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FACILITIES DEVELOPMENT

SAN DIEGO, CALIFORNIA

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

JANUARY 1980 THROUGH DECEMBER 1980

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FOREWORD

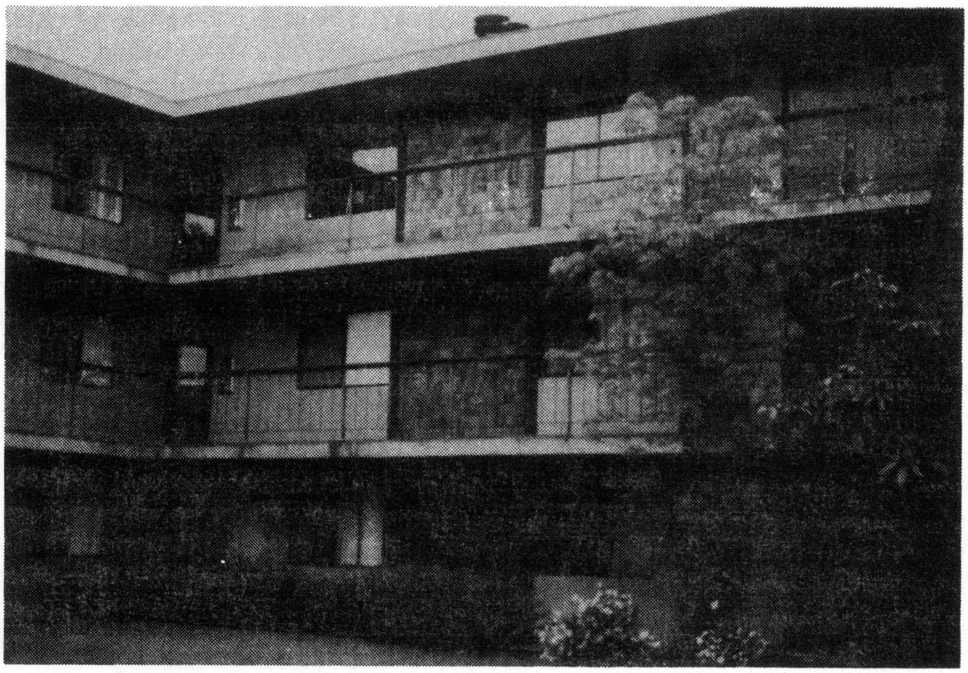
This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic 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.



FACILITIES DEVELOPMENT

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The Facilities Development site is a 31-unit apartment building in San Diego, California. The active solar energy system is designed to supply the following:

Annual Design Factors
(Million BTU)

	Total Load	Solar Contribution	% Solar
Hot Water	259.90	150.20	58

It is equipped with:

Collector	520 square feet of Revere flat-plate collectors
Storage	1,000-gallon glass-lined storage tank located underground
Auxiliary	31 conventional Ruudglas 52-gallon DHW tanks

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SECTION 1

SOLAR SYSTEM PERFORMANCE

FACILITIES DEVELOPMENT
JANUARY 1980 THROUGH DECEMBER 1980

Solar Fraction[1]	35%
Solar Savings Ratio[2]	33%
Conventional Fuel Savings[3]	25,761 kwh
Solar System COP[4]	48

Seasonal Energy Requirements
January 1980 through December 1980
(Million BTU)

	Load	Solar Consumed	% Solar
Hot Water	204.98	93.23	35

Environmental Data

	Measured Average	Long-Term Average
Outdoor temperature	61°F	62°F
Heating degree-days	1,562	1,501
Cooling degree-days	256	620
Daily incident solar energy	1,471 BTU/ft^2	1,731 BTU/ft^2

1. Solar Fraction = $\frac{\text{Solar Energy Spplied to Loads}}{\text{Total Load}}$

2. Solar Savings Ratio = $\frac{\text{Solar Energy Supplied to Load-Solar System Operating Energy}}{\text{Total Load}}$

3. Conventional Fuel Savings = $\left(\text{Solar Energy Supplied to Load} - \text{Solar System Operating Energy}\right) \times 292.8 \times 10^{-6}$ kwh/BTU

4. Solar System COP = $\frac{\text{Solar Energy Used}}{\text{Solar Unique Operating Energy}}$

1.1 SUMMARY AND CONCLUSIONS

The Facilities Development site is a three-story, 31-unit condominium located in San Diego, California. Solar energy is used to preheat the domestic hot water (DHW). The system has an array of Revere Sun-Aid flat-plate collectors with a gross area of 520 square feet. The array faces south at a tilt of 35 degrees to the horizontal. Solar energy is delivered to a 1,000-gallon Santa Fe glass-lined storage tank, insulated with polyurethane and buried undergound. Incoming cold water is preheated by the solar energy in this tank and then supplied to the individual hot water tanks on demand. Additional energy is added when required by electric heating elements within individual hot water tanks in each apartment.

The solar energy system at Facilities Development performed as predicted. The predicted performance was determined from a modified f-Chart computer simulation using measured weather, measured subsystem loads, and computed losses as inputs. The overall solar fraction was 35% as compared to a predicted solar fraction of 33%. The system collected 43% of the total incident solar radiation and used 85% of this collected energy. The system saved 87.98 million BTU or 25,761 kwh, for a monetary savings of $1,288.05 (based on $0.05 per kwh).

The average daily incident solar energy per square foot was 1,471 BTU/ft^2 which was below the long-term average of 1,731 BTU/ft^2. The ambient temperature and the heating degree-days were approximately the same as the long-term averages. The cooling degree-days for the year, 256, were below the long-term average of 620 degree-days.

Less solar energy was collected in January and May because the incident solar energy was low, resulting in a high use of auxiliary energy for these months.

The strainer in the collector loop was clogged for eight months, decreasing the flow through the collectors by a factor of two. The strainer was cleaned in September, and the performance of the collectors improved significantly.

The average storage temperatures for June and August were higher than the rest of the year due to low hot water consumption. All of the solar energy collected for preheating the DHW was not used, and, therefore, the storage tank water remained at a higher temperature.

There was no hot water operating energy used after September because the circulation loop pump P2 (See Appendix A) did not operate. A dual switch was installed in September to activate the pump only during the hours of 5:00 a.m. to 8:00 a.m. and 5:00 p.m. to 8:30 p.m. providing the temperature of the water is less than 90°F. This condition was never satisfied and, therefore, the pump was not activated.

In March, because of the higher hot water consumption, more solar and auxiliary energies were used to satisfy the hot water load than in the other months of the year.

The hot water loads from June to September were smaller than the remainder of the year due to the higher supply water temperature.

At this site, scaling has occurred on the flow meters. Scaling is the deposition of some solid, i.e., calcium carbonate and/or magnesium carbonate, on the metal surface usually resulting from some precipitating process. Scaling can be highly detrimental if the scale thickness becomes large. Scaling can narrow the flow passage and limit the flow.

This problem is due to the high mineral content of the water in San Diego and cannot be corrected.

1.2 OVERALL SYSTEM PERFORMANCE

The flow of solar energy through the Facilities Development site for the 12-month period from January 1980 through December 1980 is presented in Figure 1. This Energy Flow Diagram shows the amount of energy collected, transported, stored, consumed, or lost at each point in the system.

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

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

FACILITIES DEVELOPMENT
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED	SYSTEM LOAD	SOLAR ENERGY USED		AUXILIARY ENERGY	OPERATING ENERGY	ENERGY SAVINGS	SOLAR FRACTION (%)	
			PREDICTED	MEASURED	ELECTRICAL		ELECTRICAL	PREDICTED	MEASURED
JAN	4.80	21.10	4.47	4.23	22.21	0.12	4.11	17	9
FEB	9.44	22.88	8.17	8.30	18.73	0.84	7.46	30	37
MAR	12.68	23.80	10.78	10.60	17.93	1.02	9.58	38	43
APR	11.52	19.16	9.73	10.15	15.21	0.42	9.73	38	46
MAY	7.17	19.22	5.50	5.44	19.53	0.76	4.68	22	28
JUN	9.22	14.52	7.15	7.18	15.02	0.79	6.39	32	38
JUL	*	*	*	*	*	*	*	*	*
AUG	10.32	13.95	7.84	8.45	11.14	0.66	7.79	40	50
SEP	9.95	16.48	7.21	8.68	12.19	0.29	8.39	35	48
OCT	11.31	17.99	8.58	10.07	12.34	0.10	9.97	38	50
NOV	11.30	16.45	8.49	9.82	12.62	0.11	9.71	38	50
DEC	11.50	19.43	9.03	10.31	16.16	0.14	10.17	34	46
TOTAL	109.21	204.98	86.95	93.23	173.08	5.25	87.98	-	-
AVERAGE	9.93	18.63	7.91	8.48	15.73	0.48	8.00	33	35

*No data was collected for July.

