300
12-2-81
jsh

MASTER

(2)

SOLAR/1102-81/14
(DE82002240)

20. 6334

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

SUMMERWOOD ASSOCIATES, HOUSE M

Old Saybrook, Connecticut
June 1980 through May 1981

DHW SH

U.S. DEPARTMENT OF ENERGY
NATIONAL SOLAR DATA PROGRAM

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DISCLAIMER

"This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Printed Copy A06
Microfiche A01

Codes are used for pricing all publications. The code is determined by the number of pages in the publication. Information pertaining to the pricing codes can be found in the current issues of the following publications, which are generally available in most libraries: *Energy Research Abstracts, (ERA)*; *Government Reports Announcements and Index (GRA and I)*; *Scientific and Technical Abstract Reports (STAR)*; and publication, NTIS-PR-360 available from (NTIS) at the above address.

SUMMERWOOD ASSOCIATES, HOUSE M
OLD SAYBROOK, CONNECTICUT
SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION
JUNE 1980 THROUGH MAY 1981

Prepared by Michael Raymond

Approved: S. M. Rossi for
T. T. Bradshaw
Program Manager

Vitro Laboratories Division
Automation Industries, Inc.
14000 Georgia Avenue
Silver Spring, Maryland 20910

The National Solar Data Network
Department of Energy Contract Number DE-AC01-79CS30027
Contract Management by:
Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

G. A. McGinnis, Project Manager

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

FOREWORD

This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic hot water and annual performance reports are issued for such sites. In addition, Monthly Performance Reports, prior to 1981, are available for the solar systems in the network.

The National Solar Data Network consists of instrumented solar energy systems in buildings selected from among the 5,000 installations built (since early 1977) as part of the National Solar Heating and Cooling Demonstration Program. The overall purpose of this program is to assist in the development of solar technologies for buildings by providing data and information on the effectiveness of specific systems, the effectiveness of particular solar technologies, and the areas of potential improvement. Vitro Laboratories Division responsibility in the NSDN, under contract with the Department of Energy, is to collect data daily from the sites, analyze the data, and disseminate information to interested users.

Buildings in the National Solar Data Network are comprised of residential, commercial and institutional structures which are geographically dispersed throughout the continental United States. The variety of solar systems installed employ "active" mechanical equipment systems or "passive" design features, or both, to supply solar energy to typical building thermal loads such as space heating, space cooling, and domestic hot water. Solar systems on some sites are used to supply commercial process heat.

The buildings in the NSDN program are instrumented to monitor thermal energy flows to the space conditioning, hot water, or process loads, from both the solar system and the auxiliary or backup system. Data collection from each site, and transmission to a central computer for processing and analysis is highly automated.

SUMMERWOOD ASSOCIATES, HOUSE M

SUMMERWOOD ASSOCIATES, HOUSE M

Summerwood Associates, House M is a single-family rowhouse residence, in Old Saybrook, Connecticut. The active solar energy system is designed to supply the following:

Annual Design Factors¹ (Million BTU)

	<u>Total Load</u>	<u>Solar Contribution</u>	<u>% Solar</u>
Heating	43.40	33.90	78
Hot Water	15.50	15.50	100

It is equipped with:

Collector	378 square feet, Sunworks Slector IM LC
Storage	600-gallon site-built concrete tank in crawl space
Auxiliary	Friedrich Climate Master V-22 12AW; 21,500 BTU/hr heat pump and electrical resistance heater

1. Information supplied by Wormser Scientific Corporation, the solar system designer.

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
Foreword	iii
Site Summary	v
Table of Contents	vi
List of Illustrations	vii
List of Tables	viii
 1. SOLAR SYSTEM PERFORMANCE	 1-1
1.1 Summary and Conclusions	1-2
1.2 System Operation	1-6
1.3 Solar Energy Utilization	1-10
1.4 Solar System Availability	1-11
 2. SUBSYSTEM PERFORMANCE	 2-1
2.1 Collector	2-1
2.2 Storage	2-4
2.3 Domestic Hot Water (DHW)	2-6
2.4 Space Heating	2-8
 3. OPERATING ENERGY	 3-1
 4. ENERGY SAVINGS	 4-1
 5. WEATHER CONDITIONS	 5-1
 6. REFERENCES	 6-1
 <u>Appendices</u>	
A. System Description	A-1
B. Performance Evaluation Techniques	B-1
C. Performance Factors and Solar Terms	C-1
D. Performance Equations	D-1
E. Calculation of Predicted Values	E-1
F. Meteorological Conditions	F-1
G. Site History, Problems, Changes in Solar System	G-1
H. Conversion Factors	H-1
I. Sensor Technology	I-1
J. Typical Monthly Data	J-1

LIST OF ILLUSTRATIONS

<u>Figure Number</u>	<u>Title</u>	<u>Page</u>
1	Energy Flow Diagram for Summerwood Associates, House M, June 1980 through May 1981	1-3
2	System Thermal Performance, Summerwood Associates, House M, June 1980 through May 1981	1-4
3a	Typical Insolation Data, Summerwood Associates, House M, March 20, 1981	1-7
3b	Typical Collector Array Temperatures, Inlet/Outlet, Summerwood Associates, House M, March 20, 1981	1-7
3c	Typical Storage Fluid Temperatures, Summerwood Associates, House M, March 20, 1981	1-8
4	Typical System Operating Sequence, Summerwood Associates, House M, March 20, 1981	1-9
5	Solar Energy Use, Summerwood Associates, House M, June 1980 through May 1981	1-10
6a	Average Collector Efficiency, Summerwood Associates, House M, February 1981	2-2
6b	Average Collector Efficiency, Summerwood Associates, House M, May 1981	2-3
7	DHW Subsystem Performance, Summerwood Associates, House M, June 1980 through May 1981	2-7
8	Space Heating Subsystem, Summerwood Associates, House M, June 1980 through May 1981	2-9
A-1	Summerwood Associates, House M Solar Energy System Schematic	A-4
B-1	The National Solar Data Network	B-1

LIST OF TABLES

<u>Number</u>	<u>Title</u>	<u>Page</u>
1	Solar System Thermal Performance, Summerwood Associates, House M, June 1980 through May 1981	1-4
2	Solar Coefficient of Performance, Summerwood Associates, House M, June 1980 through May 1981	1-5
3	Solar Energy Losses, Summerwood Associates, House M, June 1980 through May 1981	1-11
4	Collector Subsystem Performance, Summerwood Associates, House M, June 1980 through May 1981	2-1
5	Storage Performance, Summerwood Associates, House M, June 1980 through May 1981	2-6
6	Domestic Hot Water Subsystem, Summerwood Associates, House M, June 1980 through May 1981	2-7
7	Space Heating Subsystem I, Summerwood Associates, House M, June 1980 through May 1981	2-8
8	Space Heating Subsystem II, Summerwood Associates, House M, June 1980 through May 1981	2-9
9	Design Heating Load by UA x Cd Method, Summerwood Associates, House M, June 1980 through May 1981	2-11
10	Solar Operating Energy, Summerwood Associates, House M, June 1980 through May 1981	3-1
11	Energy Savings, Summerwood Associates, House M, June 1980 through May 1981	4-1
12	Weather Conditions, Summerwood Associates, House M, June 1980 through May 1981	5-1

SECTION 1
SOLAR SYSTEM PERFORMANCE

SUMMERWOOD ASSOCIATES, HOUSE M
JUNE 1980 THROUGH MAY 1981

Solar Fraction ¹	58%
Solar Savings Ratio ²	0.49
Conventional Fuel Savings ³	3,563 kwh
System Performance Factor ⁴	62%
Solar System COP ⁵	6.67

Annual Energy Requirements
June 1980 through May 1981
(Million BTU)

	<u>Total Load</u>	<u>Solar Contribution</u>	<u>% Solar</u>
Heating	38.51	21.75	56
Hot Water	5.18	3.46	67

Environmental Data

	<u>Measured Average</u>	<u>Long-Term Average</u>
Outdoor temperature	51°F	52°F
Heating-degree days	5,842	5,461
Daily incident solar energy	1,272 BTU/ft ²	1,248 BTU/ft ²

1. Solar Fraction = $\frac{\text{Solar Energy Supplied to Load}}{\text{Total Load}} \times 100$
2. Solar Savings Ratio = $\frac{\text{Solar Energy Supplied to Load} - \text{Solar System Operating Energy}}{\text{Total Load}}$
3. Conventional Fuel Savings = Savings in BTU's $\times 292.8 \times 10^{-6}$ kwh/BTU
4. Ratio of system load to the total equivalent fossil energy expended or required to support the system load
5. Solar System COP = $\frac{\text{Solar Energy Used}}{\text{Solar Unique Operating Energy}}$

1.1 SUMMARY AND CONCLUSIONS

The solar energy system at Summerwood Associates, House M supplied 56% of the space heating energy requirement and 67% of the domestic hot water energy requirement in the 12-month period June 1980 through May 1981. The solar energy system saved 3,563 kwh of electricity during the year.

The flow of energy through the solar system is presented in Figure 1. The overall performance of the solar energy system is presented in Table 1 and shown graphically in Figure 2. Performance was close to the f-Chart Version 4.0 prediction of a 62% solar fraction, but below the designers expectation of 78% solar fraction for space heating, and 100% for domestic hot water.

The collector array was efficient, collecting 45.22 million BTU out of 173.33 million BTU incident upon it. In the heating months (November through March), the array collected 41% of the incident solar energy. Nearly all the collected energy, 96%, was delivered to storage as this is a drainback system with no heat exchanger between collector and storage.

The storage subsystem was the only component with performance significantly poorer than expected. This poor performance is reflected in the high storage losses shown in the flow diagram, as 16.94 million BTU were lost out of 43.43 million BTU pumped into the tank. The effective R value of the tank insulation was about R-4, based upon long-term energy flows into and out of the tank, and upon short-term tank temperature decay when no energy was pumped into or out of the tank. The insulation of the tank is thick (two inches styrofoam under tank, four inches on the sides and top) but some heat is apparently bypassing it.

Storage losses were low in November through January, because of low storage temperatures, but, in February and March, the storage losses were significant enough to hinder performance of the solar system. In the summer, losses were high, but there was much more solar energy available than needed for DHW loads. The penalty for the storage losses was the high operating energy required to run the collectors to maintain storage temperatures.

Summerwood Associates, House M uses a dual-source heat pump system to deliver solar energy to the heating load. The heat pump evaporator is supplied with energy from either the storage tank or from ambient air. When the storage temperature was below 45°F, ambient air was used for the energy source. The solar energy system is also designed to supply energy directly to the building when storage temperatures exceed 85°F. At times, however, the control system did not work properly, and supplied water at 100°F or more to the heat pump evaporator, rather than to the direct space heating coil.

Heat pump systems often use the "nonpurchased" fraction to characterize their performance. This fraction includes the energy extracted from the air as well as the solar energy in the numerator. In Summerwood Associates, House M, the nonpurchased fraction was 67%, compared to the f-Chart prediction of 68%. For a parallel heat pump system, f-Chart predicts a 72% nonpurchased fraction.

Although the performance of the solar system is in good agreement with f-Chart predictions, the performance was less than the designer anticipated. There are several reasons for this lower performance. The design DHW solar fraction

Figure 1. Energy Flow Diagram for Summerwood Associates, House M
 June 1980 through May 1981
 (All figures in million BTU)

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

SUMMERWOOD ASSOCIATES, HOUSE M
JUNE 1980 THROUGH MAY 1981

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	SOLAR ENERGY USED*		AUXILIARY ENERGY	OPERATING ENERGY	ENERGY SAVINGS	SOLAR FRACTION (%)*	
			PREDICTED	MEASURED	ELECTRICAL		ELECTRICAL	PREDICTED	MEASURED
JUN	2.61	0.73	0.53	0.72	0.01	0.32	0.39	82	99
JUL	3.15	0.66	0.63	0.65	0.01	0.37	0.28	96	98
AUG	1.48	0.22	0.25	0.10	0.12	0.16	-0.04	49	46
SEP	0.56	0.40	0.56	0.08	0.32	0.03	0.06	100	21
OCT	3.65	1.15	0.97	0.98	0.07	0.32	0.40	79	85
NOV	3.13	6.61	4.00	4.45	0.30	0.78	2.09	59	67
DEC	4.05	10.20	5.11	4.77	5.10	1.41	3.21	40	47
JAN	5.26	11.89	5.72	4.06	5.94	1.27	3.32	43	39
FEB	4.54	4.87	3.91	3.44	1.19	0.75	0.72	80	71
MAR	6.09	5.69	5.46	4.14	1.27	0.88	1.31	94	73
APR	3.59	0.70	0.55	0.69	0.00	0.28	0.26	64	99
MAY	4.31	0.57	0.63	0.57	0.00	0.34	0.17	80	98
TOTAL	45.22	43.69	27.83	25.20	14.28	6.91	12.17	-	-
AVERAGE	3.77	3.64	2.32	2.10	1.19	0.58	1.01	62	58

*Predicted performance was determined from an f-Chart 4.0 computer simulation using measured weather and measured subsystem loads as input.

Figure 2. System Thermal Performance
Summerwood Associates, House M
June 1980 through May 1981

of 100% is unattainable because of the space heating subsystem. The heat pump system for space heating uses stored heat as low as 45°F, so the storage tank temperature is often in the 50's and 60's in the winter, and almost never reaches the DHW temperature of 130°F. The collector array would have to be considerably oversized to have a 100% DHW solar fraction in the winter. (The DHW solar fraction was about 100% in the summer.) The space heating subsystem achieved a 56% solar fraction versus the 78% expected by the designers. The weather conditions were contributory causes, as the fall and winter (through January) were very much colder than normal.

The measured heating load of 38.51 million BTU was smaller than the predicted load of 43.40 million BTU. This difference was largely due to the low average house temperature, 61°F in January and February (which was partly because the heating system was undersized). Another factor in the lower load is that the house is not occupied every day of the year. The house was vacant 11 days in the winter (December-February), and 115 days scattered fairly evenly throughout the rest of the year.

Operating energy offset most of the savings in the summer, but was quite reasonable in the winter. Solar specific operating energy averaged about 0.40 million BTU per month in the winter, compared to about 5.00 million BTU of solar energy used per month. In the summer, about 0.30 million BTU of operating energy were used each month to deliver about 0.65 million BTU of solar energy. This high summer operating energy effect can also be seen in Table 2, Solar Coefficient of Performance (COP).

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

SUMMERWOOD ASSOCIATES, HOUSE M
JUNE 1980 THROUGH MAY 1981

MONTH	SOLAR ENERGY SYSTEM	COLLECTOR SUBSYSTEM	DOMESTIC HOT WATER SOLAR	SPACE HEATING SOLAR
JUN	2.25	10.44	11.27	*
JUL	1.76	10.50	9.03	NA
AUG	0.71	13.45	3.03	NA
SEP	2.67	28.00	13.67	NA
OCT	3.24	15.87	9.31	*
NOV	13.09	19.00	15.61	38.90
DEC	8.91	17.96	16.58	18.00
JAN	12.59	18.79	2.75	99.80
FEB	9.32	19.74	3.25	31.80
MAR	10.35	19.65	11.38	52.43
APR	2.65	16.32	8.39	39.00
MAY	1.73	15.39	13.89	*
WEIGHTED AVERAGE	6.67	16.32	8.24	35.47

* Denotes unavailable data.

NA Denotes not applicable.

The COP simply provides a numerical value for the relationship of solar energy used or collected and the energy required to collect or deliver it. The greater the COP value, the more efficient the subsystem. The solar energy system at Summerwood Associates, House M functioned at a reporting period weighted average COP value of 6.67 for the period June 1980 through May 1981.

The COP was high during the heating season, November through March, but was low the rest of the year when most of the solar energy was lost from the storage and DHW tanks, rather than being used to satisfy loads.

1.2 SYSTEM OPERATION

1.2.1 TYPICAL SYSTEM OPERATION

Curves showing typical system operation on a clear day (March 20, 1981) are presented in Figures 3a, 3b and 3c. Figure 3a shows the outdoor temperature and the insolation on the collector array. The plot indicates the time during which the collectors were operating. On this day the collector pump turned on briefly at 8:27 a.m., and then commenced normal operation at 8:39 a.m. The array operated continuously until 3:40 p.m., cycled back on briefly at 3:50 p.m., and then shut down.

Figure 3b shows the collector inlet and outlet temperatures. The inlet temperature sensor is on the roof, and its reading approaches outdoor ambient when the collector pump is not running. The minimum range of these sensors is 32°F. The collector outlet temperature sensor is in the attic, reading about 43°F until sunrise.

When the collector pump turned on at 8:27 a.m., the inlet temperature rose rapidly to 68°F, the temperature of the water in the bottom of the storage tank. As the absorber plates, preheated by two hours of morning sunshine (insolation was 130 BTU/ft² at 8:27 a.m.), heated the incoming water, they were cooled down. This apparently caused the pump to shut off. The inlet sensor recorded a temperature of 85°F as the water drained back to the storage tank. The collector pump turned on again at 8:37 a.m. and remained on until afternoon. The collectors are supposed to turn on when the collector-storage temperature differential is 15°F, and turn off when the differential falls to 2°F. Vitro temperature sensors do not give a direct indication of the operation of the control system as the absorber plate temperature, and the temperature of the storage tank at the locations of the control sensors are not monitored. The operation of controls on this day was typical for this system, however, with one extra cycle at each end, but no other problems. At solar noon (12:20 p.m.) the temperature rise through the collectors was 7.5°F. The flow meter read 17.3 gpm (all day), giving a collection rate of 65,000 BTU/hr. Insolation on the collectors was 326 BTU/ft²-hr, on 373 square feet of collector, a total of 121,600 BTU, so collector efficiency was 53%. The operating point was 0.20°F-ft²-hr BTU⁻¹. The measured energy collected for the whole day (seven hours of operation) was 394,000 BTU.

