SOLAR/1046-80/14

SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

LIVING SYSTEMS

Davis, California
October 1979 through February 1980
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U.S. DEPARTMENT OF ENERGY

NATIONAL SOLAR DATA PROGRAM

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DAVIS, CALIFORNIA

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OCTOBER 1979 THROUGH FEBRUARY 1980

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FOREWORD

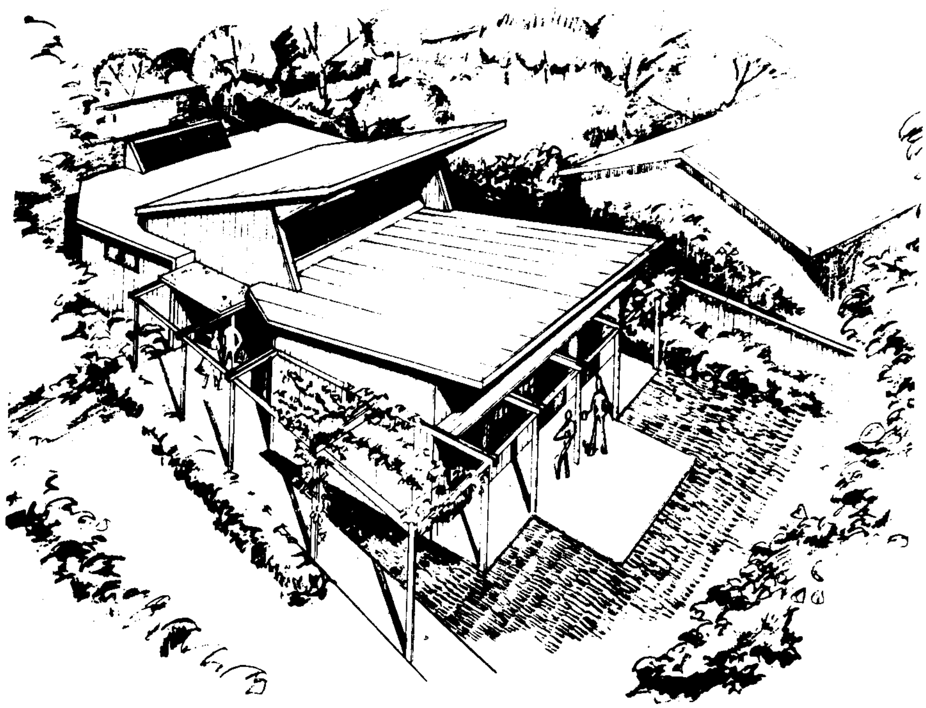
This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic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



LIVING SYSTEMS

LIVING SYSTEMS

The Living Systems site is a single-family residence in Davis, California. The solar energy system is designed to supply the following:

Seasonal Design Factors
(Million BTU)

	Total Load	Solar Contribution	% Solar
Heating	58.00	51.10	88

It is equipped with:

Collector	273 square feet of south-facing double glazing
Storage	3,343 gallons of water in site-built containers and six-inch concrete slab
Auxiliary	35,000 BTU gas furnace and 30,000 BTU wood stove

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SOLAR SYSTEM PERFORMANCE

LIVING SYSTEMS
OCTOBER 1979 THROUGH FEBRUARY 1980

Solar Fraction[1]	80%
Conventional Fuel Savings[2]	31,811 cubic feet of natural gas

Seasonal Energy Requirements
October 1979 through February 1980
(Million BTU)

	Equipment Heat Load Total	Solar Contribution	% Solar
Heating	24.28	19.40	80

Environmental Data

	Measured Total	Long-Term Average
Heating degree-days	2,052	2,099
Average daily incident solar energy	1,198 BTU/ft^2	1,310 BTU/ft^2

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

2. $\text{Conventional Fuel Savings} = 1.67 \times \text{Solar Energy Supplied to Load} \times 984.25\ BTU/ft^2$

1.1 SUMMARY AND CONCLUSIONS

The solar system system at Living Systems is a direct-gain passive system with storage in the six-inch slab floor and in water tanks located in living space.

The Living Systems passive solar energy system provided 80% of the space heating requirements for this residence in Davis, California from October 1979 through February 1980.

The overall performance of the solar system was good during the heating season. The thermal performance is summarized in Table 1 and illustrated in Figure 1.

