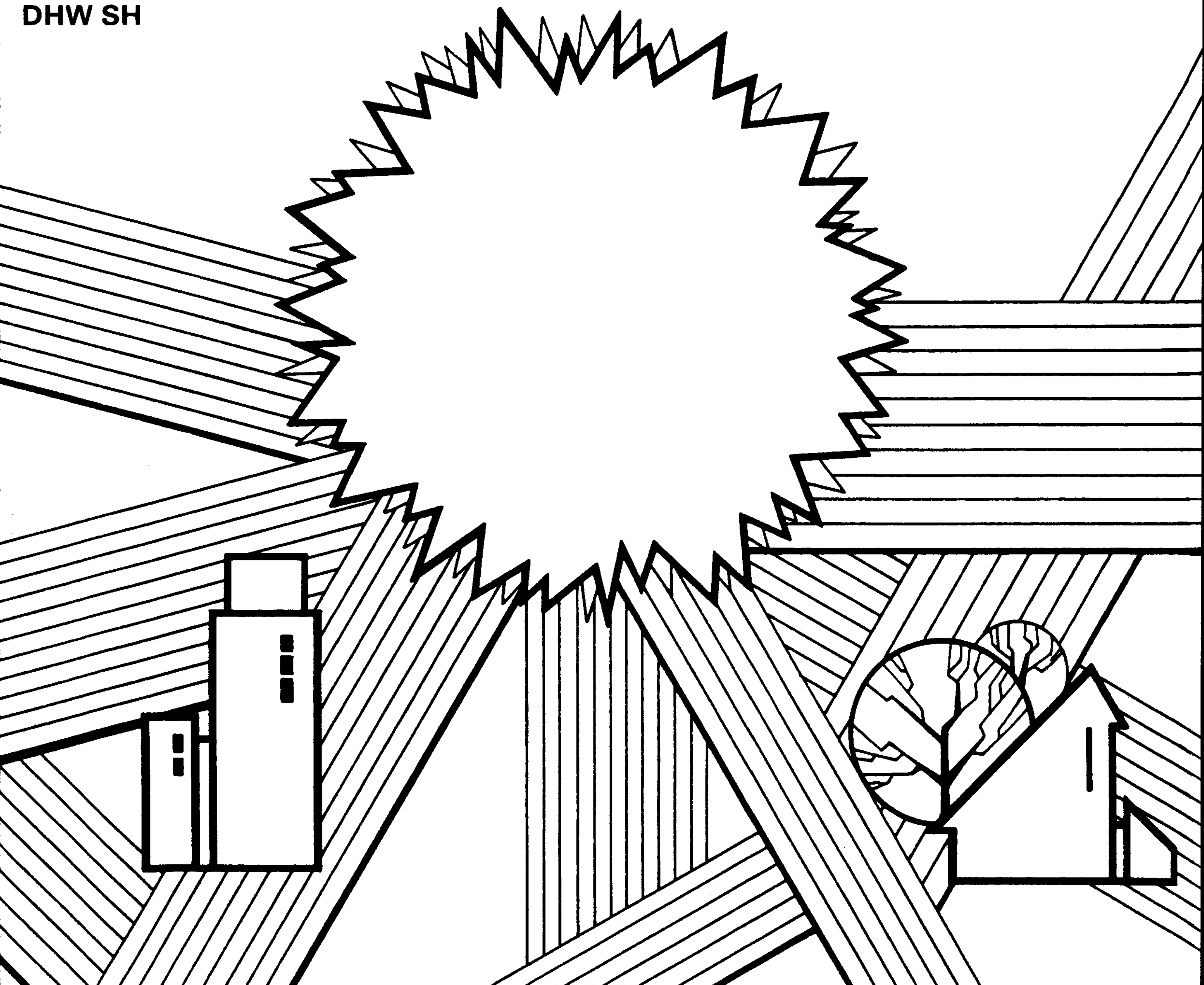
SOLAR/1045-80/14
(DE81028175)

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

MONTECITO PINES

Santa Rosa, California
November 1979 through April 1980

DHW SH



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(DE81028175)
Distribution Category UC-59

MONTECITO PINES

SANTA ROSA, CALIFORNIA

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

NOVEMBER 1979 THROUGH APRIL 1980

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Department of Energy Contract Number DE-AC01-79CS30027
Contract Management by:
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FOREWORD

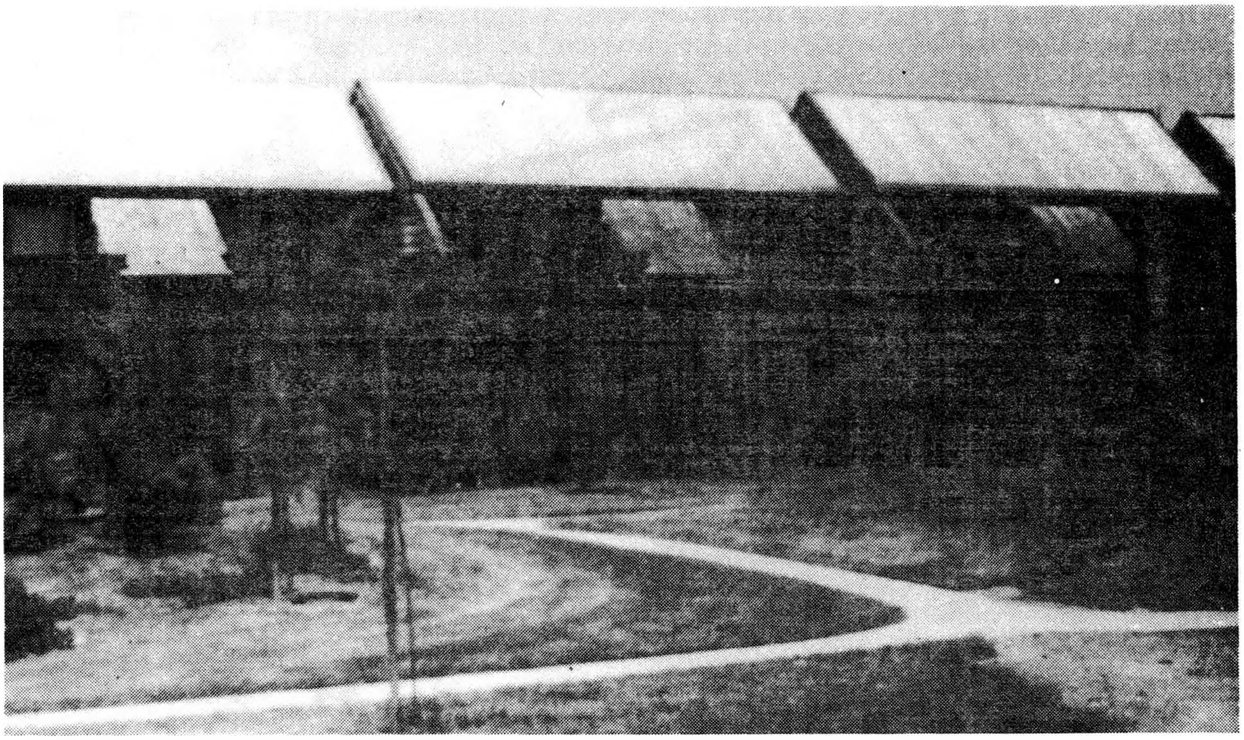
This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic hot water and annual performance reports are issued for such sites. In addition, Monthly Performance Reports 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 reduce the use of nonrenewable fuels by encouraging the application of solar energy for heating, cooling, and domestic hot water. Vitro Laboratories Division operates the NSDN, under contract with the Department of Energy, to collect daily data 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, Hawaii and Puerto Rico. 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.

In addition to these "Seasonal" Reports, NSDN information is disseminated for each operational site via Monthly Performance Reports, and special reports.



MONTECITO PINES

MONTECITO PINES

The Montecito Pines site is an apartment complex in Santa Rosa, California. The active solar energy system is designed to supply the following:

Seasonal Design Factors
(Million BTU)

	Total Load	Solar Contribution	% Solar
Heating	170.73	80.01	46
Hot Water	36.20	13.49	37

It is equipped with:

Collector Sunburst model BG-410 flat-plate collectors, gross area of 950 square feet. The array faces 23 degrees west of south at an angle of 45 degrees to the horizontal.

Storage Storage is a 2,000-gallon fiberglass underground storage tank.

Space Heating The distribution system for the space heating subsystem consists of a Taco pump designed to pump solar heated and/or auxiliary heated water through eight Lanco liquid-to-air heat exchangers and blowers.

Auxiliary Auxiliary energy to the space heating subsystem is provided by a Raypak 266 Raytherm gas-fired boiler with heat exchanger. The design energy input is 266,000 BTU/hr at its highest heat temperature. The design operating temperature is 120°F with an operating pressure of 60 psi. The DHW subsystem auxiliary energy is also provided by this gas-fired boiler.

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MONTECITO PINES
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Solar Savings Ratio[2]	12
Conventional Fuel Savings[3]	68,541 cubic feet of natural gas
System Performance Factor	14.97
Solar System COP[4]	9.88

Seasonal Energy Requirements
November 1979 through April 1980
(million BTU)

	Total Load	Solar Contribution	% Solar
Heating	184.20	20.91	11
Hot Water	36.66	20.89	44

Environmental Data

	Measured Average	Long-Term Average
Outdoor temperature	49°F	52°F
Heating degree-days (Total)	2,764	2,460
Daily incident solar energy	1,160 BTU/ft^2	1,362 BTU/ft^2

1. $\text{Solar Fraction} = \dfrac{\text{Solar Energy Supplied to Loads}}{\text{Total Load}}$

2. $\text{Solar Savings Ratio} = \dfrac{\text{Solar Energy Used by the Load Subsystem} - \text{Solar System Operating Energy}}{\text{Total Load}}$

3. Conventional Fuel Savings (in kwh) = (Savings in BTU's) x 979.4 x 10^{-6} cubic feet/BTU

4. $\text{Solar System COP} = \dfrac{\text{Solar Energy Used}}{\text{Solar Unique Operating Energy Required for Collection}}$

1.1 SUMMARY AND CONCLUSIONS

The Montecito Pines site, an apartment complex in Santa Rosa, California, in which an eight-apartment unit has been equipped with a solar energy system, is instrumented and monitored as part of the National Solar Data Network. Each apartment has approximately 864 square feet of conditioned space. Solar energy is used for space heating and preheating domestic hot water (DHW).

Sunburst flat-plate collectors with a gross area of 950 square feet collect solar energy and transfers it to a 2,000-gallon fiberglass tank insulated with polyurethane. This collector array and tank serve all eight apartments. Freeze protection is provided by a drain-down feature incorporated in the collector subsystem. Solar energy is extracted from storage by circulating city water through a heat exchanger in the storage tank for preheating. When solar energy is insufficient to satisfy the load, the gas-fired boiler provides auxiliary energy. Four modes of operation are available: (1) Collector-to-Storage; (2) Storage-to-Space Heating; (3) Auxiliary Space Heating, and (4) DHW Preheating.