Figure 3a. Typical Insolation Data
Summerwood Associates, House M
March 20, 1981

Figure 3b. Typical Collector Array Temperatures, Inlet/Outlet
Summerwood Associates, House M
March 20, 1981

The storage tank temperatures are shown in Figure 3c. During the hours of collector operation, the storage temperature rose from 75°F to 129°F, a rise of 54°F. For a 600-gallon tank, this is an increase of 270,000 BTU. Energy was being drawn out of the tank for DHW and space heat during this period. The DHW preheat pump came on at 1:40 p.m. and remained on until 6:00 p.m. During the period of collector operation, 14,000 BTU were drawn from storage to the DHW subsystem. In the morning, water was drawn from storage several times for the heat pump evaporator. The total energy drawn from storage for space heating was 25,000 BTU during the period of collector operation. This would imply a storage loss of 85,000 BTU in the seven hours of collector operation. During this time, the average storage temperature was 102°F and the storage environment averaged 65°F. These temperatures imply an R value of about 0.5, which is much too low. This calculation was repeated for a number of days throughout the year, with similar results. For this reason, and as a result of further calculations explained in the collector subsystem section, it was determined that the actual collector flow was 14.7, rather than 17.3 gallons per minute. This flow rate makes the actual energy collected equal to 335,000 BTU, with a storage loss of 26,000 BTU, and an R value of 1.6, which is still very low. The long-term average measured R value was 3.4.

All the space heating demands were satisfied by either direct solar or the solar-assisted heat pump. From midnight to 6:15 a.m., storage temperature fell to 84°F (top) and 77°F (bottom) and the system switched to the heat pump. The heat pump cycled on five times, for about 20 minutes each time, until 11:00 a.m. No further heat was needed until 5:55 p.m., at which time the storage tank was warm enough for direct solar heat. Direct solar was used for all heating until the end of the day. The drops in storage temperature when heating draws are made are apparent in the plots.

Figure 3c. Typical Storage Fluid Temperatures
Summerwood Associates, House M
March 20, 1981

1.2.2 SYSTEM OPERATING SEQUENCE

Figure 4 presents a bar chart showing the system operating sequences for March 20, 1981.

Figure 4. Typical System Operating Sequence
Summerwood Associates, House M
March 20, 1981

The domestic hot water preheat loop ran from 1:30 to 6:00 p.m. The loop is designed to operate when the DHW tank temperature falls 15°F below the solar storage tank temperature, and to continue running until the differential is 6°F. The DHW tank temperature was 113°F when the pump turned on at 1:30 p.m. and rose to 124°F at 3:30 p.m. Further circulation from 3:30 to 6:00 p.m. did not succeed in raising the tank temperature. The operating energy loss was small, as the pump draws only 88 watts. The auxiliary DHW heater turned on for 10 minutes at 6 p.m., the only time it was needed on this day.

The space heating system worked well, using direct solar energy until 6:20 a.m. when the solar-assisted heat pump took over. The thermostat was apparently raised at this time, from about 63°F to 67°F. The storage tank temperature had fallen to near 80°F, the lowest temperature for usable direct solar heating. After the collectors boosted the storage temperature, direct solar heating was again used in the evening.

1.3 SOLAR ENERGY UTILIZATION

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

Figure 5. Solar Energy Use
Summerwood Associates, House M
June 1980 through May 1981

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

Over the year, the collectors were operated only 60% of the time there was radiation. This percentage varied greatly with the season. In the summer, the load was small and the collectors shut off because the tank temperature had reached its upper limit. In the winter, this percentage was about 80%. While the collectors were operating, 43% of the insolation was collected. This percentage was a good value for annual performance. Collector-to-storage transport losses were small. Storage losses were larger than they should have been, as heat was apparently bypassing the insulation. The large measured storage-to-hot water transport losses are probably not real. They were probably part of the DHW tank losses, but a small temperature sensor bias made them appear to be line losses. A comparison of estimated and measured DHW tank losses (see DHW subsection) reveals that nearly all the energy leaving storage for the DHW tank reached the DHW tank.

Table 3. SOLAR ENERGY LOSSES

SUMMERWOOD ASSOCIATES, HOUSE M
JUNE 1980 THROUGH MAY 1981

	<u>JUN</u>	<u>JUL</u>	<u>AUG</u>	<u>SEP</u>	<u>OCT</u>	<u>NOV</u>	<u>DEC</u>	<u>JAN</u>	<u>FEB</u>	<u>MAR</u>	<u>APR</u>	<u>MAY</u>
1. SOLAR ENERGY (SE) COLLECTED - SE DIRECTLY TO LOADS (million BTU)	2.61	3.15	1.48	0.56	3.65	5.13	4.85	5.26	4.54	6.09	3.59	4.31
2. SE TO STORAGE (million BTU)	2.49	3.15	1.34	0.43	3.05	4.88	4.85	5.13	4.54	6.09	3.48	4.00
3. LOSS - COLLECTOR TO STORAGE (%)	5	0	9	23	16	5	0	2	0	0	3	7
4. CHANGE IN STORED ENERGY (million BTU)	-0.02	0.13	-0.11	0.07	-0.07	-0.01	-0.15	0.14	0.03	0.41	-0.13	0.31
5. HOT WATER SOLAR ENERGY (HWSE) FROM STORAGE (million BTU)	0.62	0.65	0.10	0.08	0.36	0.28	0.20	0.11	0.13	0.24	0.26	0.43
6. LOSS - STORAGE TO HWSE (%)	54	62	23	11	49	35	5	*	*	35	19	17
7. HEATING SOLAR ENERGY (HSE) FROM STORAGE (million BTU)	0.10	0.00	0.00	0.00	0.62	4.17	4.52	4.55	3.32	3.90	0.43	0.14
8. LOSS - STORAGE TO HSE (%)	9	-	-	-	0	0	0	0	3	5	0	7

*Denotes unavailable data.

1.4 SOLAR SYSTEM AVAILABILITY

The solar system was switched off frequently in August and September because of a control system problem. The collectors were shut off August 12-23, 25, August 28 - September 3, September 7-17, and September 19-26 and 29. Solar energy was used for hot water preheating on only 11 days in August and four days in September. There were no system problems during the year.

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

Summerwood Associates, House M's collector array is composed of 18 Sunworks Slector flat-plate collectors which use water as the heat transfer fluid. The panels are mounted on the roof in three rows of six collectors each, tilted at an angle of 50 degrees. The array faces 12 degrees west of south. All 18 panels are plumbed in parallel. The flow through the array is relatively high, 15 gallons per minute, or about 0.04 gal/sq.ft.

Collector subsystem performance for Summerwood Associates, House M is presented in Table 4.

Table 4. COLLECTOR SUBSYSTEM PERFORMANCE

SUMMERWOOD ASSOCIATES, HOUSE M
JUNE 1980 THROUGH MAY 1981

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR SUBSYSTEM EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY	COLLECTOR ARRAY OPERATIONAL EFFICIENCY (%)	ECSS OPERATING ENERGY	SOLAR ENERGY DIRECTLY TO LOADS	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE (°F)
JUN	14.95	2.61	17	9.80	27	0.25	0.0	2.49	75
JUL	17.52	3.15	18	11.14	28	0.30	0.0	3.15	85
AUG	15.92	1.48	9	4.11	36	0.11	0.0	1.34	84
SEP	17.45	0.56	3	0.66	85	0.02	0.0	0.43	77
OCT	13.03	3.65	28	9.14	40	0.23	0.0	3.05	60
NOV	11.85	5.13	43	9.41	55 ^a	0.27	0.0	4.88	48
DEC	11.45	4.85	42	9.12	53	0.27	0.0	4.85	35
JAN	12.23	5.26	42	9.85	53	0.28	0.0	5.13	29
FEB	11.13	4.54	41	8.58	53	0.23	0.0	4.54	43
MAR	15.70	6.09	39	11.96	51	0.31	0.0	6.09	46
APR	15.01	3.59	24	9.19	39	0.22	0.0	3.48	57
MAY	17.09	4.31	25	11.02	39	0.28	0.0	4.00	68
TOTAL	173.33	45.22	-	103.98	-	2.77	0.0	43.43	-
AVERAGE	14.44	3.77	26	8.67	43	0.23	0.0	3.62	59

Collector subsystem performance was excellent throughout the year. In the summer, efficiencies are low because of the very high inlet temperatures, and because the collectors do not need to run very long to keep the storage tank

hot enough to satisfy the small DHW load. This only means that subsystem efficiency is not a good characterization of summer collector performance. In the winter, inlet temperatures are low and loads are large, resulting in high collector efficiencies. Throughout the year, the control system performed well, with a very small amount of extra cycling, and the panels themselves performed to design efficiency or better.

2.1.1 SEASONAL COLLECTOR ARRAY EFFICIENCY

Figures 6a and 6b show monthly performance of the collector array for February and May 1981. The collector array efficiency curve is compared to the manufacturer's standard (ASHRAE 93-77/NBSIR 74-635) collector efficiency curve. The instantaneous collector efficiencies are plotted against the collector operating point, defined as the temperature difference between the collector inlet temperature and the ambient temperature, divided by insolation per unit collector area.

Figure 6a. Average Collector Efficiency
 Summerwood Associates, House M
 February 1981

The collector efficiencies are consistently higher than the manufacturers single-panel ASHRAE test data. The only phenomenon that might account for this is the reduction in edge losses when the individual collectors are set out in an array, but this effort is too small to account for this efficiency increase. The efficiency of the array as a whole could be at most about five percent above the single-panel curve of edge loss reduction; our measured

Figure 6b. Average Collector Efficiency
 Summerwood Associates, House M
 May 1981

points are about 15% above the single-panel curve. The temperature sensors at the collectors and the storage inlet are in good agreement; the fault appears to be with the collector loop flow sensor, which must be reading too high. This could also clear up problems with the measured storage loss based on a tank energy balance. The tank showed an energy loss even when it was cooler than its environment.

Through calculations of the storage energy balance on the hourly, daily, and monthly levels, and an assessment of the probable maximum energy collected based on the single panel curve, it was determined that the actual flow rate was 85% of the measured flow. (The measured flow was 17 ± 0.5 gallons per minute throughout the year.) This reduced flow was used for all tables in this report. The only data in this report reflecting the unreduced measured flow are the collector efficiency plots. Reducing the flow to 85% would lower each measured point to 85% of the value shown, bringing the measured points just under the single-panel curve. The storage energy losses are also more consistent when the reduced flow is used (see the Storage Subsystem section).

Collector subsystem efficiency has been computed from two bases. The first assumes that the efficiency is based upon all available solar energy. This approach makes the operation of the control system part of array efficiency. For example, energy may be available at the collector, but the collector fluid temperature is below the control minimum; thus, the energy is not collected. In this approach, collector array performance is described by comparing the net amount of collected solar energy to the incident solar energy. Energy that is deliberately or inadvertently rejected or lost from the collector subsystem is subtracted from the collected energy in computing the net value. The ratio of these two energies represents the collector array efficiency which may be expressed as

$$n_c = Q_s / Q_i$$

where: n_c = collector array efficiency
 Q_s = collected solar energy
 Q_i = incident solar energy

The monthly efficiency computed by this method is listed in the column entitled "Collector Subsystem Efficiency" in Table 4.

The second approach assumes the efficiency is based upon the incident solar energy only during the periods of collection.

Evaluation of collector efficiency using operational incident energy yields operational collector efficiency. Operational collector efficiency, n_{co} , is computed as follows:

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

where: Q_s = collected solar energy
 Q_{oi} = incident solar energy while the collector pumps operated

The monthly efficiency computed by this method is listed in the column entitled "Collector Array Operational Efficiency" in Table 4. This latter efficiency term is not the same collector efficiency as represented by the ASHRAE Standard 93-77. Both operational collector efficiency and the ASHRAE collector efficiency are defined as the ratio of actual useful energy collected to solar energy incident upon the collector, and both use the same definition of collector area. However, the ASHRAE efficiency is determined from instantaneous evaluation under tightly controlled, steady-state test conditions, while the operational collector efficiency is determined from the actual conditions of daily solar energy system operation. Measured monthly values of operational incident energy and computed values of operational collector efficiency are presented in Table 4.

2.2 STORAGE

Thermal storage for the solar system is provided by a 600-gallon concrete water tank in the crawl space under the building, outside the conditioned space of the building. The tank is six feet long, five feet wide, and four feet high, insulated with two inches of polystyrene foam on the bottom, and

four inches on the rest of the tank. The outside surface area of the tank is 161 square feet.

The performance of the storage subsystem is shown in Table 5. (See Footnote 1.) During the reporting period, total solar energy delivered to storage was 43.43 million BTU. Forty percent of this energy, 16.94 million BTU, was lost. There were 4.05 million BTU going out of storage to the DHW subsystem, and 21.84 million BTU to the space heating subsystem. The storage losses shown in the table are calculated from the storage tank energy balance. The figures for energy into storage are all reduced to 85% of the measured value (see Collector Subsystem section). The heat loss coefficients are calculated from these storage losses using measured data for the tank environment temperature. This temperature varied from 45°F to over 90°F, depending on the storage tank temperature and the season. The heat loss coefficient seems to have changed over the winter. It was measured in the 40's in the summer and fall of 1980, and in the 60's in the spring of 1981.

The effective tank insulation was also studied by plotting the storage tank temperature decay over a 36-hour period when no energy was pumped into or out of the tank. The temperature declined from 153°F to 125°F indicating an average R value of 3.5. This value was obtained on several other days throughout the year. It is difficult to calculate this precisely, because the environment temperature of the tank changes rapidly in response to tank temperature changes, and temperatures at different locations near the tank may read differently by 10° or 15°F. The tank temperature also stratifies 10°-20°F after sitting for a few days with no pumps running.

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

$$\text{STEFF} = (\text{STECH} + \text{STEO})/\text{STEI}$$

Where:

- STEFF = Storage efficiency
- STECH = Change in stored energy
- STEO = Energy removed from storage
- STEI = Energy added to storage

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

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

Where:

- c = effective storage heat loss coefficient
- T_s = average storage temperature
- T_a = average ambient temperature in the vicinity of storage
- t = number of hours in the month

Table 5. STORAGE PERFORMANCE

SUMMERWOOD ASSOCIATES, HOUSE M
JUNE 1980 THROUGH MAY 1981

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY TO STORAGE	ENERGY FROM STORAGE	CHANGE IN STORAGE ENERGY	STORAGE EFFICIENCY (%)	AVERAGE STORAGE TEMPERATURE (°F)	EFFECTIVE HEAT LOSS COEFFICIENT (BTU/hr°F)	LOSS FROM STORAGE
JUN	2.49	0.77	-0.02	30	143	43.9	1.74
JUL	3.15	0.84	0.13	31	152	47.3	2.18
AUG	1.34	0.28	-0.11	13	125	44.9	1.17
SEP	0.43	0.09	0.07	37	90	37.5	0.27
OCT	3.05	1.33	-0.07	41	138	48.1	1.79
NOV	4.88	4.56	-0.01	93	90	22.9	0.33
DEC	4.85	4.64	-0.15	93	73	37.0	0.36
JAN	5.13	4.47	0.14	90	67	58.3	0.52
FEB	4.54	3.28	0.03	73	90	61.0	1.23
MAR	6.09	4.22	0.41	76	88	65.4	1.46
APR	3.48	0.75	-0.13	18	133	66.2	2.86
MAY	4.00	0.66	0.31	24	145	62.7	3.03
TOTAL	43.43	25.89	0.60	-	-	-	16.94
AVERAGE	3.62	2.16	0.05	61	111	47.2	1.46

2.3 DOMESTIC HOT WATER (DHW)

The DHW subsystem performance for the Summerwood Associates, House M site for the reporting period is shown in Table 6 and by graphic illustration in Figure 7.

The DHW subsystem required 3.46 million BTU of solar energy and 1.72 million BTU of auxiliary electrical energy to satisfy a hot water load of 5.18 million BTU. The solar fraction of this load was 67%, with an operating energy of 0.42 million BTU. Losses from the DHW subsystem were 2.50 million BTU. A daily average of 15 gallons of DHW was consumed at an average temperature of 128°F.

The DHW subsystem achieves a high solar fraction, close to 100%, during the nonheating season of April to October. The DHW solar fraction was low in August and September only because the system was shut off for parts of those months. Energy savings are small in the summer months, because the collector pump (1/3 HP) runs exclusively to support DHW in these months. The electrical energy savings for DHW heating by the solar energy were partially offset by the relatively large amount of operating energy required to run the collector pump. To maintain the storage water at temperatures high enough to satisfy

Table 6. DOMESTIC HOT WATER SUBSYSTEM

SUMMERWOOD ASSOCIATES, HOUSE M
JUNE 1980 THROUGH MAY 1981

(All values in million BTU, unless otherwise indicated)

MONTH	HOT WATER LOAD	SOLAR FRACTION OF LOAD (%)	HOT WATER DEMAND	SOLAR FRACTION OF DEMAND (%)	SOLAR ENERGY USED	AUX THERMAL USED	AUX ELECT FUEL	OPERATING ENERGY	SUP. WATER TEMP (°F)	HOT WATER TEMP (°F)	HOT WATER CONSUMPTION (GAL)
JUN	0.63	98	0.34	90	0.62	0.01	0.01	0.06	70	135	528
JUL	0.66	98	0.36	96	0.65	0.01	0.01	0.07	74	134	584
AUG	0.22	46	0.12	57	0.10	0.12	0.12	0.03	75	138	221
SEP	0.40	21	0.25	12	0.08	0.32	0.32	0.01	70	128	518
OCT	0.38	96	0.12	93	0.36	0.02	0.02	0.04	67	131	224
NOV	0.47	59	0.33	58	0.28	0.19	0.19	0.02	62	128	597
DEC	0.68	29	0.50	33	0.20	0.48	0.48	0.01	55	133	759
JAN	0.43	26	0.28	*	0.11	0.32	0.32	0.04	51	129	435
FEB	0.33	39	0.18	*	0.13	0.20	0.20	0.04	52	111	352
MAR	0.29	82	0.24	82	0.24	0.05	0.05	0.02	53	108	522
APR	0.26	100	0.11	100	0.26	0.00	0.00	0.03	58	129	188
MAY	0.43	99	0.27	100	0.43	0.00	0.00	0.05	62	136	431
TOTAL	5.18	-	3.10	-	3.46	1.72	1.72	0.42	-	-	5,359
AVERAGE	0.43	67	0.26	64	0.27	0.14	0.14	0.04	62	128	447

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

Figure 7. DHW Subsystem Performance
Summerwood Associates, House M
June 1980 through May 1981

the DHW load, the collector pump had to operate long enough to deliver enough solar energy to storage to offset the high storage losses. Thus, much operating energy was consumed. From April to October, 19.35 million BTU were collected to support a system load of 4.43 million BTU. The operating energy for the DHW preheat loop is not large, as the pump is only 1/20 HP. It runs four hours per day on the average, but the energy delivered to the DHW tank is usually small in the last two hours. Reducing the storage losses and perhaps lowering the water level in the storage tank in the summer would increase energy savings.