TABLE 1. SOLAR SYSTEM THERMAL PERFORMANCE

LIVING SYSTEMS
OCTOBER 1979 THROUGH FEBRUARY 1980

(All values in million BTU, unless otherwise indicated)

MONTH	EMPIRICAL HEATING DEGREE DAYS	BUILDING HEAT LOAD	CONDUCTION LOSSES (UA Δτ)	INFIL LOSSES	AUX ENERGY WOOD STOVE	AUX ENERGY INTERNAL GAINS	AUX THERMAL USED	SOLAR ENERGY USED	EQUIPMENT HEAT LOAD	SOLAR FRACTION (%)
OCT	88	3.04E	2.04E	1.00E	0.00	0.70	0	2.34	2.34	100
NOV	405	6.90	4.92	1.99	0.24	0.74	0	5.92	6.16	96
DEC	586	7.97	5.72	2.25	1.33	0.93	0	5.71	7.04	81
JAN	558	6.63	4.57	2.05	1.86	1.92	0	2.85	4.71	60
FEB	415	5.70	3.76	1.94	1.45	1.67	0	2.58	4.03	64
TOTAL	2,052	30.24	21.01	9.23	4.88	5.96	0	19.40	24.28	-
AVERAGE	410	6.05	4.20	1.85	0.98	1.19	0	3.88	4.86	80

E - DENOTES ESTIMATED VALUE.

The incident solar energy was 49.23 million BTU. The operational incident solar energy was 56% of the incident solar energy, or 26.86 million BTU. The system collected 18.54 million BTU. This represents an overall collector efficiency of 38% and an operational efficiency of 69%.

The reduction of heat loss from the windows resulting from the use of the moveable insulation was 3.38 million BTU. Due to less than optimal manual operation of the shutters, 15.44 million BTU were not collected, based on an average collection efficiency of 69%.

During the reporting period, 2.93 million BTU were delivered to storage and 3.79 million BTU were delivered from storage to the space heating load.

The average storage temperature in October was still high from charging all summer and the heating season began with an average storage temperature of 75°F. The storage temperature decreased during the winter, and by February the average storage temperature was 68°F. This drop in temperature from 75°F in October to 68°F in February accounts for the fact that more energy was delivered from storage than was delivered to storage. The additional energy delivered from storage was energy collected during the summer months and released during the heating season.

The average storage temperature was highest in October, 75°F, and lowest in January, 66°F, for an average of 70°F for the season.

The wood stove provided a significant amount of energy to the south storage tubes. The wood stove is located within a few feet of one of the water storage tubes and the radiation from the stove heats the water when the stove is in operation.