The solar energy system supplied 11% of the space heating energy and 44% of the domestic hot water energy requirements for the building during the heating season from November 1979 through April 1980. The space heating subsystem operated well below the the design prediction of 46% but the hot water subsystem operated better than the design prediction of 37%. The thermal performance is summarized in Table 1.

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

MONTECITO PINES
NOVEMBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	SOLAR ENERGY USED PREDICTED	SOLAR ENERGY USED MEASURED	AUXILIARY ENERGY FOSSIL	OPERATING ENERGY	ENERGY SAVINGS FOSSIL	SOLAR FRACTION (PERCENT) PREDICTED	SOLAR FRACTION (PERCENT) MEASURED
NOV	8.77	39.05	10.76	6.82	53.70	1.79	11.33	32	22
DEC	9.01	44.65	6.01	6.42	63.72	3.15	10.70	33	17
JAN	7.31	47.42	3.50	5.02	70.67	2.91	8.37	27	11
FEB	6.82	36.32	4.07	4.63	52.82	2.57	7.72	31	15
MAR	13.84	36.94	11.10	9.62	45.53	3.35	16.02	30	32
APR	13.95	27.70	9.89	9.29	30.70	2.82	15.48	45	42
TOTAL	59.70	232.08	45.33	41.80	317.13	16.59	69.68	-	-
AVERAGE	9.95	38.68	7.56	6.97	52.86	2.77	11.61	33	18

Figure 1, Energy Flow Diagram for Montecito Pines for November 1979 through April 1980, shows that the collector array collected 59.70 million BTU or 30% of energy from a total solar radiation of 200.90 million BTU. Analysis of the monthly data indicated that the control system was functioning very well, collecting solar energy when the radiation was high enough to be usable (operational insolation). Energy transfer losses were relatively low because the system is well insulated. Operating energy, or the energy used for pumps, fans etc. (non-thermal energy) which are part of the solar system, is considered reasonable for this type of solar energy system. Recirculation losses in the DHW loop account for a large portion of the losses in the hot water system. This is a penalty that must be paid for the convenience of having hot water available on demand. Part of the space heating subsystem losses and DHW recirculation loop losses may be contributing to the building heating load but this site is not instrumented to measure these and, therefore, they are classified as losses from the subsystems.

For the reporting period, the average monthly incident solar radiation of the collector array was 1,160 BTU/ft^2-day. This average is below the estimated monthly long-term average solar radiation of 1,362 BTU/ft^2-day for a south-facing plane with a tilt of 45 degrees to the horizontal. The long-term average weather data were obtained from nearby representative National Weather Service stations. The average temperature was 49°F as compared to the long-term average of 52°F. The monthly average number of heating degree-days based on a 65°F reference was 461 as compared with the long-term average of 410.

The solar energy system at Montecito Pines has operated through two heating seasons, and, according to available information, the system has required very little upkeep. The only equipment failure occurred in October 1979 when the collector pump failed and had to be replaced. In that month, the solar energy system was turned off to enable repairs to be made on the collector pump. This report, therefore, covers the heating months of November 1979 through April 1980.

1.2 OVERALL SYSTEM PERFORMANCE

The energy flow of solar energy at the Montecito Pines site for the six-month period from November 1979 through April 1980 is presented in Figure 1. This diagram shows the amount of energy collected, transported, stored, consumed or lost at at each major point in the system.

The total incident solar energy on the collector array during the reporting period was 200.90 million BTU. Of this total, 176.05 million BTU were incident while the collector loop was operating. The amount of solar energy collected was 59.70 million BTU, representing 30% of the total incident energy and 34% of the insolation available during collector loop operation. During the transfer of energy to storage, 5.28 million BTU of the 59.70 million BTU collected were lost. The storage subsystem supplied 49.20 million BTU to the subsystem loads, of which 20.89 million BTU went to the DHW subsystem and 20.91 million BTU went to the space heating subsystem. A loss of 7.40 million BTU of energy occurred during the transfer of energy to the subsystems.

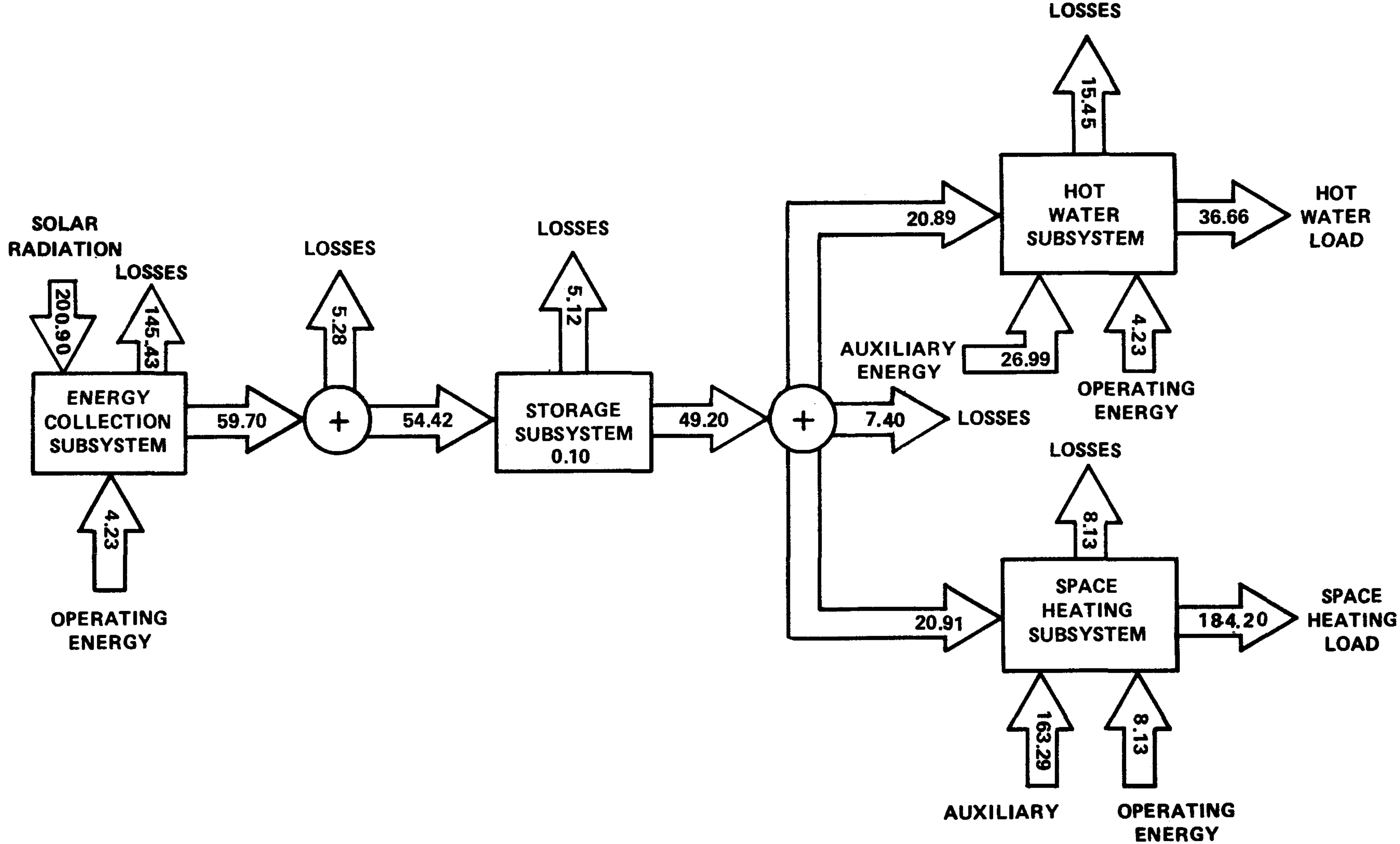
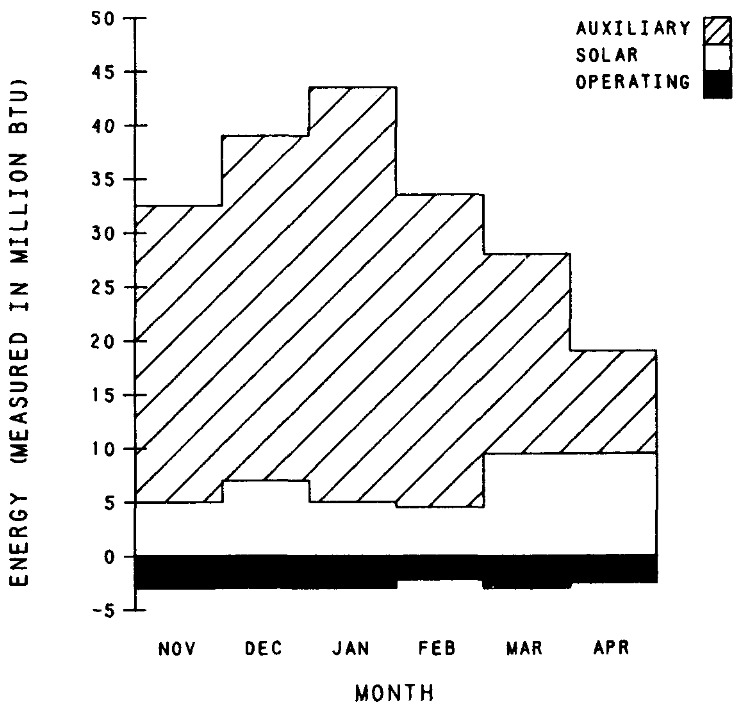


Figure 1. Energy Flow Diagram for Montecito Pines
November 1979 through April 1980
(Figures in million BTU)

The quantative proportioning of the distribution of energy which was depicted in the Energy Flow Diagram, Figure 1, for the entire apartment building was good during the reporting period. The DHW load of 36.66 million BTU of energy was satisfied by 26.99 million BTU of auxiliary thermal energy and 20.89 million BTU of solar energy. Energy lost from the DHW subsystem was 15.45 million BTU. The space heating load of 184.20 million BTU was satisfied by 20.91 million BTU of solar energy and 163.29 million BTU of auxiliary thermal energy.

The overall thermal performance of the solar energy system presented in Table 1 is shown graphically in Figure 2.



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
Montecito Pines
November 1979 through April 1980

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 Montecito Pines functioned at a reporting period weighted average COP value of 9.88 for the period November 1979 through April 1980.

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

MONTECITO PINES
NOVEMBER 1979 THROUGH APRIL 1980

MONTH	SOLAR ENERGY SYSTEM	COLLECTOR SUBSYSTEM	DOMESTIC HOT WATER SOLAR	SPACE HEATING SOLAR
NOV	6.83	18.27	5.57	4.80
DEC	4.42	12.17	5.10	1.68
JAN	5.02	13.29	4.63	1.07
FEB	4.63	11.96	4.51	1.18
MAR	9.62	12.73	4.68	3.67
APR	9.29	14.52	5.22	4.84
WEIGHTED AVERAGE	9.88	14.11	4.53	2.57

The average COP value in this table indicates that the system performed satisfactorily during the reporting season. However, the system is not instrumented to measure the solar unique operating energy for each subsystem. Therefore, the COP is calculated by using the total measured operating energy during the reporting period; thus, showing a good COP for the season.