In the heating months the solar fraction is much lower because of the use of solar energy for space heating which keeps the storage temperature lower.

2.4 SPACE HEATING

The space heating performance for the Summerwood Associates, House M site for the reporting period is shown in Tables 7 and 8 and presented graphically in Figure 8.

Table 7. SPACE HEATING SUBSYSTEM I

SUMMERWOOD ASSOCIATES, HOUSE M
JUNE 1980 THROUGH MAY 1981

(All values in million BTU, unless otherwise indicated)

MONTH	SPACE HEATING LOAD	CONTROLLED DELIVERED ENERGY	TOTAL SOLAR ENERGY USED	TOTAL AUXILIARY THERMAL USED	SOLAR FRACTION OF LOAD (%)	BLDG TEMP (°F)	AMB TEMP (°F)
JUN	0.10	0.10	0.10	0.00	100	73	66
JUL	0.00	0.00	0.00	0.00	-	75	75
AUG	0.00	0.00	0.00	0.00	-	78	75
SEP	0.00	0.00	0.00	0.00	-	74	67
OCT	0.77	0.72	0.62	0.01	80	68	52
NOV	6.14	5.76	4.17	0.10	68	68	42
DEC	9.52	8.84	4.52	4.18	48	65	29
JAN	11.46	10.69	4.55	5.10	40	61	22
FEB	4.54	4.11	3.32	0.79	72	61	36
MAR	5.40	4.72	3.90	0.87	72	63	38
APR	0.44	0.39	0.43	0.00	98	64	50
MAY	0.14	0.13	0.14	0.00	96	71	59
TOTAL	38.51*	35.46	21.74	11.05	-	-	-
AVERAGE	3.21	2.96	1.81	0.92	56	64	51

*Includes losses from solar and auxiliary heating equipment which contribute to the space heating load.

Table 8. SPACE HEATING SUBSYSTEM II

SUMMERWOOD ASSOCIATES, HOUSE M
JUNE 1980 THROUGH MAY 1981

(All values in million BTU, unless otherwise indicated)

MONTH	SPACE HEATING LOAD	MEASURED SOLAR ENERGY USED	SOLAR ENERGY LOSSES TO LOAD	TOTAL OPERATING ENERGY	SOLAR SPECIFIC OPERATING ENERGY	AUXILIARY ELECT FUEL	HEATING DEGREE DAYS
JUN	0.10	0.10	0.00	0.02	0.00	0.00	52
JUL	0.00	0.00	0.00	0.00	0.00	0.00	0
AUG	0.00	0.00	0.00	0.01	0.00	0.00	0
SEP	0.00	0.00	0.00	0.00	0.00	0.00	68
OCT	0.77	0.58	0.04	0.06	0.01	0.01	360
NOV	6.14	3.89	0.28	0.50	0.10	0.11	677
DEC	9.52	4.50	0.02	1.13	0.25	4.62	1,109
JAN	11.46	4.49	0.06	0.95	0.05	5.62	1,325
FEB	4.54	3.18	0.13	0.48	0.10	0.99	810
MAR	5.40	3.67	0.23	0.54	0.07	1.21	812
APR	0.44	0.39	0.04	0.03	0.01	0.00	442
MAY	0.14	0.13	0.01	0.01	0.00	0.00	187
TOTAL	38.51	20.93	0.81	3.73	0.59	12.56	5,842
AVERAGE	3.21	1.74	0.07	0.31	0.05	1.05	-

Figure 8. Space Heating Subsystem
Summerwood Associates, House M
June 1980 through May 1981

The space heating load of 38.51 million BTU was satisfied by 21.74 million BTU of solar energy and 11.05 million BTU of auxiliary energy. The solar fraction of this load was 56% with an operating energy expense of 0.59 million BTU. The solar energy supplied to the heat pump allowed it to operate at a seasonal COP of 3.5.

The electrical energy savings (November through March) were 11.88 million BTU. The average building temperature for the heating season was 64°F.

The operation of the heating system is as follows. When there is a demand for heat and storage temperature is above 85°F, direct solar heating is activated. If the building temperature continues to drop, one-half of the electric strip heaters come on. If the storage tank is above 40°F but below 85°F, the heat pump is used in solar-assisted mode. If the storage temperature is below 40°F and air temperature is above 10°F, the heat pump is used in air-to-air mode. The electric duct heaters are used alone if the outdoor temperature drops below 10°F and storage temperature is below 40°F.

During the heating season (November through March) the heat pump operating in solar-assisted mode supplied just over half (51%) of the controlled delivered energy (CDE). The heat pump in air-to-air mode supplied only two percent of CDE, and direct solar and the electric resistance heaters each supplied just under one quarter of the CDE. The electric resistance heaters showed significant use only in December and January, which were much colder than normal.

The space heating subsystem at Summerwood Associates, House M performed well, achieving a solar fraction of 56%, compared to the designers' expectation of 78%. The solar fraction is good because the winter from October through January was very much colder than normal. The control system always worked as designed, and the heat pump had a good coefficient of performance.

The biggest fault of the heating system is that it is undersized and in very cold weather (around 0°F) the house temperature was chilly, in the 50's.

Building load analysis by the UAC_d method is also included in Table 9. This method is designed to calculate the equipment heating load of the building, i.e., the amount of energy delivered to the building by the heating equipment, including thermal losses from the space heating equipment to the building. The overall agreement is good, although the calculated load is too large in the warmer months and too small in the colder months. The calculations are based on a building temperature of 68°F-70°F, which was not the case in the colder months. Also, there are significant passive gains through the south-facing windows into the space in which the building temperature sensor is located. Passive solar heating contributions are not fully monitored at this site.

Table 9. DESIGN HEATING LOAD BY UA x Cd METHOD

SUMMERWOOD ASSOCIATES, HOUSE M
JUNE 1980 THROUGH MAY 1981

MONTH	BUILDING TEMPERATURE (°F)	AMBIENT TEMPERATURE (°F)	HEATING DEGREE-DAYS (65°F REF)	UA x Cd VALUE (BTU/hr-°F)	DESIGN HEAT LOAD (BTU x 10 ⁶)	EQUIPMENT HEATING LOAD (BTU x 10 ⁶)
JUN	73	66	52	307	0.38	0.10
JUL	75	75	0	307	0.00	0.00
AUG	78	75	0	307	0.00	0.00
SEP	74	67	68	307	0.50	0.00
OCT	68	52	360	307	2.65	0.77
NOV	68	42	677	307	4.99	6.14
DEC	65	29	1,109	307	8.17	9.52
JAN	61	22	1,325	307	9.76	11.46
FEB	61	36	810	307	5.97	4.54
MAR	63	38	812	307	5.98	5.40
APR	64	50	442	307	3.26	0.44
MAY	71	59	187	307	1.38	0.14
TOTAL	-	-	5,842	-	43.04	38.51
AVERAGE	68	51	-	307	3.59	3.21

SECTION 3

SOLAR OPERATING ENERGY

Measured monthly values of the Summerwood Associates, House M solar energy system and subsystem operating energy for the report period are presented in Table 10. A total 3.78 million BTU of operating energy were consumed by the solar system during the reporting period.

Total system operating energy for Summerwood Associates, House M is the electrical energy required to support the collector, storage, space heating, and domestic hot water subsystems without affecting their thermal states.

Table 10. SOLAR OPERATING ENERGY

SUMMERWOOD ASSOCIATES, HOUSE M
JUNE 1980 THROUGH MAY 1981

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY	DHW OPERATING ENERGY	SHS OPERATING ENERGY	TOTAL SOLAR OPERATING ENERGY
JUN	0.25	0.06	0.00	0.31
JUL	0.30	0.07	0.00	0.37
AUG	0.11	0.03	0.00	0.14
SEP	0.02	0.01	0.00	0.03
OCT	0.23	0.04	0.01	0.28
NOV	0.27	0.02	0.10	0.39
DEC	0.27	0.01	0.25	0.53
JAN	0.28	0.04	0.05	0.37
FEB	0.23	0.04	0.10	0.37
MAR	0.31	0.02	0.07	0.40
APR	0.22	0.03	0.01	0.26
MAY	0.28	0.05	0.00	0.33
TOTAL	2.77	0.42	0.59	3.78
AVERAGE	0.23	0.04	0.05	0.32

The components which use operating energy are:

P1 - ECSS circulation pump (1/3 HP Marlow Centrifugal pump)

P2 - Heating load pump (two 1/12 HP in series Grundfos circulators)

P3 - DHW preheat pump (1/20 HP Grundfos circulator)

Distribution blower - 1/6 HP

Heat pump outside fan

DHW operating energy, though not large, was twice as large as it needed to be, because the duration of the preheat loop cycle was about twice as long as optimal, and no energy was delivered to the DHW tank in the second half of the cycle.

Space heating and ECSS operating energies were satisfactory.

In the summer, when the load is DHW only, the operating energy for the collectors is a significant portion of the possible energy savings. This expense could be lessened by lowering the level of the storage tank fluid, so the collectors could get the tank hot in less time, with less operating energy.

SECTION 4

ENERGY SAVINGS

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

Table 11. ENERGY SAVINGS

SUMMERWOOD ASSOCIATES, HOUSE M
JUNE 1980 THROUGH MAY 1981

(All values in million BTU)

MONTH	SOLAR ENERGY USED	<u>SPACE HEATING</u>	<u>DOMESTIC HOT WATER</u>	<u>ECSS OPERATING ENERGY</u>	<u>NET ENERGY SAVINGS</u>
		ELECTRICAL	ELECTRICAL	SOLAR UNIQUE	ELECTRICAL
JUN	0.72	0.08	0.57	0.25	0.39
JUL	0.65	0.00	0.58	0.30	0.28
AUG	0.10	0.00	0.07	0.11	-0.04
SEP	0.08	0.00	0.08	0.02	0.06
OCT	0.98	0.31	0.32	0.23	0.40
NOV	4.45	2.10	0.26	0.27	2.09
DEC	4.72	3.29	0.19	0.27	3.21
JAN	4.66	3.54	0.07	0.28	3.32
FEB	3.44	0.86	0.09	0.23	0.72
MAR	4.14	1.40	0.22	0.31	0.31
APR	0.69	0.24	0.23	0.22	0.26
MAY	0.57	0.06	0.38	0.28	0.17
TOTAL	25.20	11.88	3.06	2.77	12.17
AVERAGE	2.10	0.99	0.26	0.23	1.01

For this one year period, the total savings were 12.17 million BTU, for a monthly average of 1.01 million BTU. This is equivalent to 3,563 kwh of electric power. An electrical energy expense of 3.78 million BTU was incurred during the reporting period for the operation of solar energy components.

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

The auxiliary sources at the Summerwood Associates, House M site consist of electric resistance heaters in the DHW tanks and in the space heating ducts. These units are considered to be 100% efficient for computational purposes. The efficiency of the heat pump is calculated as a function of the temperature of the evaporator source (water or air).

Savings were good in the winter, negligible in the summer. Restoring the storage tank insulation back to design standards would improve the savings, particularly in the nonheating months when the storage tank is hot. (See Storage Subsystem discussion). If the water level of the storage tank were lowered in the summer to about 300 gallons, the tank could reach the DHW set point with less use of the collector pump, which would also improve savings.

SECTION 5

WEATHER CONDITIONS

Summerwood Associates, House M is located in Old Saybrook, Connecticut at 41 degrees N latitude and 72 degrees W longitude.

Monthly values of the total solar energy incident in the plane of the collector array and the average outdoor temperature measured at the site during the reporting period are presented in Table 12. Also presented in the table are the corresponding long-term average monthly values of the measured weather parameters. These long-term average weather data were obtained from nearby representative National Weather Service and SOLMET meteorological stations. The long-term average insolation values are total global horizontal radiation converted to collector tilt and azimuth orientation through a TRNSYS type radiation processor.

Table 12. WEATHER CONDITIONS

SUMMERWOOD ASSOCIATES, HOUSE M
JUNE 1980 THROUGH MAY 1981

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT ² -DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS	
	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
JUN	1,336	1,423	66	68	52	24
JUL	1,515	1,431	75	74	0	0
AUG	1,377	1,428	75	73	0	0
SEP	1,560	1,394	67	67	68	42
OCT	1,127	1,319	52	57	360	261
NOV	1,059	957	42	46	677	570
DEC	990	810	29	34	1,109	967
JAN	1,057	952	22	30	1,325	1,079
FEB	1,066	1,146	36	31	810	955
MAR	1,357	1,300	38	38	812	840
APR	1,341	1,399	50	48	442	498
MAY	1,478	1,421	59	58	187	225
TOTAL	15,263	14,980	-	-	5,842	5,461
AVERAGE	1,272	1,248	51	52	-	-

During the period from June 1980 through May 1981, the average daily total incident solar radiation on the collector array was 1,272 BTU per square foot per day. This radiation was above the estimated average daily solar radiation for this geographical area during the reporting period of 1,248 BTU per square

foot per day for a plane facing 12 degrees West of South with a tilt of 50 degrees to the horizontal. During the period, the highest monthly average insolation was 1,560 BTU per square foot per day during September. The average ambient temperature during the reporting period was 51°F as compared with the long-term annual average of 52°F. The highest monthly average ambient temperature was 75°F during July and August, and the lowest monthly average ambient temperature was 22°F during January. The number of heating degree-days for the period (based on a 65°F reference) was 5,842 as compared with the long-term average of 5,461. The range of heating degree-days was from a high of 1,325 during January to a low of zero during July and August. The lowest temperature was -12°F on December 25. The warmest was 102°F on July 21. The four-month period from October through January was very much colder than normal.

Extraterrestrial radiation values are computed (see Footnote 1) and given in the table below for each month. The ratio of total insolation on a tilted surface to extraterrestrial radiation on a parallel surface is called the clearness index.

This parameter quantifies the effects of cloudiness and atmospheric transmission on the insolation received at the earth's surface. The clearness index ranged from a high of 56% during July to a low of 33% during February.

MONTH	<u>JUN</u>	<u>JUL</u>	<u>AUG</u>	<u>SEP</u>	<u>OCT</u>	<u>NOV</u>	<u>DEC</u>	<u>JAN</u>	<u>FEB</u>	<u>MAR</u>	<u>APR</u>	<u>MAY</u>
EXTRATERRESTRIAL INSOLATION	2,656	2,718	2,963	3,194	3,228	3,059	2,928	3,018	3,218	3,270	3,094	2,814
<u>TTL INS</u> <u>EXT INS</u> (%)	50	56	46	49	35	33	34	35	33	41	43	53

For a more complete set of meteorological data see Appendix F, which contains daily average values for the months of the reporting period.

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

SECTION 6

REFERENCES

- *1. National Solar Data Network, Department of Energy, prepared under Contract Number DE-AC01-79CS30027, Vitro Laboratories, Silver Spring, Maryland, January 1980.
2. J. T. Smok, V. S. Sohoni, J. M. Nash, "Processing of Instrumented Data for the National Solar Heating and Cooling Demonstration Program," Conference on Performance Monitoring Techniques for Evaluation of Solar Heating and Cooling Systems, Washington, D.C., April 1978.
3. E. Streed, et al, Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program, NBSIR-76-1137, National Bureau of Standards, Washington, D.C., 1976.
- *4. Mears, J. C., Reference Monthly Environmental Data for Systems in the National Solar Data Network. Department of Energy report SOLAR/0019-79/36. Washington, D.C., 1979.
5. ASHRAE Standard 93-77, Methods of Testing to Determine the Thermal Performance of Solar Collectors, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, N.Y., 1977.
- **6. ASHRAE Standard 94-77, Methods of Testing Thermal Storage Devices Based on Thermal Performance, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, N.Y., 1977.
- *6A. User's Guide to Monthly Performance Reports, June 1980, SOLAR/0004-80/18, Vitro Laboratories, Silver Spring, Maryland.
- *6B. Instrumentation Installation Guidelines March 1981, Parts 1, 2, and 3, SOLAR/0001-81/15, Vitro Laboratories, Silver Spring, Maryland.
- *7. Monthly Performance Report, Summerwood Associates, House M, June 1980, SOLAR/1102-80/06, Vitro Laboratories, Silver Spring, Maryland.
- *8. Monthly Performance Report, Summerwood Associates, House M, July 1980, SOLAR/1102-80/07, Vitro Laboratories, Silver Spring, Maryland.
- *9. Monthly Performance Report, Summerwood Associates, House M, November 1980, SOLAR/1102-80/11, Vitro Laboratories, Silver Spring, Maryland.
- *10. Monthly Performance Report, Summerwood Associates, House M, December 1980, SOLAR/1102-80/12, Vitro Laboratories, Silver Spring, Maryland.

