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SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

LAWRENCE BERKELEY LABORATORY
Berkeley, California
July 1980 through June 1981
DHW SH

U.S. DEPARTMENT OF ENERGY
NATIONAL SOLAR DATA PROGRAM

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LAWRENCE BERKELEY LABORATORY
BERKELEY, CALIFORNIA
SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION
JULY 1980 THROUGH JUNE 1981

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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.

Roof-mounted Collector Array

LAWRENCE BERKELEY LABORATORY

LAWRENCE BERKELEY LABORATORY

The Lawrence Berkeley Laboratory site is an office building in Berkeley, California. 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	852	200-285	23-33
Hot Water	*	*	*

* Denotes unavailable data.

It is equipped with:

Collector: 1,428 square feet of Sunworks flat-plate collectors.

Storage: 2,000-gallon water storage tank located outside.

Auxiliary: Two gas-fired boilers used to supply auxiliary thermal energy for both space heating and domestic hot water.

¹Design data supplied by Lawrence Berkeley Laboratory.

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TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
Foreword	
Site Summary	i
Table of Contents	iii
List of Illustrations	iv
List of Tables	v
1. SOLAR SYSTEM PERFORMANCE	1-1
1.1 Summary and Conclusions	1-2
1.2 System Operation	1-15
1.3 Solar Energy Utilization	1-18
2. REFERENCES	2-1
<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. Long-Term Weather Data	E-1
F. Conversion Factors	F-1
G. Sensor Technology	G-1
H. Typical Monthly Data	H-1

LIST OF ILLUSTRATIONS

<u>Figure Number</u>	<u>Title</u>	<u>Page</u>
1	Energy Flow Diagram for Lawrence Berkeley Laboratory, July 1980 through June 1981	1-3
2	System Thermal Performance, Lawrence Berkeley Laboratory, July 1980 through June 1981	1-4
3	Average Collector Efficiency, Lawrence Berkeley Laboratory, September 1980	1-7
4a	Typical Insolation Data, Lawrence Berkeley Laboratory, April 6, 1981	1-15
4b	Typical Collector Array Temperatures, Inlet/Outlet, Lawrence Berkeley Laboratory, April 6, 1981	1-16
4c	Typical Storage Fluid Temperature, Lawrence Berkeley Laboratory, April 6, 1981	1-16
5	Typical System Operating Sequence, Lawrence Berkeley Laboratory, April 6, 1981	1-17
6	Solar Energy Use, Lawrence Berkeley Laboratory, July 1980 through June 1981	1-18
A-1	Lawrence Berkeley Laboratory Solar Energy System Schematic	A-2
B-1	The National Solar Data Network	B-1

LIST OF TABLES

<u>Table Number</u>	<u>Title</u>	<u>Page</u>
1	Solar System Thermal Performance, Lawrence Berkeley Laboratory, July 1980 through June 1981	1-2
2	Solar Coefficient of Performance, Lawrence Berkeley Laboratory, July 1980 through June 1981	1-4
3	Collector Subsystem Performance, Lawrence Berkeley Laboratory, July 1980 through June 1981	1-5
4	Storage Performance, Lawrence Berkeley Laboratory, July 1980 through June 1981	1-8
5	Domestic Hot Water Subsystem, Lawrence Berkeley Laboratory, July 1980 through June 1981	1-9
6	Space Heating Subsystem I, Lawrence Berkeley Laboratory, July 1980 through June 1981	1-10
7	Space Heating Subsystem II, Lawrence Berkeley Laboratory, July 1980 through June 1981	1-11
8	Solar Operating Energy, Lawrence Berkeley Laboratory, July 1980 through June 1981	1-12
9	Energy Savings, Lawrence Berkeley Laboratory, July 1980 through June 1981	1-12
10	Weather Conditions, Lawrence Berkeley Laboratory, July 1980 through June 1981	1-14

SECTION 1

SOLAR SYSTEM PERFORMANCE

LAWRENCE BERKELEY LABORATORY
JULY 1980 THROUGH JUNE 1981

Solar Fraction ¹	4%
Solar Savings Ratio ²	0.04
Conventional Fuel Savings ³	114,257 cubic feet of natural gas and expense of 1,253 kwh of electricity
System Performance Factor ⁴	0.75
Solar System COP ⁵	20.71

Seasonal Energy Requirements
July 1980 through June 1981
(Million BTU)

	<u>Total Load</u>	<u>Solar Contribution</u>	<u>% Solar</u>
Heating	2,208.18	73.97	3
Hot Water	78.32	14.69	19

Environmental Data

	<u>Measured Average</u>	<u>Long-Term Average</u>
Outdoor temperature	60°F	60°F
Heating degree-days (Total)	1,989	2,094
Cooling degree-days (Total)	391	444
Daily incident solar energy	1,639 BTU/ft ²	1,670 BTU/ft ²

*Denotes unavailable data.

1. Solar Fraction = $\frac{\text{Solar Energy Supplied to Loads}}{\text{Total Load}} \times 100\%$
2. Solar Savings Ratio = $\frac{\text{Solar Energy Supplied to Load} - \text{Solar System Operating Energy}}{\text{Total Load}}$
3. Conventional Fuel Savings = $\frac{\text{Savings in BTU} \times 2.928 \times 10^{-4} \text{ kwh/BTU when savings are electrical savings}}{\text{Savings in BTU} \times 979.4 \times 10^{-6} \text{ cu. ft/BTU when savings are gas savings}}$
4. Ratio of system load to the total equivalent fossil energy expended or required to support the system load.
5. Solar System COP = $\frac{\text{Solar Energy Used}}{\text{Operating Energy Required for Collection}}$

1.1 SUMMARY AND CONCLUSIONS

The Lawrence Berkeley Laboratory solar energy system performed poorly during the period July 1980 through June 1981. The flow of energies for the site for the one-year period is presented in Figure 1. The solar energy system was able to provide four percent of the total system loads for the period. The system thermal performance is summarized in Table 1 and shown graphically in Figure 2.

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

LAWRENCE BERKELEY LABORATORY
JULY 1980 THROUGH JUNE 1981

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	SOLAR ENERGY USED	AUXILIARY ENERGY		TOTAL OPERATING ENERGY	ENERGY SAVINGS		SOLAR FRACTION (%)
				FOSSIL	THERMAL		FOSSIL	ELECTRICAL	
JUL	16.98	256.78	9.93	303.40	230.58	3.27	13.06	-0.37	4
AUG	14.67	197.09	8.06	231.77	176.48	3.32	10.61	-0.36	4
SEP	12.01	111.79	5.60	158.65	98.44	3.22	7.37	-0.37	5
OCT	20.09	130.85	13.67	122.70	119.78	3.50	17.98	-0.49	10
NOV	13.42	251.19	8.17	298.82	227.10	3.12	10.75	-0.30	3
DEC	11.23	312.59	10.20	373.01	283.49	0.61	13.43	-0.31	3
JAN	6.28	281.50	2.59	343.81	261.30	1.21	3.40	-0.17	1
FEB	5.13	216.19	1.14	264.57	201.07	2.38	1.50	-0.42	1
MAR	*	*	*	*	*	*	*	*	*
APR	19.07	178.98	15.61	203.38	154.57	8.18	20.55	-0.55	9
MAY	14.69	187.24	13.05	220.45	167.55	8.52	17.17	-0.45	7
JUN	1.24	162.30	0.64	196.51	149.35	8.40	0.84	-0.49	0
TOTAL	134.81	2,286.50	88.66	2,717.07	2,069.71	45.73	116.66	-4.28	-
AVERAGE	12.26	207.86	8.06	247.01	188.16	4.16	10.79	-0.39	4

* Denotes unavailable data.

The solar energy coefficient of performance (COP) is indicated in Table 2. The COP 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 the Lawrence Berkeley Laboratory functioned at a reporting period weighted average COP value of 20.7¹.

The collector subsystem contains 68 panels of Sunworks flat-plate collectors mounted on the roof of the building. The array has a gross surface area of 1,428 square feet, and a net aperture area of 1,270 square feet. The collector flow rate per panel is approximately 0.37 gallon per minute. This is 20% higher than the manufacturer's recommended flow rate of 0.31 gallon per minute. The collector array is facing south and is tilted at an angle of 45° from horizontal. The primary heat transfer fluid is water.