1.3 ENERGY SAVINGS

Energy savings for this site for the reporting period, November 1979 through April 1980, are presented in Table 3 and shown graphically in Figure 3. For this six-month period, the net total savings were 69.68 million BTU, for a monthly average of 11.61 million BTU. These net savings are approximately 68,541 cubic feet of natural gas. An electrical energy expense of 4.23 million BTU or 1,239 kwh was incurred during the reporting period for the operation of solar energy components. These savings resulted in a monetary savings of approximately $220.00 based on an estimated cost of $4.13 per 1,000 cubic feet and $0.05 per kwh. 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 Montecito Pines site consists of a natural-gas-fired boiler. This unit is considered to be 60% efficient for computational purposes.

Table 3. ENERGY SAVINGS

MONTECITO PINES
NOVEMBER 1979 THROUGH APRIL 1980

(All values in million BTU)

MONTH	SOLAR ENERGY USED	SPACE HEATING FOSSIL FUEL	DOMESTIC HOT WATER FOSSIL FUEL	ECSS OPERATING ENERGY	NET ENERGY SAVINGS ELECTRICAL	NET ENERGY SAVINGS FOSSIL FUEL
NOV	6.83	4.93	6.40	0.48	-0.48	11.33
DEC	6.42	4.77	5.93	0.74	-0.74	10.70
JAN	5.02	2.97	5.40	0.55	-0.55	8.37
FEB	4.63	2.60	5.12	0.57	-0.57	7.72
MAR	9.62	10.32	5.70	0.93	-0.93	16.02
APR	9.29	9.20	6.28	0.96	-0.96	15.48
TOTAL	41.80	34.85	34.83	4.23	-4.23	69.68
AVERAGE	6.97	5.81	5.81	0.71	-0.71	11.61

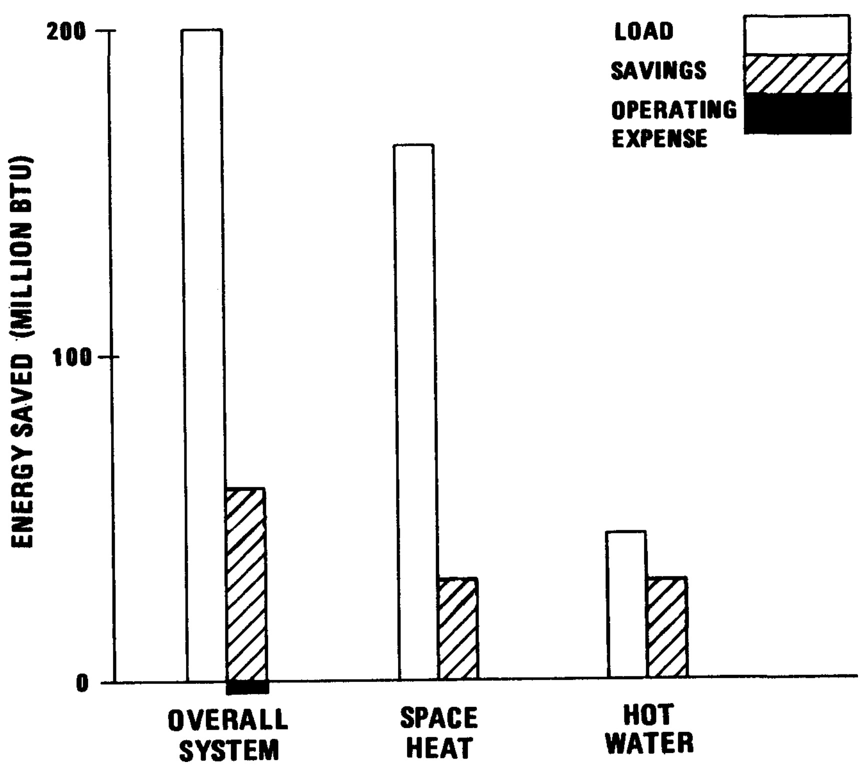


Figure 3. Thermal Energy Savings Compared to Load
Montecito Pines
November 1979 through April 1980

1.4 SOLAR ENERGY UTILIZATION

Figure 4 shows the use of solar energy and the percentage of losses.

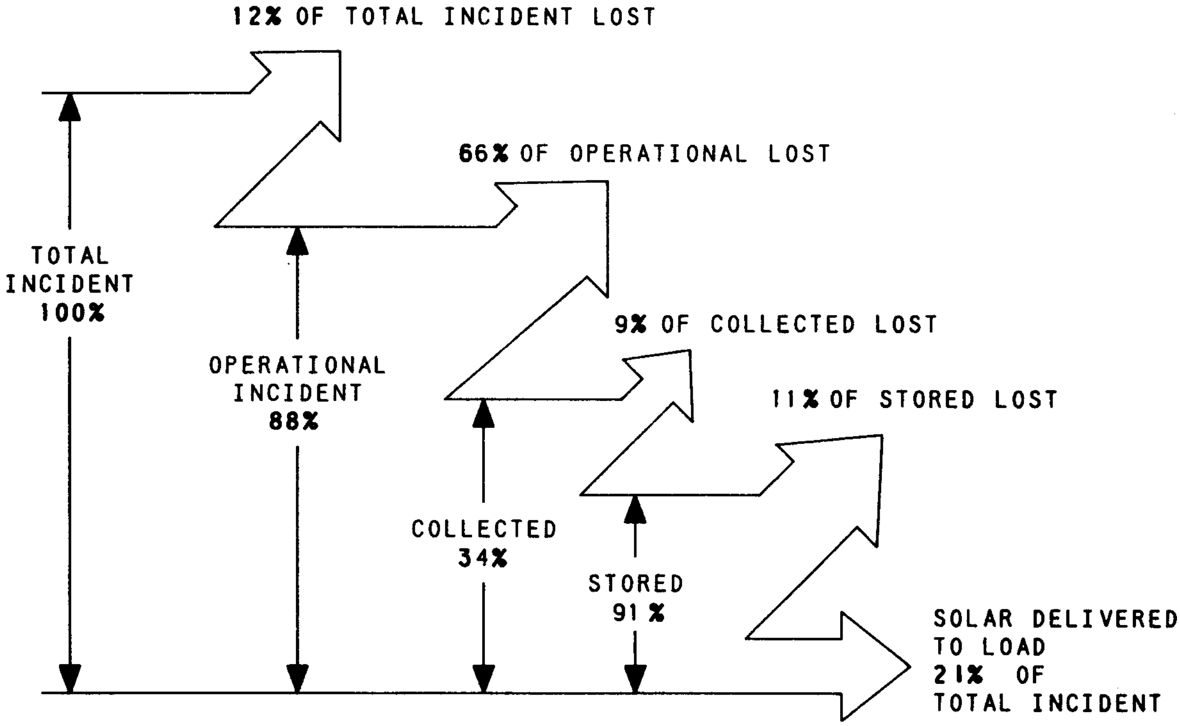


Figure 4. Solar Energy Use
Montecito Pines
November 1979 through April 1980

The losses of solar energy at the different stages through the system, from incident radiation to the load, are also presented in Table 4.

During the reporting period, the total incident solar energy on the collector array was 200.90 million BTU. Of this total, 176.05 million BTU or 88% were operational incident solar energy. Twelve percent of the incident solar energy was lost. The system collected 59.70 million BTU of solar energy or 34% of the operational incident solar energy. Of the collected solar energy, 91%, or 54.42 million BTU of energy, was transferred to storage. During the transfer of energy from the collector array to storage, 5.28 million BTU, or nine percent of the energy delivered to storage, were lost. Of the energy stored, 41.80 million BTU, or 21% of the total incident solar energy, were delivered to the DHW and space heating subsystem loads.

Table 4. SOLAR ENERGY LOSSES

MONTECITO PINES
NOVEMBER 1979 THROUGH APRIL 1980

	MONTHS					
	NOV	DEC	JAN	FEB	MAR	APR
1. SOLAR ENERGY (SE) COLLECTED MINUS SE DIRECTLY TO LOADS (million BTU)	8.77	9.01	7.31	6.82	13.84	13.95
2. SE TO STORAGE (million BTU)	8.01	8.70	6.77	6.14	12.62	12.18
3. LOSS - COLLECTOR TO STORAGE (%)	9	3	7	10	9	13
4. CHANGE IN STORED ENERGY (million BTU)	-0.08	-0.28	0.13	0.15	0.00	0.24
5. SOLAR ENERGY - STORAGE TO DHW SUBSYSTEM (million BTU)	3.84	3.56	3.24	3.07	3.42	3.76
6. SOLAR ENERGY - STORAGE TO SPACE HEATING SUBSYSTEM (million BTU)	2.99	2.86	1.78	1.76	6.20	5.52
7. LOSS FROM STORAGE (%)	12	12	17	15	7	1
8. HOT WATER SOLAR ENERGY (HWSE) FROM STORAGE (million BTU)	3.84	3.56	3.24	3.07	3.42	3.76
9. HEATING SOLAR ENERGY (HSE) FROM STORAGE (million BTU)	2.99	2.86	1.78	1.76	6.20	5.52

1.5 SYSTEM AVAILABILITY

During the reporting period of November 1979 through April 1980, the system operated without failure.

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The collector array is composed of 24 Sunburst Model BG-410 collectors which use water as the transfer fluid. The total collector area is 950 square feet.

Collector subsystem performance for the Montecito Pines site is presented in Table 5. During the period from November 1979 through April 1980, there was a total of 200.90 million BTU of solar energy incident on the collector array. Of this total, 176.05 million BTU of energy were incident while the collectors were operating. The amount of solar energy collected was 59.70 million BTU, which represented a collector array efficiency of 30% based on total insolation and 34% based on operational incident solar energy. Of the collected solar energy, 54.42 million BTU were delivered to the storage tank. Energy lost during the transfer of energy from the collector to storage was 5.28 million BTU or nine percent of the collected energy. The operating energy required to run the collector pumps was 4.23 million BTU.

As indicated in Table 5, the collector subsystem performance during the reporting season was satisfactory. The table shows the collector array efficiency to be fairly constant over the entire reporting period.

Table 5. COLLECTOR SUBSYSTEM PERFORMANCE

MONTECITO PINES
NOVEMBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR SUBSYSTEM EFFICIENCY %	OPERATIONAL INCIDENT ENERGY	OPERATIONAL COLLECTOR EFFICIENCY %	ECSS OPERATING ENERGY	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE °F
NOV	30.33	8.77	29	26.86	33	0.48	8.01	57
DEC	30.20	9.01	30	27.44	33	0.74	8.70	55
JAN	24.07	7.31	30	20.68	35	0.55	6.77	53
FEB	23.14	6.82	30	19.24	35	0.57	6.14	57
MAR	46.18	13.84	30	40.70	34	0.93	12.62	60
APR	46.98	13.95	30	41.13	34	0.96	12.18	64
TOTAL	200.90	59.70	-	176.05	-	4.23	54.42	-
AVERAGE	33.48	9.95	30	29.34	34	0.71	9.07	58

2.2 STORAGE

Storage performance data for the site for the reporting period are shown in Table 6.