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

**Note: Reference [6] only used if the heat transfer coefficient discussion in Section 5.3.1.2 applies.

APPENDIX A

SYSTEM DESCRIPTION

The Summerwood Associates site is a cluster of condominiums overlooking Long Island Sound. Two adjacent units are instrumented: a Madison model designated Summerwood M, and a Guilford model designated Summerwood G. The Summerwood M site is described in this report.

The Summerwood M site is a rowhouse residence in Old Saybrook, Connecticut. The home has approximately 1,375 square feet of conditioned space. Solar energy is used for space heating and preheating domestic hot water (DHW). The solar energy system has an array of flat-plate collectors with a gross area of 378 square feet. The array faces 12 degrees West of South at an angle of 50 degrees to the horizontal. Water is the transfer medium that delivers solar energy from the collector array to storage and to the space heating and DHW loads. Draindown provides collector freeze protection. Solar energy is stored in a 600-gallon poured-concrete insulated tank located in a crawl space. Solar heated water is supplied to a liquid-to-air heat exchanger within the space heating duct and to a heat pump for water-to-air operation. A closed heat transfer loop between the solar storage tank and a 120-gallon DHW tank provides solar energy to the DHW supply. When solar energy is insufficient to satisfy the entire space heating load, the heat pump operates in its water-to-air mode, extracting heat from the solar-heated water. When the storage tank temperature falls below 40°F, the heat pump automatically disconnects from the solar-heated water supply and operates in an air-to-air mode using an outdoor evaporator. An electric heater in the space heating duct provides auxiliary energy for space heating in conjunction with both solar and conventional heating modes. An electrical heating element in the DHW tank provides auxiliary energy for water heating.

The manufacturers of major solar system equipment and components are listed below.

<u>Equipment/Components</u>	<u>Manufacturer</u>	<u>Model No. or Type</u>
Collector	Sunworks	Solccter IM LC
Solar storage tank	Wormser Scientific Corporation	Site-built concrete
Solar storage tank insulation	Dow Chemical Co.	Polystyrene Styrofoam G
Air-handling system, including blowers, heat exchangers, heat pump and electrical resistance heater	Friedrich Air Conditioning and Refrigeration Co.	Climate Master V-22 12AW
Domestic water heater	Vaughn Corporation	E-120SNR-0
Control mode selector	Johnson Controls	147-1-2-3

The system, shown schematically in Figure A-1, has four modes of solar operation.

Mode 1 - Collector-to-Storage - This mode activates when collector temperature exceeds the storage temperature by 15°F and terminates when a temperature difference of 2°F is reached. Collector loop pump P1 is operated in this mode.

Mode 2 - Storage-to-Space Heating - Direct Solar Mode - This mode activates when there is a demand for space heating and solar storage temperature is above 85°F. Circulating pump P2 and the air-handling subsystem blower are operated in this mode.

Mode 3 - Storage-to-Space Heating - Solar-Assisted Heat Pump Mode - This mode activates when there is a demand for space heating and the solar storage temperature is less than 85°F and greater than 40°F. Circulating pump P2, the air-handling subsystem blower, and the heat pump are operated in this mode.

Mode 4 - Storage-to-DHW - This mode activates when the temperature difference between solar storage and the DHW tank exceeds 15°F and terminates when the temperature difference drops below 6°F. Pump P3 is operated in this mode.

SUBSYSTEMS

Collector - The solar collectors at Summerwood Associates, House M are Sunworks Selectors, manufactured by Sunworks, Inc., of Guilford, Connecticut. A total of 18 collectors are used - three rows of six collectors each. The collectors are three feet by seven feet, giving a gross collector area of 378 square feet. The collectors are on the roof of the building, oriented 12 degrees West of South, at a slope of 50 degrees from the horizontal.

The collectors have a single 3/16-inch low iron glass cover with 92% solar transmittance. The absorber is copper sheet with a selective black surface manufactured by Enthone. The surface has an absorptivity of 0.90 and an emissivity of 0.12. Fluid passages are one-fourth inch copper tubes spaced 16 inches apart with a one-inch copper manifold. The tubes are soft soldered to the absorber sheet. Insulation behind the absorber is two and one-half inch fiberglass. The transfer fluid used is water. All collectors are plumbed in parallel. When the collector pump turns off, all fluid drains back into the storage tank.

Storage - Solar energy storage is provided by a 600-gallon concrete site-built tank. The tank is in an unheated crawl space beneath the house. The tank has an EPDM membrane liner. Insulation is provided by two inches of polystyrene foam on the bottom, and four inches on the top and sides. The tank is five feet by six feet by four feet high.

Space Heating - The space heating subsystem consists of an electric dual source (water or air) to air heat pump and electric resistance heaters, and a solar heating coil in the duct. Solar energy from storage is used either directly in the heating coil, or as a source for the heat pump evaporator. The heat pump is a model 22-21, Climate Master, capacity 21,500 BTU, manufactured by Friedrich.

Hot Water - Energy from storage is used to heat domestic hot water in a 120-gallon Sepco Solar Energy Water Heater manufactured by the Vaughn Corp. When solar energy is insufficient to satisfy the DHW load, a 4,200 watt electrical immersion heater in the top of the DHW tank provides auxiliary energy for heating the supply water. Solar energy is transferred from the storage to the DHW tank by a heat exchanger in the storage tank, and another heat exchanger in the bottom of the DHW tank. Water is used as the transfer medium.

FEB 27, 1980

Figure A-i. Summerwood Associates, House M Solar Energy System Schematic

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

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

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

Figure B-1. The National Solar Data Network

DATA COLLECTION AND PROCESSING

Each site contains standard industrial instrumentation modified for the particular site. Sensors measure temperatures, flows, insolation, electric power, fossil fuel usage, and other parameters. These sensors are all wired into a junction box (J-box), which is in turn connected to a microprocessor data logger called the Site Data Acquisition Subsystem (SDAS). The SDAS can read up to 96 different channels, one channel for each sensor. The SDAS takes the analog voltage input to each channel and converts it to a 10-bit word. At intervals of every 320 seconds, the SDAS samples each channel and records the values on a cassette tape. Some of the channels can be sampled 10 times in each 320 second interval, and the average value is recorded in the tape.

Each SDAS is connected through a modem to voice-grade telephone lines which are used to transmit the data to a central computer facility. This facility is the Central Data Processing System (CDPS), located at Vitro Laboratories in Silver Spring, Maryland. The CDPS hardware consists of an IBM System 7, an IBM 370/145, and an IBM 3033. The System 7 periodically calls up each SDAS in the system and has the SDAS transmit the data on the cassette tape back to the System 7. Typically, the System 7 collects data from each SDAS six times a week, although the tape can hold three to five days of data, depending on the number of channels.

The data received by the System 7 are in the form of digital counts in the range of 0-1,023. These counts are then processed by software in the CDPS, where they are converted from counts to engineering units (EU) by applying appropriate calibration constants. The engineering unit data called "detailed measurements" in the software are then tabulated on a daily basis for the site analyst. The CDPS is also capable of transforming this data into plots, graphs, and processed reports.

Solar system performance reports present system parameters as monthly values. If some of the data during the month is not collected due to solar system, instrumentation system, or data acquisition problems, or if some of the collected data is invalid, then the collected valid data is extrapolated to provide the monthly performance estimates. Researchers and other users who require unextrapolated, "raw" data may obtain data by contacting Vitro Laboratories.

DATA ANALYSIS

The analyst develops a unique set of "site equations" (given in Appendix D) for each site in the NSDN, following the guidelines presented herein.

The equations calculate the flow of energy through the system, including solar energy, auxiliary energy, and losses. These equations are programmed in PL/1 and become part of the Central Data Processing System. The PL/1 program for each site is termed the site software. The site software processes the detailed data, using as input a "measurement record" containing the data for each scan interval. The site software produces as output a set of performance factors, on an hourly, daily, and monthly basis.

These performance factors (Appendix C) quantify the thermal performance of the system by computing energy flows throughout the various subsystems. The system performance may then be evaluated based on the efficiency of the system in transferring these energies.

Performance factors which are considered to be of primary importance are those which are essential for system evaluation. Without these primary performance factors (which are denoted by an asterisk in Appendix C), comparative evaluation of the wide variety of solar energy systems would be impossible. An example of a primary performance factor is SECA - Solar Energy Collected by the Array. This is quite obviously a key parameter in system analysis.

Secondary performance factors are data deemed important and useful in comparison and evaluation of solar systems, particularly with respect to component interactions and simulation. In most cases these secondary performance factors are computed as functions of primary performance factors.

There are irregularly occurring cases of missing data as is normal for any realtime data collection from mechanical equipment. When data for individual scans or whole hours are missing, values of performance factors are assigned which are interpolated from measured data. If no valid measured data are available for interpolation, a zero value is assigned. If data are missing for a whole day, each hour is interpolated separately. Data are interpolated in order to provide solar system performance factors on a whole hour, whole day and whole month basis for use by architects and designers.

REPORTING

The performance of the Summerwood Associates, House M solar energy system from June 1980 through May 1981 was analyzed and Monthly Performance Reports were published through December 1980. See the following page for a list of these reports.

In addition, data are included in this report which are not in Monthly Performance Reports.

OTHER DATA REPORTS ON THIS SITE*

Monthly Performance Reports:

April 1980, SOLAR/1102-80/04
May 1980, SOLAR/1102-80/05
June 1980, SOLAR/1102-80/06
July 1980, SOLAR/1102-80/07
November 1980, SOLAR/1102-80/11
December 1980, SOLAR/1102-80/12

* These reports can be obtained (free) by contacting: U.S. Department of Energy, Technical Information Center, P.O. Box 62, Oak Ridge, TN 37830.

APPENDIX C

PERFORMANCE FACTORS AND SOLAR TERMS

The performance factors identified in the site equations (Appendix D) by the use of acronyms or symbols are defined in this Appendix in Section 1. Section 1 includes the acronym, the actual name of the performance factor, and a short definition.

Section 2 contains a glossary of solar terminology, in alphabetical order. These terms are included for quick reference by the reader.

Section 3 describes general acronyms used in this report.

- Section 1. Performance Factor Definitions and Acronyms
- Section 2. Solar Terminology
- Section 3. General Acronyms

SECTION 1. PERFORMANCE FACTOR DEFINITIONS AND ACRONYMS

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
AXE	Auxiliary Electric Fuel Energy to Load Subsystem	Amount of electrical energy required as a fuel source for all load subsystems.
AXF	Auxiliary Fossil Fuel Energy to Load Subsystem	Amount of fossil energy required as a fuel source for all load subsystems.
* AXT	Auxiliary Thermal Energy to Load Subsystems	Thermal energy delivered to all load subsystems to support a portion of the subsystem loads, from all auxiliary sources.
CAE	SCS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the SCS to be converted and applied to the SCS load.
CAF	SCS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the SCS to be converted and applied to the SCS load.
CAREF	Collector Array Efficiency	Ratio of the collected solar energy to the incident solar energy.
CAT	SCS Auxiliary Thermal Energy	Amount of energy provided to the SCS by a BTU heat transfer fluid from an auxiliary source.
* CL	Space Cooling Subsystem Load	Energy required to satisfy the temperature control demands of the space cooling subsystem.
CLAREA	Collector Array Area	The gross area of one collector panel multiplied by the number of panels in the array.
COPE	SCS Operating Energy	Amount of energy required to support the SCS operation which is not intended to be applied directly to the SCS load.
CSAUX	Auxiliary Energy to ECSS	Amount of auxiliary energy supplied to the ECSS.
* CSCEF	ECSS Solar Conversion Efficiency	Ratio of the solar energy supplied from the ECSS to the load subsystems to the incident solar energy on the collector array.

* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
CSE	Solar Energy to SCS	Amount of solar energy delivered to the SCS.
CSEO	Energy Delivered from ECSS to Load Subsystems	Amount of energy supplied from the ECSS to the load subsystems (including any auxiliary energy supplied to the ECSS).
* CSFR	SCS Solar Fraction	Portion of the SCS load which is supported by solar energy.
CSOPE	ECSS Operating Energy	Amount of energy used to support the ECSS operation (which is not intended to be supplied to the ECSS thermal state).
CSRJE	ECSS Rejected Energy	Amount of energy intentionally rejected or dumped from the ECSS subsystem.
* CSVE	SCS Electrical Energy Savings	Difference in the electrical energy required to support an assumed similar conventional SCS and the actual electrical energy required to support the demonstration SCS, for identical SCS loads.
* CSVF	SCS Fossil Energy Savings	Difference in the fossil energy required to support an assumed similar conventional SCS and the actual fossil energy required to support the demonstration SCS, for identical loads.
HAE	SHS Auxiliary Electrical Fuel Energy	Amount of electrical energy provided to the SHS to be converted and applied to the SHS load.
HAF	SHS Auxiliary Fossil Fuel Energy	Amount of fossil energy provided to the SHS to be converted and applied to the SHS load.
HAT	SHS Auxiliary Thermal Energy	Amount of energy provided to the SHS by a heat transfer fluid from an auxiliary source.
* HL	Space Heating Subsystem Load	Energy required to satisfy the temperature control demands of the space heating subsystem.

* Primary Performance Factors

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

* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
HWOPE	HWS Operating Energy	Amount of energy required to support the HWS operation which is not intended to be applied directly to the HWS load.
HWSE	Solar Energy to HWS	Amount of solar energy delivered to the HWS.
* HWSFR	HWS Solar Fraction	Portion of the HWS load which is supported by solar energy.
* HWSVE	HWS Electrical Energy Savings	Difference in the electrical energy required to support an assumed similar conventional HWS and the actual electrical energy required to support the demonstration HWS, for identical HWS loads.
* HWSVF	HWS Fossil Energy Savings	Difference in the fossil energy required to support an assumed similar conventional HWS and the actual fossil energy required to support the demonstration HWS, for identical loads.
RELH	Relative Humidity	Average outdoor relative humidity at the site.
* SE	Incident Solar Energy	Amount of solar energy incident upon one square foot of the collector plane.
SEA	Incident Solar Energy on Array	Amount of solar energy incident upon the collector array.
* SEC	Collector Solar Energy	Amount of thermal energy added to the heat transfer fluid for each square foot of the collector area.
SECA	Collected Solar Energy by Array	Amount of thermal energy added to the heat transfer fluid by the collector array.
SEDF	Diffuse Insolation	Amount of diffuse solar energy incident upon one square foot of a collector plane.
SEOP	Operational Incident Solar Energy	Amount of incident solar energy upon the collector array whenever the collector loop is active.

* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
* SEL	Solar Energy to Load Subsystems	Amount of solar energy supplied by the ECSS to all load subsystems.
* SFR	Solar Fraction of System Load	Portion of the system load which was supported by solar energy.
STECH	Change in ECSS Stored Energy	Change in ECSS stored energy during reference time period.
STEFF	ECSS Storage Efficiency	Ratio of the sum of energy supplied by ECSS storage and the change in ECSS stored energy to the energy delivered to the ECSS storage.
STEI	Energy Delivered to ECSS Storage	Amount of energy delivered to ECSS storage by the collector array and from auxiliary sources.
STEO	Energy Supplied by ECSS Storage	Amount of energy supplied by ECSS storage to the load subsystems.
* SYSL	System Load	Energy required to satisfy all desired temperature control demands at the output of all subsystems.
* SYSOPE	System Operating Energy	Amount of energy required to support the system operation, including all subsystems, which is not intended to be applied directly to the system load.
* SYSPF	System Performance Factor	Ratio of the system load to the total equivalent fossil energy expended or required to support the system load.
* TA	Ambient Temperature	Average temperature of the ambient air.
* TB	Building Temperature	Average temperature of the controlled space of the building.
TCECOP	TCE Coefficient of Performance	Coefficient of performance of the thermodynamic conversion equipment.
TCEI	TCE Thermal Input Energy	Equivalent thermal energy which is supplied as a fuel source to thermodynamic conversion equipment.

* Primary Performance Factors

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

* Primary Performance Factors

<u>ACRONYM</u>	<u>NAME</u>	<u>DEFINITION</u>
WDIR	Wind Direction	Average wind direction at the site.
WIND	Wind Velocity	Average wind velocity at the site.

* Primary Performance Factors

SECTION 2. SOLAR TERMINOLOGY

Absorptivity	The ratio of absorbed radiation by a surface to the total incident radiated energy on that surface.
Active Solar System	A system in which a transfer fluid (liquid or air) is circulated through a solar collector where the collected energy is converted, or transferred, to energy in the medium.
Air Conditioning	Popularly defined as space cooling, more precisely, the process of treating indoor air by controlling the temperature, humidity and distribution to maintain specified comfort conditions.
Ambient Temperature	The surrounding air temperature.
Auxiliary Energy	In solar energy technology, the energy supplied to the heat or cooling load from other than the solar source, usually from a conventional heating or cooling system. Excluded are operating energy, and energy which may be supplemented in nature but does not have the auxiliary system as an origin, i.e., energy supplied to the space heating load from the external ambient environment by a heat pump. The electric energy input to a heat pump is defined as operating energy.
Auxiliary Energy Subsystem	In solar energy technology the Auxiliary Energy System is the conventional heating and/or cooling equipment used as supplemental or backup to the solar system.
Array	An assembly of a number of collector elements, or panels, into the solar collector for a solar energy system.
Backflow	Reverse flow.
Backflow Preventer	A valve or damper installed to prevent reverse flow.
Beam Radiation	Radiated energy received directly, not from scattering or reflecting sources.
Collected Solar Energy	The thermal energy added to the heat transfer fluid by the solar collector.