Figure 1. Energy Flow Diagram for Lawrence Berkeley Laboratory
 July 1980 through June 1981
 (Figures in million BTU)

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

Figure 2. System Thermal Performance
Lawrence Berkeley Laboratory
July 1980 through June 1981

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

LAWRENCE BERKELEY LABORATORY
JULY 1980 THROUGH JUNE 1981

MONTH	SOLAR ENERGY SYSTEM	COLLECTOR SUBSYSTEM	DOMESTIC HOT WATER SOLAR	SPACE HEATING SOLAR
JUL	26.84	77.12	51.50	68.46
AUG	22.39	66.68	42.00	60.17
SEP	15.14	42.89	62.00	110.00
OCT	27.90	71.75	59.70	34.00
NOV	27.23	74.56	52.00	71.30
DEC	32.90	59.11	60.00	87.27
JAN	15.24	48.31	0.00	62.75
FEB	2.71	19.73	4.50	7.50
MAR	*	*	*	*
APR	28.38	61.52	62.00	65.65
MAY	29.00	56.50	60.00	69.17
JUN	1.31	2.95	10.00	9.00
WEIGHTED AVERAGE	20.71	49.02	52.46	59.18

*Denotes unavailable data.

Table 3 represents the collector subsystem performance for the year. The collector array was able to collect 17% of the total radiation incident on the array and 26% of the radiation incident on the array when the collector loop was operational. The total collected solar energy during the period was 134.81 million BTU. The operating energy required to collect this energy was 2.75 million BTU.

The subsystem incorporates an intentional heat rejection mode for overheat protection of the storage tank. The collector controller is designed to override the normal collector pump shutdown logic if the storage tank temperature is above 190°F. In this mode, the collector pumps continue to operate, rejecting previously collected energy in storage back out through the collectors until the tank temperature falls below 185°F. During the year, the system intentionally rejected 15.41 million BTU.

Table 3. COLLECTOR SUBSYSTEM PERFORMANCE

LAWRENCE BERKELEY LABORATORY
JULY 1980 THROUGH JUNE 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	INTENTIONALLY REJECTED ENERGY	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE (°F)
JUL	82.77	16.98	21	53.46	32	0.22	0.15	16.54	72
AUG	76.20	14.67	19	50.17	29	0.22	0.11	12.95	69
SEP	72.67	12.01	17	51.05	24	0.28	0.06	10.16	71
OCT	82.51	20.09	24	59.97	34	0.28	0.44	18.28	73
NOV	60.84	13.42	22	39.37	34	0.18	0.00	11.15	65
DEC	57.41	11.23	20	36.94	30	0.19	0.03	11.47	61
JAN	43.63	6.28	14	24.27	26	0.13	0.47	6.11	57
FEB	56.77	5.13	9	39.45	13	0.26	4.67	4.84	62
MAR	*	*	*	*	*	*	*	*	*
APR	83.39	19.07	23	60.61	32	0.31	1.07	19.11	68
MAY	84.29	14.69	17	50.84	29	0.26	0.17	14.86	71
JUN	81.52	1.24	2	54.31	2	0.42	8.24	1.30	78
TOTAL	782.00	134.81	-	520.44	-	2.75	15.41	126.77	-
AVERAGE	71.09	12.26	17	47.31	26	0.25	1.40	11.52	68

* Denotes unavailable data.

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 3.

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 3. 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 3.

Figure 3 shows the monthly performance of the collector array during September 1980. The monthly 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. The graph represents a least-squares curve fit of the various operating points, in the form of a linear equation with the collector transmission/absorption product ($F_{RT\alpha}$) indicated by the y-intercept and the effective collector heat loss coefficient (F_{RU_L}) indicated by the negative of the slope of the line.

This curve compares well with the manufacturer's curve generated from single-panel test data. The collector array efficiency curve for September 1980 has a slope of -0.89 and a y-intercept of 0.65. The manufacturer's test curve has a slope of -0.76 and a y-intercept of 0.71. A slightly steeper slope and lower intercept can be expected for an array containing many panels.

Figure 3. Average Collector Efficiency
Lawrence Berkeley Laboratory
September 1980

Table 4 represents the performance of the storage subsystem for the period of July 1980 through June 1981. During this period, there were 126.77 million BTU of solar energy delivered to storage from the collector subsystem. There were 88.66 million BTU of solar energy delivered from the storage tank to the space heating and domestic hot water loads.

The solar storage tank at Lawrence Berkeley Laboratory is located aboveground outside of the building. The tank has a volume of 2,000 gallons and has a surface area of 294 square feet. The tank is insulated with three inches of polyurethane.

The losses from storage were somewhat higher than one would predict from the thermal conductivity properties of the polyurethane insulation. The effective heat transfer coefficient for three inches of polyurethane is approximately 0.06 BTU/ft²hr°F. The average value calculated from the measured data was 0.14 BTU/ft²hr°F.

During much of the month of June, pump EP200, which delivers solar heated water from storage to the load subsystems, was broken. Thus, no solar energy was delivered to the loads during this period.

Because of high supply water temperatures in the heating loop, the solar storage tank had to be maintained at high temperatures, resulting in high storage losses, 38.39 million BTU, and reduced collector efficiency. Also, because of the high

Table 4. STORAGE PERFORMANCE

LAWRENCE BERKELEY LABORATORY
JULY 1980 THROUGH JUNE 1981

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY TO STORAGE	ENERGY FROM STORAGE	CHANGE IN STORED ENERGY	STORAGE EFFICIENCY (%)	AVERAGE STORAGE TEMPERATURE (°F)	EFFECTIVE HEAT LOSS COEFFICIENT (BTU/FT ² hr°F)	LOSS FROM STORAGE
JUL	16.54	9.93	-0.33	58	179	0.27	6.94
AUG	12.95	8.06	0.03	63	178	0.19	4.86
SEP	10.16	5.60	-0.02	53	172	0.20	4.58
OCT	18.28	13.67	0.11	75	176	0.18	4.50
NOV	11.15	8.17	-0.39	70	173	0.14	3.37
DEC	11.47	10.20	0.38	92	158	0.04	0.89
JAN	6.11	2.59	-0.06	41	170	0.16	3.58
FEB	4.84	1.14	-0.09	20	185	0.15	3.79
MAR	*	*	*	*	*	*	*
APR	19.11	15.61	0.02	82	164	0.15	3.48
MAY	14.86	13.05	-0.03	88	169	0.08	1.84
JUN	1.30	0.64	0.10	57	185	0.02	0.56
TOTAL	126.77	88.66	-0.28	-	-	-	38.39
AVERAGE	11.52	8.06	-0.03	70	174	0.14	3.49

* Denotes unavailable data.

storage temperatures, the overheat protection mode further reduced solar energy availability by rejecting 15.41 million BTU of stored solar energy back out through the collectors.

The domestic hot water (DHW) subsystem required 14.69 million BTU of solar energy and 63.63 million BTU of auxiliary fossil fuel energy to satisfy a hot water load of 78.32 million BTU. The solar fraction of this load was 19%. The DHW subsystem performance is shown in Table 5.

The DHW subsystem incorporates a recirculation loop with pump (EP350, see schematic, Appendix A) operating continuously. When the temperature of the hot water falls below 108°F, pump (EP403) is activated, delivering thermal energy directly from the space heat circulation loop, until the hot water temperature rises to 115°F. This thermal energy is a mixture of both solar and auxiliary energies.

This proved to be a very inefficient method of operation. The subsystem required 78.32 million BTU of thermal energy to support a hot water demand of 3.74 million BTU. Thus, 74.58 million BTU of the thermal input to the DHW subsystem was lost to the space.

Table 5. DOMESTIC HOT WATER SUBSYSTEM

LAWRENCE BERKELEY LABORATORY
JULY 1980 THROUGH JUNE 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	OPERATING ENERGY	AUX FOSSIL FUEL	SUP WATER TEMP (°F)	HOT WATER TEMP (°F)	HOT WATER CONSUMPTION (GAL)
JUL	7.47	14	0.37	*	1.03	6.44	0.28	8.48	66	111	973
AUG	7.16	12	0.30	*	0.84	6.32	0.27	7.87	72	112	896
SEP	7.86	24	0.34	12	1.86	6.00	0.26	7.91	67	111	923
OCT	11.36	51	0.32	30	5.97	5.39	0.35	7.09	67	112	862
NOV	7.17	15	0.32	8	1.04	6.13	0.27	8.07	64	113	781
DEC	6.09	10	0.31	*	0.60	5.49	0.31	7.22	60	109	749
JAN	7.38	1	0.39	1	0.08	7.30	0.26	9.60	58	112	866
FEB	6.87	1	0.36	2	0.09	6.78	0.26	8.93	58	113	771
MAR	*	*	*	*	*	*	*	*	*	*	*
APR	6.45	38	0.40	37	2.48	3.97	0.33	5.22	61	112	953
MAY	5.40	11	0.34	13	0.60	4.80	0.30	6.31	62	112	831
JUN	5.11	2	0.29	3	0.10	5.01	0.25	6.59	66	111	782
TOTAL	78.32	-	3.74	-	14.69	63.63	3.14	83.29	-	-	9,387
AVERAGE	7.12	19	0.34	*	1.34	5.78	0.29	7.57	64	112	853

* Denotes unavailable data.