Storage consists of a 2,000-gallon fiberglass tank manufactured by North Coast Tank and Filter Company. The storage tank is insulated externally with 3.8 inches of polyurethane at the bottom and 2.5 inches of polyurethane on the top and sides.

During the reporting period, total solar energy delivered to storage was 54.42 million BTU.

There were 49.20 million BTU delivered from storage to the DHW and space heating subsystems. The change in stored energy was 0.10 million BTU. Energy loss from storage was 5.12 million BTU. This loss represents nine percent of the energy delivered to storage.

The average storage temperature was 102°F. The storage subsystem performed well. The storage efficiency was 91%. (See Footnote 1.)

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

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

Where: STEFF = Storage efficiency

STECH = Change in stored energy

STEO = Energy removed from storage

STEI = Energy added to storage

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

$$c = (STEI - STEO - STECH) / (T_s - T_a) \times t \quad \frac{BTU}{Hr\ °F}$$

Where: c = effective storage heat loss coefficient

T_s = average storage temperature

T_a = average ambient temperature in the vicinity of storage

t = number of hours in the month

Table 6. STORAGE PERFORMANCE

MONTECITO PINES
NOVEMBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY TO STORAGE	ENERGY FROM STORAGE	CHANGE IN STORED ENERGY	STORAGE EFFICIENCY (%)	AVERAGE STORAGE TEMP. (°F)	EFFECTIVE HEAT LOSS COEFFICIENT (BTU/HR °F)	LOSS FROM STORAGE
NOV	8.01	7.07	-0.08	87	102	44.22	1.02
DEC	8.70	7.68	-0.28	85	102	41.95	1.30
JAN	6.77	5.46	0.13	83	93	68.98	1.18
FEB	6.14	5.25	0.09	87	97	40.00	0.80
MAR	12.62	11.81	0.00	94	107	29.00	0.81
APR	12.18	11.93	0.24	99	111	0.33	0.01
TOTAL	54.42	49.20	0.10	-	-	-	5.12
AVERAGE	9.07	8.20	0.02	91	102	37.41	0.85

2.3 DOMESTIC HOT WATER (DHW)

The DHW subsystem performance for the reporting period is shown in Table 7 and presented graphically in Figure 5.

The DHW subsystem required 20.89 million BTU of solar energy and 26.99 million BTU of auxiliary thermal energy to satisfy a hot water load of 36.66 million BTU. The solar fraction of this load was 44%, with an operating energy of 4.23 million BTU. Losses from the DHW subsystem were 15.45 million BTU. A monthly average of 10,410 gallons of DHW was consumed at an average temperature of 134°F.

The solar fraction of 44% for the reporting period was much better than the design value. During the reporting period, the occupants used the system effectively by using the majority of the hot water during the afternoon hours. Therefore, a more efficient use of the collected solar energy was realized, thus reducing the auxiliary energy usage.

The measured hot water load is a measure of the energy contained in the hot water used from the system. This number does not include the energy consumed by the subsystem to maintain the water temperature in the tank and recirculating loop at the desired temperature. The solar energy to the measured load was 20.89 million BTU. The solar contribution to the DHW subsystem was relatively constant throughout the reporting period.

The hot water solar fraction is calculated on an hourly basis by considering the relative amounts of solar and auxiliary energy in the hot water tank (see Appendix D).

Table 7. DOMESTIC HOT WATER SUBSYSTEM PERFORMANCE

MONTECITO PINES
NOVEMBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

MONTH	DHW LOAD	ENERGY CONSUMED SOLAR	ENERGY CONSUMED AUXILIARY THERMAL	ENERGY CONSUMED OPERATING ENERGY	SOLAR FRACTION (%)	HOT WATER CONSUMPTION (GAL.)
NOV	5.52	3.84	4.20	0.69	48	9,818
DEC	6.64	3.56	4.50	0.71	44	9,304
JAN	7.06	3.24	4.53	0.70	42	9,991
FEB	6.03	3.07	4.09	0.68	43	11,921
MAR	5.58	3.42	4.47	0.73	43	11,288
APR	5.83	3.76	5.20	0.72	42	10,141
TOTAL	36.66	20.89	26.99	4.23	-	62,463
AVERAGE	6.11	3.48	4.50	0.71	44	10,410

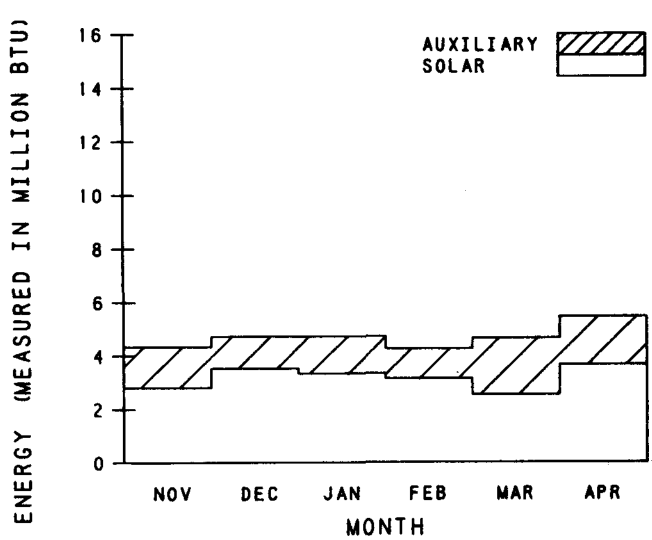

Figure 5. DHW Subsystem Performance
Montecito Pines
November 1979 through April 1980

During the latter portion of the reporting season, the DHW subsystem load decreased while the DHW consumption increased. This situation could have been caused by differences in lifestyles or the loss of and addition of occupants due to vacations, visitors, etc. However, these conditions did not affect the overall performance of the DHW subsystem. The subsystem performed very well throughout the reporting season. Energy savings provided by the DHW subsystem were 34.83 million BTU of fossil fuel (34,113 cubic feet of natural gas). The savings are approximately $141.00. The computed savings are based on an estimated fuel rate at the site of $4.13 per 1,000 cubic feet of natural gas.

2.4 SPACE HEATING

The performance of the space heating subsystem for the reporting period is shown in Table 8 and presented graphically in Figure 6.

The space heating load of 184.20 million BTU was satisfied by 20.91 million BTU of solar energy and 163.29 million BTU of auxiliary energy. The solar fraction of this load was 11% with operating energy of 8.13 million BTU.

Table 8. SPACE HEATING SUBSYSTEM

MONTECITO PINES
NOVEMBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

		ENERGY CONSUMED					
MONTH	SPACE HEATING LOAD	SOLAR	AUXILIARY THERMAL	AUXILIARY FOSSIL	OPERATING ENERGY	SOLAR FRACTION (%)	BUILDING TEMPERATURE (°F)
NOV	31.01	2.99	28.02	46.70	0.62	11	71
DEC	36.59	2.86	33.73	56.22	1.70	9	69
JAN	39.65	1.78	37.87	63.12	1.66	5	70
FEB	29.16	1.56	27.60	46.00	1.32	6	70
MAR	29.05	6.20	22.85	38.08	1.69	25	70
APR	18.74	5.52	13.22	22.03	1.14	34	71
TOTAL	184.20	20.91	163.29	272.15	8.13	-	-
AVERAGE	30.70	3.49	27.22	45.36	1.36	11	70

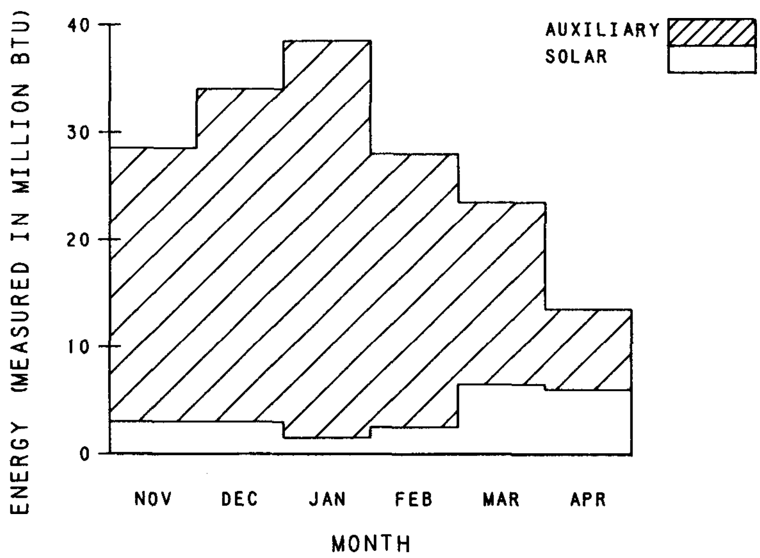

Figure 6. Space Heating Performance
Montecito Pines
November 1979 through April 1980

The solar fraction of 11% was lower than the design predicted solar fraction of 46%. The f-Chart predicted solar fraction is a more accurate indication of how the system should have performed. The f-Chart predicted solar fraction is based on the measured weather, whereas the design solar fraction is based on the long-term weather average.

The performance of the space heating subsystem is determined by comparing the amount of solar energy supplied to the subsystem with the energy supplied by the combination of solar and auxiliary thermal systems. The ratio of solar energy supplied to the load to the total load is defined as the heating solar fraction.

The heating load was larger than expected for the reporting period. The measured heating load of 184.20 million BTU was higher than the 170.73 million BTU predicted. The building interior temperature averaged 70°F over the reporting period. The monthly average number of heating degree-days was 461 as compared to the long-term average of 410. Dubin-Bloome Associates provided UAC_D figures as part of their review of the Monthly Performance Reports. Dubin-Bloome's UAC_D prediction is 2,910 BTU/hr°F. This is within the 20% claimed for the UAC_D method of calculating loads. The UAC_D method is a simplified procedure to calculate the equipment space heating load. It should be close to the measured load if the losses to the conditioned space are added to the measured load.

The total fossil energy savings were 34.85 million BTU or 34,301 cubic feet of natural gas. The savings, based on an estimated fuel rate of $4.13 per 1,000 cubic foot of gas, are approximately $142.00.

SECTION 3

OPERATING ENERGY

Measured monthly values of the Montecito Pines solar energy system and subsystem operating energy for the report period are presented in Table 9. A total 16.59 million BTU of operating energy was consumed by the entire system during the reporting period. A distribution of this operating energy among the subsystems is illustrated in Figure 7.