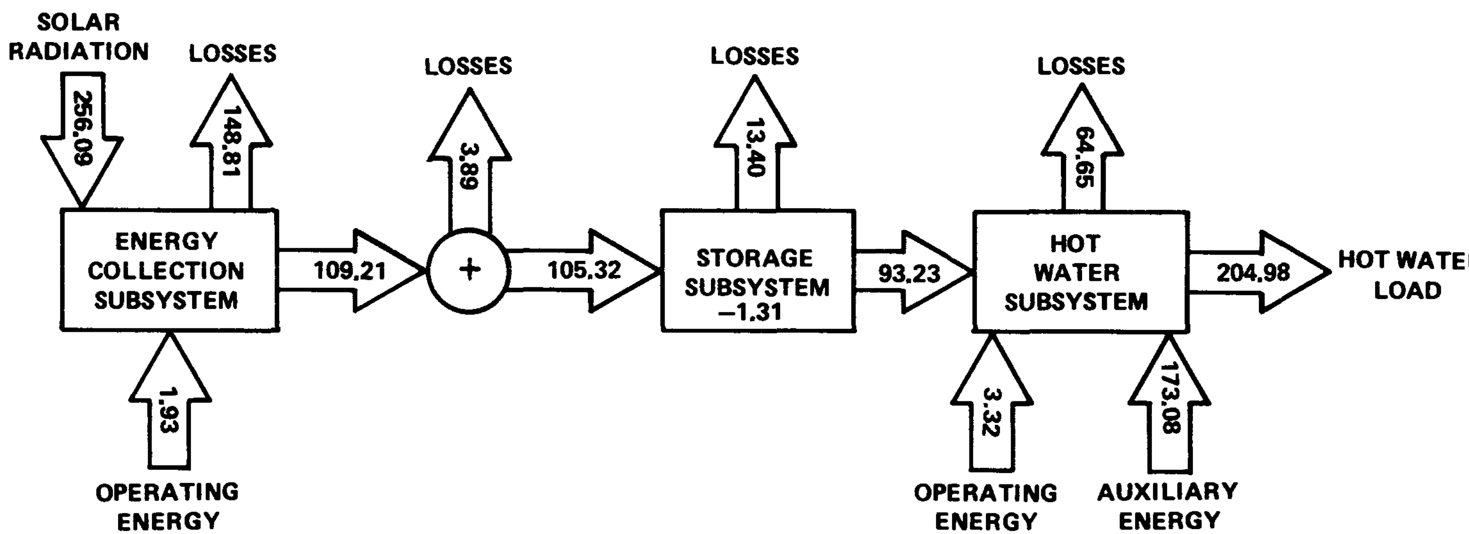
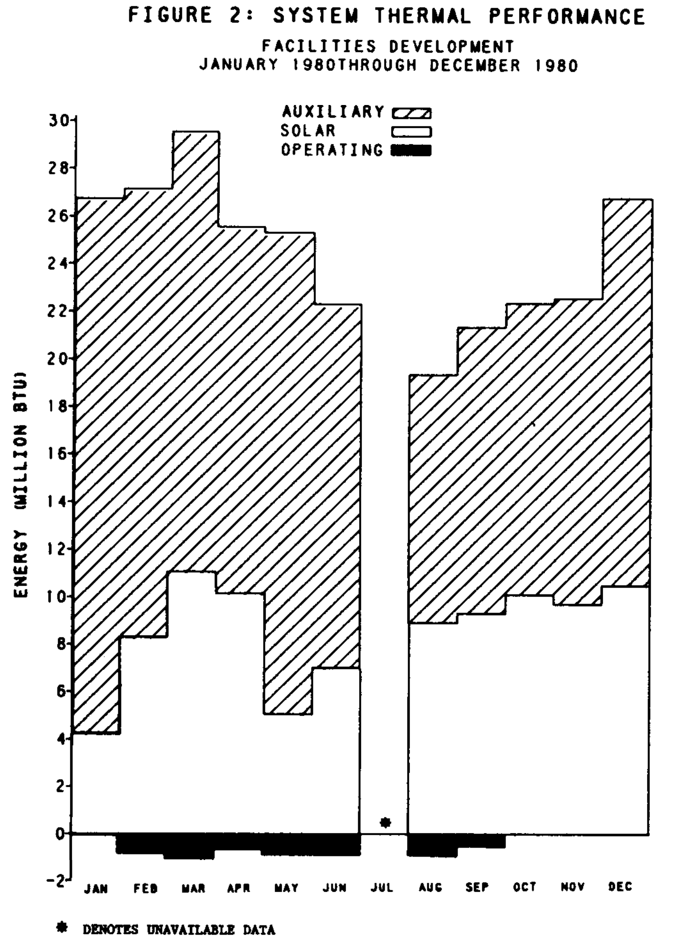


Figure 1. Energy Flow Diagram for Facilities Development
January 1980 through December 1980
(Figures in million BTU)



Operating energy for the system is considered a system penalty and is plotted as a negative value below the origin.

Figure 2. System Thermal Performance
Facilities Development
January 1980 through December 1980

The solar radiation incident on the collector array was 256.09 million BTU, of which 109.21 million BTU were collected. The operating expense for collecting energy was 1.93 million BTU. Transport losses between the collectors and storage were 3.89 million BTU, resulting in 105.32 million BTU of energy being delivered to storage. Energy loss from storage was 13.40 million BTU. The stored energy decreased by 1.31 million BTU. A total of 93.23 million BTU of solar energy and 173.08 million BTU of auxiliary energy was delivered to the DHW subsystem to satisfy the load of 204.98 million BTU. The operating energy required to deliver this thermal energy to the DHW subsystem was 3.32 million BTU. Losses from the DHW subsystem were 64.65 million BTU.

The solar energy system performed as predicted. The predicted performance was determined from a modified f-Chart computer simulation using measured weather, measured subsystem loads, and computed losses as input. The system collected 109.21 million BTU as compared to a predicted 102.04 million BTU. The system used 93.23 million BTU as compared to a predicted 86.95 million BTU. The system solar fraction was 35% as compared to a predicted 33%.

Less solar energy was collected in January and May, because the incident solar energy was low and less solar energy was available. The solar fractions for these months were low, resulting in a high use of auxiliary energy.

Solar and auxiliary energies used in March increased to satisfy the higher hot water consumption.

The solar energy coefficient of performance (COP) is indicated in Table 2. The COP is a numerical ratio of solar energy collected or used to the energy required to collect and deliver it. The greater the COP value, the more efficient the subsystem.

Table 2. SOLAR COEFFICIENT OF PERFORMANCE

FACILITIES DEVELOPMENT
JANUARY 1980 THROUGH DECEMBER 1980

MONTH	SOLAR ENERGY SYSTEM	COLLECTOR SUBSYSTEM	DOMESTIC HOT WATER SOLAR
JAN	35	40	- [1]
FEB	10	35	15
MAR	10	29	18
APR	25	115	32
MAY	7	51	9
JUN	9	49	12
JUL	*	*	*
AUG	13	52	18
SEP	31	76	54
OCT	112	113	- [1]
NOV	89	103	- [1]
DEC	74	82	- [1]
WEIGHTED AVERAGE	18	57	28

*No data was collected for July.

[1]Undefined where there is no operating energy.

During the reporting period of 1980, the solar energy system at Facilities Development operated at a weighted average COP of 18. The COP for October, November, and December was high, due to the low operating energies for these months.