One reason for the large difference between the DHW load and DHW demand was the high estimation of the DHW consumption. Daily consumption was estimated at one gallon per person per day for approximately 400 persons, or 400 gallons per day. The actual average daily consumption was only 28 gallons per day. As a result, the system was oversized for the demand.

The losses from the subsystems could have been reduced significantly by turning the recirculation loop off during periods of no use. This would also have reduced the electrical energy consumed by pump EP350. This pump, running continuously, consumed approximately 2.20 million BTU during the 11-month period. This energy consumption could have been cut by more than half by shutting the recirculation system down on weekends and during the period from approximately 1800 hours to 0600 hours each night when there is no consumption.

The space heating subsystem performed far below design expectations. Refer to Tables 6 and 7 for the monthly space heating performance during the reporting period. The solar energy system was designed to provide 23% to 33% of the space heating load but was only able to provide three percent of the load. This wide difference between predicted and actual performance was largely due to the lack of a return air loop for the space heating subsystem. There was also a system control problem which contributed to reduced solar energy collected and used.

Table 6. SPACE HEATING SUBSYSTEM I

LAWRENCE BERKELEY LABORATORY
JULY 1980 THROUGH JUNE 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)
JUL	249.31	233.04	8.90	224.14	4	75	63
AUG	189.93	177.38	7.22	170.16	4	73	59
SEP	103.93	100.14	3.74	92.44	4	76	62
OCT	119.49	118.13	7.70	114.39	6	76	63
NOV	244.02	228.10	7.13	220.97	3	73	59
DEC	306.50	287.60	9.60	278.00	3	72	56
JAN	274.12	256.51	2.51	254.00	1	72	54
FEB	209.32	195.34	1.05	194.29	1	73	57
MAR	*	*	*	*	*	*	*
APR	172.53	163.73	13.13	150.60	8	72	58
MAY	181.84	175.20	12.45	162.75	7	73	62
JUN	157.19	144.88	0.54	144.34	0	76	69
TOTAL	2,208.18	2,080.05	73.97	2,006.08			
AVERAGE	200.74	189.10	6.72	182.37	3	74	60

* Denotes unavailable data.

The projected annual space heating load for this site was 852 million BTU. The actual space heating load for the 11 months of data was 2,208.18 million BTU, 159% higher. The predicted space heating load assumed that an air return loop would be operational for the year. Instead, the air return loop was not made operational until January 14, 1981. But even after this return loop was operational, there was only a 10% reduction in heating load. Prior to January, the building required 1.15 million BTU of space heating per heating degree-day (HDD). From January through June, the building required 1.06 million BTU per HDD.

The amount of solar energy that could have been delivered to the space heating subsystem was reduced because of high temperature water in the space heating loop. The controller for the subsystem was designed to regulate the temperature of the water proportionally to the outside air temperature. The system was to have been set up to supply 140°F water at 35°F outside air temperature and 90°F water at 60°F outside air temperature. Unfortunately this control system was not installed until April 3, and when it was installed it did not work properly. As a result, the space heating water temperatures throughout the year were extremely high, generally above 185°F, and often higher. Due to the high water temperatures, little solar energy from storage could be used. The storage water temperature must be 5°F higher than the space heating supply water temperature before the pump supplying solar energy from storage to the space heating loop (EP200) is activated.

Table 7. SPACE HEATING SUBSYSTEM II

LAWRENCE BERKELEY LABORATORY
JULY 1980 THROUGH JUNE 1981

(All values in million BTU, unless otherwise indicated)

MONTH	SPACE HEATING LOAD	MEASURED SOLAR ENERGY USED	TOTAL OPERATING ENERGY	SOLAR SPECIFIC OPERATING ENERGY	AUXILIARY FOSSIL FUEL	HEATING DEGREE- DAYS
JUL	249.31	8.90	2.77	0.13	294.92	112
AUG	189.93	7.22	2.83	0.12	223.90	187
SEP	103.93	3.74	2.68	0.06	150.74	131
OCT	119.49	7.70	2.87	0.11	115.61	141
NOV	244.02	7.13	2.67	0.10	290.75	188
DEC	306.50	9.60	0.11	0.11	365.79	292
JAN	274.12	2.51	0.82	0.04	334.21	353
FEB	209.32	1.05	1.86	0.14	255.64	230
MAR	*	*	*	*	*	*
APR	172.53	13.13	7.54	0.20	198.16	212
MAY	181.84	12.45	7.96	0.18	214.14	110
JUN	157.19	0.54	7.73	0.06	189.92	33
TOTAL	2,208.18	73.97	39.84	1.25	2,633.78	1,989
AVERAGE	200.74	6.72	3.62	0.11	239.43	181

* Denotes unavailable data.

Measured monthly values of the Lawrence Berkeley Laboratory solar energy system and subsystem operating energy for the report period are presented in Table 8. A total 4.28 million BTU of operating energy were consumed by the entire system during the reporting period.

Total system operating energy for the Lawrence Berkeley Laboratory is the electrical energy required to support the energy collection, storage, domestic hot water, and space heating subsystems without affecting their thermal states.

Energy savings for this site for the reporting period are presented in Table 9.

For this 11-month period, the total fossil fuel savings were 116.66 million BTU. This is approximately 114,257 cubic feet of natural gas. An electrical energy expense of 4.28 million BTU, or 1,253 kwh, 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 source at the site consists of two gas-fired boilers which are considered to be 76% efficient for computational purposes.

Table 8. SOLAR OPERATING ENERGY

LAWRENCE BERKELEY LABORATORY

JULY 1980 THROUGH JUNE 1981

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY (SOLAR UNIQUE)	DHW OPERATING ENERGY (SOLAR)	SHS OPERATING ENERGY (SOLAR)	TOTAL SOLAR OPERATING ENERGY
JUL	0.22	0.02	0.13	0.37
AUG	0.22	0.02	0.12	0.36
SEP	0.28	0.03	0.06	0.37
OCT	0.28	0.10	0.11	0.49
NOV	0.18	0.02	0.10	0.30
DEC	0.19	0.01	0.11	0.31
JAN	0.13	0.00	0.04	0.17
FEB	0.26	0.02	0.14	0.42
MAR	*	*	*	*
APR	0.31	0.04	0.20	0.55
MAY	0.26	0.01	0.18	0.45
JUN	0.42	0.01	0.06	0.49
TOTAL	2.75	0.28	1.25	4.28
AVERAGE	0.25	0.03	0.11	0.39

* Denotes unavailable data.

Table 9. ENERGY SAVINGS

LAWRENCE BERKELEY LABORATORY

JULY 1980 THROUGH JUNE 1981

(All values in million BTU)

MONTH	SOLAR ENERGY USED	SPACE HEATING		DOMESTIC HOT WATER		ECSS OPERATING ENERGY (SOLAR UNIQUE)	ENERGY SAVINGS	
		ELECTRICAL	FOSSIL FUEL	ELECTRICAL	FOSSIL FUEL		ELECTRICAL	FOSSIL FUEL
JUL	9.93	-0.13	11.70	-0.02	1.35	0.22	-0.37	13.06
AUG	8.06	-0.12	9.50	-0.02	1.11	0.22	-0.36	10.61
SEP	5.60	-0.06	4.92	-0.03	2.45	0.28	-0.37	7.37
OCT	13.67	-0.11	10.13	-0.10	1.83	0.28	-0.49	11.98
NOV	8.17	-0.10	9.38	-0.02	1.37	0.18	-0.30	10.75
DEC	10.20	-0.11	12.63	-0.01	0.80	0.19	-0.31	13.43
JAN	2.59	-0.04	3.30	-0.00	0.10	0.13	-0.17	3.40
FEB	1.14	-0.14	1.38	-0.02	0.12	0.26	-0.42	1.50
MAR	*	*	*	*	*	*	*	*
APR	15.61	-0.20	17.28	-0.04	3.27	0.31	-0.55	20.55
MAY	13.05	-0.18	16.38	-0.01	0.79	0.26	-0.45	17.17
JUN	0.64	-0.06	0.71	-0.01	0.14	0.42	-0.49	0.84
TOTAL	88.66	-1.25	97.31	-0.28	19.35	2.75	-4.28	116.66
AVERAGE	8.06	-0.11	8.85	-0.03	1.76	0.25	0.39	10.61

* Denotes unavailable data.

