the solar loss contribution (22.89/0.60) giving an additional gross fossil energy saving of 38.15

TABLE 5-1

ENERGY SAVINGS

Month	SPACE HEATING			HOT WATER			TOTAL NET SAVINGS	
	Fossil Energy Savings (Million Btu)	ECSS Operating Energy (Million Btu)	Net Fossil Savings (Million Btu)	Solar Energy Used (Million Btu)	DHW Operating Energy (Million Btu)	Net Electrical Savings (Million Btu)	Million Btu	kWh
Mar 79	1.80	0.10	1.70	-0.02	0.02	-0.04	1.66	486
Apr 79	2.75	0.17	2.58	-0.01	0.06	-0.07	2.51	735
May 79	0.69	0.16	0.53	0.11	0.16	-0.05	0.48	141
Jun 79	0.00	0.04	-0.04	0.01	0.03	-0.02	-0.06	-18
Jul 79	0.00	0.02	-0.02	0.05	0.09	-0.04	-0.06	-18
Aug 79	0.00	0.02	-0.02	0.06	0.16	-0.10	-0.12	-35
Sep 79	0.00	0.18	-0.18	0.06	0.14	-0.08	-0.26	-76
Oct 79	0.06	0.13	-0.07	0.03	0.09	-0.06	-0.16	-47
Nov 79	2.77	0.16	2.61	0.02	0.06	-0.04	2.57	752
Dec 79	3.89	0.14	3.75	0.02	0.07	-0.05	3.70	1083
Jan 80	1.78	0.10	1.68	0.02	0.08	-0.06	1.62	474
Feb 80	2.82	0.10	2.72	0.03	0.11	-0.08	2.64	773
Total	16.56	1.32	15.24	0.38	1.07	-0.69	14.52	4254
Average	1.38	0.11	1.27	0.03	0.09	-0.06	1.21	355

million Btu. Adjustment for an operating energy requirement proportional to the measured value yields an additional net saving due to loss contributions of 35.93 million Btu. Thus, if the losses were taken into account, the net savings for the complete solar energy system would have been 50.48 million Btu, compared to the reported value of 14.52 million Btu.

6. MAINTENANCE

Significant maintenance activities carried out at the Contemporary Manchester site during the report period are summarized below:

<u>May 7, through May 11, 1979 - Correction of Excessive Air Leakage</u>

Due to excessive air leakage, especially with the system operating in the "Heating From Collectors" mode, a site visit was made to investigate and attempt correction of this problem. Close inspection and pressure measurement revealed numerous air leakage points due to improperly taped and sealed duct seams and inlet/outlet connections to the collector plenums. Round duct sections connecting to collector plenums were of insufficient length and were tapered so that proper sealing of connections to flexible ducting could not be achieved. A total of 56 of the round duct plenum connection collars of two inch length and tapered design were replaced with four inch collars of straight design. Loose plastic connection clamps were replaced with metal band type clamps and all joints sealed with tape or RTV silicone sealant. These actions resulted in the reduction of leakage (volumetric - outlet/inlet) from 140% to 73% in the "heating from collectors" mode and from 25% to 9% in the "storing heat" mode. Leakage below these limits was determined to be through the collectors and could not be eliminated due to accessibility. Later models of these collectors are sealed more thoroughly, according to the manufacturer.

<u>December 20, 1979, through January 10, 1980 - Improper Control System Operation</u>

System data revealed that system was not collecting solar energy despite high levels of insolation. It was also noted that there was off-nominal power consumption on main air handler blower motor. The problem was found to be due to a bent damper actuator arm which was repaired, restoring the system to normal operation.

February 7, 1980, through February 24, 1980 - Improper Control System Operation

System data revealed that main air handler blower was operating at an off-nominal power level when no solar heat was being supplied to the house from either collectors or storage. Collector flow was being terminated near mid-day in the presence of high levels of solar insolation. Investigation by the installation contractor showed that the system controls had been improperly switched to "summer mode" of operation. The problem was corrected by returning the system control switch to "heating mode" position.

7. SUMMARY AND CONCLUSTIONS

The following paragraphs provide a brief summary of all pertinent parameters for the Contemporary Manchester Solar Energy System for the period from March, 1979 to February, 1980. A more detailed discussion can be found in the preceding sections.

