Dr. 1752-3

SOLAR/2074-83/14
(DE83015604)

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION UPDATE

EL TORO LIBRARY
El Toro, California
December 1981 through August 1982
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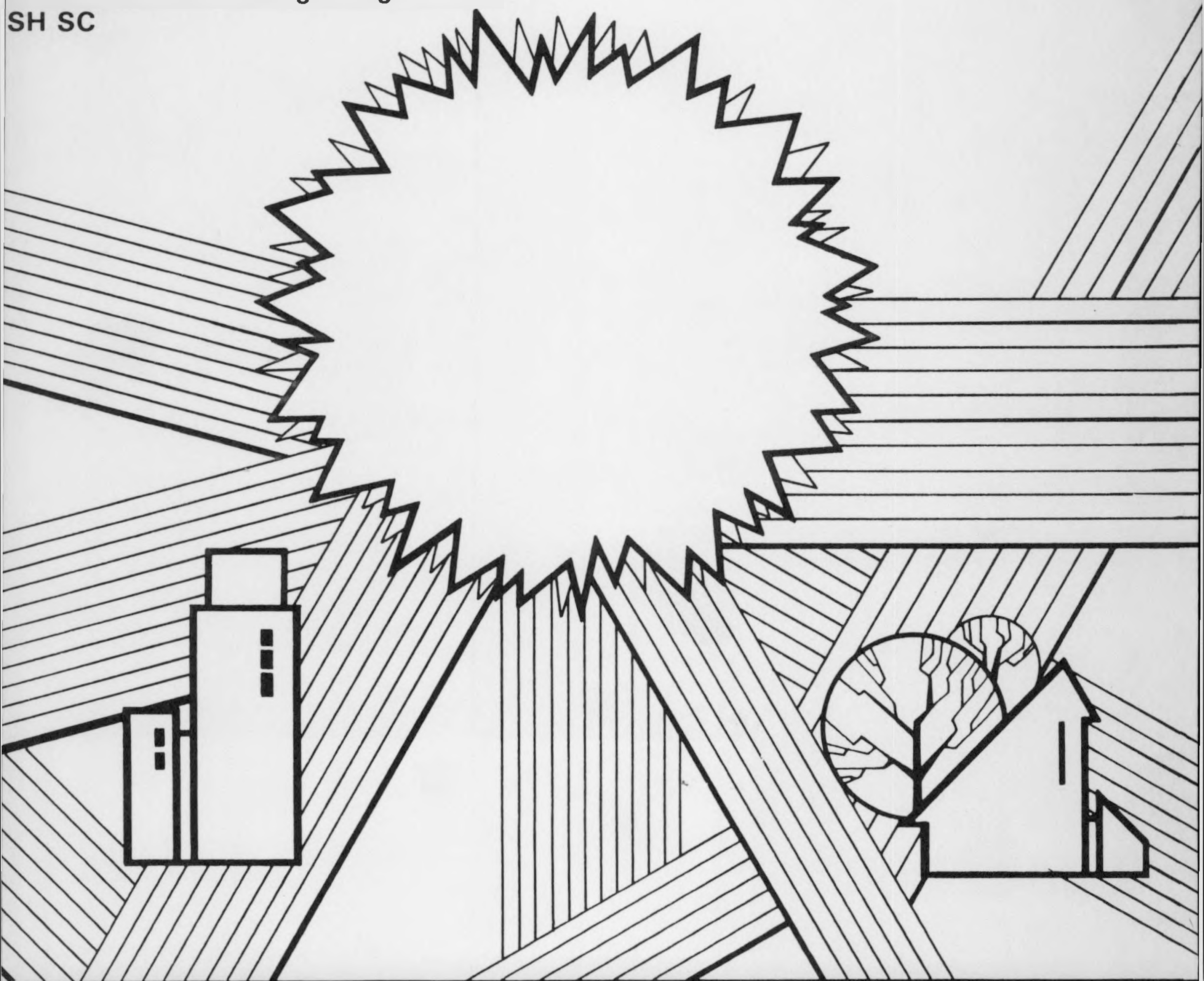

U.S. DEPARTMENT OF ENERGY

NATIONAL SOLAR DATA PROGRAM

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SOLAR/2074-83/14
(DE83015604)
Distribution Category UC-59

EL TORO LIBRARY

EL TORO, CALIFORNIA

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

UPDATE

DECEMBER 1981 THROUGH AUGUST 1982

Prepared by P.W. Kendall

Approved: T.T. Bradshaw
T.T. Bradshaw
Program Manager

Vitro Laboratories
14000 Georgia Avenue
Silver Spring, Maryland 20910

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

G.A. McGinnis, Program Manager

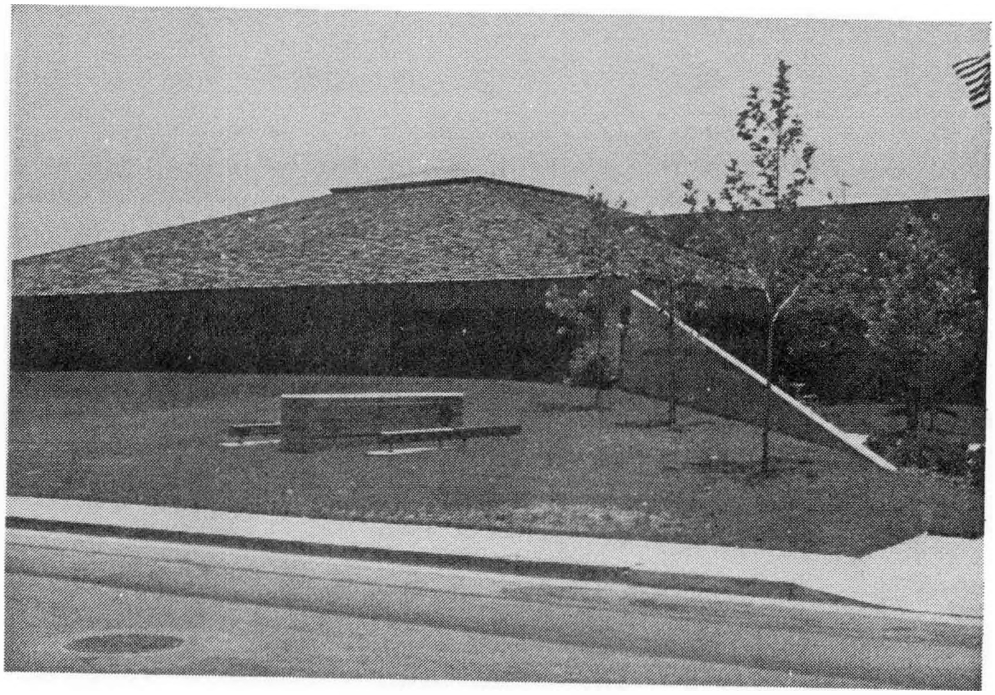
FOREWORD

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

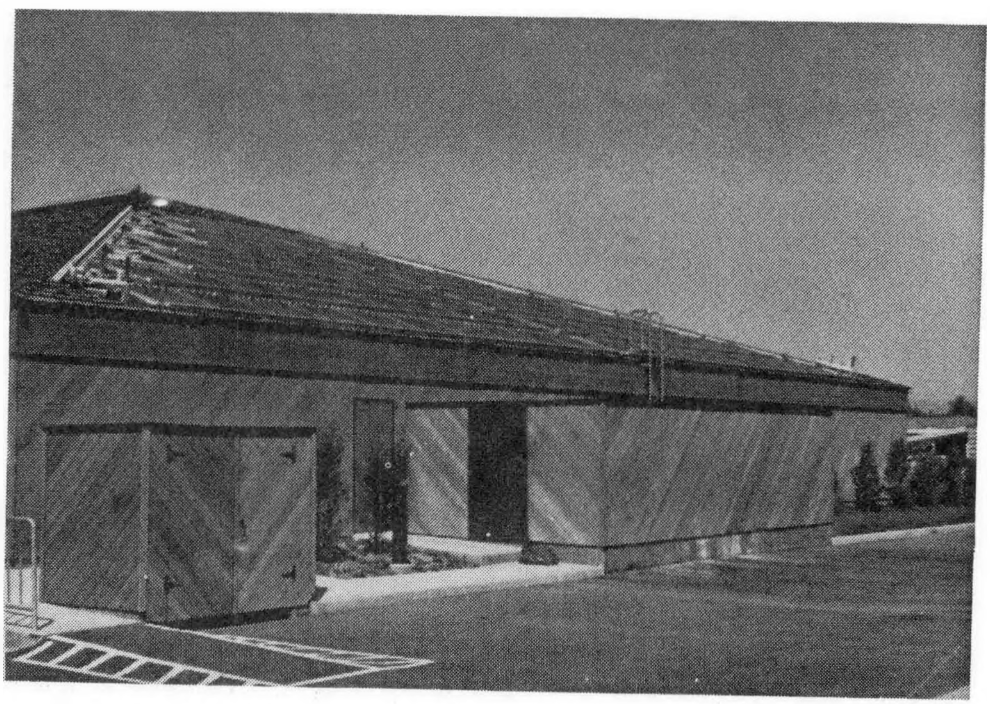
The National Solar Data Network consists of instrumented solar energy systems in buildings selected from among the 5,000 installations which are part of the National Solar Heating and Cooling Demonstration Program. Since 1981, some of the NSDN solar systems were also selected from the systems built by private industry without government funding. The overall purpose of this program is to assist in the development of solar technologies for buildings by providing data and information on the effectiveness of specific systems, the effectiveness of particular solar technologies, and the areas of potential improvement. Vitro Laboratories' responsibility in the NSDN, under contract with the Department of Energy, is to collect data daily from the sites, analyze the data, and disseminate information to interested users.