Table 9. OPERATING ENERGY

MONTECITO PINES
NOVEMBER 1979 THROUGH APRIL 1980

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY (SOLAR UNIQUE)	DHW OPERATING ENERGY	SHS OPERATING ENERGY	TOTAL SOLAR UNIQUE OPERATING ENERGY	TOTAL SYSTEM OPERATING ENERGY
NOV	0.48	0.69	0.62	0.48	1.79
DEC	0.74	0.71	1.70	0.74	3.15
JAN	0.55	0.70	1.66	0.55	2.91
FEB	0.57	0.68	1.32	0.57	2.57
MAR	0.93	0.73	1.69	0.93	3.35
APR	0.96	0.72	1.14	0.96	2.82
TOTAL	4.23	4.23	8.13	4.23	16.59
AVERAGE	0.71	0.71	1.36	0.71	2.77

A total of 4.23 million BTU of operating energy was used by the energy collection and storage subsystem (ECSS). This amount of operating energy was required by the collectors to keep the energy transfer medium circulating through the collector loop.

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

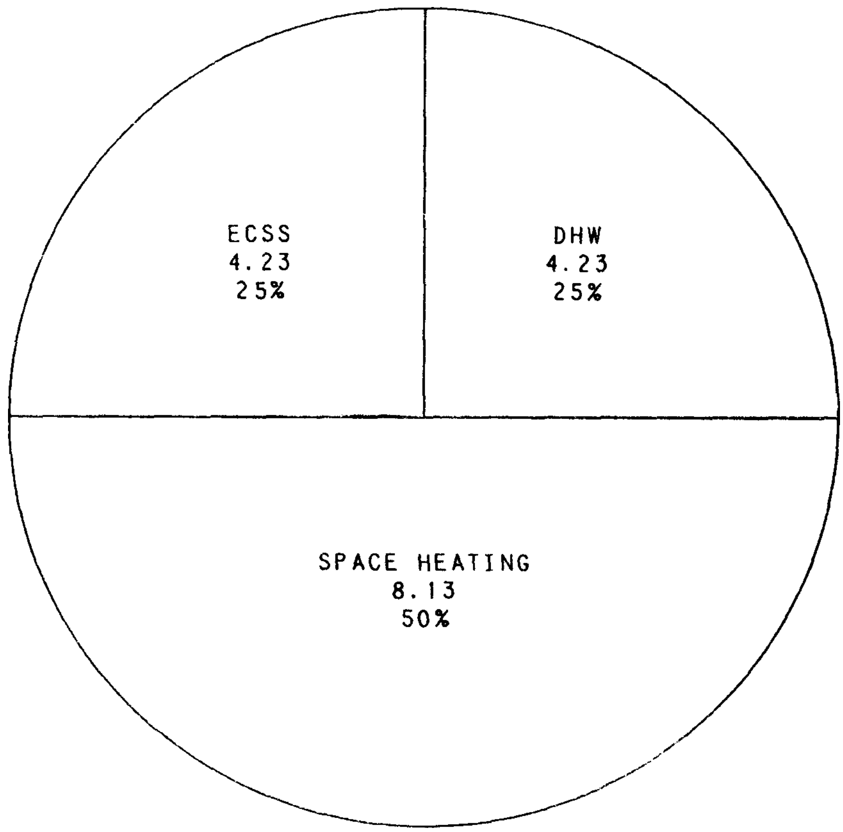

Figure 7. Total Operating Energy
Montecito Pines
November 1979 through April 1980

SECTION 4

WEATHER CONDITIONS

The Montecito Pines site is located in Santa Rosa, 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.

Table 10. WEATHER CONDITIONS

MONTECITO PINES
NOVEMBER 1979 THROUGH APRIL 1980

	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT^2-DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS	
MONTH	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
NOV	1,064	1,218	49	54	480	322
DEC	1,026	1,038	46	48	489	521
JAN	817	1,081	46	47	589	555
FEB	840	1,353	51	51	406	402
MAR	1,568	1,641	50	53	450	381
APR	1,648	1,843	53	56	350	279
TOTAL	6,963	8,174	-	-	2,764	2,460
AVERAGE	1,160	1,362	49	52	461	410

During the period from November 1979 through April 1980, the average daily total incident solar radiation on the collector array was 1,160 BTU per square foot per day. This radiation was below the estimated average daily solar radiation for this geographical area during the reporting period of 1,362 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

1,648 BTU per square foot per day during April. The average ambient temperature during the reporting period was 49°F as compared with the long-term average of 52°F. The highest monthly average ambient temperature was 53°F during April and the lowest monthly average ambient temperature was 46°F during December and January. The monthly average number of heating degree-days for the period (based on a 65°F reference) was 461 as compared with the long-term average of 410. The range of heating degree-days was from a high of 589 during January to a low of 350 during April.

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

This parameter quantifies the effects of cloudiness and atmospheric transmission on the insolation received at the earth's surface. The clearness index ranged from a high of 88% during November to a low of 60% during April.

	NOV	DEC	JAN	FEB	MAR	APR
Extra-terrestrial Insolation	1,559	1,328	1,454	1,908	2,486	3,073
TTL INS / EXT INS (%)	88	78	74	71	66	60

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

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

SECTION 5

REFERENCES

*1. National Solar Data Network, Department of Energy, prepared under Contract Number DE-AC01-79CS30027, Vitro Laboratories, Silver Spring, Maryland, January 1980.

2. J. T. Smok, V. S. Sohoni, J. M. Nash, "Processing of Instrumented Data for the National Solar Heating and Cooling Demonstration Program," Conference on Performance Monitoring Techniques for Evaluation of Solar Heating and Cooling Systems, Washington, D.C., April 1978.

3. E. Streed, et al, Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program, NBSIR-76-1137, National Bureau of Standards, Washington, D.C., 1976.

4. Mears, J. C., Reference Monthly Environmental Data for Systems in the National Solar Data Network. Department of Energy report SOLAR/0019-79/36. Washington, D.C., 1979.

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

*6. ASHRAE Standard 94-77, Methods of Testing Thermal Storage Devices Based on Thermal Performance, The American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc., New York, N.Y., 1977.

*6A. User's Guide to Monthly Performance Reports, June 1980, SOLAR/0004-80/18, Vitro Laboratories, Silver Spring, Maryland.

*6B. Instrumentation Installation Guidelines July 1980, Parts 1, 2, and 3, SOLAR/0001-80/15, Vitro Laboratories, Silver Spring, Maryland.

*7. Monthly Performance Report, November 1979, SOLAR/1045-79/11, Vitro Laboratories, Silver Spring, Maryland.

*8. Monthly Performance Report, December 1979, SOLAR/1045-79/12, Vitro Laboratories, Silver Spring, Maryland.

*9. Monthly Performance Report, January 1980, SOLAR/1045-80/01, 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, February 1980, SOLAR/1045-80/02, Vitro Laboratories, Silver Spring, Maryland.

*11. Monthly Performance Report, March 1980, SOLAR/1045-80/03, Vitro Laboratories, Silver Spring, Maryland.

*12. Monthly Performance Report, April 1980, SOLAR/1045-80/04, 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

SYSTEM

The Montecito Pines site is an apartment complex in Santa Rosa, California in which one eight-apartment unit is equipped with a solar system which is instrumented. Each apartment has approximately 864 square feet of conditioned space. Solar energy is used for space heating and preheating domestic hot water (DHW). The solar energy system which serves the entire eight-apartment unit has a single array of flat-plate Sunburst, BG-410 collectors with a gross area of 950 square feet. The array faces 23 degrees west of south at an angle of 45 degrees to the horizontal. Water is the transfer medium that delivers solar energy from the collector array to storage and to the space heating and hot water loads. Freeze protection is provided by a drain-down system. Solar energy is stored underground in a 2,000-gallon insulated tank. City water is circulated through a heat exchanger in the storage tank for preheating before entering a gas-fired boiler. This supplies the additional energy required to meet the DHW load. When solar energy is insufficient to satisfy the space heating load, the gas-fired boiler provides auxiliary energy to meet the space heating load. The system, shown schematically, has four modes of solar operation.

Mode 1 - Collector-to-Storage - This mode activates when the collector plate temperature exceeds the storage temperature by 17 degrees and terminates when a temperature difference of three degrees is reached. Collector loop pump P1 is operating.

Mode 2 - Storage-to-Space Heating - This mode activates when there is a space heating demand and the temperature at the top of the storage tank is 105°F or higher. Space heating pump P2 is operating and mode diversion valves divert the flow to the exchanger in the storage tank, bypassing the gas-fired boiler.

Mode 3 - Auxiliary Space Heating, DHW Preheating - This mode activates when there is a space heating demand and the temperature at the top of the storage tank is less than 105°F. Space heating pump P2 is operating and mode diversion valves direct the flow through the gas-fired boiler, bypassing the heat exchanger in the storage tank.

Mode 4 - DHW Preheating - This mode activates when there is a demand for DHW. Incoming city water passes through the heat exhanger in the storage tank on the way to the gas-fired boiler which supplies hot water, on demand, to the apartments.

SUBSYSTEMS

Collector - The solar energy system collectors at the Montecito Pine site, Sunburst BG-410 collectors, are manufactured by Sunburst Solar Energy Inc.

The gross collector array area (24 panels with an area of 39.6 square feet each) is 950 square feet. The collectors face at an azimuth angle of 23 degrees from the horizontal.

The collector panels have a tedlar-coated fiberglass cover ("Glasstell") and a nonselective absorber surface. The absorber surface has a solar absorptivity of 95%. Total solar transmissivity of the glazing is 82%. The absorber is coated with a flat black epoxy coating. The fluid circulated through the collectors is 100% water.

Storage - Energy storage is provided by a 2,000-gallon fiberglass storage tank (eight feet in diameter, six feet in height) located undergound. The storage tank is manufactured by North Coast Tank Filter company. The storage tank has 3.8 inches polyurethane insulation at the bottom and 2.5 inches polyurethane insulation on the top and sides.

Water is used as the medium for transferring solar energy to the DHW and space heating subsystems.

Space Heating - The space heating subsystem consists of a Raypack 266 Raytherm T/HWS natural gas-fired boiler with heat exchanger and a Taco pump designed to distribute solar energy via eight Lanco liquid-to-air heat exchangers and blowers. The boiler is designed to deliver 213,800 BTU/hour.

Domestic Hot Water - Domestic hot water is obtained on demand by circulating city water through the 2,000-gallon storage tank heat exchanger for preheating, and then through a 266 Raytherm gas-fired boiler manufactored by Raypack Inc. The distribution pumps throughout the system are made by Taco Water Pump Company. The size of the distribution pumps vary in size: 0.33 Hp 240 VAC with an operating pressure of 125 psi; 1 Hp 240 VAC with an operating pressure of 175 psi; 0.05 Hp 115 VAC with an operating pressure of 142 psi.