Collector Array Efficiency	Same as Collector Conversion Efficiency. Ratio of the collected solar energy to the incident solar energy. (See also Operational Collector Efficiency.)
Collector Subsystem	The assembly of components that absorbs incident solar energy and transfers the absorbed thermal energy to a heat transfer fluid.
Concentrating Solar Collector	A solar collector that concentrates the energy from a larger area onto an absorbing element of smaller area.
Conversion Efficiency	Ratio of thermal energy output to solar energy incident on the collector array.
Conditioned Space	The space in a building in which the air is heated or cooled to maintain a desired temperature range.
Control System or Subsystem	The assembly of electric, pneumatic, or hydraulic, sensing, and actuating devices used to control the operating equipment in a system.
Cooling Degree Days	The sum over a specified period of time of the number of degrees the average daily temperature is <u>above</u> 65°F.
Cooling Tower	A heat exchanger that transfers waste heat to outside ambient air.
Diffuse Radiation	Solar Radiation which is scattered by air molecules, dust, or water droplets and incapable of being focused.
Drain Down	An arrangement of sensors, valves and actuators to automatically drain the solar collectors and collector piping to prevent freezing in the event of cold weather.
Duct Heating Coil	A liquid-to-air heat exchanger in the duct distribution system.
Effective Heat Transfer Coefficient	The heat transfer coefficient, per unit plate area of a collector, which is a measure of the total heat losses per unit area from all sides, top, back, and edges.
Energy Gain	The thermal energy gained by the collector transfer fluid. The thermal energy output of the collector.

Energy Savings

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

Expansion Tank

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

F-Curve

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

Fixed Collector

A solar collector that is fixed in position and cannot be rotated to follow the sun daily or seasonably.

Flat Plate Collector

A solar energy collecting device consisting of a relatively thin panel of absorbing material. A container with insulated bottom and sides and covered with one or more covers transparent to visible solar energy and relatively opaque to infrared energy. Visible energy from the sun enters through the transparent cover and raises the temperature of the absorbing panel. The infrared energy re-radiated from the panel is trapped within the collector because it cannot pass through the cover. Glass is an effective cover material (see Selective Surface).

Focusing Collector

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

Fossil Fuel

Petroleum, coal, and natural gas derived fuels.

Glazing

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

Heat Exchanger	A device used to transfer energy from one heat transfer fluid to another while maintaining physical segregation of the fluids. Normally used in systems to provide an interface between two different heat transfer fluids.
Heat Transfer Fluid	The fluid circulated through a heat source (solar collector) or heat exchanger that transports the thermal energy by virtue of its temperature.
Heating Degree Days	The sum over a specified period of time of the number of degrees the average daily temperature is <u>below</u> 65°F.
Instantaneous Efficiency	The efficiency of a solar collector at one operating point, $\frac{T_i - T_a}{I}$, under steady state conditions (see Operating Point).
Instantaneous Efficiency Curve	A plot of solar collector efficiency against operating point, $\frac{T_i - T_a}{I}$ (see Operating Point).
Incidence Angle	The angle between the line to a radiating source (the sun) and a line normal to the plane of the surface being irradiated.
Incident Solar Energy	The amount of solar energy irradiating a surface taking into account the angle of incidence. The effective area receiving energy is the product of the area of the surface times the cosine of the angle of incidence.
Insolation	Incoming solar radiation.
Load	That to which energy is supplied, such as space heating load or cooling load. The system load is the total solar and auxiliary energy required to satisfy the required heating or cooling.
Manifold	The piping that distributes the transport fluid to and from the individual panels of a collector array.
Microclimate	Highly localized weather features which may differ from long term regional values due to the interaction of the local surface with the atmosphere.

Nocturnal Radiation	The loss of thermal energy by the solar collector to the night sky.
Operating Energy	The amount of energy (usually electrical energy) required to operate the solar and auxiliary equipments and to transport the thermal energy to the point of use, and which is not intended to directly affect the thermal state of the system.
Operating Point	A solar energy system has a dynamic operating range due to changes in level of insolation (I), fluid input temperature (T), and outside ambient temperature (Ta). The operating point is defined as:
	$\frac{T_i - T_a}{I} \quad \frac{^{\circ}\text{F} \times \text{hr.} \times \text{sq. ft.}}{\text{BTU}}$
Operational Collector Efficiency	Ratio of collected solar energy to incident solar energy <u>only during the time the collector fluid is being circulated with the intention of delivering solar-source energy to the system.</u>
Outgassing	The emission of gas by materials and components, usually during exposure to elevated temperature, or reduced pressure.
Passive Solar System	A system which uses architectural components of the building to collect, distribute, and store solar energy.
Pebble Bed (Rock Bed)	A space filled with uniform-sized pebbles to store solar-source energy by raising the temperature of the pebbles.
Reflected Radiation	Insolation reflected from a surface, such as the ground or a reflecting element onto the solar collector.
Rejected Energy	Energy intentionally rejected, dissipated, or dumped from the solar system.
Retrofit	The addition of a solar energy system to an existing structure.
Selective Surface	A surface that has the ability to readily absorb solar radiation, but re-radiates little of it as thermal radiation.

Sensor	A device used to monitor a physical parameter in a system, such as temperature or flow rate, for the purpose of measurement or control.
Solar Conditioned Space	The area in a building that depends on solar energy to provide a fraction of the heating and cooling needs.
Solar Fraction	The fraction of the total load supplied by solar energy. The ratio of solar energy supplied to loads divided by total load. Often expressed as a percentage.
Solar Savings Ratio	The ratio of the solar energy supplied to the load minus the solar system operating energy, divided by the system load.
Storage Efficiency, N_s	Measure of effectiveness of transfer of energy through the storage subsystem taking into account system losses.
Storage Subsystem	The assembly of components used to store solar-source energy for use during periods of low insolation.
Stratification	A phenomenon that causes a distinct thermal gradient in a heat transfer fluid, in contrast to a thermally homogeneous fluid. Results in the layering of the heat transfer fluid, with each layer at a different temperature. In solar energy systems, stratification can occur in liquid storage tanks or rock beds, and may even occur in pipes and ducts. The temperature gradient or layering may occur in a horizontal, vertical or radial direction.
System Performance Factor	Ratio of system load to the total equivalent fossil energy expended or required to support the system load.
Ton of Refrigeration	The heat equivalent to the melting of one ton (2,000 pounds) of ice at 32°F in 24 hours. A ton of refrigeration will absorb 12,000 BTU/hr, or 288,000 DTU/day.
Tracking Collector	A solar collector that moves to point in the direction of the sun.
Zone	A portion of a conditioned space that is controlled to meet heating or cooling requirements separately from the other space or other zones.

SECTION 3. GENERAL ACRONYMS

ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineering.
BTU	British Thermal Unit, a measure of heat energy. The quantity of heat required to raise the temperature of one pound of pure water one Fahrenheit degree. One BTU is equivalent to 2.932×10^{-4} kwh of electrical energy.
COP	Coefficient of Performance. The ratio of total load to solar-source energy.
DHW	Domestic Hot Water.
ECSS	Energy Collection and Storage System.
HWS	Domestic or Service Hot Water Subsystem.
KWH	Kilowatt Hours, a measure of electrical energy. The product of kilowatts of electrical power applied to a load times the hours it is applied. One kwh is equivalent to 3,413 BTU of heat energy.
NSDN	National Solar Data Network.
SCS	Space Cooling Subsystem.
SHS	Space Heating Subsystem.
SOLMET	Solar Radiation/Meteorology Data.

APPENDIX D

PERFORMANCE EQUATIONS

SUMMERWOOD ASSOCIATES, HOUSE M

INTRODUCTION

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

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

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

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

where I001 is the solar radiation measurement provided by the pyranometer in BTU per square foot per hour, AREA is the area of the collector array in square feet, Δt 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

$$\text{COLLECTED SOLAR ENERGY} = \sum [M100 \times \Delta H] \times \Delta t$$

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

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

where $\bar{C}_p$ is the average specific heat, in $\text{BTU}/\text{lb}_m\text{-}^\circ\text{F}$, of the heat transfer fluid and ΔT , in $^\circ\text{F}$, is the temperature differential across the heat exchanging component.

* See Appendix B.

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

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

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.

Letter Designations

C or CP	=	Specific Heat
D	=	Direction or Position
EE	=	Electric Energy
EP	=	Electric Power
F	=	Fuel Flow Rate
HWD	=	Functional procedure to calculate the specific heat of water at the average of the inlet and outlet temperatures
H	=	Enthalpy
HR	=	Humidity Ratio
I	=	Incident Solar Flux (Insolation)
M	=	Mass Flow Rate
N	=	Performance Parameter
P	=	Pressure
PD	=	Differential Pressure
Q	=	Thermal Energy
RHO	=	Density
T	=	Temperature
TD	=	Differential Temperature
V	=	Velocity
W	=	Heat Transport Medium Volume Flow Rate
TI	=	Time
_P	=	Appended to a function designator to signify the value of the function during the previous iteration

Subsystem Designations
Number Sequence

Subsystem/Data Group

001 to 099	Climatological
100 to 199	Collector and Heat Transport
200 to 299	Thermal Storage
300 to 399	Hot Water
400 to 499	Space Heating
500 to 599	Space Cooling
600 to 699	Building/Load

EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

AVERAGE AMBIENT TEMPERATURE (°F)

$$TA = (1/60) \times \sum T001 \times \Delta t$$

AVERAGE BUILDING TEMPERATURE (°F)

$$TB = (1/60) \times \sum T600 \times \Delta t$$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

$$TDA = (1/360) \times \sum T001 \times \Delta t$$

for $\pm$ three hours from solar noon

INCIDENT SOLAR ENERGY PER SQUARE FOOT (BTU/FT²)

$$SE = (1/60) \times \sum I001 \times \Delta t$$

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

$$SEOP = (1/60) \times \sum [I001 \times CLAREA] \times \Delta t$$

when the collector loop is active

SPECIFIC HEAT FUNCTION FOR WATER

$$H (TH, TL) = 1.01146 \times (TH - TL) - 1.17403 \times 10^{-4} \times (TH^2 - TL^2) + 3.457 \times 10^{-7} \times (TH^3 - TL^3)$$

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \sum [M100 \times (H (T101, T100))] \times \Delta t$$

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \sum [M100 \times (H(T102, T103))] \times \Delta\tau$$

AVERAGE TEMPERATURE OF STORAGE (°F)

$$TST = (1/60) \times \sum [(T200 + T202)/2] \times \Delta\tau$$

SOLAR ENERGY FROM STORAGE (BTU)

$$STEO = \sum [M400 \times H(T403, T402) + M300 \times H(T303, T302)] \times \Delta\tau$$

ENERGY DELIVERED FROM ECSS TO LOAD SUBSYSTEMS (BTU)

$$CSEO = STEO$$

ECSS OPERATING ENERGY (BTU)

$$CSOPE = 56.8833 \times \sum EP100 \times \Delta\tau$$

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$$HOPE = 56.8833 \times \sum (EP400 + EP403 + FP1) \times \Delta\tau$$

when system is in the space heating mode

FP1 is the fan power drawn by the outside heat pump fan

(air-to-air mode)

SOLAR SPECIFIC SPACE HEATING OPERATING ENERGY

$$HOPE1 = 56.8833 \sum EP400 \times \Delta\tau$$

when system is in direct solar heating mode

OPERATING LOSSES TO HEATING LOAD

$$HLOPE = 0.2 \times 56.8833 \times \sum (EP400 + EP403) \times \Delta\tau$$

SOLAR ENERGY TO SPACE HEATING SYSTEM (BTU)

$$HSE = HSEM + HSEL$$

SPACE HEATING SUBSYSTEM AUXILIARY ELECTRIC FUEL ENERGY (BTU)

$$HAE + HAE1 + HAE2$$

$$HAE1 = 56.8833 \times \sum (EP402 - FP1) \times \Delta\tau$$

$$HAE2 = 56.8833 \times \sum EP401$$

SPACE HEATING SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$$HAT = HAE2 + 0.7 \times HAE1$$

ENERGY EXTRACTED FROM OUTSIDE AIR BY HEAT PUMP

$$EAIR2 \text{ HLHP} = 0.7 \times HAE1 \text{ in air-to-air mode}$$

HEAT PUMP LOAD (BTU)

$$HLHP = M401 \times HRF \times (T405 - T404)$$

when heat pump is supplying space heat

CONTROLLED DELIVERED ENERGY

$$CDE = HAT + HSEM + EAIR$$

SOLAR ENERGY TO CDE

$$HSEM = M400 \times H (T400, T401)$$

direct solar mode and SAHP mode

SOLAR ENERGY LOSSES TO SHS

$$THLOSS = STEO (\text{SPACE HEAT}) - HSEM + 0.2 (HOPE1 + TCEOPE)$$

$$HSEL = THLOSS \times STEO(\text{SPACE HEAT}) / (STEO(SHS) + .2(HOPE1 + TCEOPE) + STEO(DHW) - HWSE)$$

SPACE HEATING SUBSYSTEM AUXILIARY THERMAL LOSSES

$$HATL = 0.3 \times HAE1$$

EQUIPMENT HEATING LOAD

$$EHL = CDE + HI.OPE + HSEL + HATL$$

SPACE HEATING SUBSYSTEM SOLAR FRACTION (PERCENT)

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

SPACE HEATING SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

$$HSVE = HSE - HOPE1 - TCEOPE \text{ [if } HSE \leq EHL \times (1 - HPFRAC)]$$

HPFRAC is the calculated fraction of the load that would be carried by the air-to-air heat pump if there were no solar system

$$HSVE = EHL(1 - HPFRAC) + \frac{FSOL \times [HSE - EHL(1 - HPFRAC)]}{(HPCOPCTA)}$$

$$+ \text{FSAHP} \times \left(\frac{\text{HSE} - \text{EHL} (1 - \text{HPFRAC})}{\text{HPCOP(TA)}} - \frac{\text{HSE} - \text{EHL} (1 - \text{HPFRAC})}{\text{HPCOP(TWATER)}} \right)$$

$$+ .25 \times 56.8833 \times \text{THEAT} \times [\text{HSE} - \text{EHL} (1 - \text{HPFRAC})]$$

$$- \text{HOPE1} - \text{TCEOPE}$$

HOT WATER CONSUMED (GALLONS)

$$\text{HWCSM} = \sum \text{WD301} \times \Delta\tau$$

SOLAR ENERGY TO HOT WATER (BTU)

$$\text{HWSE} = \sum [\text{M300} \times \text{H} (\text{T300}, \text{T301})] \times \Delta\tau$$

HOT WATER SUBSYSTEM OPERATING ENERGY (BTU)

$$\text{HWOPE} = 56.8833 \times \sum \text{EP300} \times \Delta\tau$$

SOLAR SPECIFIC DHW OPERATING ENERGY

$$\text{HWOPE1} = \text{HWOPE}$$

HOT WATER AUXILIARY ELECTRIC ENERGY (BTU)

$$\text{HWAEE} = 56.8833 \times \sum \text{EP301} \times \Delta\tau$$

HOT WATER AUXILIARY THERMAL ENERGY (BTU)

$$\text{HWAT} = \text{HWAEE}$$

HOT WATER LOAD (BTU)

$$\text{HWL} = \text{HWAT} + \text{HWSE}$$

HOT WATER DEMAND

$$\text{HWDM} = \sum \text{M301} \times \text{H} (\text{T305}, \text{T304})$$

HOT WATER SOLAR FRACTION (PERCENT)

$$\text{HWDSFR} = \text{FRACTION OF DELIVERED HOT WATER LOAD DERIVED FROM SOLAR SOURCES AFTER PRORATING STORAGE LOSSES TO SOLAR AND AUXILIARY SOURCES}$$

HOT WATER ELECTRICAL ENERGY SAVINGS (BTU)

$$\text{HWSVE} = \text{HWSE} - \text{HWOPE}$$

HOT WATER SOLAR FRACTION

$$\text{HWSFR} = \text{HWSVE}/\text{HWL}$$

SERVICE SUPPLY WATER TEMPERATURE (°F)

$$TSW = (1/60) \times \sum T_{304} \times \Delta t$$

when water is being drawn

SERVICE HOT WATER TEMPERATURE (°F)

$$THW = (1/60) \times \sum T_{305} \times \Delta t$$

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$$SEA = CLAREA \times SE$$

COLLECTED SOLAR ENERGY (BTU)

$$SEC = SECA/CLAREA$$

COLLECTOR ARRAY EFFICIENCY

$$CLEF = SECA/SEA$$

OPERATIONAL COLLECTOR ARRAY EFFICIENCY

$$CLEFOP = SECA/SEOP$$

STORAGE PERFORMANCE

$$STPER = \text{STORAGE TANK SURFACE AREA} \times (T_{ST} - T_{203})$$

CHANGE IN STORED ENERGY (BTU)

$$STECH = STECH_1 - STECH_p$$

where the subscript _p refers to a prior reference value

STORAGE LOSS

$$STLOSS = STEI - STEO - STECH$$

STORAGE EFFICIENCY

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

SOLAR ENERGY TO LOAD SUBSYSTEM (BTU)

$$SEL = HSE + HWSE$$

ECSS SOLAR CONVERSION EFFICIENCY

$$CSCEF = SEL/SEA$$

THERMODYNAMIC CONVERSION EQUIPMENT LOAD

$$TCEL = HLHP$$

TCE INPUT

$$TCEC = HAEI$$

TCE COEFFICIENT OF PERFORMANCE

$$TCECOP = TCEL/TCEI$$

SYSTEM LOAD (BTU)

$$SYSL = HWL + HL$$

SOLAR FRACTION OF SYSTEM LOAD

$$SFR = (HWSFR \times HWL + HSFR \times HL)/SYSL$$

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

$$AXT = HAT + HWAT$$

AUXILIARY ELECTRICAL ENERGY TO LOADS (BTU)

$$AXE = HWAE$$

SYSTEM OPERATING ENERGY (BTU)

$$SYSOPE = CSOPE + HWUPE + HPOPE$$

TOTAL ENERGY CONSUMED (BTU)

$$TECSM = AXE + SYSOPE + SECA$$

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

$$TSVE = HWSVE + HSVE - SCOPE$$

SYSTEM PERFORMANCE FACTOR

$$SYSPF = SYSL/[(AXE + SYSOPE) \times 3.33]$$

APPENDIX E

CALCULATION OF PREDICTED VALUES

The f-Chart 4.0 program is used by the NSDN to estimate performance of the solar system. The f-Chart program was developed by the Solar Energy laboratory, University of Wisconsin-Madison, and was originally intended to be used as a design tool. This program has been modified to use measured weather data and measured subsystem loads and losses in place of average long-term weather data and ASHRAE building heat loss (UA) estimated loads. The results help to determine if the system is performing well.