The solar energy system provided a dollar savings of approximately \$406.00 based on a national average fuel cost of \$4.22 per thousand cubic feet of natural gas and 6.06 cents per kwh. This savings is rather insignificant when the initial cost of the retrofit is considered. The total cost was estimated at \$130,000.00. At a return of \$406.00 per year, the system will require 320 years to pay for the initial estimated cost.

Savings could have been improved through better control of the space heat and domestic hot water supply water temperature. Lowering of supply water temperatures would have made more solar energy available from storage. Better control would also have significantly reduced standby losses from storage and reduced the large amounts of intentionally rejected solar energy.

The solar energy system may have been capable of providing the predicted amount of solar energy to the space heating load (200-283 million BTU) if a properly acting controller for the space supply water temperature had been installed when the solar energy system was installed. The collector array would have been required to operate at 38% to 50% operational efficiency which would have been possible with lower storage tank temperatures.

The Lawrence Berkeley Laboratory was in operation for all the months of the reporting period. During this period, the solar system was in operation until June 4, 1981 when the solar storage to load subsystem pump malfunctioned. Listed below are the major events during the reporting period.

<u>Date</u>	<u>Event</u>
7/80	SDAS failure, two days
9/80	SDAS failure, one day Solenoid valves installed in collector loop to prevent thermosiphoning
1/81	Return air heating loop completed; SDAS failure, three days
2/81	SDAS failure, five days
3/81	SDAS failure, 22 days
4/81	New space heating control system installed
6/81	Pump (EP200) failure

Lawrence Berkeley Laboratory is located in Berkeley, California at 38 degrees N latitude and 122 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 10. 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 insolation values are total global horizontal radiation converted to collector angle and azimuth orientation.

During the period from July 1980 through June 1981, the average daily total incident solar radiation on the collector array was 1,639 BTU per square foot per day. This radiation was below the estimated average daily solar radiation for

Table 10. WEATHER CONDITIONS

LAWRENCE BERKELEY LABORATORY
JULY 1980 THROUGH JUNE 1981

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT ² -DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS		COOLING DEGREE-DAYS	
	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
JUL	1,870	1,898	63	68	112	12	40	117
AUG	1,721	1,907	59	68	187	15	7	111
SEP	1,696	1,920	62	68	131	13	53	94
OCT	1,864	1,704	63	63	141	90	78	19
NOV	1,423	1,385	59	56	188	276	13	0
DEC	1,297	1,179	56	50	292	456	0	0
JAN	986	1,223	54	50	353	481	0	0
FEB	1,420	1,501	57	53	230	350	0	0
MAR	*	*	*	*	*	*	*	*
APR	1,947	1,907	58	58	212	228	39	12
MAY	1,904	1,882	62	62	110	123	13	20
JUN	1,903	1,862	69	66	33	50	148	71
TOTAL	-	-	-	-	1,989	2,094	391	444
AVERAGE	1,639	1,670	60	60	181	190	36	40

* Denotes unavailable data.

this geographical area during the reporting period of 1,670 BTU per square foot per day for a south-facing plane with a tilt of 45 degrees to the horizontal. During the period, the highest monthly average insolation was 1,947 BTU per square foot per day during April. The average ambient temperature during the reporting period was 60°F as compared with the long-term average of 60°F. The highest monthly average ambient temperature was 69°F during June, and the lowest monthly average ambient temperature was 54°F during January. The number of heating degree-days for the period (based on a 65°F reference) was 1,989 as compared with the long-term average of 2,094. The range of heating degree-days was from a high of 353 during January to a low of 33 during June.

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.

	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
Extra-terrestrial Insolation	2,900	2,987	3,034	2,897	2,602	2,399	2,487	2,795	3,017	3,046	2,956	2,883
TTL INS(x)	64	58	56	64	55	54	40	51	*	64	64	66
EXT INS												

* Denotes unavailable data.

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

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 66% during June to a low of 40% during January.

1.2 SYSTEM OPERATION

1.2.1 Typical System Operation

Curves depicting typical system operation on a clear day (April 6, 1981) are presented in Figures 4a, 4b, and 4c. Figure 4a shows the insolation on the collector array versus time of day and shows the period when the array was operating. On this particular day the array was activated at 0819 hours and shut down at 1603 hours.

Figure 4b shows typical collector array temperatures during the day. Through the early morning, the collector array inlet and outlet temperatures T100 and T150 can be seen decreasing toward the ambient temperature. At 0819 hours, collector flow is initiated and the two temperatures are seen rising rapidly. At times, around 0900 hours and 1600 hours, the collector pump shut down for several short periods for unknown reasons. This is the cause of the spikes on the collector outlet temperature profile.

Figure 4c depicts the storage fluid temperature. In the early morning, the temperature of storage degrades slowly toward the ambient due to losses through

Figure 4a. Typical Insolation Data
Lawrence Berkeley Laboratory
April 6, 1981

Figure 4b. Typical Collector Array Temperatures, Inlet/Outlet
Lawrence Berkeley Laboratory
April 6, 1981

Figure 4c. Typical Storage Fluid Temperature
Lawrence Berkeley Laboratory
April 6, 1981

the tank and very small periods of flow from storage to load. At 0715 hours, the storage to load loop is activated again and the temperature of storage drops off sharply. At 0819 hours, the collector loop is activated and the storage fluid temperature rises slowly. At 1603 hours, the collector loop shuts down and the temperature of storage drops until the storage-to-load pump shuts down for the day at 1852 hours.

1.2.2 SYSTEM OPERATING SEQUENCE

Figure 5 presents a bar chart showing a typical system operating sequence for April 6, 1981. This data correlates with the curves presented in Figures 4a, 4b, and 4c.

Figure 5. Typical System Operating Sequence
Lawrence Berkeley Laboratory
April 6, 1981

The chart makes obvious the typical continuous operation of several pumps and auxiliary boilers. These include pumps monitored by EP401, EP402, EP404, and EP350. Hot water consumption is typically small but continuous through the period of building use. From 0600 hours until 1800 hours, there were 55 gallons of hot water consumed. The pump monitored by EP403, which delivers solar and auxiliary energy to the DHW subsystem, is seen operating for long periods during the hot water usage period. The short periods of time when the collector pumps shut off can be seen distinctly on the bar graph.

1.3 SOLAR ENERGY UTILIZATION

Figure 6 shows the use of solar energy and the percentage of losses of solar energy throughout the system. Twenty-nine percent of the total incident energy was lost due to periods when insolation did not exceed the threshold level required to activate the collector pump. The system collected 17% of the incident solar energy and delivered 70% of this collected solar energy to the loads. The energy delivered to the loads represents 12% of the total incident solar energy.

Figure 6. Solar Energy Use
Lawrence Berkeley Laboratory
July 1980 through June 1981

SECTION 2

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 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, NY, 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, NY, 1977.
- *6A. User's Guide to Monthly Performance Reports, June 1980, SOLAR/0004-80/18, Vitro Laboratories, Silver Spring, Maryland.
- *6B. User's Guide to Monthly Performance Reports, November 1981, SOLAR/0004-81/18, Vitro Laboratories, Silver Spring, Maryland.
- *6C. Instrumentation Installation Guidelines March 1981, Parts 1, 2, and 3, SOLAR/0001-81/15, Vitro Laboratories, Silver Spring, Maryland.
- *7. Monthly Performance Report, Lawrence Berkeley Laboratory, September 1980, SOLAR/2050-80/09, Vitro Laboratories, Silver Spring, Maryland.
- *8. Monthly Performance Report, Lawrence Berkeley Laboratory, October 1980, SOLAR/2050-80/10, Vitro Laboratories, Silver Spring, Maryland.
- *9. Monthly Performance Report, Lawrence Berkeley Laboratory, November 1980, SOLAR/2050-80/11, 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.

- *10. Monthly Performance Report, Lawrence Berkeley Laboratory, December 1980, SOLAR/2050-80/12, Vitro Laboratories, Silver Spring, Maryland.

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

APPENDIX A
SYSTEM DESCRIPTION

The solar system at the Lawrence Berkeley Laboratory is a flat-plate collector by Sunworks. It has a selective absorber coating and cover plates of water white glass. The system is designed to provide 32% of building heat and domestic hot water. There is a 2,000-gallon hot storage tank. Water is used as the heat transfer fluid and there is a heat exchanger between storage and the loads. Gas-fired boilers are the auxiliary backup. A key factor in retrofitting this building with solar energy is the change from 100% outside air to an air recirculation loop with 10% outside air. The air recirculation loop will reduce heating loads substantially and allow water of a lower temperature to be circulated in the building heating coils.