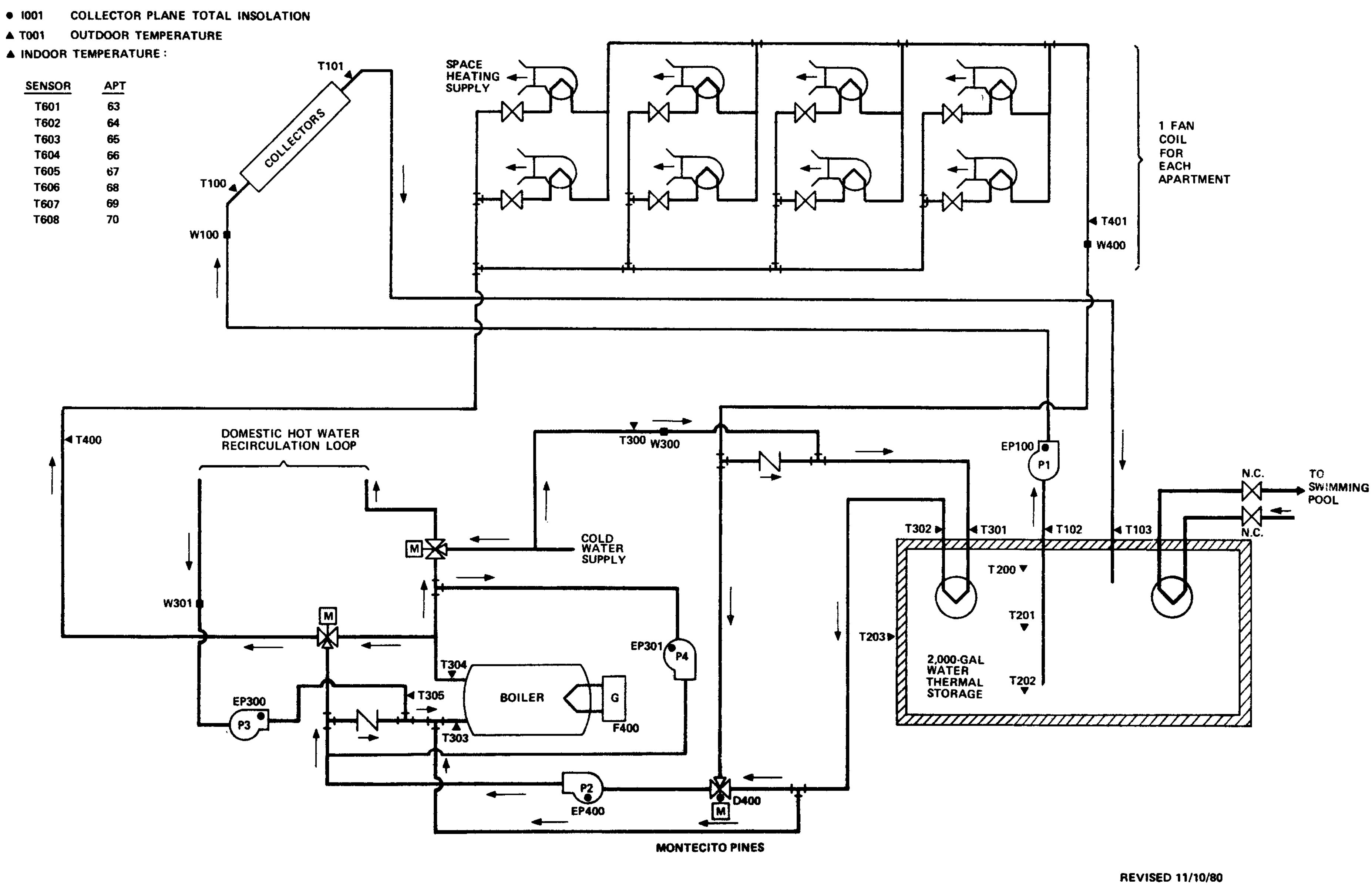

Figure A-1. Montecito Pines Solar Energy System Schematic

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Montecito Pines 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.

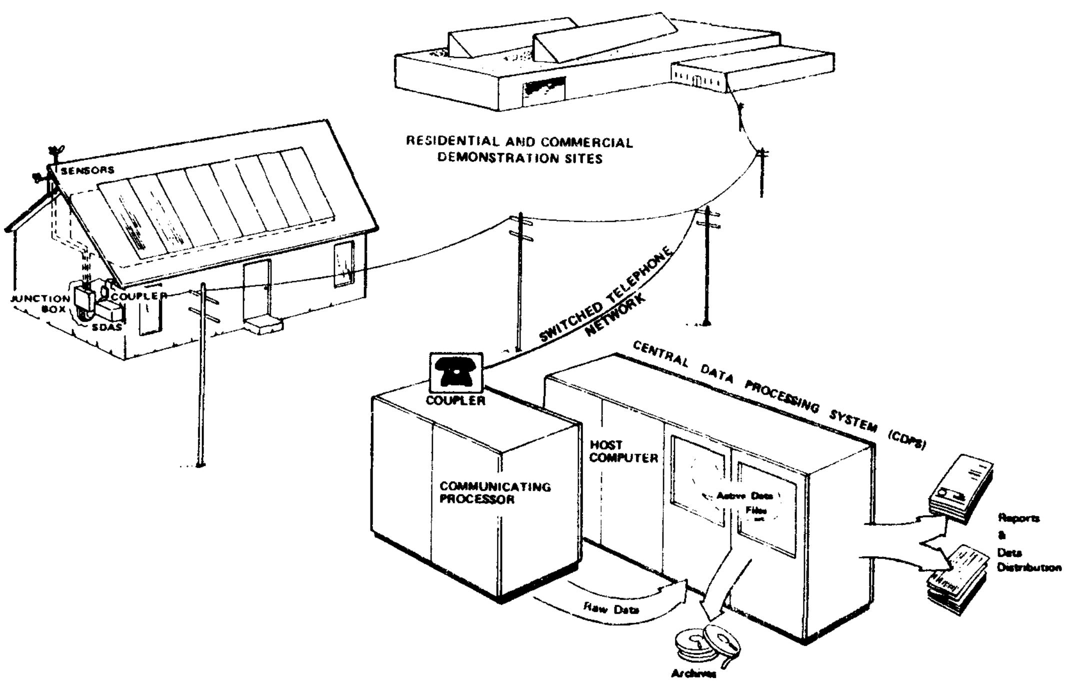

Figure B-1. The National Solar Data Network

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 micro-processor 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 five minutes (actually 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 five-minute period, and the average value is recorded in the tape.

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

The data received by the System 7 are in the form of digital counts in the range of 0-1023. 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, and these tabulations are also called "tab data." The CDPS is also capable of transforming this data into plots or graphs.

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 such 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 five-minute period. 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 measuring 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 Montecito Pines solar energy system from November 1979 through April 1980 was analyzed during the heating season, and Monthly Performance Reports were published for the months when sufficient valid data were available. 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:

August 1978, SOLAR/1045-78/08
September 1978, SOLAR/1045-78/09
October 1978, SOLAR/1045-78/10
November 1978, SOLAR/1045-78/11
December 1978, SOLAR/1045-78/12
January 1979, SOLAR/1045-79/01
February 1979, SOLAR/1045-79/02
March 1979, SOLAR/1045-79/03
April 1979, SOLAR/1045-79/04
August 1979, SOLAR/1045-79/08
September 1979, SOLAR/1045-79/09
November 1979, SOLAR/1045-79/11
December 1979, SOLAR/1045-79/12
January 1980, SOLAR/1045-80/01
February 1980, SOLAR/1045-80/02
March 1980, SOLAR/1045-80/03
April 1980, SOLAR/1045-80/04
May 1980, SOLAR/1045-80/05
July 1980, SOLAR/1045-80/07
August 1980, SOLAR/1045-80/08
September 1980, SOLAR/1045-80/09
October 1980, SOLAR/1045-80/10
November 1980, SOLAR/1045-80/11
December 1980, SOLAR/1045-80/12

Solar Energy System Performance Evaluation: SOLAR/1045-79/14

* 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

ACRONYM	NAME	DEFINITION
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

ACRONYM	NAME	DEFINITION
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

ACRONYM	NAME	DEFINITION
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

ACRONYM	NAME	DEFINITION
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

ACRONYM	NAME	DEFINITION
* 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

ACRONYM	NAME	DEFINITION
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

ACRONYM	NAME	DEFINITION
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 above 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).

Figure of Merit, FMS — A calculated number showing the relative net fraction of the system load supplied from solar energy.

$$FMS = \text{Solar Energy Supplied to Load} - \text{Solar System Operating Energy}$$

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 below 65°F.

Instantaneous Efficiency — The efficiency of a solar collector at one operating point, $\frac{Ti-Ta}{I}$, under steady state conditions (see Operating Point).

Instantaneous Efficiency Curve — A plot of solar collector efficiency against operating point, $\frac{Ti-Ta}{I}$ (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 — The solar energy received by a surface.

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.

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: $\frac{Ti-Ta}{I} \quad \frac{^\circ F \times hr. \times sq.\ ft.}{BTU}$
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 that converts energy to useful thermal energy for heating without the use of collector circulating fluid.
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 param eter 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

MONTECITO PINES

INTRODUCTION

Solar energy system performance is evaluated by performing energy balance calculations on the system and its major subsystems. These calculations are based on physical measurement data taken from each 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

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

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

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

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

For a liquid system ΔH is generally given by

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

where C_p is the average specific heat, in BTU/lb_m-°F), of the heat transfer fluid and ΔT, in °F, is the temperature differential across the heat exchanging component.

* 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

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

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

Letter Designations

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

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

EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

AVERAGE AMBIENT TEMPERATURE (°F)

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

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

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

for ± 3 hours from solar noon

INCIDENT SOLAR ENERGY PER SQUARE FOOT (BTU/FT^2)

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

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

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

when the collector loop is active

SOLAR ENERGY COLLECTED BY THE ARRAY (BTU)

$$SECA = \Sigma \; [M100 \times CP \times (T101 - T100)] \times \Delta\tau$$

SOLAR ENERGY TO STORAGE (BTU)

$$STEI = \Sigma \; [M100 \times CP \times (T103 - T102)] \times \Delta\tau$$

SOLAR ENERGY FROM STORAGE (BTU)

$$STEO = \Sigma \; [(M300 + M400) \times CP \times (T301 - T302)] \times \Delta\tau$$

for solar heating mode

$$STEO = \Sigma \; M300 \times CP \times (T301 - T302) \times \Delta\tau$$

for auxiliary heating mode

AVERAGE TEMPERATURE OF STORAGE (°F)

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

ENERGY DELIVERED FROM ECSS TO SPACE HEATING SUBSYSTEM (BTU)

$$CSEO = STEO$$

ECSS OPERATING ENERGY (BTU)

$$CSOPE = 56.8833 \times \Sigma \; EP100 \times \Delta\tau$$

SPACE HEATING SUBSYSTEM OPERATING ENERGY (BTU)

$$HOPE = 56.8833 \times \Sigma \; EP400 \times \Delta\tau$$

SOLAR ENERGY TO SPACE HEATING SUBSYSTEM (BTU)

$$HSE = \Sigma \; [M400 \times CP \times (T400 - T401)] \times \Delta\tau$$

SPACE HEATING SUBSYSTEM AUXILIARY FOSSIL FUEL ENERGY (BTU)

$$HAT = \Sigma \; [M400 \times CP \times (T400 - T401)] \times \Delta\tau$$

SPACE HEATING SUBSYSTEM LOAD (BTU)

$$HL = HSE + HAT$$

BUILDING TEMPERATURE (°F)

$$TB = 1/60 \times \Sigma \; \frac{(T601 + T602 + T603 + T604 + T605 + T606 + T607 + T608)}{8} \times \Delta\tau$$