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

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



Earth-bermed North Wall



Roof-mounted Collector Array

EL TORO LIBRARY

EL TORO LIBRARY

The El Toro Library is a public library facility located in El Toro, California. The active solar energy system is equipped with:

Collector:	1,427 square feet of TC-100 evacuated-tube collectors manufactured by General Electric
Storage:	1,500-gallon steel storage tank manufactured by Santa Fe Tank and Heater Company
Chiller:	ARKLA WFB-300 25-ton absorption chiller
Auxiliary:	Natural-gas-fired unit (480,000 BTU output) manufactured by Ray Pac

A simple low-profile compact building design of approximately 10,000 square feet was utilized to maximize the tempered air distribution efficiency and minimize the amount of exterior walls subject to heat loss. Northerly exterior walls were designed to include earth-berming to provide good insulation and achieve a pleasant architectural effect. The remaining exterior walls are of wood frame construction insulated with fiberglass and surfaced with cedar siding and exterior stucco.

Glazing of solar bronze glass has been used strategically to achieve maximum visual quality with a minimum of glass area. Large overhangs protect most glazing areas and careful attention to landscape materials provides for protection at more exposed glass areas.

The roof system is heavy timber beam and wood joist construction with medium heavy cedar shake weather proofing. Foil-faced fiberglass insulation between joists and tongue and groove cedar sheathing on the interior face of joists were used.

A north-facing skylight has been located over the Librarian Station to provide a good natural quality alternate to artificial lighting. Solar collector panels are located as an architectural feature on the south-facing sloped roof.

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SOLAR SYSTEM PERFORMANCE

EL TORO LIBRARY
DECEMBER 1981 THROUGH AUGUST 1982

Solar Fraction (SFR)[1]	22% E
Solar Savings Ratio (SSR)[2]	19% E
Conventional Fuel Savings (TSVF, TSVE)[3]	171,000 (E) cubic feet [1,710 (E) therms] of natural gas at the expense of 1,165 kwh of electrical energy
System Performance Factor (SYSPF)[4]	0.24 E
Solar System COP (COP)[5]	31 E

Seasonal Energy Requirements
December 1981 through August 1982
(Million BTU)

	Subsystem Load	Solar Contributions	% Solar
Heating	12.0	-3.93 E	-20 E
Cooling	208	49.9 E*	24 E

Environmental Data

	Measured Average	Long-Term Average
Outdoor Temperature	65°F	61°F
Heating Degree-Days (Total)	935	1,599
Cooling Degree-Days (Total)	907	512
Daily Incident Solar Energy	1,481 BTU/ft^2	1,786 BTU/ft^2

1. $$\text{Solar Fraction} = \frac{\text{Solar Contribution to Loads (EHL} \times \text{HSFR)} + (\text{CL} \times \text{CSFR)}}{\text{Total Load (SYSL)}} \times 100$$

2. $$\text{Solar Savings Ratio} = \frac{\text{Solar Contribution to Loads (HSE + CLS*)} - \text{Solar Unique Operating Energy (SYSOPE1)}}{\text{Total Load (SYSL)}} \times 100$$

3. $$\text{Conventional Fuel Savings} = \begin{matrix}\text{Savings in BTU} \times 10^{-6}\ ft^3/\text{BTU} \\ \text{Electrical Expense in BTU} \times 292.8 \times 10^{-6}\ \text{kwh/BTU}\end{matrix}$$

4. $$\text{System Performance Factor} = \frac{\text{System Load (SYSL)}}{\text{Auxiliary Fossil Fuel (AXF)} + 3.33 \times \text{Electrical Operating Energy (SYSOPE)}}$$

5. $$\text{Solar System COP} = \frac{\text{Solar Energy Used (SEL)}}{\text{Solar-Unique Operating Energy (SYSOPE1)}}$$

E Denotes estimated data.
* Proportion of cooling load provided as a result of the use of solar energy.

For a description of acronyms in parentheses, refer to Appendix C of Reference 1.

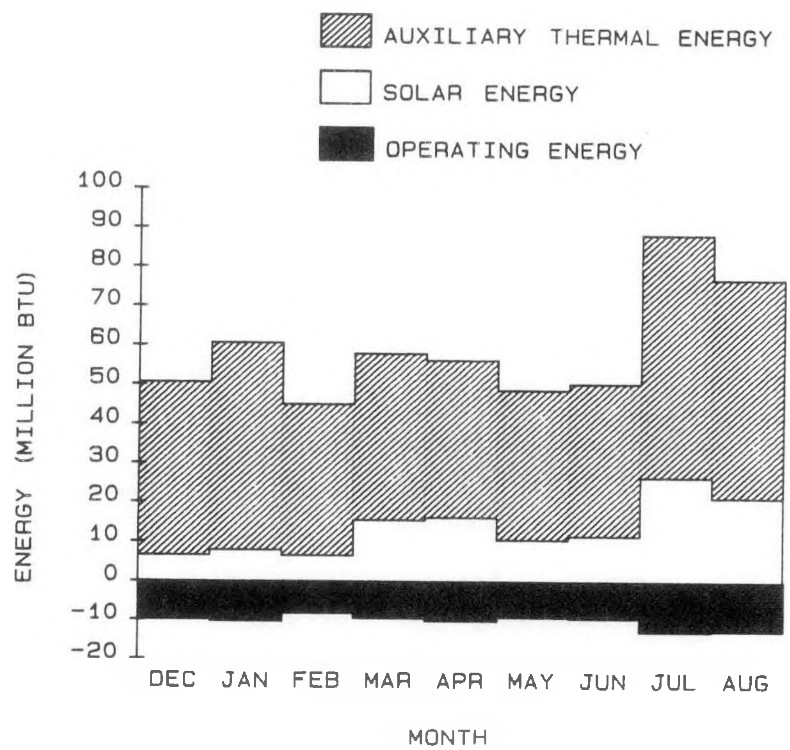
1.1 SUMMARY AND CONCLUSIONS

This report is the second in a series of performance evaluation reports on the El Toro Library, located in El Toro, California. Readers are referred to the following report to aid in their understanding of this document:

> *Solar Energy System Performance Evaluation, El Toro Library, March 1981 through November 1981, SOLAR/2074-81/14 (Reference 1)

This report updates the performance evaluation contained in the above document.

The graphical representation of the system thermal performance depicted in Figure 1 illustrates the difference between solar and auxiliary energy utilized to meet the space conditioning requirements. Figure 1 clearly shows that a small percentage of solar energy was used in comparison to auxiliary thermal energy. The operating energy was high during the nine months; however, this operation is typical for an absorption cooling system.



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

Figure 1. System Thermal Performance
El Toro Library
December 1981 through August 1982

* Copies of this report are available from the Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830.

Table 1 presents a summary of system thermal performance over the nine-month monitoring period.

As compared to the previous year, performance over the nine-month monitoring period was improved, based on overall solar contribution to the load. When compared to design values, the overall performance was poor.

Overall solar fraction was an estimated 22% of the 220 million BTU system load. A total of 122 million BTU of solar energy was used by the space conditioning system.

Auxiliary fossil fuel consumption was 608 million BTU, or 595,800 cubic feet of natural gas. Auxiliary thermal energy was a measured 68% of the auxiliary fossil fuel consumed.

The solar savings ratio, a measure of the solar contribution to the load discounted by solar operating energy, averaged 19% during the analysis period. The previous year, the solar savings ratio was 16%.

Table 1. SOLAR SYSTEM THERMAL PERFORMANCE

EL TORO LIBRARY
DECEMBER 1981 THROUGH AUGUST 1982

(All values in million BTU, unless otherwise indicated)

MONTH	SOLAR ENERGY COLLECTED (SECA)	SYSTEM LOAD (SYSL)	SOLAR ENERGY USED (SEL)	AUXILIARY ENERGY FOSSIL (AXF)	AUXILIARY ENERGY THERMAL (AXT)	OPERATING ENERGY (SYSOPE)	ENERGY SAVINGS FOSSIL (TSVF)	ENERGY SAVINGS ELECTRICAL (TSVE)	SOLAR FRACTION (%) (SFR)
DEC	12.5	20.9	6.56 E	55.2	44.0	9.99	9.38 E	-0.35	12 E
JAN	14.2	23.3	7.88 E	80.9	52.8	10.4	11.3 E	-0.36	12 E
FEB	13.1	17.5	6.44 E	59.0	38.6	8.37	9.20 E	-0.30	9 E
MAR	17.1	19.0	15.4 E	65.0	42.6	9.63	22.1 E	-0.40	28 E
APR	24.6	21.7	16.1 E	61.1	40.2	10.3	27.2 E	-0.56	28 E
MAY	19.1	21.4	10.5 E	58.0	38.2	9.37	15.0 E	-0.42	22 E
JUN	19.3	17.4	11.5 E	57.6	38.8	9.58	16.5 E	-0.44	23 E
JUL	33.4	41.9	26.4	90.2	61.8	12.9	37.7	-0.65	30
AUG	25.1	37.0	21.2	81.3	55.7	12.7	30.3	-0.50	25
TOTAL	178	220	122 E	608	413	93.2	179 E	-3.98	-
AVERAGE	19.8	24.4	13.6 E	67.6	45.9	10.4	19.9 E	-0.44	22 E

E Denotes estimated value.

For a description of acronyms in parentheses, refer to Appendix C of Reference 1.

System problems affected thermal performance over the nine-month period. Control problems affected the storage valve V8, which controls the utilization of solar energy from the hot storage tank. The controls allowed auxiliary thermal energy to enter the storage tank, and resulted in a "negative" solar contribution from the heating load during several months. (See Footnote 1.)