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

<u>Equipment/Components</u>	<u>Manufacturer</u>	<u>Model No.</u>
Collectors	Sunworks	IMLC
Heat Exchanger	Bell & Gossett	-
Storage Tank	Santa Fe T Co.	-

The solar system, shown schematically in Figure A-1, has the following operating modes:

Mode 1 - Collector-to-Storage - The collector pump is turned on anytime plate temperature (T1) is greater than the temperature of the bottom of storage (T2) by 20°F. It is turned off when the difference between T1 and T2 is less than 3°F. If the plate temperature (T1) is less than 37°F, the collector pump is turned on for one minute to provide freeze protection. When the temperature of the bottom of storage is greater than 185°F, the collector pump is left on to reject heat to the environment. This is to reduce high temperature stress on the collectors and to prevent collector pump cavitation.

Mode 2 - Storage-to-Load - Solar heating is provided to the building heating loop via a heat exchanger. The control sensors, T3 and T4, are located at the top of storage and in the piping loop upstream of the heat exchanger, respectively. When T3 is greater than T4 by 5°F, the heat exchanger pump is turned on. If the difference between T3 and T4 is less than 3°F, the heat exchanger pump is turned off.

There are no other modes of operation for the solar system. However, the domestic hot water for the building is heated from the space heating circulation loop. Therefore, an attempt has been made to proportion the solar energy used to satisfy the building thermal energy requirements between the DHW and space heating loads. Solar energy is proportioned by the ratio of the DHW to the total load which exists at the time solar energy is used.

Figure A-1. Lawrence Berkeley Laboratory Solar Energy System Schematic

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Lawrence Berkeley Laboratory 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 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 0-1023. 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 real time 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 Lawrence Berkeley Laboratory solar energy system from July 1980 through June 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:

September 1980, SOLAR/2050-80/09
October 1980, SOLAR/2050-80/10
November 1980, SOLAR/2050-80/11
December 1980, SOLAR/2050-80/12

* 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 only during the time the collector fluid is being circulated with the intention of delivering solar-source energy to the system.

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 BTU/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

LAWRENCE BERKELEY LABORATORY

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

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

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, $\Delta\tau$ is the sampling interval in minutes, and the factor (1/60) is included to correct the solar radiation "rate" to the proper units of time.

Similarly, the energy flow within a system is given typically by

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

where M100 is the mass flow rate of the heat transfer fluid in lb_m/min and ΔH is the enthalpy change, in BTU/lb_m , of the fluid as it passes through the heat exchanging component.

For a liquid system ΔH is generally given by

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

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

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

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

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
<u>P</u>	=	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)

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

US WEATHER STATION AVERAGE AMBIENT TEMPERATURE (°F)

$$TAVE = T001 \text{ daily maximum} - T001 \text{ minimum}$$

HEATING DEGREE-DAYS/COOLING DEGREE-DAYS

$$CDD = TAVE - 65^{\circ}F$$

$$\text{if } TAVE > 65^{\circ}$$

$$HDD = 65^{\circ}F - TAVE$$

$$\text{if } TAVE < 65^{\circ}$$

AVERAGE BUILDING TEMPERATURE (°F)

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

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

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

for $\pm$ three hours from solar noon

INCIDENT SOLAR ENERGY PER SQUARE FOOT (BTU/FT²)

$$SE = (1/60) \times \Sigma I001 \times \Delta\tau$$

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

$$SEOP = (1/60) \times \Sigma (I001 \times CLAREA) \times \Delta\tau$$

when the collector loop is active

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \Sigma I100 \times HWD (T150, T100) \times \Delta\tau$$

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$$SEA = CLAREA \times SE$$

COLLECTED SOLAR ENERGY (BTU/FT²)

$$SEC = SECA/CLAREA$$

COLLECTOR ARRAY EFFICIENCY

$$CAREF = SECA/SEA$$

OPERATIONAL COLLECTOR ARRAY EFFICIENCY

$$CAREFOP = SECA/SEOP$$

ECSS OPERATING ENERGY (BTU)

$$CSOPE = 56.8833 \times \Sigma (EP101 + EP100) \times \Delta\tau$$

ECSS REJECTED ENERGY (BTU)

$$CSRJE = \Sigma I100 \times HWD (T100, T150) \times \Delta\tau$$

when SECA < 0 and TST > 185

STORAGE SUBSYSTEM

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \Sigma I100 \times HWD (T101, T151) \times \Delta\tau$$

SOLAR ENERGY FROM STORAGE (BTU)

$$STEO = \Sigma I200 \times HWD (T200, T250) \times \Delta\tau$$

CHANGE IN STORED ENERGY (BTU)

$$\text{STECH} = \text{Storage Capacity} \times (\text{heat content previous hour} - \text{heat content present hour})$$

where storage capacity is the active volume of the tank

STORAGE EFFICIENCY

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

STORAGE LOSS (BTU)

$$\text{STLOSS} = \text{STEI} - \text{STEO} - \text{STECH}$$

AVERAGE TEMPERATURE OF STORAGE (°F)

$$\text{TST} = 1/60 \times \Sigma(\text{T201} + \text{T202} + \text{T203})/3 \times \Delta\tau$$

HOT WATER SUBSYSTEM

HOT WATER CONSUMED (GAL)

$$\text{HWSCM} = \text{W300}$$

SUPPLY WATER TEMPERATURE (°F)

$$\text{TSW} = \frac{\text{T300} \times \text{M300}}{\text{M300}} \quad \begin{array}{l} \text{The mass flow is used to insure that the supply water} \\ \text{temperature is recorded only when there is consumption.} \end{array}$$

DELIVERY WATER TEMPERATURE (°F)

$$\text{THW} = \frac{\text{T351} \times \text{M300}}{\text{M300}} \quad \begin{array}{l} \text{The mass flow is used to insure that the delivery water} \\ \text{temperature is recorded only when there is consumption.} \end{array}$$

HOT WATER LOAD (BTU)

$$\text{HWL} = \Sigma\text{M403} \times \text{HWD} (\text{T400}, \text{T403}) \times \Delta\tau$$

HOT WATER SOLAR ENERGY (BTU)

$$\text{HWSE} = \text{SEL} \times \text{HWL}/(\text{HWL} + \text{HL1})$$

$$\text{where HL1} = \Sigma\text{M401} \times \text{HWD} (\text{T401}, \text{T450}) \times \Delta\tau$$

HOT WATER AUXILIARY THERMAL ENERGY (BTU)

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

HOT WATER AUXILIARY THERMAL ENERGY (BTU)

$$HWAf = HWAT / .76$$

HOT WATER DEMAND (BTU)

$$HWDm = \Sigma M300 \times HWD (T351, T300) \times \Delta \tau$$

HOT WATER SOLAR FRACTION (%)

$$HWSFR = HWSE / HWL \times 100\%$$

HOT WATER DEMAND SOLAR FRACTION (%)

$$HWDsFR = \text{Fraction of delivered hot water load derived from solar sources} \\ \text{after proportioning storage losses to solar and auxiliary sources.}$$

SOLAR SPECIFIC HOT WATER OPERATING ENERGY (BTU)

$$HWOPE1 = (56.8833 \times \Sigma EP200 \times \Delta \tau) \times \frac{HWL}{HWL + HL1}$$

HOT WATER OPERATING ENERGY (BTU)

$$HWOPE = (56.8833 \times \Sigma (EP350 + EP403) \times \Delta \tau) + HWOPE1$$

HOT WATER SAVINGS FOSSIL (BTU)

$$HWSVF = HWSE / 0.76$$

HOT WATER SAVINGS ELECTRIC (BTU)

$$HWSVE = -HWOPE1$$

HOT WATER SOLAR SAVING RATIO

$$HWSSR = \frac{HWSE - (1 - MEFF) \times (HWOPE1 + (HWSE / SEL) \times CSOPE)}{HWL}$$

SPACE HEATING SUBSYSTEM

SOLAR ENERGY TO SPACE HEATING (BTU)

$$HSE = SEL - HWSE$$

SPACE HEATING AUXILIARY THERMAL ENERGY (BTU)

$$HAT = AXT - HWAT$$

CONTROLLED DELIVERED ENERGY (BTU)

$$CDE = HAT + HSE$$

SOLAR SPECIFIC SPACE HEATING OPERATING ENERGY (BTU)

$$HOPE1 = (56.8833 \times \Sigma EP200 \times \Delta\tau) - HWOPE1$$

SPACE HEATING OPERATING ENERGY (BTU)

$$HOPE = (56.8833 \times \Sigma (EP401 + EP402 + EP403) \times \Delta\tau) + HOPE1$$

EQUIPMENT HEATING LOAD (BTU)

$$EHL = CDE + (AXF - AXT) \times 0.21 + 0.3 \times (HOPE + HWOPE + CSOPE)$$

HEATING SOLAR FRACTION (%)