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$$SEA = CLAREA \times SE$$

COLLECTED SOLAR ENERGY (BTU)

$$SEC = SECA/CLAREA$$

COLLECTOR ARRAY EFFICIENCY

CAREF = SECA/SEA

CHANGE IN STORED ENERGY (BTU)

$STECH = STECH1 - STECH1_p$

where the subscript $_p$ refers to a prior reference value

STORAGE EFFICIENCY

STEFF = (STECH + STEO)/STEI

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

SEL = CSEO

ESCC SOLAR CONVERSION EFFICIENCY

CSCEF = SEL/SEA

SPACE HEATING SUBSYSTEM SOLAR FRACTION (PERCENT)

HSFR = 100 x HSE/HL

SPACE HEATING FOSSIL FUEL SAVINGS

HSVF = HSE/FEFF

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

AXT = HAT + HWAT

HOT WATER CONSUMED (GAL)

HWCSM = WD300 = W300 - W300_P

HOT WATER LOAD

HWL = M300 x HWD (T304, T300)

HOT WATER SOLAR ENERGY (BTU)

HWSE = M300 x HWD (T302, T300)

HOT WATER SOLAR FRACTION (PERCENT)

HWSFR = 100 x HWTKSE/HWTKSE + HWTKAUX);

where: HWCAP = capacity of hot water tank,

RHO = density of the fluid in the hot water tank

THW = supply water temperature

HWTKAUX = total auxiliary energy in hot water tank at the end of the hour

HWTKSE = total solar energy in hot water tank at the end of the hour

TANKE = energy in tank referred to tank

TANKE = HWCAP x [RHO (THW) x CP (THW) x THW - RHO (TSW) x CP (TSW) x TSW]

HWTKAUX = (1 - HWSFR_P/100) x (TANKE - HWSE - HWAT) + HWAT

HWTKSE = (HWSFR_P/100) x (TANKE - HWSE - HWAT) + HWSE

HOT WATER AUXILIARY THERMAL ENERGY

HWAT = Σ [(M300 + M301) x CP x (T304 - T303)] x $\Delta\tau$

HOT WATER FOSSIL ENERGY SAVINGS

HWSVF = HWSE/BOILER EFFICIENCY

SUPPLY WATER TEMPERATURE (°F)

TSW = TSW1/TSW2

where: TSW1 = Σ (M300 x T304) x $\Delta\tau$

TSW2 = Σ (M300) x $\Delta\tau$

DELIVERY WATER TEMPERATURE (°F)

THW = THW1/TSW2

where: THW1 = M300 x T300 x $\Delta\tau$
TSW2 = M300 x $\Delta\tau$

SYSTEM LOAD (BTU)

SYSL = HL + HWL

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

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

SYSTEM OPERATING ENERGY (BTU)

SYSOPE = HOPE + CSOPE + HWOPE

TOTAL ENERGY CONSUMED (BTU)

TECSM = SYSOPE + AXF + SECA

SYSTEM PERFORMANCE FACTOR

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

APPENDIX E

CALCULATION OF PREDICTED VALUES

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

In addition to the assumptions made for a normal f-Chart analysis, the modified f-Chart assumes that all subsystem loads and losses are reasonable and are the result of good design and insulation practice.

Ref:

(1) Solar Heating Design by the F-Chart Method. William A. Beckman, Sanford A. Klein, John A. Duffie, Wiley Interscience, N.Y. (1977)

(2) F-Chart User's Manual. EES Report 49-3, SERI, Department of Energy, (June 1978)

SYSTEM PERFORMANCE SUMMARY (f-CHART)*
MONTECITO PINES
NOVEMBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

MONTH	ESFR (%)	ASFR (%)	LOAD	LOSS	STECH	ESECA	ASECA	ESEU	ASEU	LOSS (%)
NOV	32	19	31.49	1.94	-0.08	9.10	8.77	10.76	6.83	22
DEC	33	17	38.52	2.59	-0.28	9.30	9.01	6.01	6.42	29
JAN	27	11	46.03	2.29	0.13	9.88	7.31	3.50	5.02	31
FEB	31	15	31.14	2.19	0.09	8.63	6.82	4.07	4.63	32
MAR	30	32	30.49	1.48	0.00	15.21	13.84	11.10	9.62	30
APR	45	42	22.30	4.63	0.24	15.00	13.95	9.89	9.29	33
TOTAL	-	-	199.97	15.12	0.10	67.12	59.70	45.33	41.80	-
AVERAGE	33	23	33.33	2.52	0.16	11.18	9.95	7.55	6.97	30

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

GLOSSARY OF f-CHART TERMS

ESFR - Expected (predicted) solar fraction

ASFR - Actual (measured) solar fraction

LOAD - Measured total system load

LOSS - Total system losses (transport and storage)

STECH - Change in stored energy

ESECA - Expected (predicted) solar energy collected

ASECA - Actual (measured) solar energy collected

ESFU - Expected (predicted) solar energy used

ASEU - Actual (measured) solar energy used

LOSS (%) - 100 x (ASECA - ASEU)/ASECA

APPENDIX F

METEOROLOGICAL CONDITIONS

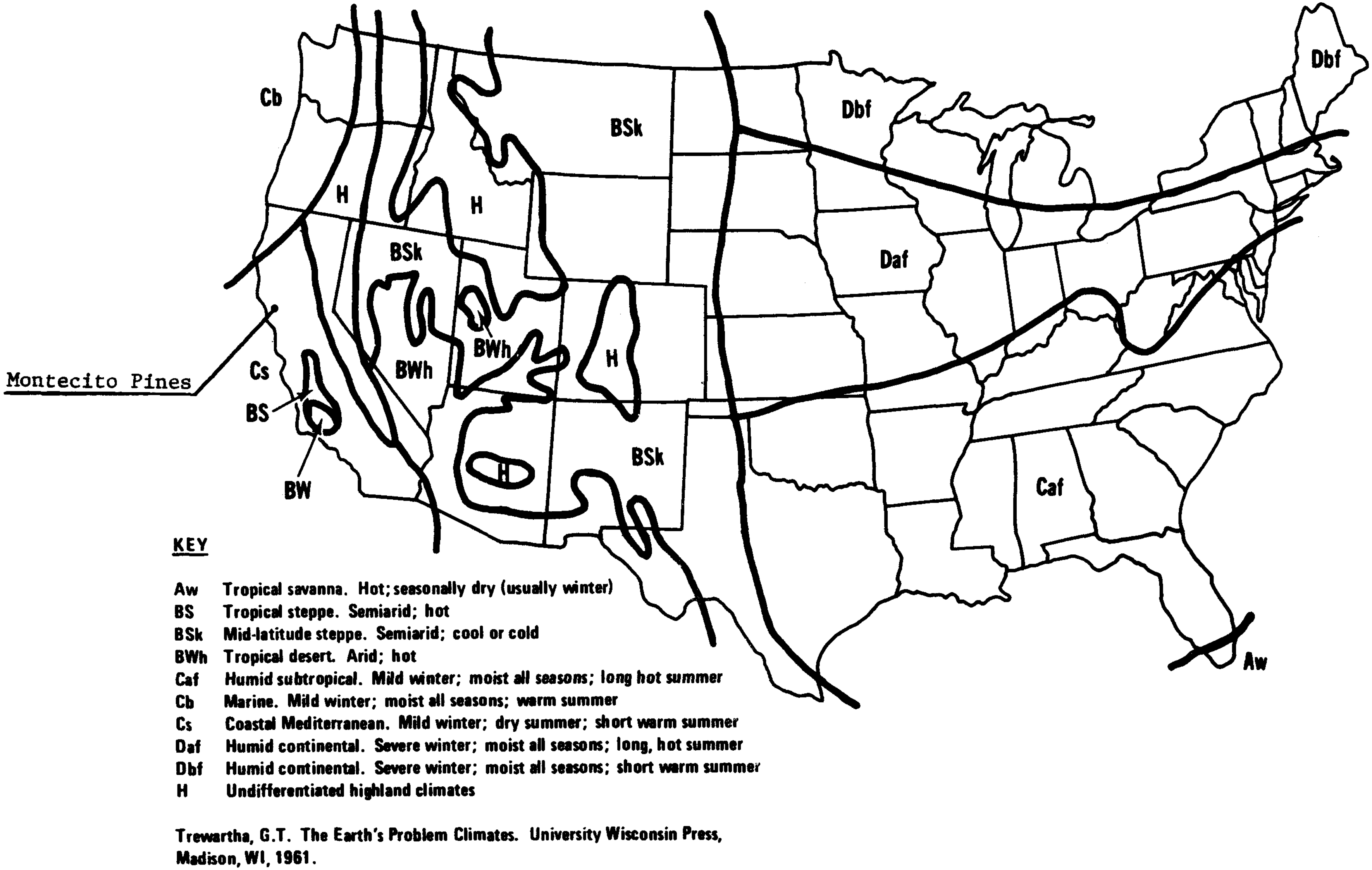

Figure F-1. Meteorological Map of the United States Showing Montecito Pines Location

MONTECITO PINES LONG-TERM WEATHER DATA

COLLECTOR TILT: 45 DEGREES
LATITUDE: 38 DEGREES

LOCATION: SANTA ROSA, CALIFORNIA
COLLECTOR AZIMUTH: 23 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
NOV	1,559	774	0.49678	1.573	1,218	332	0	54
DEC	1,328	612	0.46084	1.697	1,038	521	0	48
JAN	1,454	671	0.46154	1.611	1,081	555	0	47
FEB	1,908	970	0.50813	1.397	1,355	402	0	51
MAR	2,486	1,386	0.55772	1.184	1,641	381	0	53
APR	3,073	1,851	0.60230	0.996	1,843	279	10	56

LEGEND:

HOBAR - Monthly average daily extraterrestrial radiation (ideal) in BTU/day-ft^2.

HBAR - Monthly average daily radiation (modeled from SOLMET) in BTU/day-ft^2.

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-ft^2.

HDD - Number of heating degree-days per month.

CDD - Number of cooling degree-days per month.

TBAR - Average ambient temperature in degrees Fahrenheit.