During the report period, the measured daily average incident insolation in the plane of the collector array was 1,288 Btu/Ft^2. This was 18 percent above the long-term daily average of 1,089 Btu/Ft^2. During the same period the measured average outdoor ambient temperature was 53^{o}F. This was seven degrees above the long-term average of 46^{o}F. As a result, only 5,884 heating degree-days were accumulated as compared to the long-term average of 7,360 heating degree days. Climatic conditions had a favorable influence on the performance of the solar energy system.

The solar energy system satisfied 29 percent of the total measured load (hot water plus space heating) during the 12 month reporting period. This value was somewhat lower than the expected solar fraction of 41 percent obtained from the f-Chart analysis. However, when system losses into the heated space from duct leaks, storage, etc., are included, the solar fraction increases to 56 percent.

A total of 378.64 million Btu of incident solar energy was measured in the plane of the collector array during the reporting period. The system collected 45.70 million Btu of the available energy, which represents a collector array efficiency of 12 percent. During periods where the collector array was active, a total of 209.67 million Btu was measured in the plane of the collector array. Therefore, the operational collector efficiency was 22 percent.

During the reporting period a total of 38.66 million Btu was delivered to the storage bin. During the same time 11.34 million Btu were removed from storage for support of the space heating load. During the period, June through October, there was no energy output from storage because the heating load was zero or negligibly small. In this same period, energy was delivered into storage, presumably due to a control system malfunction. The average storage efficiency based on the full 12 month report period was 0.23. However, in view of the control anomaly cited above, an efficiency using only those months when the storage subsystem was supporting a heating load is considered more meaningful. The efficiency computed on this basis for the primary heating season (November through April) was 0.49. During this active period the net change in stored energy was -0.20 million Btu and 11.38 million Btu were lost from storage. The average storage temperature was 88°F during the active period and 97°F over the full report period.

The hot water load for the 12 month reporting period was 1.63 million Btu. A total of 2.33 million Btu of solar energy and 3.76 million Btu of auxiliary energy were supplied to the hot water subsystem. Due to the extremely low hot water usage (actually leakage) of about 11 gallons per day and the corresponding low hot water energy demand, most of the energy applied to the hot water subsystem (4.46 million Btu) was dissipated as hot water system standby losses. The average hot water delivery temperature over the 12 month report period was 124°F but this value is believed to be artifically high because of the low hot water usage.

The measured space heating load was 33.27 million Btu for the 12 month reporting period. All of the space heating demand occurred during the October through May time period. During the six month primary heating season (November through April) the measured space heating load was 32.38 million Btu, or 97 percent of the total. The heating solar fraction for the full 12 month period was 30 percent, whereas, for the primary heating season, it was 31 percent. During the six month primary heating season a total of 9.48 million Btu of measured solar energy and 22.89 million Btu of auxiliary thermal energy were actually delivered to the space heating load, and this energy maintained an average building temperature of 69°F.

A total of 2.32 million Btu, or 680 kWh of electrical operating energy was required to support the Contemporary Manchester Solar Energy System during the 12 month reporting period.

The gross fossil energy savings for the 12 month report period were 16.56 million Btu. However, when the ECSS operating energy of 1.32 million Btu and an electrical penalty of 0.69 million Btu for the hot water system are taken into account, the net energy savings were 14.52 million Btu. It should be noted that the energy savings are based only on the measured amount of solar energy delivered to the space heating subsystem. As discussed in Section 5., the energy savings will increase significantly if the uncontrolled solar energy input to the building is considered.

Performance analysis of the Contemporary Manchester Solar Energy System was somewhat degraded by the fact that the building was unoccupied throughout the data assessment and analysis period, and therefore not used as it as designed for. The unoccupied status prevented the normal manual adjustment of heating and ventilating controls for maintenance of comfort levels within the building. This lack of occupancy also prevented the typical family hot water usage which would have allowed for more realistic evaluation of the hot water subsystem.

8. REFERENCES

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APPENDIX A
DEFINITION OF PERFORMANCE FACTORS
AND
SOLAR TERMS

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 reported collector array efficiency.

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.

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.

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

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

- <u>CHANGE IN STORED ENERGY</u> (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).

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

- <u>STORAGE EFFICIENCY</u> (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.

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.

- <u>AUXILIARY ELECTRICAL FUEL</u> (HWAE) is the amount of electrical energy supplied directly to the subsystem.

- <u>ELECTRICAL ENERGY SAVINGS</u> (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.

- <u>SUPPLY WATER TEMPERATURE</u> (TSW) is the average inlet temperature of the water supplied to the subsystem.