Ref:

- (1) Solar Engineering of Thermal Processes, John A. Duffie and William A. Beckman, Wiley Interscience, NY (1980).
- (2) FCHART, A Design Program for Solar Heating Systems, Version 4.0, EES Report 50, J. C. Mitchell, J. E. Braun, W. E. Buckles, S. A. Klein, W. A. Beckman, D. M. Uteinger, J. Sheridan, Solar Energy Laboratory, University of Wisconsin-Madison, Madison, Wisconsin (1980).

SYSTEM PERFORMANCE SUMMARY (f-CHART, VERSION 4.0)* SUMMERWOOD ASSOCIATES, HOUSE M JUNE 1980 THROUGH MAY 1981

(All values in million BTU, unless otherwise indicated)

	HT	TA (°F)	SHLOAD	HWLOAD	QU	QLOSS	DELTE	FNP (%)	FDHW (%)	FW (%)
JUN	14.95	66	0.00	0.65	1.13	0.55	0.04	82	82	0
JUL	17.52	75	0.00	0.66	1.48	0.63	0.10	96	96	0
AUG	15.92	75	0.00	0.51	1.16	0.68	0.00	49	49	0
SEP	17.46	67	0.00	0.56	1.68	0.65	0.00	1.00	1.00	0
OCT	13.03	52	0.77	0.46	1.19	0.55	-0.33	79	44	0
NOV	11.85	42	6.14	0.64	3.69	0.17	-0.48	76	28	18
DEC	11.45	29	9.52	0.84	5.08	-0.03	0.00	53	0	38
JAN	12.22	22	11.46	0.61	5.23	-0.04	0.00	51	0	41
FEB	11.13	36	4.54	0.35	4.13	0.05	0.17	86	13	7
MAR	15.69	38	5.40	0.41	5.36	0.07	-0.17	94	16	0
APR	15.01	50	0.44	0.42	3.12	0.30	0.80	64	26	0
MAY	17.09	59	0.14	0.65	1.11	0.62	-0.14	80	76	0
TOTAL	173.32	-	38.41	6.76	34.37	4.20	0.00	-	-	-
AVERAGE	14.44	51	3.20	0.56	2.86	0.35	0.00	68	45	23

PURCHASED ENERGY SUMMARY

	GAS	ELECTRIC	OIL	TOTAL
USE (MMBTU)	0.0	14.53	0.0	14.53
COST (\$)	0.0	91.57	0.0	91.57

*See next page for glossary of f-Chart Version 4.0 terms.

*See next page for glossary of f-Chart Version 4.0 terms.

GLOSSARY OF f-CHART VERSION 4.0 TERMS

HT	-	Incident radiation on tilted surface
TA	-	Average ambient temperature
SHLOAD	-	Space heating load
HWLOAD	-	Hot water load
QU	-	Energy collected
QLOSS	-	Energy lost from storage
DELTE	-	Change in stored energy
FNP	-	Nonpurchased fraction
FDHW	-	Hot water solar fraction
FW	-	Fraction of total load which is work input to the heat pump

APPENDIX F
METEOROLOGICAL CONDITIONS

SUMMERWOOD ASSOCIATES, HOUSE M LONG-TERM WEATHER DATA

COLLECTOR TILT: 50 DEGREES
LATITUDE: 41 DEGREES

LOCATION: OLD SAYBROOK, CONNECTICUT
COLLECTOR AZIMUTH: -12 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JUN	3,643	1,792	0.49190	0.794	1,423	24	111	68
JUL	3,543	1,751	0.49431	0.817	1,431	0	273	74
AUG	3,165	1,552	0.49044	0.920	1,428	0	241	73
SEP	2,574	1,254	0.48704	1.112	1,394	42	87	67
OCT	1,907	936	0.49096	1.408	1,319	261	6	57
NOV	1,369	571	0.41732	1.675	957	570	0	46
DEC	1,134	442	0.39016	1.831	810	967	0	34
JAN	1,261	535	0.42397	1.781	952	1,079	0	30
FEB	1,730	774	0.44756	1.481	1,146	955	0	31
MAR	2,343	1,084	0.46255	1.199	1,300	840	0	38
APR	2,990	1,427	0.47717	0.981	1,399	498	0	48
MAY	3,452	1,678	0.48591	0.847	1,421	225	17	58

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 x HBAR) in BTU/day-ft².

HDD - Number of heating degrees-days per month.

CDD - Number of cooling degrees-days per month.

TBAR - Average ambient temperature in degrees Fahrenheit.

MONTHLY REPORT: SUMMERWOOD ASSOCIATES, HOUSE M
JUNE 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (QC01)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1663	72	*
2	662	69	75
3	811	68	74
4	1585	69	79
5	1441	63	72
6	1791	64	*
7	166	63	65
8	398	61	63
9	1022	56	64
10	746	56	61
11	1870	59	72
12	1967	60	74
13	1877	61	72
14	1240	61	68
15	1009	66	*
16	1781	67	73
17	2024	65	75
18	1211	66	*
19	1851	62	71
20	511	63	66
21	1536	68	78
22	1848	71	86
23	1807	73	88
24	1732	76	91
25	1706	79	93
26	1858	74	82
27	1464	78	89
28	1257	68	78
29	405	64	68
30	837	66	72
SUM	40079	-	-
AVG	1336	66	75

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SUMMERWOOD ASSOCIATES, HOUSE M
JULY 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (QC01)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1606	71	83
2	806	71	80
3	491	69	71
4	1913	76	87
5	1631	72	83
6	1939	70	77
7	1847	71	85
8	901	69	76
9	1744	74	88
10	1500	71	77
11	1461	74	85
12	1941	74	82
13	1597	72	82
14	1871	76	91
15	1720	78	88
16	1628	80	91
17	1155	79	87
18	1798	79	90
19	1141	74	79
20	1458	83	95
21	1767	87	99
22	1714	81	94
23	500	76	83
24	1820	74	81
25	1900	78	92
26	1782	78	93
27	1190	77	*
28	1855	73	80
29	160	71	71
30	1879	78	90
31	1856	77	91
SUM	46975	-	-
AVG	1515	75	85

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: SUMMERWOOD ASSOCIATES, HOUSE M
AUGUST 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1291	76	85
2	1611	79	93
3	1582	79	89
4	1441	82	94
5	1665	78	86
6	1282	82	94
7	1843	81	94
8	1536	82	96
9	1725	83	92
10	1839	75	85
11	759	73	74
12	1304	77	87
13	1707	77	89
14	716	71	79
15	874	76	81
16	1534	68	76
17	1961	69	81
18	1791	71	88
19	588	71	75
20	752	67	71
21	658	65	69
22	1470	68	74
23	2009	71	81
24	1936	75	90
25	1555	76	89
26	1993	74	79
27	1712	80	95
28	1029	74	87
29	512	68	71
30	643	72	76
31	1370	78	89
SUM	42686	-	-
AVG	1377	75	84

MONTHLY REPORT: SUMMERWOOD ASSOCIATES, HOUSE M
SEPTEMBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1478	78	89
2	1928	80	92
3	2092	73	83
4	2136	69	80
5	808	73	81
6	1969	75	87
7	1972	69	81
8	2145	65	80
9	2075	66	76
10	1914	66	74
11	2139	67	83
12	1061	66	75
13	995	67	71
14	1138	75	86
15	959	64	66
16	2079	60	69
17	923	66	77
18	1179	67	72
19	1956	60	75
20	1848	67	79
21	1502	75	86
22	1451	78	90
23	1357	74	86
24	1642	57	64
25	382	57	60
26	1545	62	75
27	1954	51	61
28	1812	58	75
29	1377	55	59
30	1407	58	65
SUM	47235	-	-
AVG	1574	67	77

MONTHLY REPORT: SUMMERWOOD ASSOCIATES, HOUSE M
OCTOBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1076	62	70
2	580	64	66
3	167	59	61
4	1822	61	72
5	815	54	64
6	790	52	60
7	1039	50	60
8	1369	58	66
9	1941	58	66
10	2053	48	56
11	113	62	66
12	1446	54	65
13	585	44	52
14	2031	45	56
15	679	49	58
16	1140	59	67
17	1543	65	77
18	84	65	67
19	1122	59	64
20	1740	53	64
21	338	49	58
22	1394	47	56
23	1984	39	49
24	1773	44	52
25	16	52	52
26	866	49	52
27	1979	48	56
28	40	48	51
29	1781	42	53
30	836	39	50
31	1794	47	57
SUM	34932	-	-
AVG	1127	52	60

MONTHLY REPORT: SUMMERWOOD ASSOCIATES, HOUSE M
NOVEMBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	747	47	53
2	1898	38	48
3	1692	40	49
4	426	54	60
5	1306	48	55
6	1727	43	51
7	1587	54	63
8	1254	51	62
9	344	42	49
10	763	42	51
11	1399	36	39
12	1476	38	44
13	1050	44	50
14	994	54	63
15	333	41	44
16	1801	36	42
17	1222	34	41
18	106	34	35
19	1826	32	38
20	1245	35	47
21	1300	42	55
22	1591	41	48
23	717	41	49
24	58	49	50
25	959	47	51
26	1732	37	44
27	393	35	39
28	0	45	45
29	417	40	44
30	1407	40	47
SUM	31770	-	-
AVG	1059	42	48

MONTHLY REPORT: SUMMERWOOD ASSOCIATES, HOUSE M
DECEMBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1070	46	53
2	590	48	53
3	1168	32	33
4	1789	25	31
5	1769	27	34
6	1663	30	37
7	1220	36	48
8	655	46	53
9	591	45	46
10	631	37	41
11	1708	25	26
12	1286	32	38
13	874	42	49
14	715	26	34
15	821	24	30
16	108	33	36
17	1593	23	26
18	355	28	36
19	244	30	36
20	1532	14	24
21	1648	18	31
22	1346	23	30
23	1	31	31
24	426	29	37
25	1786	0	-1
26	1129	12	25
27	990	23	27
28	118	34	37
29	448	40	44
30	1286	34	40
31	1129	17	23
SUM	30691	-	-
AVG	990	29	35

MONTHLY REPORT: SUMMERWOOD ASSOCIATES, HOUSE M
JANUARY 1981
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	219	23	26
2	506	25	32
3	149	11	13
4	1237	4	9
5	1506	14	24
6	854	26	34
7	241	30	34
8	1739	13	21
9	992	14	27
10	1084	17	22
11	1767	8	16
12	1776	3	11
13	1781	10	18
14	313	17	24
15	134	22	27
16	171	24	27
17	495	19	22
18	1367	19	27
19	1456	34	42
20	1217	30	39
21	1675	22	32
22	285	24	33
23	881	33	43
24	1382	30	37
25	1856	27	37
26	357	36	43
27	1510	38	49
28	710	30	39
29	1227	28	36
30	1923	20	29
31	1970	21	30
SUM	32780	-	-
AVG	1057	22	29

MONTHLY REPORT: SUMMERWOOD ASSOCIATES, HOUSE M
FEBRUARY 1981
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	920	29	39
2	20	42	46
3	1020#	29#	43#
4	1183	15	22
5	1421	25	29
6	531	31	37
7	1633	30	39
8	382	37	40
9	1971	28	36
10	1275	31	39
11	95	47	52
12	2130	25	28
13	2032	21	29
14	1991	28	42
15	1796	31	38
16	1830	35	51
17	1700	44	56
18	1426	46	51
19	287	44	49
20	21	45	44
21	365	53	56
22	1745	50	57
23	588	42	45
24	148	45	46
25	523	40	44
26	339	41	45
27	1926	42	47
28	542	36	40
SUM	29841	-	-
AVG	1065	36	43

- <40% VALID DATA.

MONTHLY REPORT: SUMMERWOOD ASSOCIATES, HOUSE M
MARCH 1981
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1486	40	47
2	343	36	43
3	2143	30	35
4	1758	31	39
5	30	32	31
6	872	36	43
7	327	35	38
8	194	37	40
9	437	39	45
10	937	38	46
11	1704	38	51
12	2001	37	48
13	2032	46	55
14	2118	31	33
15	1723	38	48
16	260	37	46
17	1668	30	38
18	2123	27	36
19	1986	30	39
20	2232	31	43
21	835	34	40
22	1569	38	50
23	1085	33	43
24	1347	39	53
25	922	36	43
26	1795	40	50
27	1063	44	52
28	2111	44	56
29	1906	51	63
30	653	50	58
31	2058	59	70
SUM	42077	-	-
AVG	1357	38	46

MONTHLY REPORT: SUMMERWOOD ASSOCIATES, HOUSE M
APRIL 1981
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1040	46	47
2	1595	51	55
3	2022	51	67
4	567	52	56
5	485	52	57
6	788	43	51
7	2299	45	57
8	2162	49	64
9	1363	53	65
10	2271	53	63
11	659	52	56
12	1420	51	55
13	2248	45	49
14	54	45	46
15	2316	43	48
16	2168	44	57
17	468	50	56
18	1782	61	72
19	1899	51	59
20	1248	47	55
21	2259	40	45
22	2211	45	56
23	210	44	47
24	760	49	53
25	608	49	53
26	1740	52	62
27	1312	55	65
28	946	56	68
29	440	56	60
30	898	57	65
SUM	40239	-	-
AVG	1341	50	57

MONTHLY REPORT: SUMMERWOOD ASSOCIATES, HOUSE M
MAY 1981
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1668	52	58
2	640	52	55
3	2039	59	67
4	1210	58	66
5	1957	56	64
6	1737	61	69
7	2136	52	59
8	2077	51	59
9	2013	50	60
10	305	53	55
11	811	57	62
12	381	57	60
13	1939	59	67
14	1522	58	64
15	424	57	60
16	1092	60	70
17	2073	58	67
18	2020	58	69
19	1563	54	66
20	2009	58	75
21	1613	55	66
22	1942	57	68
23	1828	62	72
24	1967	68	81
25	1732	70	87
26	1278	71	88
27	1481#	61#	68#
28	1039	66	74
29	642	63	69
30	1533	68	77
31	1152	69	81
SUM	45822	-	-
AVG	1478	59	68

- <40% VALID DATA.

APPENDIX G

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

There were no problems with or changes to the solar system during the reporting period.

APPENDIX H
CONVERSION FACTORS

Energy Conversion Factors

<u>Fuel Type</u>	<u>Energy Content</u>	<u>Fuel Source Conversion Factor</u>
Distillate fuel oil ¹	138,690 BTU/gallon	7.21×10^{-6} gallon/BTU
Residual fuel oil ²	149,690 BTU/gallon	6.68×10^{-6} gallon/BTU
Kerosene	135,000 BTU/gallon	7.41×10^{-6} gallon/BTU
Propane	91,500 BTU/gallon	10.93×10^{-6} gallon/BTU
Natural gas	1,021 BTU/cubic feet	979.4×10^{-6} cubic feet/ BTU
Electricity	3,413 BTU/kilowatt-hour	292.3×10^{-6} kwh/BTU

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

²No. 5 and No. 6 fuel oils

APPENDIX I

SENSOR TECHNOLOGY

Temperature Sensors

Temperatures are measured by a Minco Products S53P platinum Resistance Temperature Detector (RTD). Because the resistance of platinum wire varies as a function of temperature, measurement of the resistance of a calibrated length of platinum wire can be used to accurately determine the temperature of the wire. This is the principle of the platinum RTD which utilizes a tiny coil of platinum wire encased in a copper-tipped probe to measure temperature.

Ambient temperature sensors are housed in a WeatherMeasure Radiation Shield in order to protect the probe from solar radiation. Care is taken to locate the sensor away from extraneous heat sources which could produce erroneous temperature readings. Temperature probes mounted in pipes are installed in stainless steel thermowells for physical protection of the sensor and to allow easy removal and replacement of the sensors. A thermally-conductive grease is used between the probe and the thermowell to assure faster temperature response.

All temperature sensors are individually calibrated at the factory. In addition, the bridge circuit is calibrated in the field using a five-point check.

Nominal Resistance @ 25°C:	100 ohms
No. of Leads:	3
Electrical Connection:	Wheatstone Bridge
Time Constant	1.5 seconds max. in water at 3 fps
Self Heating:	27 mw/°F

WIND SENSOR

Wind speed and direction are measured by a WeatherMeasure W102-P-DC/540 or W101-P-DC/540 wind sensor. Wind speed is measured by means of a four-bladed propeller coupled to a DC generator.

Wind direction is sensed by means of a dual-wiper 1,000-ohm long-life conductive plastic potentiometer. It is attached to the stainless steel shaft which supports and rotates with the upper body assembly.