Additional problems, identified in the previous seasonal performance evaluation, continued through this reporting period. They are:

- The El Toro Library has 57 square feet of solar collector per ton of cooling capacity. This value appears to be one-half of the area required, based on comparison of the El Toro Library to other cooling sites in the NSDN. If all of the collector output were utilized, solar fraction would still be lower than design expectations.

- Chiller Coefficient of Performance (COP) averaged 0.45 over the nine-month period, which is about 15% lower than what is considered a good chiller COP value of 0.6. Chiller COP was nearly identical (although slightly higher) to the COP of 0.43 measured the previous year, although it showed an increase later in the season.

- Cycling between heating and cooling occurs at the El Toro Library. The heating/cooling set point thermostat has no deadband between cooling and heating. This allows the heating and cooling subsystems to cycle between heating and cooling during marginal periods. A more sophisticated control system would rectify this problem, and is under consideration by site personnel.

- Valve V8, the storage bypass valve, was stuck in an open position, allowing flow through the tank when flow should have bypassed the tank. Two problems apparently resulted in the failure of the valve to operate correctly: one was a temperature sensor location problem, and the other was a short-circuited control wire. The misplaced probe allowed water to return to the tank at a higher temperature than it left during heating operation. Later in the season, a control sensor wire became shorted and caused a similar effect during all modes of operation.

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[1] Solar contribution refers to the output from both the space heating and space cooling subsystems, through the application of solar energy. For this site, total solar contribution equals the heating solar energy used (HSE) plus the solar chiller cooling output (TCEL). Factors such as cooling solar fraction (CSFR), overall solar fraction (SFR), and solar savings ratio (SSR) used the output of the solar chiller in calculation.

Solar energy used (SEL) refers to the solar input to the subsystens (in the case of heating, input equals output), and represents the heating solar energy used (HSE) plus the solar chiller input (TCEI), Factors such as fossil energy savings, cooling solar energy used (CSE), and COPs are based on the input side of the subsystems in question.

- Valve V5-11, the collector loop storage bypass valve, also had operational problems. The valve stuck in an open position, due to a signal processing problem in the central circuitry. This anomaly allowed energy to be rejected from the tank in an unintentional mode.

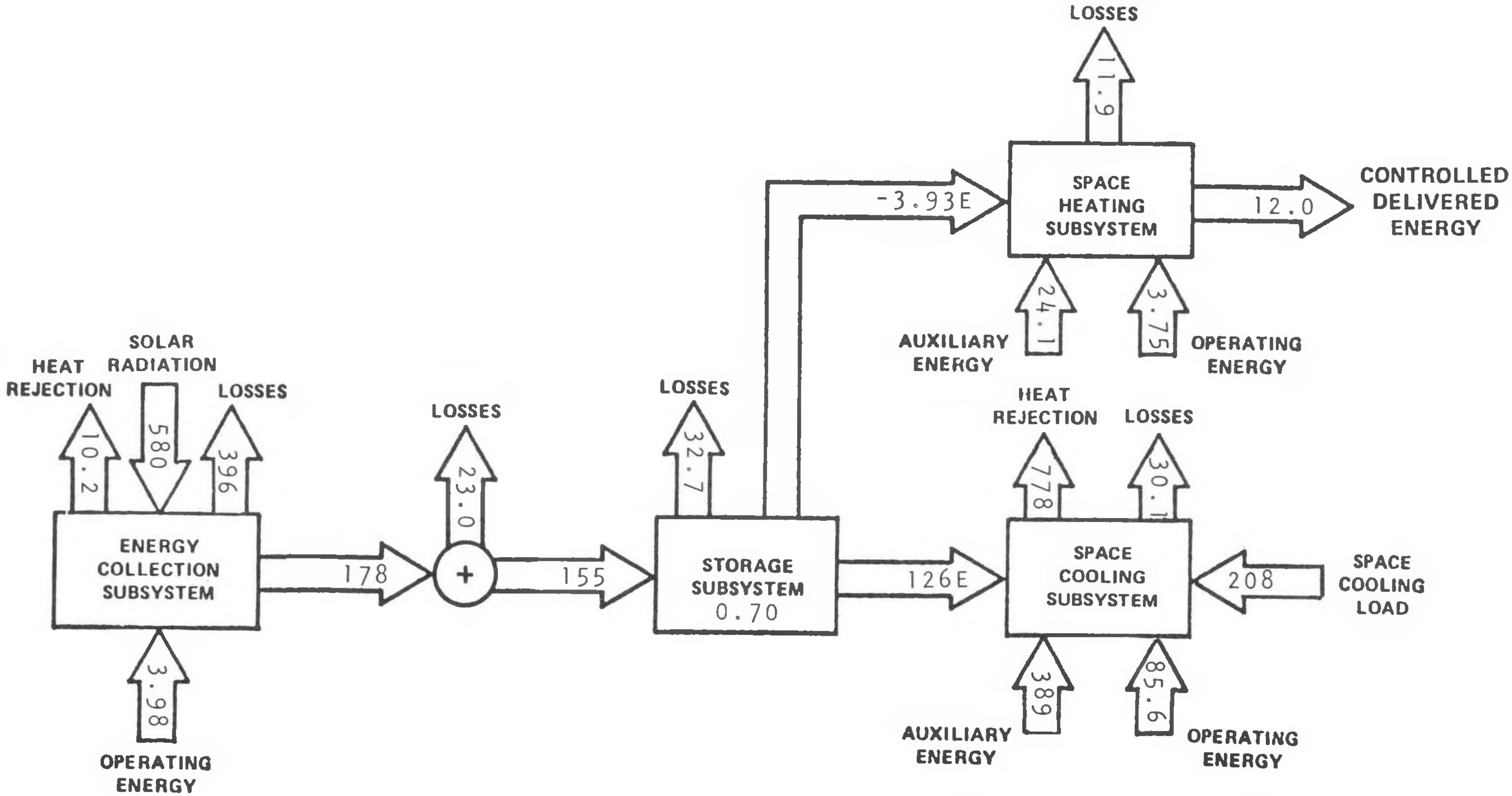
Figure 2 is an energy flow diagram showing the flow of energy through the various points within the solar system.

Solar collection was one of the subsystems which showed consistently high performance, based on overall percentage of incident energy collected. The collectors captured 178 million BTU, or 31% of the available energy at the array.

Losses from collection to storage totaled 23.0 million BTU, or 13% of the total energy collected. Storage losses were 32.7 million BTU, or 18% of the energy collected.

Note the "negative" space heating solar contribution of -3.93 million BTU, which represents auxiliary energy added to storage during operation of the space heating subsystem.

The daily operation of the system included both heating and cooling; determination of the exact breakdown of energy use at the library was complicated by simultaneous cooling and heating. A control scheme which allowed cycling between cooling and heating during marginal cooling days also added to the uncertainty of energy flow analysis at the site.



E Denotes estimated value.

Figure 2. Energy Flow Diagram for El Toro Library
December 1981 through August 1982
(Figures in million BTU)

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 ENERGY COLLECTION SUBSYSTEM

The solar collector array at the El Toro Library consists of 82 solar panels (gross area of 1,427 square feet) manufactured by the General Electric Company. The collectors are evacuated-tube glass units designed to operate at high inlet temperatures. Table 2 presents the collector performance in detail.

Table 2. COLLECTION SUBSYSTEM PERFORMANCE

EL TORO LIBRARY
DECEMBER 1981 THROUGH AUGUST 1982

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION (SEA)	COLLECTED SOLAR ENERGY (SECA)	COLLECTION SUBSYSTEM EFFICIENCY (%) (CLEF)	OPERATIONAL INCIDENT ENERGY (SEOP)	COLLECTOR ARRAY OPERATIONAL EFFICIENCY (%) (CLEFOP)	ECSS REJECTED ENERGY (CSRJE)	ECSS OPERATING ENERGY (CSOPE)	SOLAR ENERGY TO LOADS (CSEO)	SOLAR ENERGY TO STORAGE (STEI)	DAYTIME AMBIENT TEMPERATURE (°F) (TA)
DEC	46.9	12.5	27	43.7	29	0.00	0.35	6.56	11.4	69
JAN	51.3	14.2	28	48.3	29	0.00	0.36	7.88	12.7	64
FEB	46.0	13.1	28	41.5	31	0.02	0.30	6.44E	11.5	68
MAR	59.8	17.1	29	51.7	33	0.69	0.40	15.4 E	15.2	67
APR	75.1	24.6	33	70.7	35	1.64	0.56	16.1 E	21.8	72
MAY	61.5	19.1	31	52.0	37	1.25	0.42	10.5 E	16.4	71
JUN	63.4	19.3	31	50.8	38	2.58	0.44	11.5	14.3	72
JUL	93.5	33.4	36	88.8	38	2.59	0.65	26.4	29.5	87
AUG	82.7	25.1	30	68.6	37	1.38	0.50	21.2	22.6	86
TOTAL	580	178	-	516	-	10.2	3.98	122 E	155	-
AVERAGE	64.5	19.8	31	57.3	35	1.13	0.44	13.6 E	17.3	73

E Denotes estimated value.

For a description of acronyms in parentheses, refer to Appendix C of Reference 1.

Over the nine-month monitoring period, 31% of the 580 million BTU of incident solar radiation available at the plane of the collector array was collected. The performance of the array during the period of time that the collector pump was operational was slightly better than the previous year, at 35% vs. 31%.