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

- <u>HOT WATER USED</u> (HWCSM) is the volume of water used.

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 CONTEMPORARY MANCHESTER

APPENDIX B

SOLAR ENERGY SYSTEM PERFORMANCE EQUATIONS FOR CONTEMPORARY MANCHESTER

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. Examples of these general forms are 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.

II. PERFORMANCE EQUATIONS

The performance equations for Contemporary Manchester used for the data evaluation of this report are contained in the following pages and have been included for technical reference and information.

EQUATIONS USED IN MONTHLY PERFORMANCE ASSESSMENT

NOTE: MEASUREMENT NUMBERS REFERENCE SYSTEM SCHEMATIC FIGURE 2-1

AVERAGE AMBIENT TEMPERATURE (°F)

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

AVERAGE BUILDING TEMPERATURE (°F)

$$TB = (1/60) \times \Sigma\ (T600 + T601 + T602)/3 \times \Delta\tau$$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

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

FOR $\pm$ 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

ENTHALPY FUNCTION FOR WATER (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)

$$SECA = \Sigma\ [(M100 \times (T150 - T100) \times HRF) + (M300 \times (T350 - T300) \times HWD)] \times \Delta\tau$$

NOTE THAT THIS EQUATION ACCOUNTS FOR SOLAR ENERGY COLLECTED IN THE SUMMER OPERATING MODE WHEN ONLY THE DOMESTIC HOT WATER HEATING SYSTEM IS ACTIVE AS WELL AS SPACE HEATING SOLAR ENERGY COLLECTED IN WINTER MONTHS.

SOLAR ENERGY TO LOAD FROM COLLECTOR ARRAY (BTU)

$$CSE02 = \Sigma\ [M401 \times HRF \times (T401 - T451)] \times \Delta\tau$$

WHEN HEATING FROM THE COLLECTOR ARRAY

SOLAR ENERGY TO LOAD FROM STORAGE (BTU)

$$HSE1 = \Sigma\ [M401 \times HRF \times (T401 - T451] \times \Delta\tau$$

WHEN HEATING FROM STORAGE

SOLAR ENERGY TO SPACE HEATING SUBSSYTEM (BTU)

$$HSE = HSE1 + CSE02$$

WHENEVER THE SYSTEM IS HEATING FROM COLLECTORS OR STORAGE

HEATING AUXILIARY THERMAL ENERGY TO LOAD (BTU)

$$HAT = \Sigma\ [M400 \times HRF \times (T450 - T400)] \times \Delta\tau$$

WHEN HEATING FROM THE AUXILIARY SOURCE

SPACE HEATING LOAD (BTU)

$$HL = HSE + HAT$$

WHENEVER THE SYSTEM IS IN A SPACE HEATING MODE

AVERAGE TEMPERATURE OF STORAGE (°F)

$$TST = (1/60) \times [(T201 + T202 + T203)/3 + T204 + T205]/3 \times \Delta\tau$$

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \Sigma\ [M100 \times HRF \times (T200 - T250)] \times \Delta\tau$$

WHEN THE SYSTEM IS IN A STORING HEAT MODE

SOLAR ENERGY FROM STORAGE (BTU)

$$STEO = \Sigma\ [M401 \times HRF \times (T200 - T250)] \times \Delta\tau$$

WHEN THE SYSTEM IS IN HEATING FROM STORAGE MODE

ECSS OPERATING ENERGY (BTU)

$$CSOPE = 56.8833 \times \Sigma\ EP400 \times \Delta\tau$$

WHEN THE SYSTEM IS IN A STORING HEAT MODE

$$CSOPE = 56.8833 \times \Sigma\ (EP400/2) \times \Delta\tau$$

WHEN THE SYSTEM IS IN A HEATING FROM COLLECTORS MODE

HOT WATER CONSUMED (GALLONS)

$$HWCSM = \Sigma\ WD301$$

HOT WATER LOAD

$$HWL = \Sigma\ [M301 \times HWD(T352, T301)] \times \Delta\tau$$

SOLAR ENERGY TO HOT WATER SUBSYSTEM

$$HWSE = \Sigma\ [M500 \times HWD(T350, T300)] \times \Delta\tau$$

SOLAR ENERGY TO HOT WATER LOAD

$$HWSE1 = \Sigma\ [M301 \times HWD(T351, T301)] \times \Delta\tau$$

HOT WATER SUBSYSTEM OPERATING ENERGY (BTU)

$$HWOPE = 56.8833 \times \Sigma\ EP300 \times \Delta\tau$$

HOT WATER SUBSYSTEM AUXILIARY ELECTRICAL FUEL ENERGY (BTU)

$$HWAE = 56.8833 \times \Sigma\ EP301 \times \Delta\tau$$

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$$HOPE1 = 56.8833 \times \Sigma\ EP400/2 \times \Delta\tau$$