MONTHLY REPORT: MONTECITO PINES
NOVEMBER 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1325	50	60
2	216	51	55
3	108	52	51
4	774	52	56
5	286	54	57
6	362	55	60
7	912	55	62
8	2067	56	67
9	2348	53	63
10	1076	47	56
11	1556	49	62
12	*	*	*
13	*	*	*
14	2250	54	65
15	852	53	61
16	22	54	55
17	1190	51	57
18	1608	46	57
19	1803	44	57
20	1702	43	60
21	1368	43	55
22	30	45	44
23	786	49	52
24	94	51	52
25	679	48	51
26	1620	43	55
27	1202	42	55
28	1224	45	59
29	1025	47	61
30	1306	48	63
SUM	31921	-	-
AVG	1064	49	57

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: MONTECITO PINES
DECEMBER 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	860	46	53
2	520	49	58
3	934	46	56
4	1354	45	*
5	1571	50	68
6	1517	50	64
7	1377	51	65
8	1338	50	64
9	1185	50	60
10	1665	51	64
11	1690	50	59
12	1545	42	57
13	1443	41	*
14	1367	42	57
15	1406	43	59
16	1428	45	58
17	1349	42	57
18	658	43	50
19	56	48	49
20	52	48	48
21	990	47	51
22	1507	41	53
23	6	43	41
24	31	46	47
25	967	45	51
26	1591	46	55
27	1586	43	54
28	142	38	41
29	962	41	48
30	456	51	54
31	243	54	*
SUM	31795	-	-
AVG	1026	46	55

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: MONTECITO PINES
JANUARY 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1542	50	59
2	1354	44	55
3	1342	44	55
4	199	46	48
5	191	47	51
6	186	49	54
7	1307	50	59
8	215	50	53
9	48	49	51
10	642	43	47
11	38	49	47
12	119	59	60
13	4	57	57
14	244	53	56
15	66	47	47
16	184	53	55
17	385	48	51
18	1751	44	51
19	1702	44	57
20	1623	42	57
21	1610	44	57
22	1549	48	59
23	1370	43	54
24	1153	42	51
25	601	41	45
26	216	41	44
27	701	41	50
28	1637	36	50
29	1751	36	49
30	1478	39	52
31	128	46	*
SUM	25332	-	-
AVG	817	46	53

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: MONTECITO PINES
FEBRUARY 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	699	51	59
2	343	48	53
3	358	52	54
4	879	50	57
5	416	50	53
6	1753	53	62
7	1878	56	59
8	1698	55	66
9	1737	46	61
10	1457	46	59
11	1024	44	54
12	1597	47	62
13	1476	48	61
14	150	50	51
15	261	52	53
16	101	53	*
17	33	54	52
18	276	56	57
19	570	51	53
20	544	48	52
21	1519	51	57
22	908	51	59
23	983	51	60
24	413	53	58
25	602	56	62
26	838	56	*
27	123	53	*
28	886	50	*
29	1875	50	63
SUM	25397	-	-
AVG	876	51	58

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: MONTECITO PINES
MARCH 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	318	49	55
2	553	51	57
3	794	50	57
4	612	47	55
5	652	48	53
6	1420	46	54
7	1112	46	56
8	1824	50	63
9	2027	51	67
10	2038	51	67
11	1701	48	57
12	2013	45	58
13	553	49	*
14	182	51	54
15	1822	45	53
16	2086	46	60
17	1300	46	57
18	2154	51	59
19	2086	56	70
20	1741	48	57
21	1939	51	61
22	2095	56	68
23	2110	55	71
24	2095	51	62
25	1034	45	49
26	1829	48	60
27	2075	50	64
28	2122	54	71
29	2108	55	71
30	2193	54	63
31	2023	51	63
SUM	48613	-	-
AVG	1568	50	60

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: MONTECITO PINES
APRIL 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	2150	52	62
2	2021	49	61
3	783	47	*
4	140	47	48
5	1465	53	59
6	1045	50	55
7	1759	48	64
8	1702	52	67
9	1387	54	62
10	2148	54	69
11	2246	61	77
12	2113	60	78
13	2000	57	73
14	1533	54	63
15	2147	57	72
16	2011	58	75
17	1425	52	62
18	2009	55	68
19	2084	57	69
20	581	50	53
21	1281	45	51
22	891	48	54
23	1242	55	62
24	2040	54	65
25	1998	51	63
26	2097	53	65
27	1946	59	73
28	1058	53	60
29	2016	57	69
30	2133	58	75
SUM	49451	-	-
AVG	1648	53	64

* DENOTES UNAVAILABLE DATA.

APPENDIX G

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

Montecito Pines was occupied for all of the reporting period. The solar system operated for the entire reporting period, November 1978 through April 1980. This system has been in operation since August 1978. Since being put into operation, there have been major operational problems.

Interruptions in data collection and reporting were:

Date	Event
September 1978	Collection loop turned off to check the collector loop pump and to drain the storage tank.
October 1978	SDAS malfunctioned and no data was collected for the month. Also the collector pump (P1) was repaired.

APPENDIX H

CONVERSION FACTORS

Energy Conversion Factors

Fuel Type	Energy Content	Fuel Source Conversion Factor
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

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

[2] No. 5 and No. 6 fuel oils

APPENDIX I

SENSOR TECHNOLOGY

Temperature Sensors

Temperatures are measured by a Minco Products S53P platinum Resistance Temperature Detector (RTD). Because the resistance of platinum wire varies as a function of temperature, measurement of the resistance of a calibrated length of platinum wire can be used to accurately determine the temperature of the wire. This is the principle of the platinum RTD which utilizes a tiny coil of platinum wire encased in a copper-tipped probe to measure temperature. The probes are designed to have a normal resistance of 100 Ohms at 32°F.

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 ducts or 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.

The RTDs are connected in a Wheatstone bridge arrangement to yield an output signal of 0-100 millivolts, which is measured by the SDAS. Different resistance values are used in the bridge, depending on the temperature range the sensor must measure. A third wire is brought out from the sensor and connected into the bridge to compensate for the resistance of the lead wires between the sensor and the SDAS.

The RTDs are individually calibrated by the manufacturer to National Bureau of Standards traceable standards. In addition, a five-point transmission system calibration check is done at the site to compensate for any deviation of the measurement system from nominal values.

The data-processing software takes these checks and calibrations into account, using a third-order polynomial curve fit to relate SDAS output to temperature.

Wind Sensor

Wind speed and direction are measured by a Model W101-P-DC/540 (or W102-P-DC/540) sensor made by the WeatherMeasure Corporation. This sensor is rugged, reliable and accurate and will withstand severe environments such as icing and hurricane winds.

Wind speed is measured by a four-bladed propeller vehicle coupled to a DC generator. The balanced propeller is fabricated from a special low-density, fiberglass-reinforced plastic to yield maximum sensitivity and strength. The DC generator has excellent linearity but somewhat higher threshold due to brush friction.

Dual-wiper, precious-metal slip rings are used to connect the wind speed generator signal (15 Volts DC at 100 miles per hour) to the data transmission lines. These generally provide trouble-free use for several years.

Wind direction is measured by means of a dual-wiper 1000-Ohm long-life conductive plastic potentiometer housed in the base of the sensor (0-540°). It is attached to the stainless steel shaft which supports and rotates with the upper body assembly.

The potentiometer is of high commercial grade and has sealed bearings. The conductive plastic resistance element has infinite resolution and a lifetime about 10 times that of wire-wound potentiometers. The base is of aluminum, and corrosion-resistant materials are used in the construction.

Humidity Sensors

Relative humidity is measured by a WeatherMeasure Corporation Model HM111-P/HM14-P sensor. This measurement is of particular importance in solar cooling systems.

This solid-state sensor measures relative humidity over the full range of 0-100%. Response of the sensing element is linear within approximately 1%, from 0-80% relative humidity, with small hysteresis and negligible temperature dependence.

The sensor is based upon the capacitance change of a 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. The thin polymer layer reacts very quickly and, therefore, the response time is very short (one second to 90% humidity change at 68°F).

The polymer material is resistant to most chemicals. Because the sensor response is based on "bulk" effect, under normal conditions dust and dirt do not easily influence its operation. For use outdoors, a sintered filter is used because sulphur dioxide absorbed on small particles can corrode the thin film electrodes of the sensor. The smaller the pore size of the filter, the greater the protection. The response time, however, is increased.

The sensor is mounted in a small probe which contains all the electronics necessary to provide a millivolt output. The output of the probe electronics is linear from 0-100% relative humidity. Because the capacitance change of the sensor is sensitive only to ambient water vapor, temperature compensation is not required in most situations.

Insolation Sensors

Eppley pyranometers and shadowband pyranometers are used to measure the amount of radiant energy incident on a surface. A standard pyranometer measures the total amount of solar energy available, including both the direct beam component and the diffuse component, while the shadowband instrument is designed to measure the diffuse component only. The instruments are calibrated in the horizontal position, with an Eppley thermopile used as the signal generator of the sensor. The heating of the thermopile by the radiation of the sun generates the signal, with the response being linear over the operating range. Measurements are in BTU/ft^2-hr.

The addition of a shadowband to a pyranometer enables the instrument to record only the diffuse portion of the sunlight by shielding the sensor from the direct rays of the sun (the beam component). The amount of beam radiation available is readily calculated by subtracting the diffuse radiation measurement from the total radiation measured by the unshaded standard pyranometer. This beam radiation measurement is useful when working with focusing solar collectors. When using the shadowband pyranometer, the accuracy of its measurement depends on the correct adjustment of the shadowband to be certain that the sensor is shielded from the direct rays of the sun.

The pyranometer includes a circular multijunction thermopile of the wire-wound type. The thermopile has the advantage of withstanding some mechanical vibration and shock. The receiver is circular, and coated with Parsons black lacquer. The instrument has a pair of removable precision ground and polished hemispheres of Schott optical glass. It also has a spirit level and a desiccator that can be readily inspected. The clear glass is transparent from a wavelength of about 285 to 2,800 nanometers. The temperature dependence is ±1% over the range of -4°F to 104°F. It has a response time of one second and a linearity of ±5% over the range of the instrument.

Flow Sensors

The Ramapo flowmeter is an accurate and sensitive liquid flow rate measuring device. The dynamic force of fluid flow, or velocity head of the approaching stream, is sensed as a drag force on a target (disc) suspended in the flow stream. This force is transmitted via a lever rod and flexure tube to an externally bonded, four active arm strain gauge bridge. This strain gauge bridge circuit translates the mechanical stress due to the sensor (target) drag into a directly proportional electrical output. Translation is linear, with infinite resolution, and is hysteresis free. The drag force itself is usually proportional to the flow rate squared. The electrical output is unaffected by variations in fluid temperature or static pressure head, within the stated limitations of the unit.

Power Sensors

A major component of the wattmeter is a concentrating magnetic core (usually a toroid). The conductor carrying current to the load is passed through the window (eye) of the magnetic core one or more times. The magnetic field surrounding the conductor (load-carrying wire) is instantaneously proportional to the current flowing in the conductor. This field is intercepted by the magnetic core, producing a magnetic flux which is also instantaneously proportional to the current flowing in the conductor. A Hall effect transducer is cemented into a thin slot milled through the concentrating magnetic core.

In this position it intercepts nearly all of the magnetic flux present in the core. Two of the transducer's terminals provide a full scale output of 50MVDC. The remaining two terminals are referred to as a control input. The output of the Hall transducer is not only proportional to the magnetic flux passing through it but also to any EMF which appears across its control terminals. The load voltage is applied to the transducer's control terminals.

The resultant measurements of the wattmeter are summarized below:

1. Output is directly proportional to the flux in the magnetic core which in turn is directly proportional to the load current (I).

2. Output is directly proportional to the load voltage (E).

3. Final output is directly proportional to the vector product of E, I, and cos ϕ (power factor angle). This output is read into the SDAS as an electrical power in watts.

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