The operating energy of October through December is lower than the previous months because the pump in the circulation loop (See Appendix A) did not operate. This pump operated for part of the month of September. In September, a dual switch was added to activate the pump during the hours of 5:00 a.m. to 8:00 a.m. and 5:00 p.m. and 8:30 p.m., if the water temperature was less than 90°F. These conditions were not satisfied during October, November, December, and part of September.

1.3 ENERGY SAVINGS

Energy savings for this site for the reporting period, January 1980 through December 1980, are presented in Table 3 and shown graphically in Figure 3. For this 12-month period, the total savings were 87.98 million BTU, for a monthly average of 8.00 million BTU. This is approximately 634 gallons of oil, or 143,614 cubic feet of natural gas, or 25,761 kwh of electricity. An electrical energy expense of 5.25 million BTU was incurred during the reporting period for the operation of solar energy components.

Table 3. ENERGY SAVINGS

FACILITIES DEVELOPMENT
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU)

MONTH	SOLAR ENERGY USED	DOMESTIC HOT WATER ELECTRICAL	ECSS OPERATING ENERGY	ENERGY SAVINGS ELECTRICAL
JAN	4.23	4.23	0.12	4.11
FEB	8.30	7.73	0.27	7.46
MAR	10.60	10.01	0.43	9.58
APR	10.15	9.83	0.10	9.73
MAY	5.44	4.82	0.14	4.68
JUN	7.18	6.58	0.19	6.39
JUL	*	*	*	*
AUG	8.45	7.99	0.20	7.79
SEP	8.68	8.52	0.13	8.39
OCT	10.07	10.07	0.10	9.97
NOV	9.82	9.82	0.11	9.71
DEC	10.31	10.31	0.14	10.17
TOTAL	93.23	89.91	1.93	87.98
AVERAGE	8.48	8.18	0.18	8.00

*No data was collected for July.

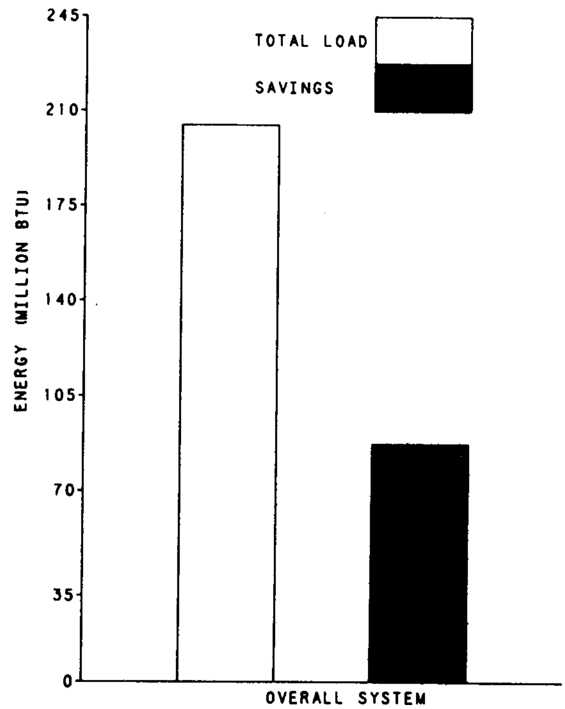


Figure 3. Combined Thermal Energy Savings Compared to Load
Facilities Development
January 1980 through December 1980

Solar energy system savings were realized whenever energy provided by the solar energy system was 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 energy at Facilities Development is provided by electric heating elements in each of the 31 individual Ruudglas hot water tanks. These units are considered to be 100% efficient for computational purposes.

The solar energy use of 93.23 million BTU is divided by the electrical efficiency (1.00) to obtain the electrical energy savings of 93.23 million BTU. The electrical energy expense is subtracted from the electrical savings to obtain an overall electrical savings.

The total electrical energy expended was 5.25 million BTU, for an overall savings 87.98 million BTU. The total net energy savings are approximately equal to $1,288.05. These savings are based on an estimated rate of $0.05 per kwh.

1.4 SOLAR ENERGY UTILIZATION

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

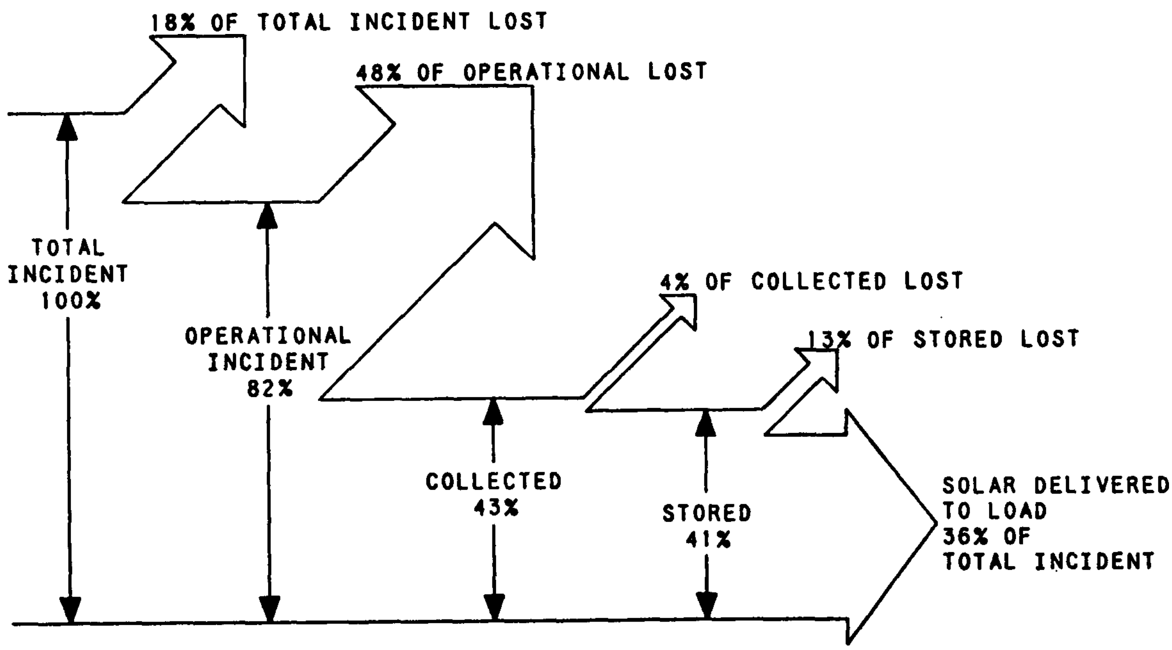


Figure 4. Solar Energy Use
Facilities Development
January 1980 through December 1980

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

Of the total solar energy incident on the collector array for the year 1980, 82% was incident while the collector pump was operating. This is called operational incident energy. Fifty-two percent of this operational incident energy was collected. Of the collected energy, 96% was delivered to storage, and 13% of the stored energy was lost. Of the total incident solar radiation, 36% was delivered to the hot water subsystem (See Figure 4).

The solar energy transport losses from storage amounted to 13.40 million BTU (see Table 4). No energy loss was indicated from storage to the DHW subsystem because the same sensors are used to determine the energy from storage and the solar energy used. [This calculation used temperature sensors T350 and T358, and flow meter W300 (see Appendix A)].

Table 4. SOLAR ENERGY LOSSES

FACILITIES DEVELOPMENT
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED MINUS SOLAR ENERGY DIRECTLY TO LOADS	SOLAR ENERGY TO STORAGE	LOSS COLLECTOR TO STORAGE (%)	CHANGE IN STORED ENERGY	HOT WATER SOLAR ENERGY FROM STORAGE
JAN	4.80	4.55	5	-0.31	4.23
FEB	9.44	9.05	4	-0.27	8.30
MAR	12.68	12.18	4	0.19	10.60
APR	11.52	11.24	2	-0.15	10.15
MAY	7.17	6.83	5	-0.11	5.44
JUN	9.22	8.71	6	0.11	7.18
JUL	*	*	*	*	*
AUG	10.32	10.07	2	-0.18	8.45
SEP	9.95	9.64	3	-0.20	8.68
OCT	11.31	11.01	3	-0.22	10.07
NOV	11.30	10.92	3	-0.12	9.82
DEC	11.50	11.12	3	-0.05	10.31

*No data was collected for July.