Size:	29-3/4"L X 30"H
Starting Speed:	1 mph
Complete Tracking:	3 mph
Maximum Speed:	200 mph
Distance Constant (30 mph):	6.2'
Accuracy:	± 1% below 25 mph ± 3% above 25 mph
Time Constant:	0.145 second

HUMIDITY SENSORS

The WeatherMeasure HMP-14U Solid State Relative Humidity Probe is used for the measurement of relative humidity. The operation of the sensor is based upon the capacitance of the polymer thin film capacitor. A one-micron-thick dielectric polymer layer absorbs water molecules through a thin metal electrode and causes capacitance change proportional to relative humidity.

Range:	0-100% R.H.
Response Time:	1 second to 90% humidity change at 20°C
Temperature Coefficient:	0.05% R.H./°C
Accuracy:	± 3% from 0-80% R.H. ± 5-6% 80-100% R.H.
Sensitivity:	0.2% R.H.

INSOLATION SENSORS

The Eppley Model PSP pyranometer is used for the measurement of insolation. The pyranometer consists of a circular multijunction thermopile of the plated, (copper-constantan) wirewound type which is temperature compensated to render the response essentially independent of ambient temperature. The receiver is coated with Parsons' black lacquer (non-wavelength-selective absorption). The instrument is supplied with a pair of precision-ground polished concentric hemispheres of Schott optical glass transparent to light between 285 and 2800 nm of wavelength. The instrument is provided with a dessicator which may be readily inspected. Pyranometers designated as shadowband pyranometers are equipped with a shadowband which may be adjusted to block out any direct solar radiation. These instruments are used for the measurement of diffuse insolation.

Sensitivity:	9 μ V/W/m ²
Temperature Dependence:	± 1% over ambient temperature range -20°C to 40°C
Linearity:	0.5% from 0 to 2,800 W/M ²
Response Time:	1 second
Cosine Error:	± 1% 0-70° zenith angle ± 3% 70-80° zenith angle

LIQUID FLOW SENSORS (NON-TOTALIZING)

The Ramapo Mark V strain gauge flow meters are used for the measurement of liquid flow. The flow meters sense the flow of the liquids by measuring the force exerted by the flow on a target suspended in the flow stream. This force is transmitted to a four active arm strain gauge bridge to provide a signal proportional to flow rate squared. The flow meters are available in a screwed end configuration, a flanged configuration, and a wafer configuration. Each flow meter is calibrated for the particular fluid being used in the application.

Materials:	Target - 17-PH stainless steel
	Body - Brass or stainless steel
	Seals - Buna-N
Fluid Temperature:	-40°F to 250°F
Calibration Accuracy:	± 1% ($\frac{1}{2}$ " to $3\frac{1}{2}$ " line size)
	± 2% (4" and greater line size)
Repeatability and Hysteresis:	0.25% of reading

LIQUID FLOW SENSORS (TOTALIZING)

Hersey Series 400 flow meters are used to measure totalized liquid flow. The meter is a nutating disk, positive displacement type meter. An R-15 register with an SPDT reed switch is used to provide an output to the data acquisition subsystem.

The output of the reed switch is input to a Martin DR-1 Digital Ramp which counts the number of pulses and produces a zero to five volt analog signal corresponding to the pulse count.

Materials:	Meter body	- bronze
	Measuring chamber	- plastic
Accuracy:	± 1.5%	

AIR FLOW SENSORS

The Kurz 430 Series of thermal anemometers is used for the measurement of air flow. The basic sensing element is a probe which consists of a velocity sensor and a temperature sensor. The velocity sensor is heated and operated as a constant temperature thermal anemometer which responds to a "standard" velocity (referenced to 25°C and 760 mm Hg) or mass flow by sensing the cooling effect of the air as it passes over the heated sensor. The temperature sensor compensates for variations in ambient temperature.

Since the probe measures air velocity at only one point in the cross section of the duct, it is necessary to perform a careful duct mapping to relate the probe reading to the amount of air flowing through the entire duct. This is done by dividing the duct into small areas and taking a reading at the center of each area using a portable probe. The readings are then averaged to determine the overall duct velocity. The reading at the permanently installed probe is then ratioed to this reading. This duct mapping is done for each mode.

Accuracy:	± 2% of full scale over temperature range -20°C to 60°C
	± 5% of full scale over temperature range -60°C to 250°C
Response Time:	0.025 second
Repeatability:	0.25% full scale

FUEL OIL FLOW SENSOR

The Kent Mini-Major is used as a flow oil flow meter. The meter utilizes an oscillating piston as a positive displacement element. The oscillating piston is connected to a pulser which sends pulses to the Site Data Acquisition Subsystem for totalization.

Operating Temperature:	100°C (max)
Flow Range:	0.6 to 48 gph
Accuracy:	± 1% of full scale

FUEL GAS FLOW SENSOR

The American AC-175 gas meter is used for the measurement of totalized fuel gas flow. The drop in pressure between the inlet and outlet of the meter is responsible for the action of the meter. The principle of measurement is positive displacement. Four chambers in the meter fill and empty in sequence. The exact volume of compartments is known, so by counting the number of displacements the volume is measured. Sliding control valves control the entrance and exit of the gas to the compartments. The meter is temperature compensated to reference all volumetric readings to 60°F.

Rated Capacity:	175 cubic ft/hr
Max Working Pressure:	5 psi

ELECTRIC POWER SENSORS

Ohio Semitronics Series PC5 wattmeters are used as electric power sensors. They utilize Hall effect devices as multipliers taking the product of the instantaneous voltage and current readings to determine the electrical power. This technique automatically takes power factor into consideration and produces a true power reading.

Power Factor Range:	1 to 0 (lead or lag)
Response Time:	250 ms
Temperature Effect:	1% of reading
Accuracy:	0.5% of full scale

HEAT FLUX SENSORS

The Hy-Cal Engineering Model BI-7X heat flow sensor is used for the measurement of heat flux. The sensor consists basically of an insulating wafer, with a series of thermocouples arranged such that consecutive thermoelectric junctions fall on opposite sides of the wafer. This assembly is bonded to a heat sink to assure heat flow through the sensor. Heat is received on the exposed surface of the wafer and conducted through the heat sink. A temperature drop across the wafer is thus developed and is measured directly by each junction combination embodied along the wafer. Since the differential thermocouples are connected electrically in series, the voltages produced by each set of junctions is additive, thereby amplifying the signal directly proportional to

the number of junctions. The temperature drop across the wafer, and thus the output signal, is directly proportional to the heating rate.

Operation Temperature:	-50° to 200°F
Response Time:	6 seconds
Linearity:	2%
Repeatability:	0.5%
Sensitivity:	2 mv/BTU/ft ² -hr
Size:	2" X 2"

APPENDIX J
TYPICAL MONTHLY DATA

MONTHLY REPORT: FEBRUARY 1981
SITE SUMMARY: SUMMERWOOD ASSOCIATES M

CONVENTIONAL UNITS

GENERAL SITE DATA:

INCIDENT SOLAR ENERGY	11.131 MILLION BTU
	29841 BTU/SQ.FT.
COLLECTED SOLAR ENERGY	5.023 MILLION BTU
	13468 BTU/SQ.FT.
PERCENT OF COLLECTED TO LOADS	66 PERCENT
COLLECTOR ARRAY EFFICIENCY	0.451
COLLECTOR ARRAY OPERATIONAL EFFICIENCY	0.585
AVERAGE AMBIENT TEMPERATURE	36 DEGREES F
AVERAGE BUILDING TEMPERATURE	61 DEGREES F
ECSS SOLAR CONVERSION EFFICIENCY	0.30
ECSS OPERATING ENERGY	0.228 MILLION BTU
ECSS PERFORMANCE FACTOR	8890 BTU/SQ.FT.
TOTAL SYSTEM OPERATING ENERGY	0.745 MILLION BTU
TOTAL ENERGY CONSUMED	6.961 MILLION BTU
SOLAR DELIVERED/BUILDING AREA	N.A. BTU/SQ.FT.
AUXILIARY USED/BUILDING AREA	N.A. BTU/SQ.FT.

SUBSYSTEM SUMMARY:

	HOT WATER	HEATING	COOLING	SYSTEM TOTAL
LOAD	0.200	4.538	N.A.	4.738 MILLION BTU
SOLAR FRACTION	0	72	N.A.	69 PERCENT
SOLAR SAVINGS RATIO	0.000	0.000	N.A.	0.000
SOLAR ENERGY USED	0.000	3.316	N.A.	3.316 MILLION BTU
OPERATING ENERGY	0.042	0.476	N.A.	0.745 MILLION BTU
AUX. THERMAL ENERGY	0.200	0.790	N.A.	0.990 MILLION BTU
AUX. ELECTRIC FUEL	0.200	0.992	N.A.	1.192 MILLION BTU
AUX. FOSSIL FUEL	N.A.	N.A.	N.A.	N.A. MILLION BTU
ELECTRICAL SAVINGS	-0.042	0.858	N.A.	0.588 MILLION BTU
FOSSIL SAVINGS	N.A.	N.A.	N.A.	N.A. MILLION BTU

INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS: 8.86

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

REFERENCE: USER'S GUIDE TO MONTHLY PERFORMANCE REPORTS, JUNE 1980.

SOLAR/0004-80/18

READ THIS BEFORE TURNING PAGE.

MONTHLY REPORT: FEBRUARY 1981
SITE SUMMARY: SUMMERWOOD ASSOCIATES M

	CONVENTIONAL UNITS
GENERAL SITE DATA:	
INCIDENT SOLAR ENERGY	11.131 MILLION BTU 29841 BTU/SQ.FT.
COLLECTED SOLAR ENERGY	5.023 MILLION BTU 13468 BTU/SQ.FT.
AVERAGE AMBIENT TEMPERATURE	36 DEGREES F
AVERAGE BUILDING TEMPERATURE	61 DEGREES F
ECSS SOLAR CONVERSION EFFICIENCY	0.30
ECSS OPERATING ENERGY	0.228 MILLION BTU
STORAGE EFFICIENCY	62.11 PERCENT
EFFECTIVE HEAT TRANSFER COEFFICIENT	0.667 BTU/DEG F- SQ FT-HR
TOTAL SYSTEM OPERATING ENERGY	0.745 MILLION BTU
TOTAL ENERGY CONSUMED	6.961 MILLION BTU

SUBSYSTEM SUMMARY:

	HOT WATER	HEATING	COOLING	SYSTEM TOTAL
LOAD	0.200	4.538	N.A.	4.738 MILLION BTU
SOLAR FRACTION	0	72	N.A.	69 PERCENT
SOLAR ENERGY USED	0.000	3.316	N.A.	3.316 MILLION BTU
OPERATING ENERGY	0.042	0.476	N.A.	0.745 MILLION BTU
AUX. THERMAL ENERGY	0.200	0.790	N.A.	0.990 MILLION BTU
AUX. ELECTRIC FUEL	0.200	0.992	N.A.	1.192 MILLION BTU
AUX. FOSSIL FUEL	N.A.	N.A.	N.A.	N.A. MILLION BTU
ELECTRICAL SAVINGS	-0.042	0.858	N.A.	0.588 MILLION BTU
FOSSIL SAVINGS	N.A.	N.A.	N.A.	N.A. MILLION BTU

SYSTEM PERFORMANCE FACTOR: 0.73

INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS: 8.86

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

REFERENCE: USER'S GUIDE TO MONTHLY PERFORMANCE REPORTS, JUNE 1980.

SOLAR/0004-80/18

READ THIS BEFORE TURNING PAGE.

MONTHLY REPORT: FEBRUARY 1981
SITE SUMMARY: SUMMERWOOD ASSOCIATES M

SI UNITS

GENERAL SITE DATA:

INCIDENT SOLAR ENERGY

11.743 GIGA JOULES
338879 KJ/SQ.M.

COLLECTED SOLAR ENERGY

5.300 GIGA JOULES
152939 KJ/SQ.M.

AVERAGE AMBIENT TEMPERATURE

2 DEGREES C

AVERAGE BUILDING TEMPERATURE

16 DEGREES C

ECSS SOLAR CONVERSION EFFICIENCY

0.30

ECSS OPERATING ENERGY

0.240 GIGA JOULES

STORAGE EFFICIENCY

62.11 PERCENT

EFFECTIVE HEAT TRANSFER COEFFICIENT

3.790 W/SQ M-DEG K

TOTAL SYSTEM OPERATING ENERGY

0.786 GIGA JOULES

TOTAL ENERGY CONSUMED

7.344 GIGA JOULES

SUBSYSTEM SUMMARY:

	HOT WATER	HEATING	COOLING	SYSTEM TOTAL
LOAD	0.211	4.788	N.A.	4.999 GIGA JOULES
SOLAR FRACTION	0	72	N.A.	69 PERCENT
SOLAR ENERGY USED	0.000	3.498	N.A.	3.498 GIGA JOULES
OPERATING ENERGY	0.044	0.502	N.A.	0.786 GIGA JOULES
AUX. THERMAL ENG	0.211	0.833	N.A.	1.044 GIGA JOULES
AUX. ELECTRIC FUEL	0.211	1.046	N.A.	1.258 GIGA JOULES
AUX. FOSSIL FUEL	N.A.	N.A.	N.A.	N.A. GIGA JOULES
ELECTRICAL SAVINGS	-0.044	0.905	N.A.	0.621 GIGA JOULES
FOSSIL SAVINGS	N.A.	N.A.	N.A.	N.A. GIGA JOULES

SYSTEM PERFORMANCE FACTOR: 0.73

INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS: 8.86

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

REFERENCE: USER'S GUIDE TO MONTHLY PERFORMANCE REPORTS, JUNE 1980.

SOLAR/0004-80/18

MONTHLY REPORT: SUMMERWOOD ASSOCIATES M
ENERGY COLLECTION AND STORAGE SUBSYSTEM (ECSS)

FEBRUARY 1981

DAY OF MONTH	INCIDENT SOLAR ENERGY MILLION BTU	AMBIENT TEMP DEG-F	ENERGY TO LOADS MILLION BTU	AUX THERMAL TO ECSS MILLION BTU	ECSS OPERATING ENERGY MILLION BTU	ECSS ENERGY REJECTED MILLION BTU	ECSS SOLAR CONVERSION EFFICIENCY
(NBS ID)	(Q001)	(N113)			(Q102)		(N111)
1	0.343	29	0.175	N	0.009	N	0.513
2	0.008	42	0.050	O	0.000	O	6.639
3	0.380*	29*	0.179*	T	0.008*	T	0.475*
4	0.441	15	0.203		0.009		0.469
5	0.530	25	0.093	A	0.012	A	0.182
6	0.198	31	0.070	P	0.002	P	0.361
7	0.609	30	0.052	P	0.014	P	0.086
8	0.142	37	0.000	L	0.001	L	0.000
9	0.735	28	0.196	I	0.014	I	0.268
10	0.476	31	0.225	C	0.010	C	0.478
11	0.036	47	0.084	A	0.000	A	2.371
12	0.795	25	0.149	B	0.017	B	0.189
13	0.758	21	0.294	L	0.016	L	0.391
14	0.743	28	0.223	E	0.016	E	0.303
15	0.670	31	0.190		0.015		0.287
16	0.683	35	0.151		0.016		0.224
17	0.634	44	0.086		0.014		0.136
18	0.532	46	0.065		0.011		0.123
19	0.107	44	0.041		0.000		0.383
20	0.008	45	0.068		0.000		8.766
21	0.136	53	0.037		0.003		0.270
22	0.651	50	0.000		0.014		0.000
23	0.219	42	0.087		0.001		0.396
24	0.055	45	0.094		0.000		1.715
25	0.195	40	0.117		0.003		0.606
26	0.127	41	0.125		0.002		1.003
27	0.718	42	0.059		0.016		0.083
28	0.202	36	0.170		0.004		0.851
SUM	11.131	-	3.284	N.A.	0.228	N.A.	-
AVG	0.398	36	0.117	N.A.	0.008	N.A.	0.298
PFRV	0.9345	0.9345	0.9345	N.A.	0.9345	N.A.	0.9345

* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; # <40% VALID DATA; PFRV RELIABILITY VALUE.

MONTHLY REPORT: SUMMERWOOD ASSOCIATES M
COLLECTOR SUBSYSTEM PERFORMANCE

FEBRUARY 1981

DAY OF MONTH (NBSID)	INCIDENT SOLAR ENERGY MILLION BTU (Q001)	OPERATIONAL INCIDENT ENERGY MILLION BTU	COLLECTED SOLAR ENERGY MILLION BTU (Q100)	DAYTIME AMBIENT TEMP DEG F	COLLECTOR SUBSYSTEM EFFICIENCY (N100)	OPERATIONAL COLLECTOR SUBSYSTEM EFFICIENCY
1	0.343	0.235	0.137	39	0.399	0.583
2	0.008	0.000	0.000	46	0.000	0.000
3	0.380#	0.288#	0.172#	43#	0.453#	0.598#
4	0.441	0.350	0.219	22	0.497	0.627
5	0.530	0.444	0.246	29	0.464	0.554
6	0.198	0.042	0.032	37	0.164	0.768
7	0.609	0.557	0.333	39	0.547	0.599
8	0.142	0.040	0.007	40	0.049	0.172
9	0.735	0.621	0.307	36	0.418	0.495
10	0.476	0.341	0.213	39	0.448	0.624
11	0.036	0.000	0.000	52	0.000	0.000
12	0.795	0.725	0.410	28	0.516	0.566
13	0.758	0.673	0.394	29	0.520	0.586
14	0.743	0.652	0.388	42	0.522	0.594
15	0.670	0.565	0.325	38	0.486	0.576
16	0.683	0.607	0.364	51	0.533	0.599
17	0.634	0.555	0.315	56	0.496	0.567
18	0.532	0.388	0.208	61	0.391	0.537
19	0.107	0.000	0.000	49	0.000	0.000
20	0.008	0.000	0.000	44	0.000	0.000
21	0.136	0.054	0.035	56	0.257	0.653
22	0.651	0.576	0.342	57	0.526	0.594
23	0.219	0.023	0.001	45	0.003	0.033
24	0.055	0.000	0.000	46	0.000	0.000
25	0.195	0.054	0.032	44	0.166	0.593
26	0.127	0.027	0.036	45	0.282	1.319
27	0.718	0.678	0.438	47	0.610	0.647
28	0.202	0.087	0.067	40	0.333	0.773
SUM	11.131	8.582	5.023	-	-	-
AVG	0.398	0.307	0.179	43	0.451	0.585
PFRV	0.9345	0.9345	0.9345	0.9345	0.9345	0.9345

* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; # <40% VALID DATA; PFRV RELIABILITY VALUE.