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

SPACE HEATING AUXILIARY FOSSIL ENERGY (BTU)

$$HAF = HAT/0.76$$

SPACE HEATING FOSSIL SAVINGS (BTU)

$$HSVF = HSE/0.76$$

SPACE HEATING ELECTRICAL SAVINGS (BTU)

$$HSVE = -HOPE1$$

SPACE HEATING SOLAR ENERGY RATIO

$$HSSR = \frac{HSE - (1 - MEFF) \times (HOPE1 + (HSE/SEL) \times CSOPE)}{EHL}$$

SYSTEM LEVEL PERFORMANCE FACTORS

SYSTEM LOAD (BTU)

$$SYSL = EHL + HWL$$

SOLAR ENERGY TO THE LOADS SUBSYSTEM (BTU)

$$SEL = STEO$$

SYSTEM SOLAR FRACTION OF SYSTEM LOAD (%)

$$SFR = SEL/SYSL \times 100\%$$

TOTAL AUXILIARY FOSSIL ENERGY TO SYSTEM LOADS (BTU)

$$AXF = \Sigma F400 \times FCONST \times \Delta \tau$$

TOTAL AUXILIARY THERMAL ENERGY TO SYSTEM LOADS (BTU)

$$AXT = AXF \times 0.76$$

SYSTEM OPERATING ENERGY (BTU)

$$SYSOPE = HOPE + HWOPE + CSOPE$$

TOTAL ENERGY CONSUMED (BTU)

$$TECSM = SYSOPE \times AXF + SECA$$

TOTAL FOSSIL ENERGY SAVINGS (BTU)

$$TSVF = HSVF + HWSVF$$

TOTAL ELECTRICAL SAVINGS (BTU)

$$TSVE = HSVE + HWSVE - CSOPE$$

SOLAR SPECIFIC OPERATING ENERGY (BTU)

$$SYSOPE1 = HOPE1 + HWOPE1 + CSOPE$$

SYSTEM PERFORMANCE FACTOR

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

SOLAR SAVINGS RATIO

$$SSSR = \frac{SEL - (1 - MEFF) \times SYSOPE1}{SYSL}$$

ESCC SOLAR CONVERSION EFFICIENCY

$$CSCEF = SEL / SEA$$

APPENDIX E
LONG-TERM WEATHER DATA

LAWRENCE BERKELEY LABORATORY LONG-TERM WEATHER DATA

COLLECTOR TILT: 45 DEGREES
LATITUDE: 38 DEGREES

LOCATION: BERKELEY, CALIFORNIA
COLLECTOR AZIMUTH: 0 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JUL	3,549	2,323	0.65446	0.817	1,898	12	117	68
AUG	3,219	2,054	0.63804	0.928	1,907	15	111	68
SEP	2,685	1,700	0.63312	1.130	1,920	13	94	68
OCT	2,062	1,213	0.58834	1.405	1,704	90	19	63
NOV	1,544	822	0.53253	1.685	1,385	276	0	56
DEC	1,313	645	0.49141	1.827	1,179	456	0	50
JAN	1,439	708	0.49196	1.728	1,223	481	0	50
FEB	1,895	1,018	0.53709	1.475	1,501	350	0	53
MAR	2,475	1,456	0.58844	1.219	1,775	322	0	55
APR	3,067	1,921	0.62633	0.993	1,907	228	12	58
MAY	3,474	2,212	0.63673	0.851	1,882	123	20	62
JUN	3,636	2,349	0.64589	0.793	1,862	50	71	66

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 heating degree-days per month.

CDD - Number of cooling degree-days per month.

TBAR - Average ambient temperature in degrees Fahrenheit.

APPENDIX F
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	292.8×10^{-6} kwh/BTU

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

²No. 5 and No. 6 fuel oils

APPENDIX G

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 H
TYPICAL MONTHLY DATA

MONTHLY REPORT: FEBRUARY 1981
SITE SUMMARY: LAWRENCE-BERKELEY LABORATORY

	CONVENTIONAL UNITS
GENERAL SITE DATA:	
INCIDENT SOLAR ENERGY	56.773 MILLION BTU 39757 BTU/SQ.FT.
COLLECTED SOLAR ENERGY	5.126 MILLION BTU 3590 BTU/SQ.FT.
AVERAGE AMBIENT TEMPERATURE	55 DEGREES F
AVERAGE BUILDING TEMPERATURE	73 DEGREES F
ECSS SOLAR CONVERSION EFFICIENCY	0.02
ECSS OPERATING ENERGY	0.263 MILLION BTU
STORAGE EFFICIENCY	20.89 PERCENT
EFFECTIVE HEAT TRANSFER COEFFICIENT	0.158 BTU/DEG F- SQ FT-HR
TOTAL SYSTEM OPERATING ENERGY	2.380 MILLION BTU
TOTAL ENERGY CONSUMED	271.970 MILLION BTU

SUBSYSTEM SUMMARY:

	HOT WATER	HEATING	COOLING	SYSTEM TOTAL
LOAD	6.874	209.315	N.A.	216.188 MILLION BTU
SOLAR FRACTION	1	1	N.A.	1 PERCENT
SOLAR ENERGY USED	0.090	1.050	N.A.	1.140 MILLION BTU
OPERATING ENERGY	0.255	1.863	N.A.	2.380 MILLION BTU
AUX. THERMAL ENERGY	6.784	194.289	N.A.	201.074 MILLION BTU
AUX. ELECTRIC FUEL	N.A.	N.A.	N.A.	N.A. MILLION BTU
AUX. FOSSIL FUEL	8.926	255.644	N.A.	264.571 MILLION BTU
ELECTRICAL SAVINGS	-0.015	-0.144	N.A.	-0.422 MILLION BTU
FOSSIL SAVINGS	0.118	1.382	N.A.	1.500 MILLION BTU

SYSTEM PERFORMANCE FACTOR:

0.79

INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS: 32.14

* = 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: LAWRENCE-BERKELEY LABORATORY

SI UNITS

GENERAL SITE DATA:

INCIDENT SOLAR ENERGY	59.895 GIGA JOULES
	451479 KJ/SQ.M.
COLLECTED SOLAR ENERGY	5.408 GIGA JOULES
	40766 KJ/SQ.M.
AVERAGE AMBIENT TEMPERATURE	13 DEGREES C
AVERAGE BUILDING TEMPERATURE	23 DEGREES C
ECSS SOLAR CONVERSION EFFICIENCY	0.02
ECSS OPERATING ENERGY	0.277 GIGA JOULES
STORAGE EFFICIENCY	20.89 PERCENT
EFFECTIVE HEAT TRANSFER COEFFICIENT	0.899 W/SQ M-DEG K
TOTAL SYSTEM OPERATING ENERGY	2.511 GIGA JOULES
TOTAL ENERGY CONSUMED	286.928 GIGA JOULES

SUBSYSTEM SUMMARY:

	HOT WATER	HEATING	COOLING	SYSTEM TOTAL
LOAD	7.252	220.827	N.A.	228.079 GIGA JOULES
SOLAR FRACTION	1	1	N.A.	1 PERCENT
SOLAR ENERGY USED	0.095	1.108	N.A.	1.203 GIGA JOULES
OPERATING ENERGY	0.269	1.965	N.A.	2.511 GIGA JOULES
AUX. THERMAL ENG	7.157	204.975	N.A.	212.132 GIGA JOULES
AUX. ELECTRIC FUEL	N.A.	N.A.	N.A.	N.A. GIGA JOULES
AUX. FOSSIL FUEL	9.417	269.704	N.A.	279.122 GIGA JOULES
ELECTRICAL SAVINGS	-0.016	-0.152	N.A.	-0.445 GIGA JOULES
FOSSIL SAVINGS	0.124	1.458	N.A.	1.583 GIGA JOULES

SYSTEM PERFORMANCE FACTOR:

0.79

INTERPOLATED PERFORMANCE FACTORS, PERCENT OF HOURS: 32.14

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

REFERENCE: USER'S GUIDE TO MONTHLY PERFORMANCE REPORTS, JUNE 1980.
 SOLAR/0034-80/18

MONTHLY REPORT: LAWERENCE-BERKELEY LABORATORY
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 (N111)
(NBS ID)	(Q001)	(N113)			(Q102)		
1	2.375	49	0.074	N	0.013	0.221	0.031
2	2.856	53	0.064	O	0.016	0.369	0.022
3	2.668	54	0.091	T	0.016	0.324	0.034
4	2.572	53	0.046		0.015	0.277	0.018
5	2.021	52	0.070	A	0.011	0.188	0.034
6	2.095	51	0.006	P	0.005	0.000	0.003
7	1.646	51	0.000	P	0.003	0.000	0.000
8	0.271	49	0.000	L	0.000	0.000	0.000
9	2.356	53	0.033	I	0.007	0.000	0.014
10	1.437	54	0.004	C	0.003	0.000	0.003
11	0.882	54	0.019	A	0.000	0.000	0.022
12	2.607	59	0.080	B	0.015	0.262	0.031
13	0.589	58	0.008	L	0.000	0.000	0.013
14	2.627	59	0.020	E	0.009	0.000	0.008
15	2.299	57	0.055		0.015	0.364	0.024
16	2.023	58	0.034		0.007	0.000	0.017
17	2.264	58	0.114		0.015	0.368	0.054
18	2.845	63	0.047		0.018	0.421	0.017
19	0.508	54	0.011		0.003	0.118	0.044
20	2.881#	54#	0.022#		0.012#	0.168#	0.014#
21	2.840	58	0.079		0.017	0.421	0.028
22	3.097	61	0.062		0.020	0.498	0.020
23	1.922	55	0.001		0.004	0.000	0.001
24	0.901	46	0.001		0.000	0.000	0.001
25	2.048#	55#	0.040#		0.010#	0.168#	0.020#
26	2.048#	55#	0.040#		0.010#	0.168#	0.020#
27	2.048#	55#	0.040#		0.010#	0.168#	0.020#
28	2.048#	55#	0.040#		0.010#	0.168#	0.020#
SUM	56.773	-	1.099	N.A.	0.263	4.671	-
AVG	2.028	55	0.039	N.A.	0.009	0.167	0.020
PFRV	0.7902	0.7902	0.7902	N.A.	0.7902	0.7902	0.7768

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

MONTHLY REPORT: LAWRENCE-BERKELEY LABORATORY
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	2.375	1.971	0.268	59	0.113	0.136
2	2.856	2.387	0.225	61	0.079	0.094
3	2.668	2.333	0.268	64	0.101	0.115
4	2.572	2.058	0.201	64	0.078	0.097
5	2.021	1.589	0.206	60	0.102	0.130
6	2.095	1.033	0.274	53	0.131	0.266
7	1.646	0.579	0.119	54	0.072	0.205
8	0.271	0.000	0.000	54	0.000	0.000
9	2.356	1.379	0.391	60	0.166	0.284
10	1.437	0.534	0.157	61	0.109	0.294
11	0.882	0.089	0.000	58	0.000	0.000
12	2.607	2.205	0.334	69	0.128	0.151
13	0.589	0.000	0.000	57	0.000	0.000
14	2.627	1.805	0.478	65	0.182	0.265
15	2.299	1.690	-0.032	70	-0.014	-0.019
16	2.023	1.215	0.305	70	0.151	0.251
17	2.264	1.916	0.135	68	0.060	0.070
18	2.845	2.477	0.237	73	0.083	0.096
19	0.508	0.154	-0.109	56	-0.215	-0.710
20	2.881#	2.243#	0.374#	65#	0.130#	0.167#
21	2.840	2.492	0.147	63	0.052	0.059
22	3.097	2.706	0.227	70	0.073	0.084
23	1.922	0.867	0.162	63	0.084	0.187
24	0.901	0.000	0.000	48	0.000	0.000
25	2.048#	1.433#	0.190#	62#	0.093#	0.132#
26	2.048#	1.433#	0.190#	62#	0.093#	0.132#
27	2.048#	1.433#	0.190#	62#	0.093#	0.132#
28	2.048#	1.433#	0.190#	62#	0.093#	0.132#
SUM	56.773	39.454	5.126	-	-	-
AVG	2.028	1.409	0.183	62	0.090	0.130
PFRV	0.7902	0.7902	0.7902	0.7902	0.7902	0.7902

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

MONTHLY REPORT: LAWRENCE-BERKELEY LABORATORY
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	0.254	0.074	-0.006	184	0.19
2	0.216	0.064	-0.005	186	0.17
3	0.243	0.091	0.003	185	0.16
4	0.174	0.046	0.003	185	0.13
5	0.190	0.070	0.003	183	0.13
6	0.273	0.006	0.100	185	0.18
7	0.110	0.000	-0.018	188	0.13
8	0.000	0.000	-0.076	185	0.08
9	0.367	0.033	0.137	185	0.21
10	0.148	0.004	-0.056	188	0.21
11	0.000	0.019	-0.155	182	0.15
12	0.313	0.080	0.087	182	0.17
13	0.000	0.008	-0.123	178	0.14
14	0.482	0.020	0.306	183	0.18
15	-0.041	0.055	-0.179	191	0.09
16	0.318	0.034	0.151	186	0.15
17	0.113	0.114	-0.153	190	0.16
18	0.212	0.047	-0.005	186	0.19
19	-0.110	0.011	-0.087	180	0.04
20	0.360#	0.022#	0.096	182#	0.27#
21	0.128	0.079	-0.206	188	0.28
22	0.195	0.062	-0.006	188	0.16
23	0.174	0.001	0.047	182	0.14
24	0.000	0.001	-0.096	180	0.10
25	0.179#	0.040#	*	185#	*
26	0.179#	0.040#	*	185#	*
27	0.179#	0.040#	*	185#	*
28	0.179#	0.040#	*	185#	*
SUM	4.836	1.099	-0.089	-	-
AVG	0.173	0.039	-0.003	185	0.16
PFRV	0.7902	0.7902	N.A.	0.7902	0.7902

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

MONTHLY REPORT: LAWRENCE-BERKELEY LABORATORY
SPACE HEATING SUBSYSTEM I

FEBRUARY 1981

DAY OF MONTH	SPACE HEATING LOAD MILLION BTU	CONTROLLED DELIVERED ENERGY MILLION BTU	TOTAL SOLAR ENERGY USED MILLION BTU	TOTAL AUXILIARY THERMAL USED MILLION BTU	SOLAR FRACTION OF LOAD PCT	ELECT ENERGY SAVINGS MILLION BTU	FOSSIL ENERGY SAVINGS MILLION BTU	BLDG TEMP DEG F	AMB TEMP DEG F
(NBS ID)	(Q402)		(Q400)	(Q401)	(N400)	(Q415)	(Q417)	(N406)	(N113)
1	2.456	2.278	0.061	2.218	2	-0.004	0.080	70	49
2	12.482	11.659	0.062	11.597	0	-0.013	0.082	72	53
3	11.580	10.817	0.088	10.728	1	-0.011	0.116	73	54
4	10.220	9.543	0.044	9.499	0	-0.009	0.058	72	53
5	9.438	8.816	0.066	8.750	1	-0.006	0.087	73	52
6	9.336	8.718	0.005	8.713	0	-0.001	0.007	72	51
7	2.542	2.358	0.000	2.358	0	0.000	0.000	72	51
8	2.680	2.491	0.000	2.491	0	0.000	0.000	71	49
9	10.303	9.624	0.032	9.592	0	-0.006	0.042	72	53
10	9.630	8.996	0.004	8.993	0	-0.001	0.005	72	54
11	8.633	8.062	0.019	8.043	0	0.000	0.025	73	54
12	7.354	6.856	0.077	6.779	1	-0.008	0.101	74	59
13	5.950	5.543	0.007	5.536	0	0.000	0.009	75	58
14	2.443	2.263	0.020	2.243	1	-0.002	0.026	75	59
15	2.354	2.176	0.050	2.126	2	-0.010	0.065	74	57
16	7.875	7.362	0.034	7.328	0	-0.004	0.045	73	58
17	7.909	7.386	0.117	7.269	1	-0.011	0.154	74	58
18	5.288	4.921	0.033	4.887	1	-0.007	0.044	75	63
19	7.964	7.433	0.020	7.413	1	-0.004	0.026	75	54
20	7.545#	7.042#	0.037#	7.005#	1#	-0.005#	0.049#	73#	54#
21	5.191	4.835	0.074	4.761	1	-0.010	0.097	73	58
22	2.497	2.311	0.051	2.260	2	-0.010	0.067	73	61
23	11.285	10.546	0.001	10.545	0	-0.001	0.001	74	55
24	16.178	15.137	0.001	15.136	0	0.000	0.001	74	46
25	7.545#	7.042#	0.037#	7.005#	1#	-0.005#	0.049#	73#	55#
26	7.545#	7.042#	0.037#	7.005#	1#	-0.005#	0.049#	73#	55#
27	7.545#	7.042#	0.037#	7.005#	1#	-0.005#	0.049#	73#	55#
28	7.545#	7.042#	0.037#	7.005#	1#	-0.005#	0.049#	73#	55#
SUM	209.315	195.340	1.050	194.289	-	-0.144	1.382	-	-
AVG	7.476	6.976	0.038	6.939	1	-0.005	0.049	73	55
PFRV	0.7768	0.7768	0.7768	0.7768	0.7768	0.7768	0.7768	0.7902	0.7902