1.5 SOLAR SYSTEM AVAILABILITY

The solar energy system was operational for the whole year. No data was collected for July because the Site Data Acquisition Subsystem (SDAS) was not operational (see Appendix B).

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The Facilities Development collector array is composed of 28 Revere Sun Aid No. 211 flat-plate collectors, which use water as the heat transfer medium. For freeze protection, the collector water drains down to the storage tank. Total collector area is 520 square feet and the collectors face south at a tilt of 42 degrees to the horizontal.

The total incident solar energy on the collector array was 256.09 million BTU of which 209.94 million BTU were incident while the collector pump was operating. Total solar energy collected was 109.21 million BTU, resulting in a collector array efficiency of 43% based on the total incident solar energy, or 52% based on the operational incident solar energy. Of the collected solar energy, 109.21 million BTU, 3.89 million BTU were lost during transit to storage, resulting in 105.32 million BTU arriving at storage. The operating energy required to support the collector subsystem was 1.93 million BTU. This operating energy is the energy required to drive the collector loop pump P1 (see Appendix A). The average daytime ambient temperature was 67°F. (See Table 5.)

Table 5. COLLECTOR SUBSYSTEM PERFORMANCE

FACILITIES DEVELOPMENT
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR SUBSYSTEM EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY	COLLECTOR ARRAY OPERATIONAL EFFICIENCY (%)	ECSS OPERATING ENERGY	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE (°F)
JAN	14.36	4.80	34	8.88	54	0.12	4.55	63
FEB	21.79	9.44	43	18.60	51	0.27	9.05	66
MAR	29.44	12.68	43	27.17	47	0.43	12.18	65
APR	26.66	11.52	43	23.16	50	0.10	11.24	66
MAY	20.10	7.17	36	13.82	52	0.14	6.83	63
JUN	24.11	9.22	38	20.26	46	0.19	8.71	68
JUL	*	*	*	*	*	*	*	*
AUG	25.16	10.32	41	21.59	48	0.20	10.07	75
SEP	21.95	9.95	45	17.72	56	0.13	9.64	71
OCT	24.49	11.31	46	19.77	57	0.10	11.01	70
NOV	24.06	11.30	47	19.42	58	0.11	10.92	67
DEC	23.97	11.50	48	19.55	59	0.14	11.12	65
TOTAL	256.09	109.21	-	209.94	-	1.93	105.32	-
AVERAGE	23.28	9.93	43	19.09	52	0.18	9.58	67

*No data was collected for July.

The collector array efficiency of 43% is very good, but not unexpected considering the mild San Diego climate.

The strainer in the collector loop was clogged for the first eight months of the year, and decreased the flow rate by a factor of two. The strainer was clogged because of scaling.

The strainer should be cleaned at least once a year to prevent this problem. The strainer was cleaned in September and improved the collector efficiency. If the strainer had been unclogged for the whole year, the collector array efficiency might have been better.

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

$$n_c = Q_s/Q_i$$

where: n_c = collector array efficiency

Q_s = collected solar energy

Q_i = incident solar energy

The monthly efficiency computed by this method is listed in the column entitled "Collector Subsystem Efficiency" in Table 5.

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

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

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

where: Q_s = collected solar energy

Q_{oi} = incident solar energy while the collector pumps operated

The monthly efficiency computed by this method is listed in the column entitled "Collector Array Operational Efficiency" in Table 5. This latter efficiency term is not the same collector efficiency as represented by the ASHRAE

Standard 93-77. Both operational collector efficiency and the ASHRAE collector efficiency are defined as the ratio of actual useful energy collected to solar energy incident upon the collector, and both use the same definition of collector area. However, the ASHRAE efficiency is determined from instantaneous evaluation under tightly controlled, steady-state test conditions, while the operational collector efficiency is determined from the actual conditions of daily solar energy system operation. Measured monthly values of operational incident energy and computed values of operational collector efficiency are presented in Table 5.

2.2 STORAGE

The storage tank is a 1,000-gallon glass-lined Santa Fe tank insulated with polyurethane and buried underground.

During the year of 1980, the total solar energy delivered to storage was 105.32 million BTU. There were 93.23 million BTU delivered to the DHW subsystem, and the stored energy decreased by 1.31 million BTU. Energy loss from storage was 13.40 million BTU, resulting in a storage efficiency of 87%. (See Footnote 1.) The average storage temperature was 89°F. (See Table 6.)

The average storage temperatures for the summer months of June and August, were lower than the monthly averages for the remainder of the year. This was due to low DHW usage and less than optimum use of solar energy, i.e., all of the available solar energy was not used.

Evaluation of the system storage performance under actual solar energy system operation and weather conditions can be performed using the parameters. The utility of these measured data in evaluation of the overall storage design is illustrated. (See Footnote 1.)

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1. Storage subsystem performance is evaluated by comparison of energy to storage, energy from storage, and the change in stored energy. The ratio of the sum of energy from storage and the change in stored energy, to the energy delivered 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

The solar fractions for the last half of the year were better than the first half of the year. This is because more solar and less auxiliary energies were used in the last half of the year.

At this site, seven of the 31 apartments are instrumented with flow meters (W301-W307, see Appendix A). Many of these flow meters have been clogged due to scaling.

Scaling is the deposition of some solid, i.e. calcium carbonate and/or magnesium carbonate, on the metal surface usually resulting from some precipitating process. Scaling can be highly detrimental if the scale thickness becomes large. Scaling can narrow the flow passage and limit the flow.

This problem is due to the high mineral content of the water in San Diego and cannot be corrected.

The solar system at this site performed well. It performed a little better than the f-Chart predicted solar fraction (33%) but not as well as the design predicted solar fraction (60%). The f-Chart predicted solar fraction is a better comparison to the performance of the system because it uses the actual weather and load conditions. This report is one month short of a year (July) to make an accurate comparison to the design predicted solar fraction.

The energy savings of $1,288.05 are very good.

SECTION 3

OPERATING ENERGY

The total system operating energy for Facilities Development is the electrical energy required to support the DHW subsystem without affecting its thermal state. The operating energy expense is the energy required to collect and deliver solar energy to the load. The energy required to drive both pumps, P1 and P2 (See Appendix A), is unique to the solar system and is considered an expense.

The operating energy expended to collect solar energy was 1.93 million BTU, and 3.32 million BTU were expended to deliver solar energy to the load. The total operating expense was 5.25 million BTU. (See Table 8.)

Table 8. OPERATING ENERGY

FACILITIES DEVELOPMENT
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY (SOLAR UNIQUE)	DHW OPERATING ENERGY SOLAR UNIQUE	TOTAL SOLAR UNIQUE OPERATING ENERGY	TOTAL SYSTEM OPERATING ENERGY
JAN	0.12	0.00	0.12	0.12
FEB	0.27	0.57	0.84	0.84
MAR	0.43	0.59	1.02	1.02
APR	0.10	0.32	0.42	0.42
MAY	0.14	0.62	0.76	0.76
JUN	0.19	0.60	0.79	0.79
JUL	*	*	*	*
AUG	0.20	0.46	0.66	0.66
SEP	0.13	0.16	0.29	0.29
OCT	0.10	0.00	0.10	0.10
NOV	0.11	0.00	0.11	0.11
DEC	0.14	0.00	0.14	0.14
TOTAL	1.93	3.32	5.25	5.25
AVERAGE	0.18	0.30	0.48	0.48

*No data was collected for July.

The DHW operating energy was zero after September because pump P2 (See Appendix A) did not operate. This pump operated for the first part of September. In September, two switches connected in series were added to activate the pump. One switch is a timer, on from 5:00 a.m. to 8:00 a.m. and 5:00 p.m. to 8:30 p.m., and the other switch is on if the circulation loop water is below 90°F. Both of these conditions were satisfied simultaneously during October, November, December, and part of September.

The hot water operating energy for January could not be calculated due to instrumentation problems.