Rejected energy totaled 10.2 million BTU, which represents an increase in the level of energy rejection as compared to the previous year. Review of the data indicated that the controller which allows the solar collection subsystem to transfer energy to the storage tank allowed some of this energy to be rejected from storage. Additionally, the insolation-level sensor mechanism (which activates the solar collector pump when insolation increases above a predetermined level) was set too low at times. This allowed energy rejection to occur in the morning and afternoon. Additional energy was intentionally rejected to prevent collection subsystem overheating, primarily in June, July, and August.

The overall efficiency of collection increased from 27% in December to a high value of 36% in July. This appeared to be a change in pattern as compared to the previous year, when winter efficiencies were higher than summer efficiencies.

A typical plot of collector operating characteristics is presented in Figure 3.

The manufacturer's single-panel test result curve is shown as the solid line on the figure. The dashed line represents the measured efficiency curve for May 1982.

The overall array performance was 10% to 12% below the single-panel test curve, with outlying points nearly achieving test result efficiency levels. Actually, in comparison to other similarly constructed and operating solar systems, the array performance at the El Toro Library was excellent.

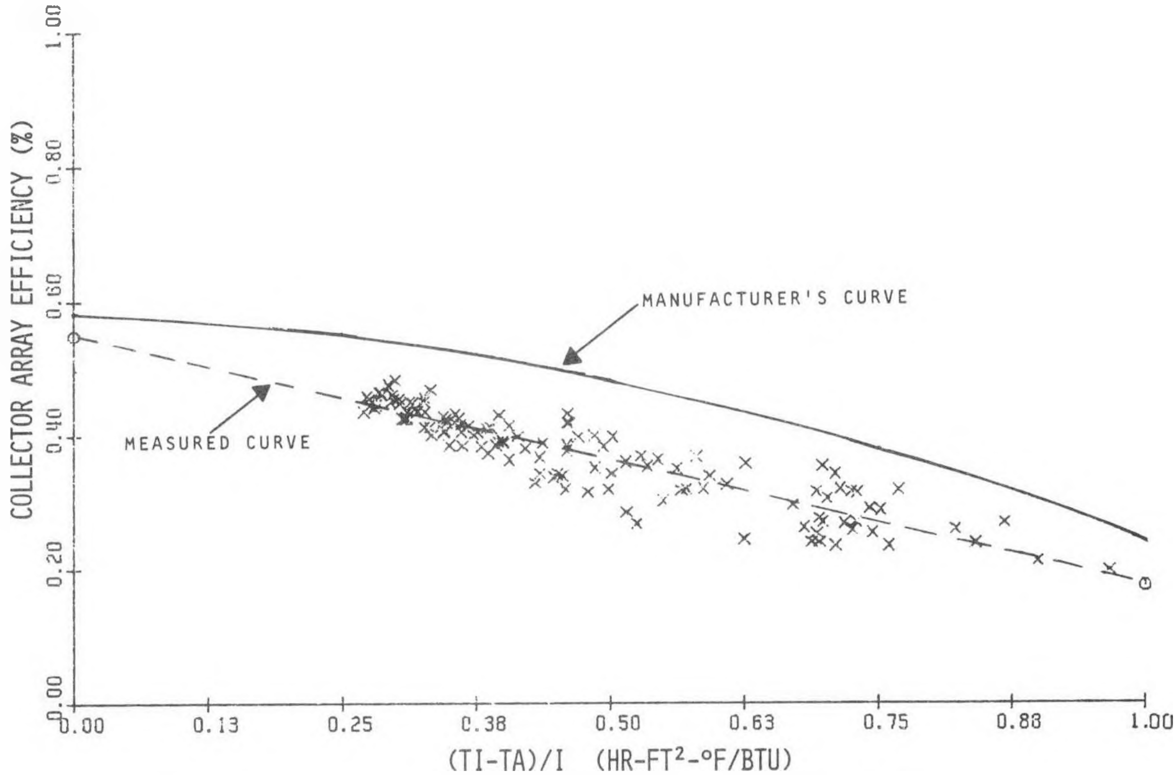


Figure 3. Average Collector Efficiency
El Toro Library
May 1982

There is evidence, however, that the collection subsystem is undersized in comparison to the actual loads at the site. An analysis of the cooling load at the site indicates that at least twice the collector area could have been utilized (assuming a concomitant increase in storage volume). The solar chiller utilized an average of 51.4 million BTU per month, while the collector output was averaging 19.8 million BTU. Storage inefficiency also reduced the amount of solar energy utilized.

2.2 STORAGE SUBSYSTEM

The 1,500-gallon storage tank is located outside the library, which reduces internal energy gains at the site but increases the overall storage loss rate.

Performance of the insulated steel tank is presented in Table 3. Several performance factors (STEO, STEFF, STLOSS) were estimated due to the failure of a critical storage flow meter, WT201. Average flow rates based on previous data were used to estimate the values for Energy from Storage (STEO).

Table 3. STORAGE PERFORMANCE

EL TORO LIBRARY
DECEMBER 1981 THROUGH AUGUST 1982

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY TO STORAGE (STEI)	ENERGY FROM STORAGE (STEO)	CHANGE IN STORED ENERGY (STECH)	STORAGE EFFICIENCY (%) (STEFF)	AVERAGE STORAGE TEMPERATURE (°F) (TST)	EFFECTIVE HEAT LOSS COEFFICIENT (BTU/hr-ft^2-°F)	LOSS FROM STORAGE (STLOSS)
DEC	11.4	6.56	-0.12	57	159	0.25	4.96
JAN	12.7	7.88	0.44	66	159	0.23	4.38
FEB	11.5	6.44E	0.00	64 E	164	0.23 E	5.06 E
MAR	15.2	15.4 E	-0.33	100 E	169	0.31 E	0.13 E
APR	21.8	16.1 E	-0.11	84 E	169	I	5.81 E
MAY	16.4	10.5 E	0.81	69 E	171	0.60 E	5.09 E
JUN	14.3	11.5	-0.57	76	176	0.21	3.37
JUL	29.5	26.4	-0.04	89	176	0.14	3.14
AUG	22.6	21.2	0.62	97	172	0.19	0.78
TOTAL	155	122 E	0.70	-	-	-	32.7 E
AVERAGE	17.3	13.6 E	0.08	79 E	168	0.2 E	3.64 E

E Denotes estimated value.
I Denotes invalid data.

For a description of acronyms in parentheses, refer to Appendix C of Reference 1.

The most significant improvement in storage performance at the El Toro Library was the increase in storage efficiency from 55% the previous season to 79% this season.

March data showed small storage losses, however the estimated value for STEO (due to flow meter WT201 failure) may have been slightly higher than actual, which would reduce the loss value.

2.3 SPACE HEATING SUBSYSTEM

The space heating subsystem at the El Toro Library uses hot storage water circulated directly through the heat exchanger in the air handlers, with auxiliary energy added through the combustion of natural gas. Valve V8, the storage control/bypass valve, malfunctioned by sticking in an open position, which allowed water which was warmed by auxiliary energy to return to the tank, rather than bypassing the tank. This resulted in a "negative" solar contribution for the season as a whole.

Tables 4 and 4a present measured data from the nine-month monitoring period for the space heating subsystem. The overall space heating load of 12.0 million BTU was satisfied by the combustion of 36.4 million BTU, while the net solar contribution was negative (-3.93 million BTU).

Table 4. SPACE HEATING SUBSYSTEM

EL TORO LIBRARY
DECEMBER 1981 THROUGH AUGUST 1982

(All values in million BTU, unless otherwise indicated)

MONTH	SPACE HEATING LOAD (EHL)	CONTROLLED DELIVERED ENERGY (CDE)	TOTAL SOLAR ENERGY USED (HSE)	TOTAL AUXILIARY THERMAL USED (HAT)	SOLAR FRACTION OF LOAD (%) (HSFR)	BUILDING TEMPERATURE (°F) (TB)	AMBIENT TEMPERATURE (°F) (TA)
DEC	2.66	2.66	-0.10 E	3.32	-3 E	72	60
JAN	3.76	3.76	-0.57 E	4.71	-14 E	71	56
FEB	2.15	2.15	-2.08 E	5.13	-68 E	72	61
MAR	1.73	1.73	0.22 E	6.25	3 E	72	59
APR	1.20	1.20	-1.40 E	3.93	-55 E	74	63
MAY	0.45	0.45	0.00	0.63	0	74	65
JUN	0.04	0.04	0.00	0.10	0	77	67
JUL	0.00	0.00	0.00	0.00	-	78	76
AUG	0.00	0.00	0.00	0.03	-	78	74
TOTAL	12.0	12.0	-3.93 E	24.1	-	-	-
AVERAGE	1.33	1.33	-0.44 E	2.68	-20 E	74	65

E Denotes estimated value.

For a description of acronyms in parentheses, refer to Appendix C of Reference 1.

Table 4a. SPACE HEATING SUBSYSTEM (Continued)

EL TORO LIBRARY
DECEMBER 1981 THROUGH AUGUST 1982

(All values in million BTU, unless otherwise indicated)

MONTH	SPACE HEATING LOAD (EHL)	TOTAL SOLAR ENERGY USED (HSE)	TOTAL OPERATING ENERGY (HOPE)	FOSSIL ENERGY SAVINGS (HSVF)	AUXILIARY FOSSIL FUEL (HAF)	HEATING DEGREE-DAYS (#) (HDD)
DEC	2.66	-0.10 E	0.54	-0.14 E	4.93	163
JAN	3.76	-0.57 E	0.69	-0.81 E	7.16	282
FEB	2.15	-2.08 E	0.69	-2.97 E	7.87	131
MAR	1.73	0.22 E	0.83	0.31 E	9.39	196
APR	1.20	-1.40 E	0.51	-2.00 E	6.03	106
MAY	0.45	0.00	0.33	0.00	0.91	42
JUN	0.04	0.00	0.11	0.00	0.13	10
JUL	0.00	0.00	0.00	0.00	0.00	5
AUG	0.00	0.00	0.05	0.00	0.00	0
TOTAL	12.0	-3.93 E	3.75	-5.61 E	36.4	935
AVERAGE	1.33	-0.44 E	0.42	-0.62 E	4.05	104

E Denotes estimated value.