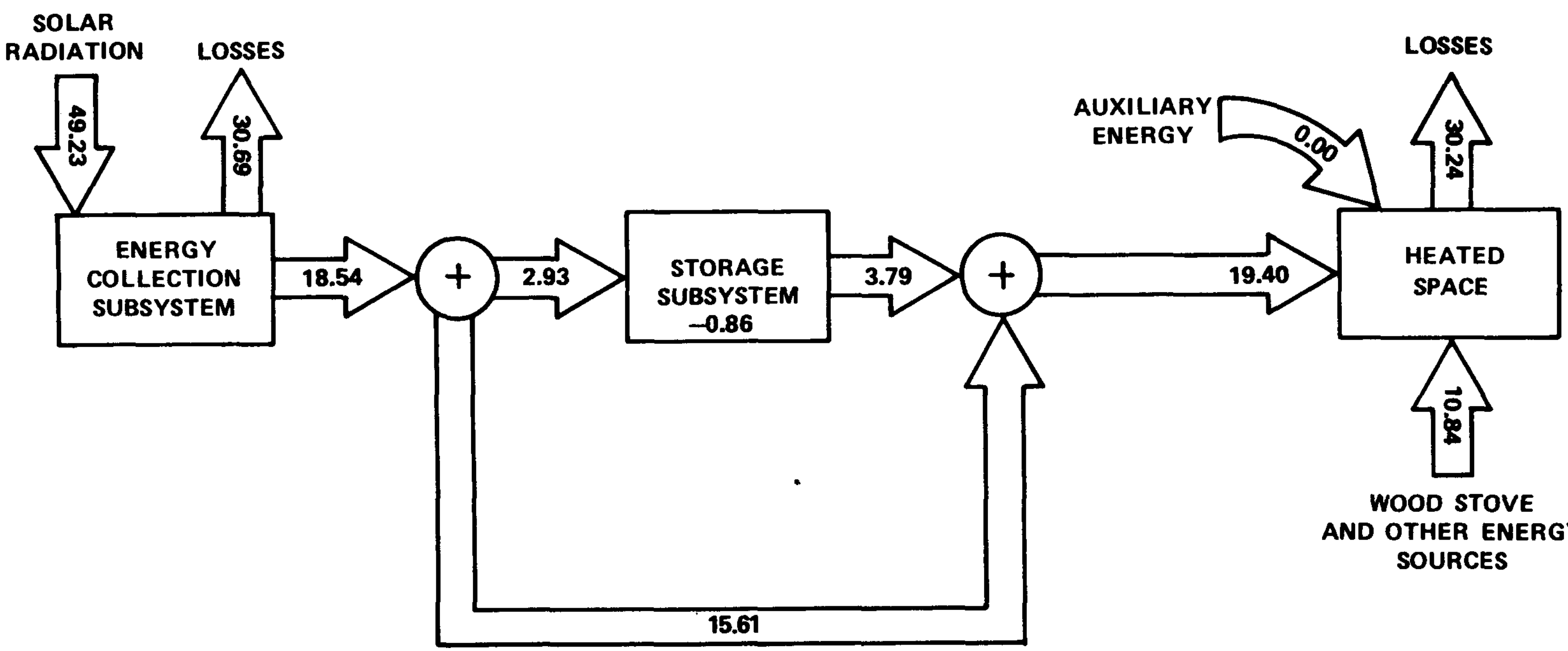

Figure 1. Energy Flow Diagram for Living Systems
October 1979 through February 1980
(Figures in million BTU)

The heating losses from the house (UA $\Delta\tau$ + infiltration) of 30.24 million BTU were satisfied by 64% solar energy, 20% internal gains, and 16% from the wood stove. The building heat loss (UA $\Delta\tau$) is the product of the thermal transmission coefficient (U) of the walls, floors and roof, and the area of each element (A) and the temperature differential across each element ($\Delta\tau$). The result is BTUs per hour loss by conduction through the building elements. The auxiliary gas furnace was not used during the entire period.

The natural gas savings for the season were approximately 318 therms. At $0.36 per therm, this represents about $114.00 savings.

1.2 OVERALL SYSTEM PERFORMANCE

The overall performance of the system was very good with an annual solar fraction of 80%. If the internal gains had been lower for January and February, the system could have used more solar energy and the annual solar fraction would have been higher. (See Figure 2.)

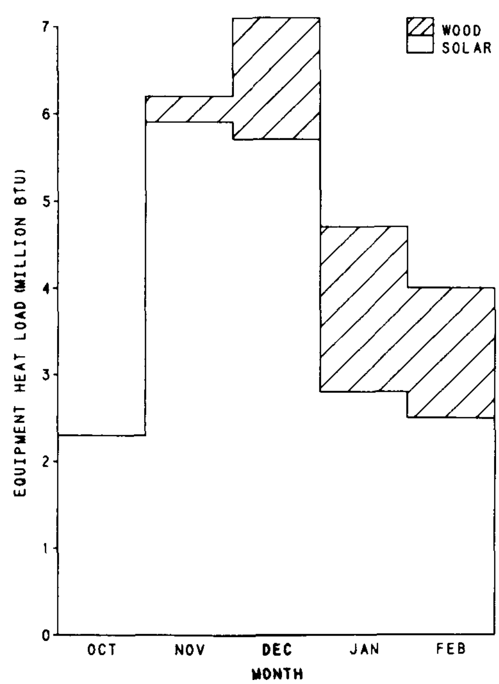

Figure 2. System Thermal Performance
Living Systems
October 1979 through February 1980

The system was designed with a good collector to storage ratio which prevented large temperature swings inside the building.

The overall system performance suffered somewhat due to the manual operation of the movable insulation. The net savings from the use of the movable insulation were 3.38 million BTU, but, because the shutters and curtains were only open to collect 56% of the available solar energy, 15.44 million BTU of solar energy were lost or not collected (based on an average collection efficiency of 69%).