SECTION 4

WEATHER CONDITIONS

The Facilities Development site is located in San Diego, California at 32 degrees N latitude and 117 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 9. 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 9. WEATHER CONDITIONS

FACILITIES DEVELOPMENT
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU, unless otherwise indicated)

	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT^2-DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS		COOLING DEGREE-DAYS	
MONTH	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
JAN	891	1,571	58	55	222	314	0	10
FEB	1,445	1,757	59	57	175	237	0	0
MAR	1,826	1,892	58	58	221	219	0	0
APR	1,709	1,855	60	61	155	144	0	15
MAY	1,247	1,676	60	63	153	79	0	26
JUN	1,546	1,626	64	66	71	52	13	67
JUL†	*	1,761	*	70	*	6	*	149
AUG	1,561	1,857	71	71	0	0	175	201
SEP	1,407	1,840	67	70	0	16	61	163
OCT	1,519	1,797	64	66	53	43	7	77
NOV	1,542	1,649	58	61	222	140	0	61
DEC	1,487	1,521	56	57	290	257	0	0
TOTAL	-	-	-	-	1,562	1,501	256	620
AVERAGE	1,471	1,731	61	62	142	136	23	56

*No data was collected for July.
†July is not included in the long-term totals and averages. It is included for information only.

During the period from January 1980 through December 1980, the average daily total incident solar radiation on the collector array was 1,471 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 1,731 BTU per square foot per day for a south-facing plane with a tilt of 42 degrees to the horizontal. During the period, the highest monthly average insolation was 1,826 BTU per square foot per day during March. The average ambient temperature during the reporting period was 61°F as compared with the long-term average of 62°F. The highest monthly average ambient temperature was 71°F during August, and the lowest monthly average ambient temperature was 55°F during January. The number of heating degree-days for the period (based on a 65°F reference) was 1,562 as compared with the long-term average of 1,501. The range of heating degree-days was from a high of 290 during December to a low of zero during August and September.

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

This parameter quantifies the effects of cloudiness and atmospheric transmission on the insolation received at the earth's surface. The clearness index ranged from a high of 60% during June to a low of 28% during January.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EXTRA-TERRESTRIAL INSOLATION	3,207	3,330	3,322	3,076	2,778	2,615	2,680	2,855	3,320	3,315	3,226	3,170
TTL INS / EXT INS (%)	28	44	54	54	43	60	61	55	42	46	48	47

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, Facilities Development, February 1980, SOLAR/1017-80/02, Vitro Laboratories, Silver Spring, Maryland.

*8. Monthly Performance Report, Facilities Development, March 1980, SOLAR/1017-80/03, Vitro Laboratories, Silver Spring, Maryland.

*9. Monthly Performance Report, Facilities Development, April 1980, SOLAR/1017-80/04, Vitro Laboratories, Silver Spring, Maryland.

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* 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, Facilities Development, May 1980, SOLAR/1017-80/05, Vitro Laboratories, Silver Spring, Maryland.

*11. Monthly Performance Report, Facilities Development, June 1980, SOLAR/1017-80/06, Vitro Laboratories, Silver Spring, Maryland.

*12. Monthly Performance Report, Facilities Development, August 1980, SOLAR/1017-80/08, Vitro Laboratories, Silver Spring, Maryland.

*13. Monthly Performance Report, Facilities Development, September 1980, SOLAR/1017-80/09, Vitro Laboratories, Silver Spring, Maryland.

*14. Monthly Performance Report, Facilities Development, October 1980, SOLAR/1017-80/10, Vitro Laboratories, Silver Spring, Maryland.

*15. Monthly Performance Report, Facilities Development, November 1980, SOLAR/1017-80/11, Vitro Laboratories, Silver Spring, Maryland.

*16. Monthly Performance Report, Facilities Development, December 1980, SOLAR/1017-80/12, Vitro Laboratories, Silver Spring, Maryland.

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

APPENDIX A

SYSTEM DESCRIPTION

The Facilities Development Company site is a three-story multifamily condominium consisting of 31 units in San Diego, California. Solar energy is used for preheating domestic hot water (DHW) for the complex. The solar energy system has an array of flat-plate Revere collectors with a gross area of 520 square feet. The array faces south at an angle of 42 degrees to the horizontal. Potable water is the transfer medium that transports solar energy from the collector array to an underground insulated 1,000-gallon glass-lined Santa Fe storage tank. Preheated water from the storage tank is supplied, on demand, to 31 conventional Ruudglas 52-gallon DHW tanks. When solar energy is insufficient to satisfy the load, electric heating elements within the individual DHW tanks are energized. The system, shown schematically, has two modes of solar operation.

Mode 1 - Collector-to-Storage - This mode activates when the water temperature in the collectors is 9°F higher than the temperature of the storage tank. Water is pumped through the collectors and circulates back to storage until the temperature difference is 3°F or less.

Mode 2 - Storage-to-DHW Tank - This mode activates when there is a demand for hot water replenishment by an individual DHW tank. Water from storage circulates through a supply service loop to the individual DHW tank and returns through a service line to storage. The water temperature in each DHW tank is thermostatically controlled. When required, additional energy is supplied by electric heating elements within each tank.

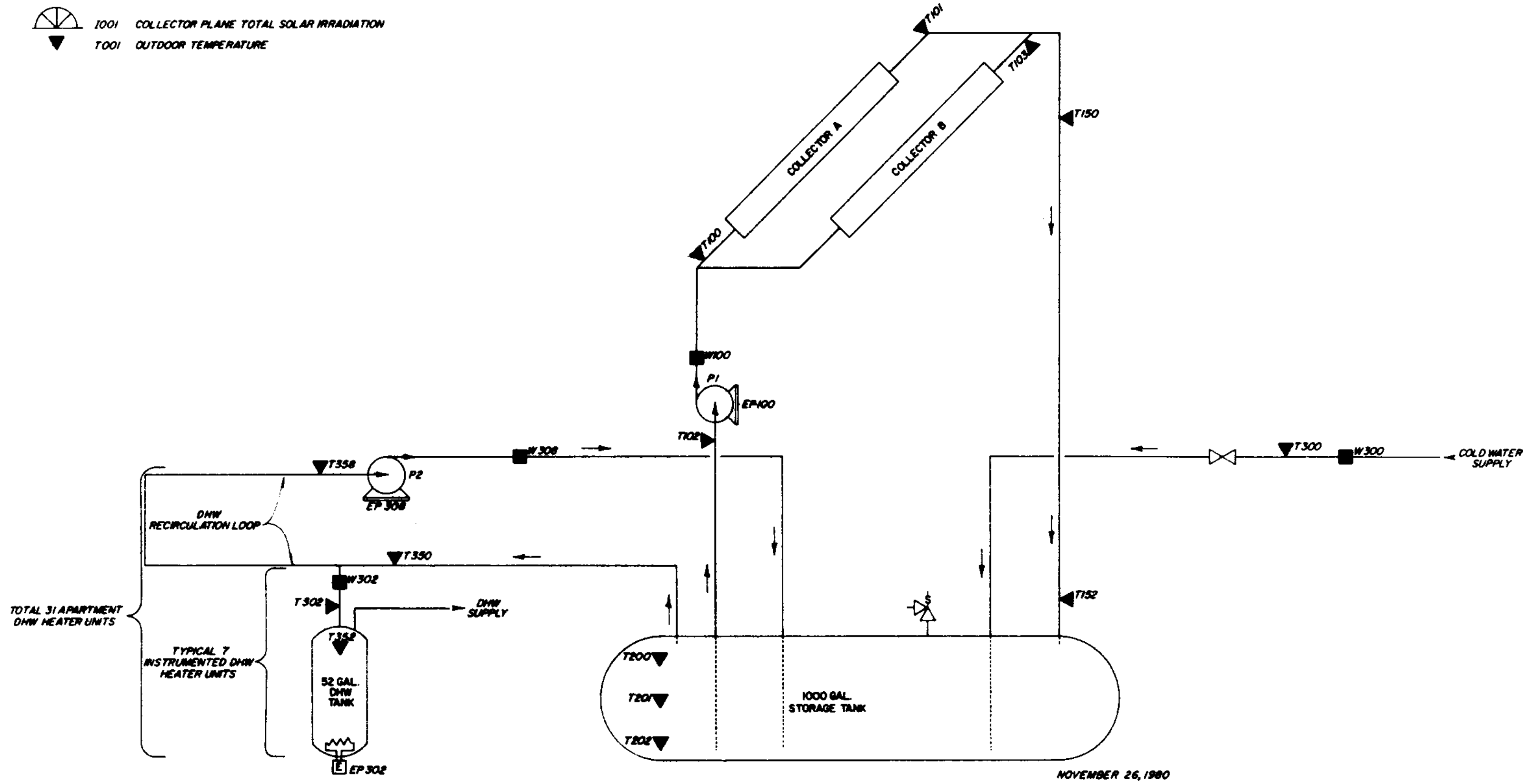
SUBSYSTEMS

Collector - The gross collector array area (18.57 feet x 28.00 feet) is 520 square feet. The collectors face south and are tilted to an altitude angle of 42 degrees from the horizontal. Orientation of the collectors is close to the optimum orientation for a system of this type, at a site latitude of 32 degrees North. Optimum collctor orientation at this site is estimated to be south-facing at a tilt of 32 degrees.