For a description of acronyms in parentheses, refer to Appendix C of Reference 1.

The valve V8 control problem allowed hot water to return to storage from the heating distribution loop at a temperature warmer than the storage supply temperature, which was considered a "negative" solar contribution. The actual energy flows were both positive and negative, however the net value was negative. Boiler energy was usually added to the tank during the morning hours, before solar collection increased the tank temperature. One month (March) showed a positive solar contribution, however the overall solar contribution during that month was three percent.

The performance of the heating subsystem was expected to improve as of the end of April, when valve V8 was repaired. The heat load dropped off considerably, however, so May data showed a very small heating load, which was satisfied by auxiliary energy consumption rather than through the use of solar energy. This was evidence that the system was still not adjusted correctly.

The design value for the space heating subsystem solar fraction at the El Toro Library is 97%, which should be achieved consistently with a tank temperature of 170°F, low heating loads, and night/weekend set-back controls. The highest heating solar fraction measured on a monthly basis has been three percent, indicating that the system has fundamental problems in the area of controls, which need to be rectified before expected performance levels can be achieved.

The controlled delivered (solar plus auxiliary energy) building heating load at the El Toro Library, based on total energy delivered per square foot per degree day, was 1.3 BTU/ft^2-heating degree-day. This value indicates that the heating load on the structure was less than that on a similarly-located conventional building, probably due to the earth-berming of the structure, internal energy gains, and the few window openings designed into the building's exterior skin. Heating and cooling can occur on the same day at the El Toro Library, due to the nature of Southern California's climate, which requires a morning heating period at times, followed by afternoon/early evening cooling. Internal energy gains from lighting equipment and other sources (people, passive gain, etc.) are not measured, but contributed to the load.

2.4 SPACE COOLING SUBSYSTEM

The El Toro Library was designed as a modern earth-sheltered structure, and was, therefore, expected to be an energy-conserving structure utilizing a fully-integrated solar heating and cooling system. The overall performance of the solar system has not met original goals to date; however, the building itself appears to meet energy conservation goals established during the design phase.

The space cooling subsystem performance for the nine-month monitoring period is presented in Table 5.

Table 5. SPACE COOLING SUBSYSTEM

EL TORO LIBRARY
DECEMBER 1981 THROUGH AUGUST 1982

(All values in million BTU, unless otherwise indicated)

MONTH	COOLING LOAD (CL)	SOLAR FRACTION OF LOAD (CSFR)	SOLAR ENERGY USED (CSE)	OPERATING ENERGY (COPE)	AUXILIARY THERMAL USED (CAT)	FOSSIL ENERGY SAVINGS (CSVF)	AUXILIARY FOSSIL FUEL (CAF)	BUILDING TEMPERATURE (°F) (TB)
DEC	18.2	14	6.66	9.10	40.6	9.51	50.3	72
JAN	19.5	15	8.45	9.39	48.0	12.1	73.8	71
FEB	15.4	20 E	8.52E	7.38	33.5	12.2 E	51.1	72
MAR	17.3	30 E	15.2 E	8.40	36.4	21.7 E	55.6	72
APR	20.5	33 E	17.5 E	9.22	36.3	25.0 E	55.0	74
MAY	20.9	22 E	10.5 E	8.62	37.6	15.0 E	57.1	74
JUN	17.4	23	11.5	9.03	38.7	16.4	57.5	77
JUL	41.9	30	26.4	12.3	61.8	37.7	90.2	78
AUG	37.0	25	21.2	12.2	55.6	30.3	81.2	78
TOTAL	208	-	126 E	85.6	389	180 E	572	-
AVERAGE	23.1	24 E	14.0 E	9.51	43.2	20.0 E	63.5	74

E Denotes estimated value.

For a description of acronyms in parentheses, refer to Appendix C of Reference 1.

Overall cooling performance was improved this year, over the 16% solar contribution during 1981. This season's solar contribution was an estimated 24% of the cooling load, which represented a fairly significant improvement in performance. However, the design expectation of achieving 60% of the cooling load appears to be an over-optimistic performance level for this solar site.

The space cooling subsystem utilizes an ARKLA WFB-300 absorption chiller to provide cooling for the 10,000-square-foot library. Auxiliary thermal energy is provided through the use of a natural-gas boiler to augment the use of stored solar energy from the collection subsystem.

The solar fraction of the cooling load (CSFR) is based on the fraction of the total energy input to the space cooling subsystem derived from the solar storage tank, or 24% of the 515 million BTU of thermal energy input to the cooling subsystem. The overall cooling load was 208 million BTU, which is equivalent to a cooling load of 23 BTU/ft^2-cooling degree-day. This value was considerably greater than the previous year's cooling load of 12.9 BTU/ft^2-cooling degree-day. The building temperature during this year's analysis period averaged 74°F, versus 75°F the previous year, which accounts for a portion of the increase. Although the time periods differ, the cooling load values are weighted by building area and cooling degree-days. Internal energy gains are a large part of the cooling load at this site.

The previously-mentioned cycling between cooling and heating is another reason for an increase in net cooling load per square foot per degree-day. Space heating of the building occurred simultaneously with space cooling, or soon after the heating system cycled off. Since additional excess heat had to be removed, the cooling load was increased.

An estimated total of 126 million BTU of solar energy was used by the space cooling subsystem, at the expense of 85.6 million BTU of operating energy, none of which is considered "solar-unique." Operation of the chiller loops, the chiller, cooling towers, and air handlers would be required even if the solar system was not installed. If a reciprocating or other type of mechanically powered vapor compression unit were the auxiliary cooling source, then the energy required to operate the chiller, the pipe loop, and the cooling towers would have to be charged against net energy savings. For the purpose of this report, it is assumed that the conventional system would have utilized an identical absorption chiller.

All of the months studied had a cooling load, with monthly solar fractions ranging from 14% to 33%. The overall solar contribution of 24% was considerably better than the previous year's value of 16% for the solar cooling subsystem, although not yet approaching the 60% design contribution.

The absorption chiller performance is presented in Table 6.

The total load on the chiller was 208 million BTU, which required 462 million BTU of thermal energy input, resulting in a Coefficient of Performance (COP) of 0.45 over the season.

Twenty-four percent of the input to the unit was solar energy.

Table 6. ABSORPTION CHILLER PERFORMANCE

EL TORO LIBRARY
DECEMBER 1981 THROUGH AUGUST 1982

(All values in million BTU, unless otherwise indicated)

MONTH	EQUIPMENT LOAD (TCEL)	THERMAL ENERGY INPUT (TCEI)	OPERATING ENERGY (TCEOPE)	REJECTED ENERGY (TCERJE)	COEFFICIENT OF PERFORMANCE (COP) (TCEI/TCEL)
DEC	18.2	45.3	5.70	72.5	0.40
JAN	19.5	52.8	5.72	86.1	0.37
FEB	15.4	40.6	4.43	66.2	0.38
MAR	17.3	46.1	5.06	75.5	0.37
APR	20.5	49.4	5.71	81.5	0.42
MAY	20.9	43.4	5.34	74.3	0.48
JUN	17.4	43.4	5.44	68.3	0.40
JUL	41.9	76.6	8.28	136	0.55
AUG	37.0	64.8	8.08	118	0.57
TOTAL	208	462	53.8	776	-
AVERAGE	23.1	51.4	5.97	86.4	0.45

For a description of acronyms in parentheses, refer to Appendix C of Reference 1.

Comparing the values of chiller input energy (TCEI) against the sum of solar energy used for cooling (CSE) and cooling auxiliary thermal energy indicates an energy imbalance of 52 million BTU.

Storage energy contribution to the chiller was an estimated 126 million BTU, while auxiliary thermal energy was 389 million BTU. The total energy delivered to the cooling subsystem was the sum of these, or 515 million BTU. Measured chiller input was 462 million BTU, which results in a 53 million BTU imbalance.

Six basic system operational characteristics may have added to the imbalance.

1. Storage energy output was measured across temperature sensors T201 and T251 (see the schematic in Appendix A-1) using flow meter WT201. WT201 had operational problems

during much of the season, resulting in the need for a flow rate estimation. For this reason, the solar contribution of 126 million BTU is probably a bit higher than actual, since the actual flow rate may have been lower.

2. Valve V8 operational problems resulted in addition of auxiliary energy to storage during operation of the space heating loop. This confused the breakdown of solar vs. auxiliary energy between heating and cooling.

3. In March, temperature probe T551 was found to be unseated from the base of the probe's thermowell, thus cooling tower output (rejected energy, TCERJE) was suspected to be lower than actual. Temperature probes T551 and T501 are located on the cooling tower.

4. Auxiliary thermal energy is calculated using the flow rate and temperature difference across the natural-gas boiler. Apportioning of the auxiliary thermal energy between cooling (chiller input) and heating (output from the duct heat exchanger) is very difficult to quantify, since simultaneous heating and cooling can and did occur over the monitoring period. Apportioning auxiliary thermal energy depends on identification of time periods when cooling or heating occur, and these two modes are supposed to be mutually exclusive. Therefore, some of the auxiliary energy charged to the cooling subsystem probably ends up as heating auxiliary energy.