MONTHLY REPORT: SUMMERWOOD ASSOCIATES M
STORAGE PERFORMANCE

FEBRUARY 1981

DAY OF MONTH (NBS ID)	ENERGY TO STORAGE MILLION BTU (Q200)	ENERGY FROM STORAGE MILLION BTU (Q201)	CHANGE IN STORED ENERGY MILLION BTU (Q202)	STORAGE AVERAGE TEMP DEG F	EFFECTIVE HEAT TRANSFER COEFFICIENT BTU/DEG F/ SQ FT/HR
1	0.120	0.175	-0.046	82	0.09
2	0.000	0.050	-0.027	81	0.25
3	0.183#	0.179#	-0.092	84#	1.02#
4	0.210	0.203	-0.007	63	0.31
5	0.251	0.093	0.051	80	1.26
6	0.033	0.070	0.042	72	1.29
7	0.359	0.052	0.191	86	0.87
8	0.000	0.000	-0.026	101	0.14
9	0.307	0.196	-0.056	104	0.87
10	0.237	0.225	-0.016	85	0.30
11	0.000	0.084	-0.068	68	0.73
12	0.458	0.149	0.130	85	1.85
13	0.424	0.294	0.002	91	1.15
14	0.421	0.223	0.070	93	1.12
15	0.341	0.190	0.046	99	0.77
16	0.387	0.151	0.081	104	0.99
17	0.321	0.086	0.080	119	0.74
18	0.218	0.065	0.009	126	0.62
19	0.000	0.041	-0.101	116	0.29
20	0.000	0.068	-0.082	97	0.10
21	0.047	0.037	-0.016	86	0.34
22	0.353	0.000	0.195	110	0.94
23	0.010	0.087	-0.127	111	0.28
24	0.000	0.094	-0.094	87	0.00
25	0.048	0.117	-0.082	71	0.44
26	0.050	0.125	-0.069	52	0.13
27	0.478	0.059	0.264	81	1.31
28	0.079	0.170	-0.118	78	0.48
SUM	5.337	3.284	0.031	-	-
AVG	0.191	0.117	0.001	90	0.67
PFRV	0.9345	0.9345	N.A.	0.9345	0.9345

* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; # <40% VALID DATA; PFRV RELIABILITY VALUE.

MONTHLY REPORT: SUMMERWOOD ASSOCIATES M
HOT WATER SUBSYSTEM I

FEBRUARY 1981

DAY OF MON.	HOT WATER LOAD MILLION BTU	SOLAR FR.OF LOAD PER.	HOT WATER DEMAND MILLION BTU	SOLAR FR.OF DEMAND BTU	SOLAR ENERGY USED MILLION BTU	OPER ENERGY MILLION BTU	AUX THERMAL USED MILLION BTU
(NBS ID)	(N300)	(Q302)			(Q300)	(Q303)	(Q301)
1	0.000	0	0.000	50	0.000	0.004	0.000
2	0.002	0	0.001	13	0.000	0.005	0.002
3	0.003#	0#	0.005#	15#	0.000#	0.003#	0.003#
4	0.000	0	0.000	0	0.000	0.000	0.000
5	0.004	0	0.002	14	0.000	0.001	0.004
6	0.001	0	0.002	15	0.000	0.000	0.001
7	0.000	0	0.000	50	0.000	0.000	0.000
8	0.000	0	0.000	0	0.000	0.000	0.000
9	0.034	0	0.001	30	0.000	0.000	0.034
10	0.015	0	0.020	5	0.000	0.000	0.015
11	0.000	0	0.005	4	0.000	0.000	0.000
12	0.000	0	0.005	4	0.000	0.000	0.000
13	0.000	0	0.002	4	0.000	0.000	0.000
14	0.000	0	0.003	4	0.000	0.000	0.000
15	0.033	0	0.007	2	0.000	0.000	0.033
16	0.015	0	0.027	2	0.000	0.000	0.015
17	0.000	0	0.003	1	0.000	0.004	0.000
18	0.000	0	0.002	1	0.000	0.004	0.000
19	0.000	0	0.002	1	0.000	0.002	0.000
20	0.021	0	0.004	1	0.000	0.000	0.021
21	0.020	0	0.015	1	0.000	0.000	0.020
22	0.030	0	0.040	0	0.000	0.000	0.030
23	0.000	0	0.005	0	0.000	0.002	0.000
24	0.018	0	0.001	0	0.000	0.005	0.018
25	0.004	0	0.024	0	0.000	0.003	0.004
26	0.000	0	0.001	0	0.000	0.000	0.000
27	0.000	0	0.001	0	0.000	0.003	0.000
28	0.000	0	0.001	0	0.000	0.005	0.000
SUM	0.200	-	0.177	-	0.000	0.042	0.200
AVG	0.007	0	0.006	2	0.000	0.001	0.007
PFRV	0.9345	0.9345	0.9315	0.9345	0.9345	0.9345	0.9345

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

<40% VALID DATA; PFRV RELIABILITY VALUE.

MONTHLY REPORT: SUMMERWOOD ASSOCIATES M
HOT WATER SUBSYSTEM II

FEBRUARY 1981

DAY OF MON.	AUX ELECT FUEL MILLION BTU (Q305)	AUX FOSSIL FUEL MILLION BTU (Q306)	ELECT ENERGY SAVINGS MILLION BTU (Q311)	FOSSIL ENERGY SAVINGS MILLION BTU (Q313)	SUPPLY WATER TEMP DEG F (Q305)	HOT WATER TEMP DEG F (N307)	HOT WATER USED GAL (N308)	SOLAR SPECIFIC OPER ENERGY MILLION BTU
1	0.000	N	-0.004	N	55	68	0	0.004
2	0.002	O	-0.005	O	54	88	1	0.005
3	0.003#	T	-0.003#	T	54#	92#	9#	0.003#
4	0.000		0.000		55	68	0	0.000
5	0.004	A	-0.001	A	55	89	5	0.001
6	0.001	P	0.000	P	55	93	3	0.000
7	0.000	P	0.000	P	53	59	0	0.000
8	0.000	L	0.000	L	53	59	0	0.000
9	0.034	I	0.000	I	52	65	9	0.000
10	0.015	C	0.000	C	50	133	30	0.000
11	0.000	A	0.000	A	51	111	11	0.000
12	0.000	B	0.000	B	52	86	18	0.000
13	0.000	L	0.000	L	52	76	10	0.000
14	0.000	E	0.000	E	52	71	16	0.000
15	0.033		0.000		52	107	14	0.000
16	0.015		0.000		53	136	38	0.000
17	0.000		-0.004		53	110	6	0.004
18	0.000		-0.004		54	91	6	0.004
19	0.000		-0.002		55	79	11	0.002
20	0.021		0.000		53	79	19	0.000
21	0.020		0.000		53	137	21	0.000
22	0.030		0.000		51	135	58	0.000
23	0.000		-0.002		53	114	10	0.002
24	0.018		-0.005		56	84	2	0.005
25	0.004		-0.003		52	124	40	0.003
26	0.000		0.000		52	77	6	0.000
27	0.000		-0.003		54	71	5	0.003
28	0.000		-0.005		54	70	4	0.005
SUM	0.200	N.A.	-0.042	N.A.	-	-	352	0.042
AVG	0.007	N.A.	-0.001	N.A.	52	111	13	0.001
PFRV	0.9345	N.A.	0.9345	N.A.	0.9315	0.9315	0.9315	0.9345

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

<40% VALID DATA; PFRV RELIABILITY VALUE.

MONTHLY REPORT: SUMMERWOOD ASSOCIATES M
SPACE HEATING SUBSYSTEM I

FEBRUARY 1981

DAY OF MONTH (NBS ID)	SPACE HEATING LOAD MILLION BTU (Q402)	CONTROLLED DELIVERED ENERGY MILLION BTU	TOTAL SOLAR ENERGY USED MILLION BTU (Q400)	TOTAL AUXILIARY THERMAL USED MILLION BTU (Q401)	SOLAR FRACTION OF LOAD PCT (N400)	ELECT ENERGY SAVINGS MILLION BTU (Q415)	FOSSIL ENERGY SAVINGS MILLION BTU (Q417)	BLDG TEMP DEG F (N406)	AMB TEMP DEG F (N113)
1	0.211	0.189	0.176	0.021	84	0.048	N	57	29
2	0.064	0.058	0.050	0.009	63	0.003	O	57	42
3	0.256#	0.229#	0.181#	0.049#	66#	0.128#	T	59#	29#
4	0.329	0.318	0.207	0.097	64	0.110		56	15
5	0.234	0.226	0.097	0.128	32	0.025	A	58	25
6	0.169	0.153	0.071	0.080	37	0.026	P	56	31
7	0.074	0.064	0.052	0.014	71	0.046	P	52	30
8	0.000	0.000	0.000	0.000	0	0.000	L	51	37
9	0.200	0.191	0.197	0.000	98	0.000	I	54	28
10	0.267	0.240	0.228	0.023	85	0.064	C	62	31
11	0.126	0.103	0.084	0.027	67	0.016	A	63	47
12	0.197	0.173	0.150	0.033	76	0.050	B	63	25
13	0.386	0.357	0.297	0.068	77	0.124	L	62	21
14	0.295	0.271	0.225	0.053	76	0.095	E	63	28
15	0.211	0.193	0.192	0.010	91	0.031		64	31
16	0.167	0.155	0.153	0.007	91	0.005		64	35
17	0.088	0.079	0.086	0.000	98	0.000		65	44
18	0.066	0.061	0.065	0.000	99	0.000		66	46
19	0.042	0.037	0.041	0.000	99	0.000		63	44
20	0.070	0.064	0.069	0.000	98	0.000		64	45
21	0.045	0.039	0.037	0.005	82	0.001		66	53
22	0.000	0.000	0.000	0.000	0	0.000		67	50
23	0.088	0.080	0.087	0.000	99	0.000		63	42
24	0.111	0.096	0.095	0.010	86	0.004		63	45
25	0.176	0.146	0.118	0.038	67	0.029		64	40
26	0.239	0.209	0.127	0.060	53	0.020		64	41
27	0.212	0.189	0.059	0.030	28	0.000		65	42
28	0.216	0.190	0.172	0.028	80	0.032		64	36
SUM	4.538	4.110	3.316	0.790	-	0.858	N.A.	-	-
AVG	0.162	0.147	0.118	0.028	72	0.031	N.A.	61	36
PFRV	0.9345	0.9345	0.9345	0.9345	0.9345	0.9345	N.A.	0.9345	0.9345

* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; # <40% VALID DATA; PFRV RELIABILITY VALUE.

MONTHLY REPORT: SUMMERWOOD ASSOCIATES M

FEBRUARY 1981

SPACE HEATING SUBSYSTEM II

DAY OF MONTH (NBS ID)	SPACE HEATING LOAD MILLION BTU (Q402)	MEASURED SOLAR ENERGY USED MILLION BTU	SOLAR ENERGY LOSSES TO LOAD MILLION BTU	TOTAL OPERATING ENERGY MILLION BTU (Q403)	SOLAR SPECIFIC OPERATING ENERGY MILLION BTU	AUX ELECT FUEL MILLION BTU	AUX FOSSIL FUEL MILLION BTU (Q410)	HEATING DEGREE DAYS
1	0.211	0.168	0.008	0.022	0.005	0.030	N	40
2	0.064	0.049	0.002	0.006	0.001	0.013	O	23
3	0.256#	0.175#	0.005#	0.023#	0.002#	0.065#	T	49
4	0.329	0.222	-0.015	0.044	0.009	0.113		48
5	0.234	0.097	-0.001	0.034	0.013	0.130	A	54
6	0.169	0.069	0.002	0.017	0.002	0.090	P	34
7	0.074	0.050	0.002	0.007	0.000	0.020	P	31
8	0.000	0.000	0.000	0.000	0.000	0.000	L	27
9	0.200	0.191	0.006	0.017	0.007	0.000	I	35
10	0.267	0.216	0.011	0.031	0.008	0.033	C	34
11	0.126	0.076	0.009	0.012	0.000	0.039	A	20
12	0.197	0.140	0.010	0.019	0.003	0.043	B	36
13	0.386	0.289	0.007	0.036	0.009	0.082	L	41
14	0.295	0.218	0.006	0.029	0.006	0.065	E	35
15	0.211	0.183	0.009	0.023	0.007	0.014		32
16	0.167	0.147	0.005	0.021	0.007	0.010		27
17	0.088	0.079	0.007	0.007	0.003	0.000		19
18	0.066	0.061	0.004	0.003	0.001	0.000		16
19	0.042	0.037	0.004	0.003	0.001	0.000		21
20	0.070	0.064	0.004	0.006	0.002	0.000		20
21	0.045	0.034	0.003	0.004	0.001	0.008		13
22	0.000	0.000	0.000	0.000	0.000	0.000		15
23	0.088	0.080	0.007	0.006	0.002	0.000		23
24	0.111	0.087	0.008	0.011	0.003	0.014		20
25	0.176	0.107	0.011	0.017	0.000	0.055		23
26	0.239	0.129	-0.002	0.031	0.000	0.086		23
27	0.212	0.052	0.008	0.022	0.002	0.042		23
28	0.216	0.162	0.010	0.024	0.005	0.040		28
SUM	4.538	3.183	0.133	0.476	0.099	0.992	N.A.	810
AVG	0.162	0.114	0.005	0.017	0.004	0.035	N.A.	29
PFRV	0.9345	0.9345	0.9345	0.9345	0.9345	0.9345	N.A.	N.A.

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

<40% VALID DATA; PFRV RELIABILITY VALUE.

MONTHLY REPORT: SUMMERWOOD ASSOCIATES M
THERMODYNAMIC CONVERSION EQUIPMENT

FEBRUARY 1981

DAY OF MONTH	EQUIPMENT LOAD MILLION BTU	THERMAL ENERGY INPUT MILLION BTU	OPERATING ENERGY MILLION BTU	ENERGY REJECTED MILLION BTU	COEFFICIENT OF PERFORMANCE (SEE NOTE)
1	0.109	0.030	0.004	N	3.592
2	0.044	0.012	0.001	O	2.227
3	0.232#	0.055#	0.007#	T	2.743#
4	0.223	0.054	0.008		4.102
5	0.024	0.006	0.001	A	0.865
6	0.068	0.035	0.005	P	1.226
7	0.088	0.020	0.003	P	4.388
8	0.000	0.000	0.000	L	0.000
9	0.000	0.000	0.000	I	0.000
10	0.150	0.033	0.004	C	4.534
11	0.143	0.039	0.005	A	3.653
12	0.120	0.032	0.004	B	3.701
13	0.191	0.046	0.006	L	4.140
14	0.169	0.041	0.005	E	4.113
15	0.060	0.014	0.002		4.179
16	0.042	0.010	0.001		4.144
17	0.000	0.000	0.000		0.000
18	0.000	0.000	0.000		0.000
19	0.000	0.000	0.000		0.000
20	0.000	0.000	0.000		0.000
21	0.034	0.008	0.001		4.600
22	0.000	0.000	0.000		0.000
23	0.000	0.000	0.000		0.000
24	0.051	0.013	0.002		3.803
25	0.207	0.055	0.007		3.783
26	0.289	0.086	0.011		3.354
27	0.145	0.042	0.000		3.450
28	0.159	0.040	0.005		4.017
SUM	2.549	0.674	0.081	N.A.	-
AVG	0.091	0.024	0.003	N.A.	3.387
PFRV	0.9345	0.9345	0.9345	N.A.	0.9345

* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; # <40% VALID DATA; PFRV RELIABILITY VALUE.

MONTHLY REPORT: SUMMERWOOD ASSOCIATES M
ENVIRONMENTAL SUMMARY

FEBRUARY 1981

DAY OF MONTH	TOTAL INSOLATION BTU/SQ.FT (NBS ID) (Q001)	DIFFUSE INSOLATION BTU/SQ.FT	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	920	N	29	39	N	N	N
2	20	O	42	46	O	O	O
3	1020#	T	29#	43#	T	T	T
4	1183		15	22			
5	1421	A	25	29	A	A	A
6	531	P	31	37	P	P	P
7	1633	P	30	39	P	P	P
8	382	L	37	40	L	L	L
9	1971	I	28	36	I	I	I
10	1275	C	31	39	C	C	C
11	95	A	47	52	A	A	A
12	2130	B	25	28	B	B	B
13	2032	L	21	29	L	L	L
14	1991	E	28	42	E	E	E
15	1796		31	38			
16	1830		35	51			
17	1700		44	56			
18	1426		46	61			
19	287		44	49			
20	21		45	44			
21	365		53	56			
22	1745		50	57			
23	588		42	45			
24	148		45	46			
25	523		40	44			
26	339		41	45			
27	1926		42	47			
28	542		36	40			
SUM	29841	N.A.	-	-	-	-	-
AVG	1066	N.A.	36	43	N.A.	N.A.	N.A.
PFRV	0.9345	N.A.	0.9345	0.9345	N.A.	N.A.	N.A.

* UNAVAILABLE; N.A. NOT APPLICABLE; I INVALID; E ESTIMATED; # <40% VALID DATA; PFRV RELIABILITY VALUE.

J-12