The Revere collector panels have two glass covers and a nonselective absorber surface. The absorber surface has a solar absorptivity of 0.96 and an infrared emissivity of 0.11. Total solar transmissivity of the glazing is 0.86. The absorber surface is composed of black painted copper. The fluid circulated through the collectors is water.

Storage - Solar energy storage is provided by a 1,000-gallon glass-lined Santa Fe steel storage tank, buried underground. The storage tank is insulated with polyurethane and water is used as the medium to transfer solar energy to the DHW system.

Domestic Hot Water - City water is preheated and stored in a 1,000-gallon storage tank and supplied, on demand, to 31 conventional 52-gallon Ruuglas DHW tanks. When solar energy is insufficient to satisfy the DHW load, an electrical immersion heater in the DHW tank provides auxiliary energy for heating the supply water.



DHW HEATER INSTRUMENTATION				
APT NO.	TEMP IN	TEMP OUT	FLOW	POWER
109	T301	T351	—	EP301
107	T302	T352	W302	EP302
207	T303	T353	—	EP303
307	T304	T354	W304	EP304
101	T305	T355	—	EP305
201	T306	T356	—	EP306
301	T307	T357	W307	EP307

Figure A-1. Facilities Development Solar Energy System Schematic

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Facilities Development 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.

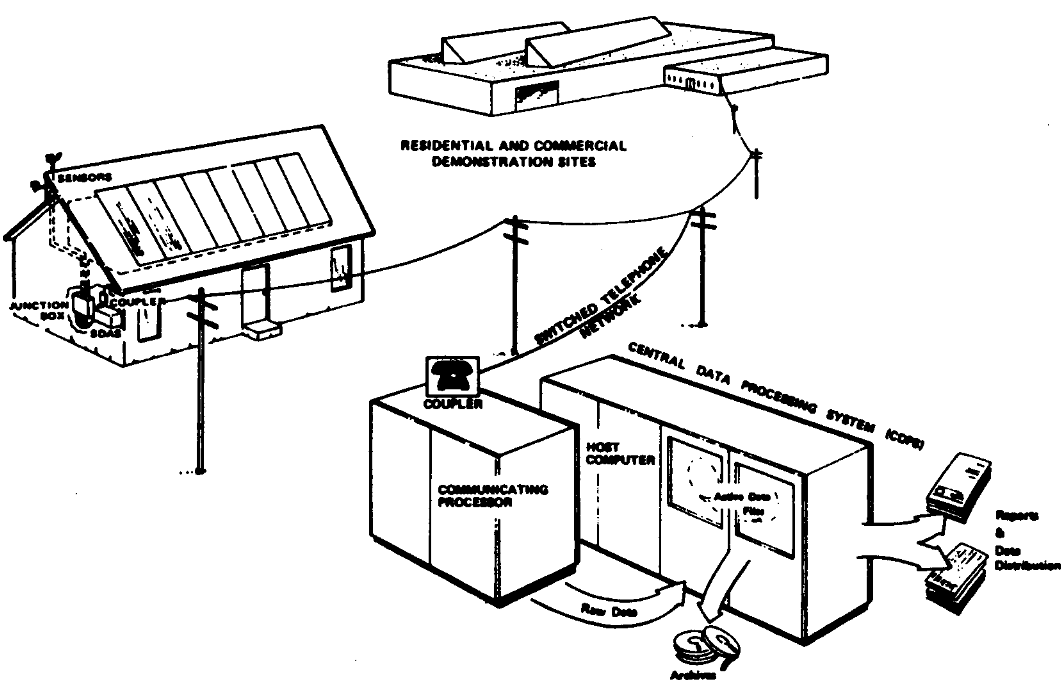


Figure B-1. The National Solar Data Network

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 Facilities Development solar energy system from January 1980 through December 1980 was analyzed during the year, 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:

March 1978, SOLAR/1017-80/03
April 1978, SOLAR/1017-80/04
May 1978, SOLAR/1017-80/05
June 1978, SOLAR/1017-80/06
July 1978, SOLAR/1017-80/07
August 1978, SOLAR/1017-80/08
September 1978, SOLAR/1017-80/09
January 1979, SOLAR/1017-79/01
February 1979, SOLAR/1017-79/02
March 1979, SOLAR/1017-79/03
April 1979, SOLAR/1017-79/04
May 1979, SOLAR/1017-79/05
June 1979, SOLAR/1017-79/06
July 1979, SOLAR/1017-79/07
August 1979, SOLAR/1017-79/08
September 1979, SOLAR/1017-79/09
October 1979, SOLAR/1017-79/10
February 1980, SOLAR/1017-80/02
March 1980, SOLAR/1017-80/03
April 1980, SOLAR/1017-80/04
May 1980, SOLAR/1017-80/05
June 1980, SOLAR/1017-80/06
August 1980, SOLAR/1017-80/08
September 1980, SOLAR/1017-80/09
October 1980, SOLAR/1017-80/10
November 1980, SOLAR/1017-80/11
December 1980, SOLAR/1017-80/12

Solar Energy System Performance Evaluations:

November 1978, SOLAR/1017-78/14
June 1979, SOLAR/1017-79/14

Solar Project Description, SOLAR/1017-79/50

Thermal Performance Evaluation of Facilities Development Company Solar Energy Hot Water System, SOLAR/1017-78/42

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

APPENDIX C

PERFORMANCE FACTORS AND SOLAR TERMS

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

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

Section 3 describes general acronyms used in this report.

Section 1. Performance Factor Definitions and Acronyms

Section 2. Solar Terminology

Section 3. General Acronyms

SECTION 1. PERFORMANCE FACTOR DEFINITION 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
* 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 oi 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: $\frac{Ti-Ta}{I}$ $\frac{°F \times hr. \times sq.\ ft.}{BTU}$
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

FACILITIES DEVELOPMENT

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.

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* 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

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

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
$\dot{V}$	=	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 ± three 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)

$SECA = \Sigma\ [M100 \times C \times (T150 - T100)] \times \Delta\tau$

SOLAR ENERGY TO STORAGE (BTU)

$STEI = \Sigma\ [M100 \times C \times (T152 - T102)] \times \Delta\tau$

SOLAR ENERGY FROM STORAGE (BTU)

$STEO = \Sigma\ [M300 \times C \times (T350 - T300)] \times \Delta\tau$

AVERAGE COLD WATER SUPPLY TEMPERATURE (°F)

$TSW = 1/60 \times \Sigma\ T300 \times \Delta\tau$

when there is flow

AVERAGE HOT WATER TEMPERATURE (°F)

$THW = 1/60 \times \Sigma(T351 + T352 + T353 + T354 + T355 + T356 + T357)/7 \times \Delta\tau$

when there is hot water use

AVERAGE TEMPERATURE OF STORAGE (°F)

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

ENERGY DELIVERED FROM ECSS TO HOT WATER SUBSYSTEM (BTU)

CSEO = STEO

ECSS OPERATING ENERGY (BTU)

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

when system is in the collector-to-storage mode

HOT WATER SUBSYSTEM OPERATING ENERGY (BTU)

$HWOPE = 56.8833 \times \Sigma\ EP308 \times \Delta\tau$

HWOPE1 = HWOPE

when system is in the storage-to-hot water mode

SOLAR ENERGY TO HOT WATER SUBSYSTEM (BTU)