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

MONTHLY REPORT: LAWERENCE-BERKELEY LABORATORY
SPACE HEATING SUBSYSTEM II

FEBRUARY 1981

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	2.456	N	N	0.066	0.004	N	2.918	13
2	12.482	O	O	0.074	0.013	O	15.260	10
3	11.580	T	T	0.072	0.011	T	14.116	11
4	10.220			0.071	0.009		12.498	9
5	9.438	A	A	0.068	0.006	A	11.513	10
6	9.336	P	P	0.062	0.001	P	11.464	13
7	2.542	P	P	0.062	0.000	P	3.103	12
8	2.680	L	L	0.062	0.000	L	3.278	15
9	10.303	I	I	0.067	0.006	I	12.621	9
10	9.630	C	C	0.062	0.001	C	11.832	8
11	8.633	A	A	0.062	0.000	A	10.582	8
H-7 12	7.354	B	B	0.069	0.008	B	8.919	4
13	5.950	L	L	0.061	0.000	L	7.284	6
14	2.443	E	E	0.064	0.002	E	2.952	3
15	2.354			0.072	0.010		2.798	5
16	7.875			0.066	0.004		9.642	5
17	7.909			0.072	0.011		9.564	3
18	5.288			0.069	0.007		6.431	1
19	7.964			0.064	0.004		9.754	10
20	7.545#			0.065#	0.005#		9.217#	11
21	5.191			0.072	0.010		6.265	3
22	2.497			0.072	0.010		2.974	2
23	11.285			0.062	0.001		13.875	7
24	16.178			0.062	0.000		19.915	17
25	7.545#			0.067#	0.005#		9.217#	*
26	7.545#			0.067#	0.005#		9.217#	*
27	7.545#			0.067#	0.005#		9.217#	*
28	7.545#			0.067#	0.005#		9.217#	*
SUM	209.315	N.A.	N.A.	1.863	0.144	N.A.	255.644	230
AVG	7.476	N.A.	N.A.	0.067	0.005	N.A.	9.130	8
PFRV	0.7768	N.A.	N.A.	0.7902	0.7768	N.A.	0.7768	N.A.

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

MONTHLY REPORT: LAWRENCE-BERKELEY LABORATORY
ENVIRONMENTAL SUMMARY

FEBRUARY 1981

DAY OF MONTH	TOTAL INSOLATION BTU/SQ.FT (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	1663	N	49	59	N	N	N
2	2000	O	53	61	O	O	O
3	1869	T	54	64	T	T	T
4	1801		53	64			
5	1416	A	52	60	A	A	A
6	1467	P	51	53	P	P	P
7	1153	P	51	54	P	P	P
8	190	L	49	54	L	L	L
9	1650	I	53	60	I	I	I
10	1006	C	54	61	C	C	C
11	617	A	54	58	A	A	A
12	1826	B	59	69	B	B	B
13	413	L	58	57	L	L	L
14	1839	E	59	65	E	E	E
15	1610		57	70			
16	1417		58	70			
17	1585		58	68			
18	1993		63	73			
19	356		54	56			
20	2017#		54#	65#			
21	1989		58	63			
22	2169		61	70			
23	1346		55	63			
24	631		46	48			
25	1434#		55#	62#			
26	1434#		55#	62#			
27	1434#		55#	62#			
28	1434#		55#	62#			
SUM	39757	N.A.	-	-	-	-	-
AVG	1420	N.A.	55	62	N.A.	N.A.	N.A.
PFRV	0.7902	N.A.	0.7902	0.7902	N.A.	N.A.	N.A.

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MONTHLY REPORT: LAWRENCE-BERKELEY LABORATORY
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	0.107	13	0.000	33	0.014	0.010	0.093
2	0.396	0	0.024	4	0.001	0.010	0.395
3	0.381	1	0.028	1	0.003	0.010	0.379
4	0.316	1	0.023	1	0.002	0.009	0.314
5	0.279	1	0.017	2	0.004	0.009	0.276
6	0.300	0	0.017	0	0.000	0.009	0.300
7	0.126	0	0.001	0	0.000	0.008	0.126
8	0.082	0	0.000	0	0.000	0.008	0.082
9	0.314	1	0.017	0	0.002	0.009	0.312
10	0.276	0	0.019	0	0.000	0.009	0.276
11	0.284	0	0.015	0	0.000	0.009	0.284
12	0.359	1	0.020	0	0.003	0.009	0.356
13	0.338	0	0.017	1	0.001	0.010	0.337
14	0.140	0	0.001	0	0.000	0.008	0.140
15	0.165	3	0.000	2	0.005	0.009	0.160
16	0.078	0	0.001	2	0.000	0.007	0.078
17	0.254	3	0.016	3	0.006	0.009	0.247
18	0.256	5	0.020	2	0.014	0.011	0.242
19	0.279	1	0.017	3	0.002	0.009	0.277
20	0.246#	1#	0.013#	3#	0.003#	0.010#	0.243#
21	0.201	2	0.007	3	0.005	0.009	0.196
22	0.127	9	0.001	7	0.011	0.010	0.116
23	0.304	0	0.018	2	0.000	0.009	0.304
24	0.281	0	0.017	0	0.000	0.009	0.281
25	0.246#	1#	0.013#	3#	0.003#	0.009#	0.243#
26	0.246#	1#	0.013#	3#	0.003#	0.009#	0.243#
27	0.246#	1#	0.013#	3#	0.003#	0.009#	0.243#
28	0.246#	1#	0.013#	3#	0.003#	0.009#	0.243#
SUM	6.874	-	0.358	-	0.090	0.255	6.784
AVG	0.245	1	0.013	2	0.003	0.009	0.242
PFRV	0.7768	0.7768	0.7753	0.7763	0.7768	0.7902	0.7768

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MONTHLY REPORT: LAWERENCE-BERKELEY LABORATORY
HOT WATER SUBSYSTEM II

FEBRUARY 1981

DAY OF MON.	AUX ELECT FUEL MILLION BTU	AUX FOSSIL FUEL MILLION BTU	ELECT ENERGY SAVINGS MILLION BTU	FOSSIL ENERGY SAVINGS MILLION BTU	SUPPLY WATER TEMP DEG F	HOT WATER TEMP DEG F	HOT WATER USED GAL	SOLAR SPECIFIC OPER ENERGY MILLION BTU
(NBS)	(Q305)	(Q306)	(Q311)	(Q313)	(Q305)	(N307)	(N308)	
1	N	0.123	-0.002	0.018	73	110	1	0.002
2	O	0.519	0.000	0.002	56	111	54	0.000
3	T	0.498	-0.001	0.003	55	112	60	0.001
4		0.413	0.000	0.003	56	113	47	0.000
5	A	0.363	0.000	0.005	56	113	36	0.000
6	P	0.394	0.000	0.000	56	114	34	0.000
7	P	0.165	0.000	0.000	65	113	2	0.000
8	L	0.108	0.000	0.000	70	113	1	0.000
9	I	0.411	0.000	0.002	56	113	36	0.000
10	C	0.363	0.000	0.000	57	114	39	0.000
11	A	0.374	0.000	0.000	56	113	31	0.000
12	B	0.468	-0.001	0.003	56	113	42	0.001
13	L	0.443	0.000	0.001	57	113	36	0.000
14	E	0.184	0.000	0.000	70	112	2	0.000
15		0.210	-0.001	0.007	71	113	1	0.001
16		0.102	0.000	0.000	68	112	2	0.000
17		0.325	0.000	0.003	58	113	35	0.000
18		0.319	-0.003	0.013	58	112	44	0.003
19		0.364	-0.001	0.003	58	113	36	0.001
20		0.320#	-0.001#	0.004#	61#	113#	28#	0.001#
21		0.257	-0.001	0.007	62	113	16	0.001
22		0.153	-0.002	0.014	68	111	2	0.002
23		0.400	0.000	0.000	57	112	39	0.000
24		0.370	0.000	0.000	59	113	37	0.000
25		0.320#	-0.001#	0.004#	61#	113#	28#	0.001#
26		0.320#	-0.001#	0.004#	61#	113#	28#	0.001#
27		0.320#	-0.001#	0.004#	61#	113#	28#	0.001#
28		0.320#	-0.001#	0.004#	61#	113#	28#	0.001#
SUM	N.A.	8.925	-0.015	0.118	-	-	771	0.015
AVG	N.A.	0.319	-0.001	0.004	58	113	28	0.001
PFRV	N.A.	0.7763	0.7768	0.7763	0.7753	0.7902	0.7753	0.7768

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