WHEN THE SYSTEM IS IN A HEATING FROM COLLECTORS MODE

$$HOPE2 = 56.8833 \times \Sigma\ EP400 \times \Delta\tau$$

WHEN THE SYSTEM IS IN A HEATING FROM STORAGE MODE

$$HOPE3 = 56.883 \times \Sigma\ EP401 \times \Delta\tau$$

WHEN THE SYSTEM IS IN A HEATING FROM AUXILIARY MODE

HOPE = HOPE1 + HOPE2 + HOPE3

AUXILIARY FOSSIL FUE ENERGY TO OIL FIRED FURNACE (BTU)

HAF = HAT/0.6

WHERE 0.6 IS THE FURNACE EFFICIENCY

SUPPLY WATER TEMPERATURE (°F)

TSW = T301

HOT WATER TEMPERATURE (°F)

THW = T352

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

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

SEA = CLAREA x SE

COLLECTED SOLAR ENERGY PER UNIT AREA (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 LOAD SUBSYSTEMS (BTU)

CSEO = STEO + HWSE + CSEO2

AUXILIARY THERMAL ENERGY TO HOT WATER SUBSYSTEM (BTU)

HWAT = HWAE

HOT WATER SOLAR FRACTION (PERCENT)

HWSFR = 100 x 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 = HWSE1 - HWOPE

SPACE HEATING SUBSYSTEM SOLAR FRACTION (PERCENT)

HSFR = 100 x HSE/HL

SPACE HEATING SUBSYSTEM FOSSIL ENERGY SAVINGS (BTU)

HSVF = HSE/FEFF

WHERE 0.6 IS THE FURNACE EFFICIENCY

SYSTEM LOAD (BTU)

SYSL = HL + HWL

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

SFR = (HL x HSFR + HWL x HWSFR)/SYSL

SYSTEM OPERATING ENERGY (BTU)

SYSOPE = HOPE + HWOPE + CSOPE

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

AXT = HAT + HWAT

AUXILIARY ELECTRICAL ENERGY TO LOADS (BTU)

AXE = HWAE

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

SEL = HWSE + HSE

ECSS SOLAR CONVERSION EFFICIENCY

CSCEF = CSEO/SEA

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

TSVE = HWSVE - CSOPE

TOTAL FOSSIL ENERGY SAVINGS (BTU)

TSVF = HSVF

TOTAL ENERGY CONSUMED (BTU)

TECSM = SYSOPE + AXE + AXF + SECA

SYSTEM PERFORMANCE FACTOR

SYSPF = SYSL/(AXE + AXT + SYSOPE) x 3.33

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.

SITE: CONTEMP. SYS. 122. LOCATION: MANCHESTER NH

ANALYST: R. MANDT FORIVE NO.: 36.

COLLECTOR TILT: 60.00 (DEGREES) COLLECTOR AZIMUTH: 15.00 (DEGREES)

LATITUDE: 43.07 (DEGREES) RUN DATE: 4/11/79

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JAN	1152.	461.	0.39677	1.844	850.	1376	0	21.
FEB	1636.	686.	0.41912	1.490	1022.	1157	0	23.
MAR	2267.	973.	0.42940	1.166	1137.	1014	0	32.
APR	2943.	1316.	0.44719	0.931	1225.	624	0	44.
MAY	3435.	1582.	0.46027	0.786	1243.	315	3	55.
JUN	3642.	1703.	0.46758	0.730	1241.	58	49	65.
JUL	3536.	1674.	0.47340	0.754	1261.	16	162	70.
AUG	3131.	1456.	0.46514	0.865	1260.	45	113	67.
SEP	2508.	1139.	0.45418	1.074	1223.	182	17	60.
OCT	1819.	819.	0.44997	1.398	1144.	467	0	49.
NOV	1271.	465.	0.36539	1.665	774.	810	0	39.
DEC	1035.	361.	0.34924	1.853	672.	1246	0	25.

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.

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