HWSE = STEO

HOT WATER SUBSYSTEM AUXILIARY ELECTRICAL FUEL ENERGY (BTU)

$$HWAE = 56.8833 \times \Sigma(EP301 + EP302 + EP303 + EP304 + EP306 + EP307) \times (31/6) \times \Delta\tau$$

HOT WATER SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$$HWAT = HWAE$$

HOT WATER SUBSYSTEM LOAD (BTU)

$$HWL = \Sigma\ M300 \times C\ [T351 + T352 + T353 + T354 + T355 + T356 + T357)/7] - T300 \times \Delta\tau$$

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)

$$SEL = CSEO$$

ECSS SOLAR CONVERSION EFFICIENCY

$$CSCEF = SEL/SEA$$

HOT WATER SUBSYSTEM SOLAR FRACTION (PERCENT)

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

HOT WATER SUBSYSTEM ELECTRICAL ENERGY SAVINGS (BTU)

$$HWSVE = HWSE - HWOPE$$

SYSTEM LOAD (BTU)

SYSL = HWL

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

SFR = HWSFR

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

AXT = HWAE

AUXILIARY ELECTRICAL ENERGY TO LOADS (BTU)

AXE = HWAE

SYSTEM OPERATING ENERGY (BTU)

SYSOPE = HWOPE + CSOPE

TOTAL ENERGY CONSUMED (BTU)

TECSM = SYSOPE + AXE + SECA

TOTAL ELECTRICAL ENERGY SAVINGS (BTU)

TSVE = HWSVE - CSOPE

SYSTEM PERFORMANCE FACTOR

SYSPF = SYSL/[(AXE + 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)*
FACILITIES DEVELOPMENT
JANUARY 1980 THROUGH DECEMBER 1980

(All values in million BTU, unless otherwise indicated)

MONTH	ESFR (%)	ASFR (%)	LOAD	LOSS	STECH	ESECA	ASECA	ESEU	ASEU	LOSS (%)
JAN	17	9	26.44	0.88	-0.31	5.07	4.80	4.47	4.23	12
FEB	30	37	27.03	1.41	-0.27	9.29	9.44	8.17	8.30	12
MAR	38	43	28.53	1.89	0.19	12.90	12.68	10.78	10.60	16
APR	38	46	25.36	1.52	-0.15	11.04	11.52	9.73	10.15	12
MAY	22	28	24.97	1.84	-0.11	7.25	7.17	5.50	5.44	24
JUN	32	38	22.20	2.24	-0.20	9.19	9.22	7.15	7.18	22
JUL	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
AUG	40	50	19.60	2.05	-0.18	9.57	10.32	7.84	8.45	18
SEP	35	48	20.86	1.47	-0.20	8.26	9.95	7.21	8.68	13
OCT	38	50	22.40	1.46	-0.22	9.63	11.31	8.58	10.07	11
NOV	38	50	22.44	1.91	-0.43	9.77	11.30	8.49	9.82	13
DEC	34	46	26.47	1.66	-0.47	10.07	11.50	9.03	10.31	10
TOTAL	-	-	266.30	18.33	-2.35	102.04	109.21	86.94	93.22	-
AVERAGE	33	40	24.21	16.66	-0.21	92.76	99.28	79.04	84.75	15

*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

ESEU - Expected (predicted) solar energy used

ASEU - Actual (measured) solar energy used

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

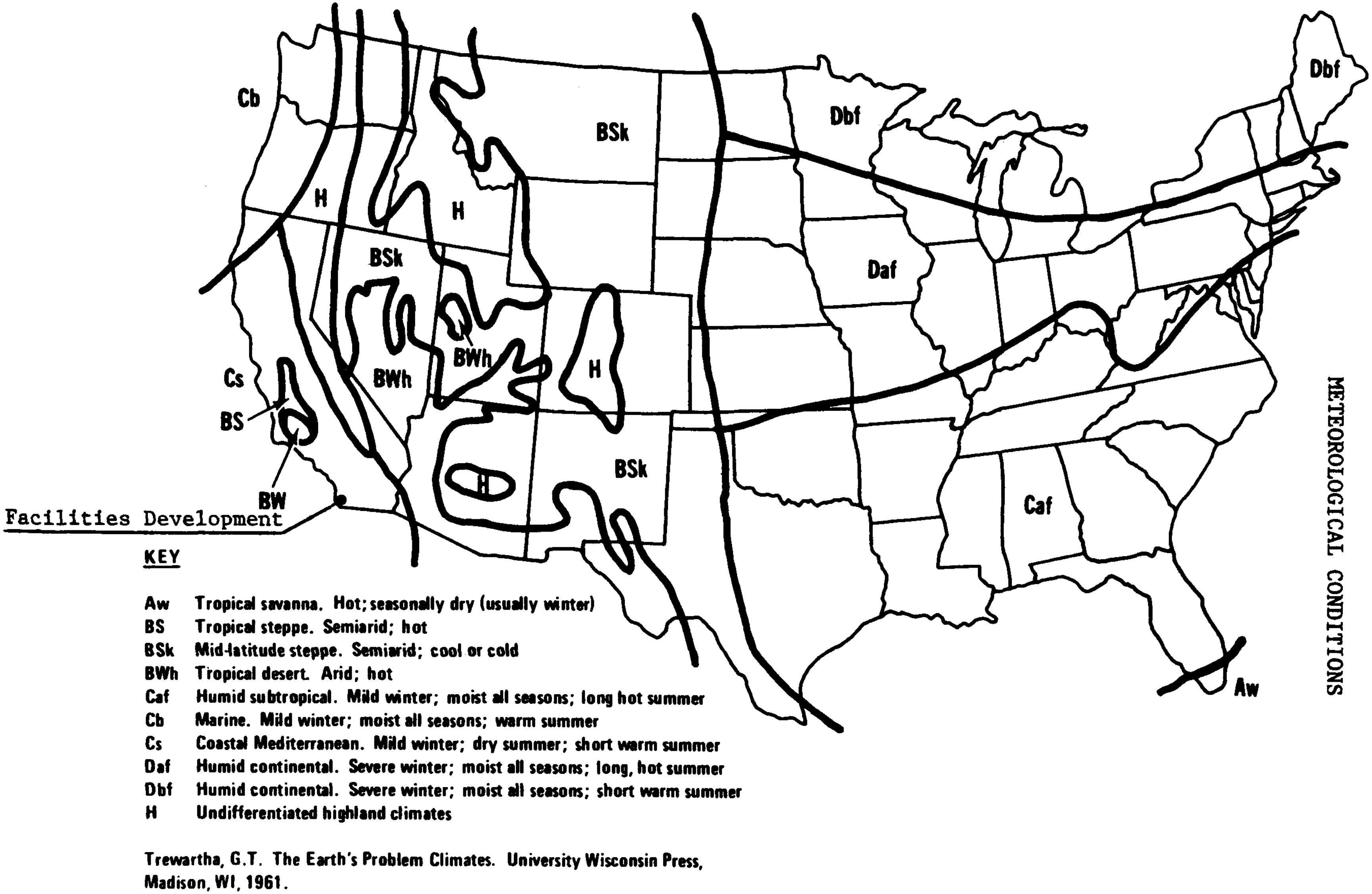

Figure F-1. Meteorological Map of the United States Showing Facilities Development Location

FACILITIES DEVELOPMENT LONG-TERM WEATHER DATA

COLLECTOR TILT: 42 DEGREES
LATITUDE: 32 DEGREES

LOCATION: SAN DIEGO, CALIFORNIA
COLLECTOR AZIMUTH: 0 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
JAN	1,716	977	0.56944	1.608	1,571	314	10	55
FEB	2,143	1,268	0.59174	1.385	1,757	237	0	57
MAR	2,665	1,633	0.61286	1.158	1,892	219	0	58
APR	3,168	1,936	0.61101	0.958	1,855	144	15	61
MAY	3,490	2,002	0.57365	0.837	1,676	79	26	63
JUN	3,609	2,061	0,57110	0.789	1,626	52	67	66
JUL	3,541	2,186	0.61741	0.805	1,761	6	149	70
AUG	3,284	2,057	0.62650	0.902	1,857	0	201	71
SEP	2,841	1,718	0.60482	1.071	1,840	16	163	70
OCT	2,292	1,375	0.60007	1.307	1,797	43	77	66
NOV	1,813	1,062	0.58554	1.553	1,649	140	14	61
DEC	1,594	903	0.56673	1.684	1,521	257	0	57

LEGEND:

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

HBAR - Monthly average daily radiation (actual) 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 degrees days per month.