5. The solar heating and cooling system exhibited rapid cycling in the heat transfer loop from storage to the loads. The cycling allows parcels of heated water to enter the loop, on a frequency less than the five-minute 32-second scan rate. Sampling the temperatures in various locations in the system creates an apparent temperature rise or drop in the loop, which may result in energy balance errors. This effect of simultaneous heating and cooling was observed by Vitro personnel during a site inspection visit.

6. Pipe losses which occur during circulation also may be a portion of the imbalance. There was no way to verify these losses, since the ambient temperatures surrounding the pipes are unknown.

Since the system did consume auxiliary and solar energy in the proportion of 24% of the input to the cooling subsystem, this was the value which was used as the space cooling solar fraction. An assumed 49.9 million BTU, or 24% of the 208 million BTU cooling load, were attributed to solar energy, and were termed solar cooling output (CLS).

Chiller Coefficient of Performance (COP) is an indication of the effectiveness of the chiller in converting input thermal energy to cooling. The estimated design COP for a WFB-300 chiller should be 0.60.

January, February, and March COPs were around 0.37, while later months (with the exception of June, when the cooling tower for the chiller showed some mechanical difficulties) showed COPs of 0.42 to 0.57.

Loads were lower in the winter months as would be expected, but energy used for cooling remained fairly constant (between 40 and 53 million BTU per month) from December through June.

The chiller was operating poorly in June due to problems with the cooling tower pump and fan. These components were repaired in late June, and apparently the system was very efficient during July and August.

The total energy input to the chiller during December through June was 321 million BTU, which provided 129 million BTU of cooling. The COP during these seven months averaged 0.40.

If the COP had been 0.55, for example, then the total energy input would have been 235 million BTU for December through June. The solar energy used during these seven months totaled 78.3 million BTU. If all of that solar energy could have been applied to the load, then the solar fraction would have been 33%, rather than the 24% measured fraction over the seven-month period prior to July 1982.

If the chiller could have utilized more of the collected energy at a chiller COP of 0.55, for example 90% of the 120 million BTU collected during the seven months prior to July, then the solar fraction would have increased from a 33% projected fraction to 46%, which is still below the 60% design value.

Weather conditions (Section 3.3) also affected the performance of the solar cooling subsystem. For example, consider the effect of two environmental factors: insolation and cooling degree-days.

Solar radiation averaged 17% below long-term (expected) values. Had the measured solar radiation been equal to the long-term solar radiation (which designers might use to predict system performance) and the increased insolation been collected and utilized, then the cooling solar fraction would show an improvement to an estimated 33% of the cooling load at present solar utilization and chiller efficiency.

Cooling degree-days were significantly greater than long-term and resulted in an estimated 42% increase in cooling load in July and August. If the cooling degree-days had been equal to the long-term average, then the cooling solar fraction would have increased to 36% at present solar utilization and chiller efficiency.

Note that the cooling load increases dramatically in July and August, see Table 5. There is an average base cooling load of about 17.6 million BTU due to internal gains. Subtracting the base cooling load from the measured cooling load yields the amount of cooling load due to outside temperatures. This load averages about six BTU per square foot of floor area per cooling degree-day. This value is quite low, but compares well with other NSDN cooling sites.

The combined effects of increased insolation and reduced building load would have permitted a projected solar cooling contribution of 43%. Some system improvements necessary for this system to reach design levels of performance are an increase in chiller COP, a decrease in system losses, and improved system control.

SECTION 3

OPERATING ENERGY, ENERGY SAVINGS, AND WEATHER CONDITIONS

3.1 OPERATING ENERGY

Table 7 indicates the solar portion of the operating energy used at the El Toro Library over the nine-month time period.

The solar collection operating energy was the only "solar-unique" portion of operating energy considered in analysis.

The total solar-unique operating energy consumed by the space conditioning subsystem was 3.98 million BTU.

Total system operating energy (from Table 1 on Page 3) was 93.2 million BTU. A simple ratio of solar energy supplied to the load and auxiliary energy used showed that 24% of the operating energy could be termed "solar-unique;" however, these values are not shown in Table 7.

Table 7. SOLAR OPERATING ENERGY

EL TORO LIBRARY
DECEMBER 1981 THROUGH AUGUST 1982

(All values in million BTU)

MONTH	ECSS OPERATING ENERGY (SOLAR-UNIQUE) (CSOPE1)	TOTAL SOLAR OPERATING ENERGY (SYSOPE1)
DEC	0.35	0.35
JAN	0.36	0.36
FEB	0.30	0.30
MAR	0.40	0.40
APR	0.56	0.56
MAY	0.42	0.42
JUN	0.44	0.44
JUL	0.65	0.65
AUG	0.50	0.50
TOTAL	3.98	3.98
AVERAGE	0.44	0.44

For a description of acronyms in parentheses, refer to Appendix C of Reference 1.

The solar energy Coefficient of Performance (COP) is depicted in Table 8. The COP simply provides a numerical value for the relationship of solar energy used or collected and the amount of conventional electrical energy required to collect or deliver it. The greater the COP value, the more efficient the process. During the reporting period, the overall solar energy system provided a weighted seasonal average COP value of 31. The collection subsystem functioned at a COP of 45.

Both values improved over the previous season's values of 22 for the system COP and 43 for the collection COP.

Table 8. SOLAR COEFFICIENT OF PERFORMANCE

EL TORO LIBRARY
DECEMBER 1981 THROUGH AUGUST 1982

MONTH	SOLAR ENERGY SYSTEM $\left(\frac{SEL}{SYSOPE1}\right)$	COLLECTION SUBSYSTEM $\left(\frac{SECA}{CSOPE}\right)$
DEC	19 E	36
JAN	22 E	39
FEB	21 E	44
MAR	39 E	43
APR	29 E	44
MAY	25 E	45
JUN	26 E	44
JUL	41	51
AUG	42	51
WEIGHTED AVERAGE*	31 E	45

* Weighted using $\Sigma(SEL_{month})/\Sigma(SYSOPE1_{month})$ and

$$\Sigma(SECA_{month})/\Sigma(CSOPE_{month})$$

For a description of acronyms in parentheses, refer to Appendix C of Reference 1.

3.2 ENERGY SAVINGS

Table 9 presents the calculated energy savings (in terms of displaced fossil fuel) resulting from operation of the solar system at the El Toro Library during the nine-month analysis period.

The assumptions which were used to calculate the energy savings are as follows:

- A measured boiler efficiency of 70%, based on input divided into output from the gas heater.

- The only components of the system which are solar-unique (components which are related to solar portions of the system) are the solar collectors, collector pumps, heat rejectors, and storage tank. Pumps P1 and P2 and the heat rejectors, therefore, are the only parasitic energy consumers. Pump P3, the air handler, pump P4, the chiller power, and the cooling tower pump and fan would be employed in a conventional system, and are not solar-unique.

- Negative contributions represent thermal energy returning to the storage tank.

Based on the above, net fossil savings at the site were 174 million BTU at the expense of 3.98 million BTU of electrical power. The 174 million BTU are equivalent to 171,000 cubic feet (1,710 therms) of natural gas, valued at approximately $855. Natural gas was assumed to cost $0.50 per therm (100 cubic feet). The electrical expense of 3.98 million BTU is equivalent to 1,165 kwh, valued at $69.90 at an average cost of $0.06 per kwh.

Net savings increased over the previous year, when 1,202 therms were saved over a longer time period, at an expense of 1,162 kwh.

Table 9. ENERGY SAVINGS

EL TORO LIBRARY
DECEMBER 1981 THROUGH AUGUST 1982

(All values in million BTU)

MONTH	SOLAR ENERGY USED (SEL)	SPACE HEATING FOSSIL FUEL (HSVF)	SPACE COOLING FOSSIL FUEL (CSVF)	NET OPERATING ENERGY (CSOPE)	NET ENERGY SAVINGS ELECTRICAL (TSVE)	NET ENERGY SAVINGS FOSSIL FUEL (TSVF)
DEC	6.56 E	-0.14 E	9.51	-0.35	-0.35	9.37 E
JAN	7.88 E	-0.81 E	12.1	-0.36	-0.36	11.3 E
FEB	6.44 E	-2.97 E	12.2 E	-0.30	-0.30	9.23 E
MAR	15.4 E	0.31 E	21.7 E	-0.40	-0.40	22.0 E
APR	16.1 E	-2.00 E	25.0 E	-0.56	-0.56	23.0 E
MAY	10.5 E	0.00	15.0 E	-0.42	-0.42	15.0 E
JUN	11.5	0.00	16.4	-0.44	-0.44	16.4
JUL	26.4	0.00	37.7	-0.65	-0.65	37.7
AUG	21.2	0.00	30.3	-0.50	-0.50	30.3
TOTAL	122 E	-5.61 E	180 E	-3.98	-3.98	174 E
AVERAGE	13.6 E	-0.62 E	20.0 E	-0.44	-0.44	19.4 E

E Denotes estimated value.

For a description of acronyms in parentheses, refer to Appendix C of Reference 1.

3.3 WEATHER CONDITIONS

The weather conditions at the El Toro Library are presented in Table 10.

Incident solar radiation averaged 1,481 BTU/ft^2-day, which was 17% lower than the long-term average of 1,786 BTU/ft^2-day.

Two months, May and June, showed large differences between long-term insolation values and actual values. This effect was probably due to local microclimatic variations.

Ambient temperatures averaged 65°F vs. a 61°F expected value.

Heating degree-days were 935 vs. 1,599 expected.

Cooling degree-days were higher than expected, at 907 vs. 512 for the analysis period.

The effects of these differences between measured and long-term weather data are discussed in Section 2.4.

Table 10. WEATHER CONDITIONS

EL TORO LIBRARY
DECEMBER 1981 THROUGH AUGUST 1982

MONTH	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT2-DAY) MEASURED (SE)	LONG-TERM AVERAGE	AMBIENT TEMPERATURE (°F) MEASURED (TA)	LONG-TERM AVERAGE	HEATING DEGREE-DAYS MEASURED (HDD)	LONG-TERM AVERAGE	COOLING DEGREE-DAYS MEASURED (CDD)	LONG-TERM AVERAGE
DEC	1,060	1,167	60	54	163	341	0	0
JAN	1,158	1,240	56	53	282	372	0	0
FEB	1,151	1,498	61	55	131	298	13	7
MAR	1,351	1,611	59	56	196	279	5	0
APR	1,755	1,993	63	59	106	177	32	9
MAY	1,390	2,024	65	63	42	94	57	29
JUN	1,480	2,090	67	66	10	38	73	77
JUL	2,114	2,274	76	71	5	0	348	181
AUG	1,870	2,178	74	72	0	0	379	209
TOTAL	-	-	-	-	935	1,599	907	512
AVERAGE	1,481	1,786	65	61	104	178	101	57

For a description of acronyms in parentheses, refer to Appendix C of Reference 1.

SECTION 4

REFERENCES

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

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

*6A. User's Guide to Monthly Performance Reports, November 1981, SOLAR/0004-81/18, Vitro Laboratories, Silver Spring, Maryland.

*6B. Instrumentation Installation Guidelines, March 1981, Parts 1, 2, and 3, SOLAR/0001-81/15, Vitro Laboratories, Silver Spring, Maryland.

7. Monthly Performance Report, El Toro Library, December 1981, Vitro Laboratories, Silver Spring, Maryland.

8. Monthly Performance Report, El Toro Library, January 1982, Vitro Laboratories, Silver Spring, Maryland.

9. Monthly Performance Report, El Toro Library, February 1982, Vitro Laboratories, Silver Spring, Maryland.

10. Monthly Performance Report, El Toro Library, March 1982, Vitro Laboratories, Silver Spring, Maryland.

11. Monthly Performance Report, El Toro Library, April 1982, 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.

12. Monthly Performance Report, El Toro Library, May 1982, Vitro Laboratories, Silver Spring, Maryland.

13. Monthly Performance Report, El Toro Library, June 1982, Vitro Laboratories, Silver Spring, Maryland.

14. Monthly Performance Report, El Toro Library, July 1982, Vitro Laboratories, Silver Spring, Maryland.

APPENDIX A

SYSTEM DESCRIPTION

APPENDIX A-1

SYSTEM DESCRIPTION

The El Toro Library is a one-story facility of modern design, located in El Toro, California. The building contains 10,000 square feet of floor area with very few windows, located at the building entrances. The library is functional year-round and is occupied Tuesday through Saturday.

The building was designed to incorporate a solar energy system on the south-facing roof. The solar energy system is interconnected to the building space heating and cooling equipment. The solar energy system was designed to provide 97% of the space heating load and 60% of the space cooling load.

The solar energy system incorporates 82 panels with a gross area of 1,427 square feet of evacuated tubular glass collectors (TC-100) manufactured by General Electric. The collectors are oriented 30 degrees west of due south at a tilt of 19 degrees from the horizontal. The collection subsystem utilizes treated city water as a transfer medium from collector to storage tank. The storage tank is a 1,500-gallon insulated steel tank which is located outside, above ground level. The storage tank provides thermal storage for the collected solar energy before delivery to the building load.

The space heating subsystem uses solar energy from storage and/or thermal energy from the natural-gas-fired boiler. The thermal energy is delivered to the air-handling unit, which distributes the energy to the conditioned space.

The space cooling subsystem uses an absorption chiller to provide chilled water to the air-handling unit. The generator portion of the absorption chiller unit uses hot water from solar storage and/or hot water supplied by the natural-gas-fired boiler.

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

Equipment/Component	Manufacturer	Model No.
Evacuated-Tube Collectors	General Electric	TC-100
Heat Rejector	Young Radiator Co.	22D20
Solar Storage Tank	Santa Fe Tank & Heater Co.	18333
Gas-Fired Boiler	Ray Pak	E602-T
Absorption Chiller	ARKLA Corp.	WFB-300
Cooling Tower	Baltimore Aircoil of CA	VXT-45C
Air-Handling Unit (AHU)	Air Dynamics, Inc.	MTW-90
Pumps P1, P2, P3, P4, P5	Frederick Pump Engineering	
3-Way Valves V3, V4, V5-11 V8, V12, V13	Barber Colman	
Expansion Tanks	Wood Products, Inc.	

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

Mode 1 - Solar Energy Collection - Solar energy collection occurs when insolation levels are sufficient (as controlled by a Barber Colman comparator). When the insolation levels exceed the predetermined set point, collector pump P1 or P2 will activate flow for solar energy collection. This mode behaves like a collector loop warm-up method, since all the flow bypasses the storage tank. Pump P1 or P2 will deactivate when insolation levels fall below the set point.

Mode 2 - Collector-to-Storage Flow - Solar energy is delivered to the storage tank when the collector outlet temperature exceeds the temperature in the storage tank. Three-way control valve V5-11 will change position to allow full flow into the storage tank. When the collector outlet temperature falls below the storage tank temperature, valve V5-11 will reverse its position and flow will again bypass the storage tank. (Collector pump P1 or P2 must be operating.) Valve V5-11 has complete control of this mode.

Mode 3 - Solar Storage-to-Space Heating/Cooling Load - This mode occurs when there is a cooling or heating demand and the storage tank temperature is greater than the load loop return temperature. Control valve V8 will allow flow from the load loop return into storage and provide solar heated water to the loads. Valve V8 will continue to deliver stored energy until the load loop return temperature exceeds the storage temperature. Valve V8 will then change position and all flow will bypass the storage tank. Valve V8 has complete control of solar energy delivered to the loads.

Mode 4 - Auxiliary Energy for Heating/Cooling - When the boiler set point is greater than the storage tank temperature, then the auxiliary natural-gas-fired boiler will turn on to meet the energy needs of the building. The boiler will provide energy for the space heating coils or to the generator inlet of the absorption chiller.

Mode 5 - Solar Energy Heat Rejection - This mode will activate when the storage tank temperature exceeds 210°F. Control valve V3 will allow flow to the heat rejector and the fan will dissipate excess collected energy to the environment. The heat rejection mode is for equipment protection from high temperatures.

Mode 6 - Freeze Protection - Stage 1 - This mode will activate collector pump P1 or P2 when the ambient temperature falls below 38°F. All the collector flow will bypass storage and this is the first stage of freeze protection.

Mode 7 - Freeze Protection - Stage 2 - This second stage of freeze protection follows the first stage of freeze protection. The second stage will allow modulation valve V5-11 to use stored energy into the collector loop.

Mode 8 - Freeze Protection - Stage 3 - The third stage of freeze protection will allow flow of city water to the collector loop when the collector outlet temperature falls below 35°F. Valves V1 and V2 will purge city water and discharge flushing water to drain.

Mode 9 - Collector Over-Temperature - If the collector array experiences temperatures greater than 320°F, then the control sensor will lock out solar pumps P1 and P2 and retain valves V1 and V2 in their closed position. This will prevent thermal shock in the collector array.