CDD - Number of cooling degrees days per month.

TBAR - Average ambient temperature in degrees Fahrenheit.

MONTHLY REPORT: FACILITIES DEVELOPMENT
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	1374	54	61
2	1906	58	72
3	1510	56	70
4	1791	53	68
5	962	52	62
6	1057	56	64
7	423	58	63
8	836	60	63
9	186	60	61
10	313	60	64
11	151	61	60
12	178	62	62
13	718	62	64
14	326	62	64
15	1314	61	66
16	440	60	64
17	448	60	63
18	651	57	58
19	1904	53	60
20	1989	52	62
21	1931	52	62
22	*	*	*
23	*	*	*
24	*	*	*
25	1000	54	63
26	852	59	63
27	226	58	61
28	232	58	59
29	69	58	57
30	305	61	*
31	1853	62	*
SUM	27618	-	-
AVG	891	58	63

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FACILITIES DEVELOPMENT
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	1633	60	*
2	1938	59	70
3	1363	57	66
4	1633	57	66
5	*	*	*
6	*	*	*
7	*	*	*
8	*	*	*
9	2076	56	69
10	2123	53	65
11	1977	52	63
12	2032	55	67
13	265	60	61
14	774	62	64
15	978	62	65
16	286	61	62
17	*	*	*
18	916	63	67
19	493	62	65
20	1149	60	64
21	1121	61	63
22	1947	58	63
23	*	*	*
24	*	*	*
25	*	*	*
26	2057	62	76
27	2443	62	74
28	1300	58	65
29	1848	58	66
SUM	41912	-	-
AVG	1445	59	66

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FACILITIES DEVELOPMENT
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	686	59	64
2	1024	59	64
3	1403	59	63
4	1722	59	63
5	1889	57	64
6	1243	57	58
7	*	*	*
8	*	*	*
9	2101	59	67
10	*	*	*
11	*	*	*
12	3024	61	66
13	*	*	*
14	2014	58	69
15	1882	59	69
16	1893	60	67
17	2166	59	70
18	1050	54	*
19	2112	56	63
20	1495	56	*
21	1411	57	61
22	2053	55	64
23	2148	57	65
24	1776	57	63
25	2675	57	63
26	*	*	*
27	1878	58	63
28	2085	57	64
29	2153	60	73
30	1759	57	66
31	2015	59	65
SUM	56613	-	-
AVG	1826	58	65

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FACILITIES DEVELOPMENT
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	1415	56	58
2	1304	55	58
3	2109	55	61
4	1911	56	63
5	2633	57	65
6	*	*	*
7	2025	59	67
8	2051	64	75
9	2055	62	70
10	1968	63	68
11	1248	62	*
12	2138	65	77
13	2070	65	78
14	2711	60	*
15	*	*	*
16	1928	62	68
17	1901	63	70
18	1827	62	67
19	1934	61	67
20	1385	62	64
21	1521	58	60
22	*	*	*
23	837	54	59
24	1933	56	63
25	1841	60	65
26	1321	61	63
27	1294	61	65
28	1293	61	66
29	643	57	61
30	854	58	61
SUM	51278	-	-
AVG	1709	60	66

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FACILITIES DEVELOPMENT
MAY 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	1134	59	64
2	2847	62	66
3	*	*	*
4	2129	62	65
5	758	60	63
6	1201	61	64
7	331	59	61
8	*	*	*
9	1229	61	64
10	597	59	58
11	1723	58	62
12	1412	58	63
13	398	57	60
14	651	59	60
15	1352	60	65
16	1362	62	64
17	1580	63	66
18	1092	62	66
19	503	61	64
20	395	60	62
21	944	62	67
22	1766	62	64
23	*	*	*
24	1881	58	60
25	*	*	*
26	*	*	*
27	*	*	*
28	1777	58	63
29	1819	59	64
30	1598	60	63
31	698	60	61
SUM	38660	-	-
AVG	1247	60	63

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FACILITIES DEVELOPMENT
JUNE 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	1451	61	63
2	858	61	63
3	1514	61	65
4	1774	60	65
5	1768	60	65
6	1719	60	65
7	*	*	*
8	*	*	*
9	*	*	*
10	*	*	*
11	1680	63	66
12	1719	63	69
13	1754	62	68
14	1774	65	71
15	1765	65	70
16	1475	64	67
17	967	62	66
18	1533	63	66
19	1573	63	67
20	1382	62	67
21	1669	62	65
22	1598	63	67
23	1719	65	70
24	1709	65	69
25	1714	65	70
26	1591	68	74
27	1580	69	75
28	813	71	*
29	*	*	*
30	*	*	*
SUM	46373	-	-
AVG	1546	64	68

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FACILITIES DEVELOPMENT
JULY 1980
ENVIRONMENTAL SUMMARY

(NO DATA AVAILABLE)

MONTHLY REPORT: FACILITIES DEVELOPMENT
AUGUST 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1561	76	79
2	1391	73	77
3	1679	72	76
4	1595	71	76
5	1707	72	76
6	1781	71	76
7	1758	72	76
8	1727	73	77
9	1685	73	78
10	1751	72	78
11	1607	73	79
12	935	72	76
13	1508	73	78
14	939	72	76
15	1020	70	*
16	1638	69	73
17	1282	69	73
18	1205	69	73
19	1380	70	73
20	1875	70	75
21	1810	70	75
22	999	69	71
23	1827	69	73
24	1858	70	75
25	1868	70	75
26	1792	69	73
27	1229	68	71
28	1576	68	71
29	1818	69	73
30	1983	68	74
31	1606	68	72
SUM	48390	-	-
AVG	1561	71	75

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FACILITIES DEVELOPMENT
SEPTEMBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1601	68	72
2	1279	68	71
3	1833	69	71
4	1809	68	71
5	1674	68	71
6	971	68	70
7	605	66	68
8	1549	66	71
9	1222	66	72
10	891	68	*
11	622	67	*
12	254	66	*
13	578	65	69
14	1358	66	*
15	1197	65	71
16	1947	70	77
17	1978	72	78
18	2017	69	75
19	1646	67	70
20	1768	67	72
21	1627	67	72
22	1736	66	72
23	960	66	70
24	1813	66	69
25	1607	66	70
26	1451	67	71
27	1285	66	70
28	1463	66	70
29	1828	65	70
30	1644	67	73
SUM	42211	-	-
AVG	1407	67	71

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: FACILITIES DEVELOPMENT
OCTOBER 1980
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F
1	1918	66	*
2	1703	65	69
3	1307	65	68
4	1477	65	70
5	1158	66	70
6	770	66	69
7	1388	66	69
8	741	65	68
9	729	65	69
10	514	64	67
11	1232	64	69
12	1129	65	70
13	1413	65	71
14	1212	63	67
15	1562	62	64
16	1786	59	66
17	1907	58	65
18	2009	61	71
19	2029	62	72
20	1951	65	77
21	2003	67	80
22	1796	60	69
23	1882	61	71
24	2014	63	75
25	1593	61	68
26	778	62	65
27	1879	60	66
28	2078	66	79
29	2099	64	77
30	*	*	*
31	*	*	*
SUM	47096	-	-
AVG	1519	64	70

* DENOTES UNAVAILABLE DATA.

APPENDIX G

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

The Facilities Development site was occupied for all of the reporting period. During this time, the solar system operated for the entire period. This system has been in operation since June 1977. Since being put into operation, there have been major operational problems. These include:

Date	Event
8/79	A pump was installed to circulate water from the solar storage tank to the individual apartments. The water was previously delivered by thermosiphon, but there was not enough water pressure to open the valves. The apartments closest to the tank received most of the hot water.
9/80	A timer was added to the above pump to circulate the solar heated water only during the hours of 5:00 a.m. to 8:00 a.m. and 5:00 p.m. to 8:30 p.m., if the temperature of the water was below 90°F. The pump was previously operating continuously and caused high line losses.

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.

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

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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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