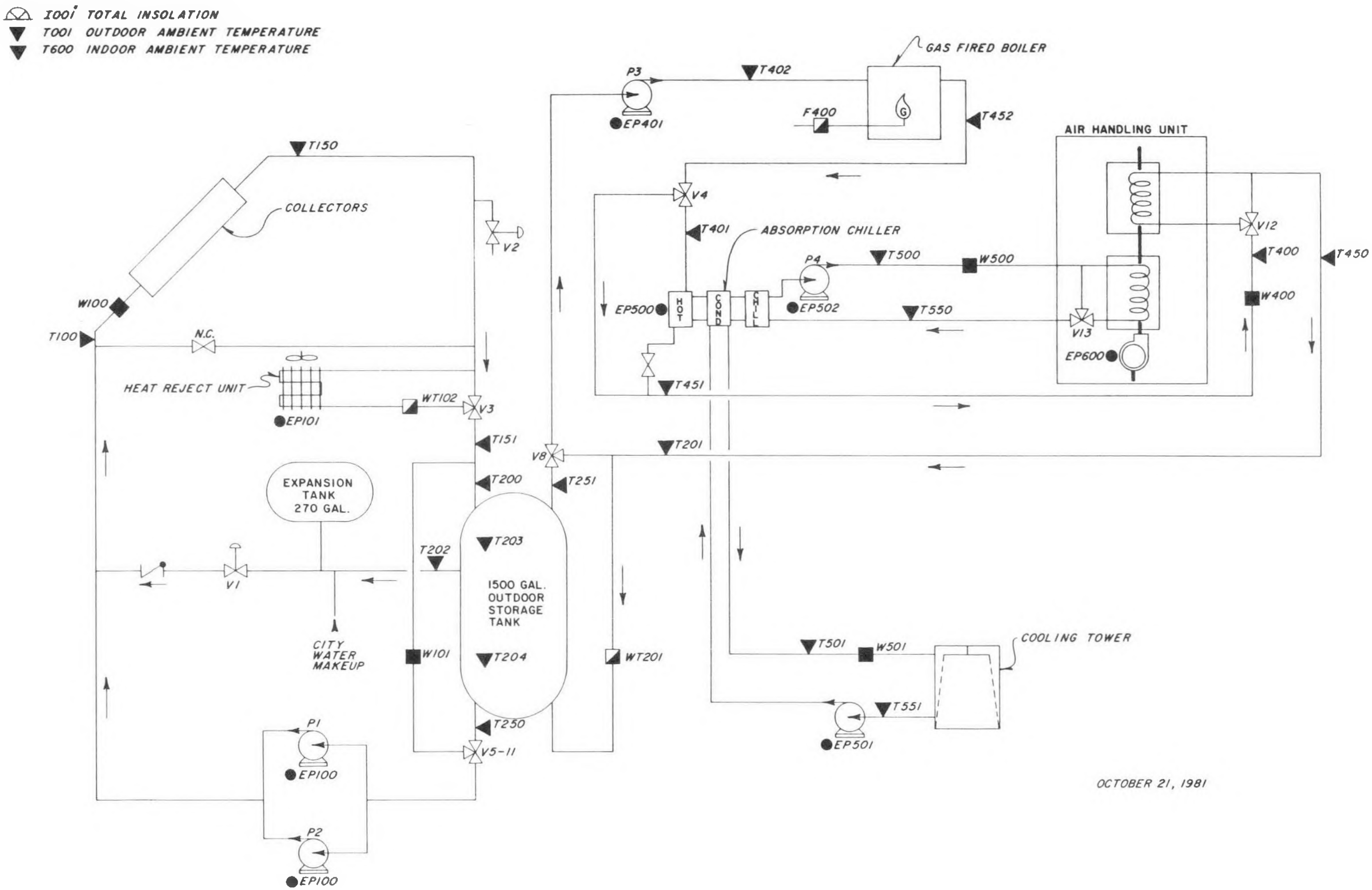

Figure A-1. El Toro Library Solar Energy System Schematic

APPENDIX A-2

SITE HISTORY, PROBLEMS, AND MODIFICATIONS

Date	Event/Anomaly
12/1/81	Valve V8, the load bypass valve which controls the output from storage to the space conditioning subsystems, failed to operate properly, due to control problems. The control sensor which measures the temperature of the flow returning to the tank was apparently misplaced in the piping loop, and required either a longer probe (which would internally relocate the sensor element) or relocation entirely, to correct for stratification in the tank.
12/7/81	A longer well was installed on the control sensor of valve V8.
12/18/81	Set point of valve V8 required further adjustment. Return water still entering tank warmer than the tank itself.
1/12/82	Temperature probe T401 was replaced due to suspected temperature bias.
1/13/82	Valve V5-11 was stuck open and allowed energy rejection from storage, through the collection loop.
1/22/82	Flow meter WT201, located in the storage bypass loop, exhibited improper flow readings, and fluctuated rapidly. Readings were invalidated.
1/29/82	Valve V8 showed improved action, due to further adjustments in set points.
2/22/82	The control for valve V5-11 was repaired during a site visit by a DOE contractor (ETEC, from Rockwell International). Apparently, the valve was stuck in an open position, due to a signal processing problem within the control circuitry.
2/23/82	Valve V8 problems reappeared. A short circuit in one of the sensor cables caused the valve to remain completely open. The building thermostats were adjusted to attempt to prevent simultaneous heating and cooling.

Date	Event/Anomaly
3/3/82	Collector deactivation was occurring at 39 BTU/ft^2-hr, allowing energy rejection from storage.
3/23/82	Vitro technicians repaired flow meter WT201. T501, a temperature probe located on the cooling tower loop, was found to be unseated in the thermowell.
4/11/82	Valve V8 was allowing boiler energy to enter storage. SDAS inoperable; batteries in the unit were replaced April 12.
4/19/82	Solar collection set point for initiation of collection was set too low. Collectors were operating during periods of low insolation.
4/29/82	Valve V8 appeared to be operating better. Sensor wiring problems were fixed.
5/20/82	Boiler operation appeared erratic. Solar chiller was operating while the air-handling units were off.
6/5/82	The cooling tower pumps failed. The solar cooling system was not operating.
6/9/82	The cooling tower pump was repaired.
6/12/82	The cooling tower pump failed to operate correctly. Motor heaters were apparently sized too small.
7/7/82	SDAS inoperable; was repaired July 14.

APPENDIX B

DATA ACCURACY

APPENDIX B

DATA ACCURACY

INTRODUCTION

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

DATA ACCURACY ESTIMATES

The primary tool used to determine the data requirements and the selection of instrumentation is the analytical heat balance. Sufficient heat balance calculations are required to equate the total energy input to the total energy output for the subsystem or component under study to provide an energy balance closure of less than 10%. As a general rule, a six percent accuracy is assumed for NSDN performance results, based on the requirements described in Reference B-1 and other theoretical calculations and tests from Reference B-2.

Errors greater than approximately 10% for active systems and 15% for passive systems will not permit useful comparison between different systems. Error analysis of most performance evaluation factors for active NSDN solar energy systems has shown that the experimental data is obtained with accuracy of about ± six percent using the sensors shown in Table B-1. (Reference B-2)

The data accuracy conclusions were based on a composite of all available information sources, including:

- Field data from selected sample sites (Reference B-2)
- Manufacturers' accuracy data (Reference B-2)
- Internal laboratory calibration data (Reference B-2)
- Site verification from special accuracy tests (Reference B-2)
- Special tests required to verify system accuracy

Table B-1. SENSOR ACCURACY

THE NATIONAL SOLAR DATA NETWORK

PARAMETER	SENSOR TYPE	MANUFACTURER	ACCURACY (% of Full Scale unless indicated)
Temperature	3-wire Platinum Resistance Thermometer (RDT)	Minco	± 0.5°F
Insolation	Precision Spectral Pyranometer	Eppley	± 3% 0-70° Angle ± 6% 70-80° Angle
Wind	Propeller-type Anemometer	WeatherMeasure	± 1% $<$25 mph ± 3% $>$25 mph
Humidity	Solid State	WeatherMeasure	± 3% $<$80% RH ± 6% $>$80% RH
Liquid Flow (Rate)	Impact-type Target Flow Meter	Ramapo	± 1% ½" to 3½" Pipe ± 2% 4" Pipe
Liquid Flow (Total)	Nutating Disk Flow Meter	Hersey	± 1.5% Total Flow
Air Flow	Thermal Anemometer	Kurz	± 2% -68 - 140°F
Fùel Flow	Oscillating Piston Flow Meter	Kent	± 1% Full Scale
Gas Flow	Bellows Type-4 Chamber	American	± 1% Full Scale
Electric Power	Hall Effect Transducer	Ohio Semitronics	± 0.5% Full Scale
Heat Flux	Thermoelectric Junction	Hy-Cal Engineering	± 2% Linearity ± 0.5% Repeatability

The error elements of the NSDN data system are categorized into three major groups. These are the sensor error sources, the Site Data Acquisition Subsystem (SDAS) error sources, and the computational error sources. Each of these areas is briefly discussed below. Additional detail is available in Reference B-2.

Sensor errors are defined as all error sources arising between the point of measurement and the input to the SDAS. Sensor errors are of two types. The first type is inherent sensor error. These errors are independent of the installation of a sensor at a particular location. The sources for quantifying these errors are manufacturers' references and laboratory tests conducted at the manufacturers' facilities. Estimates of these errors are given in Table B-1.

The second type of sensor error is 'in-situ' or location error. These errors are specific to the sensor location, sensor wiring, installation technique, and to the state of the system where the measurement is made. In general, sensors for all sites have been installed in accordance with manufacturers' and National Bureau of Standards (NBS) standards, in order to minimize errors due to sensor location. (See Reference B-2.)

SDAS errors are defined as all errors propagated in the Site Data Acquisition Subsystem.

Two sources of SDAS accuracy data are available. An unpublished report details the results of testing performed at Argonne National Laboratory (ANL). Error numbers related to the variation of regulated voltages within the SDAS from several sources were established and found to be less than 0.05% in most cases. A significant area of concern was long-term drift of readings at many sites. Line voltage variation, temperature regime of the SDAS, and repair/replacement were found to have less significance. Secondly, side-by-side testing of a fully deployed sensor/SDAS system resulted in performance factor accuracy within ± six percent of reference measurement.

Computational errors are propagated from application of analytical techniques to the data stream, and include rounding errors, data gap errors and sampling rate errors.

Estimation of actual computational errors was accomplished using computer simulation to determine round-off and sampling rate errors, the effect of data gap bridging, and the effect of errors in the measurement of certain constants and auxiliary parameters that affect performance factor computations. The effects of these errors were established by actual measurement at the test sites, data acquired from other sources, and from analytical techniques. Results of these tests are available in Reference B-2. In general, the results showed no significant introduction of error in computations at most sites.

Data is occasionally lost at NSDN sites for a variety of reasons. Values for missing data elements are created by a data bridging routine. There will always be some error associated with the estimation process.

For data losses of 10% or less, the performance factor accuracy is not significantly affected. Most errors are less than three percent. All but one are four percent or less. The significant exception is change in stored energy, which is very sensitive to data loss.

Some performance factors are stable with relatively large data loss. Calculation of overall system performance generally remains stable with less than 20% data loss. (Reference B-2)

The results of several related studies indicate that the measurement of the performance of typical active solar systems can be accomplished with a relatively high degree of accuracy. Performance factor accuracy is within the National Bureau of Standards (NBS) criteria of six percent accuracy. (Reference B-1) Exceptions are those performance factors which depend directly on the estimation of burner efficiency or estimates due to known sensor failures.

APPENDIX B

REFERENCES

B-1 Streed, E., et al. Thermal Requirements and Performance Evaluation Procedures for the National Heating and Cooling Demonstration Program, NBSIR 76-1137, National Bureau of Standards, Washington, D.C., 1976.

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