The solar fraction of the equipment heat load for the season is calculated by dividing the solar energy used by the equipment heat load. The equipment heat load is the building load minus the internal gains from appliances, lights and overall electric consumption. The building heat load is the sum of the conduction heat lost through the walls, floor and roof (UA $\Delta\tau$) and the infiltration loss. There was no auxiliary thermal energy from the gas furnace used for the season. The furnace was turned off all winter. The degree-days for the five-month period were 2,052. This is the difference between 65°F and the average temperature for the day totaled for the season. The only other energy used in the building besides the solar and internal gains was from a wood stove, which provided 4.88 million BTU to the equipment heat load.

The overall system performance for each month is graphically presented in Figures 3 through 7.

The month of October (Figure 3) was very mild and heating was only required for the second half of the month. The building heat load of 3.04 million BTU was met by 0.70 million BTU of internal gains and 2.34 million BTU of solar energy. The building was 100% solar heated for the month of October. The building heat load was 67% conduction loss through the building envelope (UA $\Delta\tau$) and 33% through air infiltration.

November (Figure 4) had 405 heating degree-days and the building heat load was 6.90 million BTU. The building heat load was 71% through conduction (UA $\Delta\tau$) and 29% through infiltration. The internal gains reduced the building load by 11% (0.74 million BTU) The equipment heat load was satisfied by 0.24 million BTU from the wood stove and 5.92 million BTU of solar. The building was 96% solar heated for the month of November. The wood stove was only used for the last 10 days of the month when the average outside temperatures dropped into the 40's°F.

December (Figure 5) was the coldest month of the season with 586 heating degree-days. The building heat load was 7.97 million BTU. This was 72% through conduction (UA $\Delta\tau$) and 28% through air infiltration. The building heat load was reduced by 12% (0.93 million BTU) to give an equipment heat load of 7.04 million BTU. This was satisfied by 1.33 million BTU from the wood stove (19%) and 5.71 million BTU of solar (81%). The average temperatures were in the 40's°F for most of the month with a few days dropping into the high 30's°F. The wood stove was used primarily on days with very low incident solar energy and at night. The storage temperatures and building temperatures dropped from approximately 70°F at the beginning of the month to approximately 65°F by the end of the month. This was due to increasingly cooler temperatures and many very overcast days. The result was a reduced amount of solar energy available to the system.

January (Figure 6) had relatively mild temperatures for the first half of the month but was very overcast. The last half of the month had colder temperatures but fairly clear skies. The building heat load for the month was 6.63

million BTU. This was 69% through conduction (UA $\Delta\tau$) and 31% through infiltration. The building heat load was reduced by 29% from internal gains, resulting in an equipment heat load of 4.71. The increased internal gains (from 0.93 million BTU in December to 1.92 million BTU in January) were a result of increased use of electrical appliances and lights during the month. The increased internal gains had the net effect of reducing the percent of the load that was satisfied by solar energy. For the month of January, the building heat load was satisfied by 29% internal gains, 29% from the wood stove, and 43% solar. The equipment load was satisfied by 60% solar and 40% wood stove.

February (Figure 7) had warmer temperatures and relatively clear skies. The building heat load was 5.70 million BTU. This was 66% conduction loss (UA $\Delta\tau$) and 34% infiltration. The internal gains were 1.67 million BTU. This was 29% of the building heat load, resulting in an equipment heat load of 4.03 million BTU. The internal gains were again very high for the month of February. This was due to increased use of electrical appliances and lights. The wood stove provided 25% of the building load, internal gains provided 29%, and solar provided 46%. The equipment heat load was satisfied by 64% solar and 36% wood.

The wood stove was used on many days in February when it was not needed to meet the load. The excess heat went into storage and increased the building temperature. This effect can be seen on February 6, 7, 8 and 9. The average temperatures were in the 60's°F and there was good solar energy available. The use of the stove and the solar raised the storage temperature from an average of 66°F on February 4 to 72°F on February 7. This stored energy was released during the last half of the month when the ambient temperature dropped to the 50's°F and the skies were overcast.

The overall system performed very well for the season. The water thermal mass responded very quickly to increased solar and increased loads.

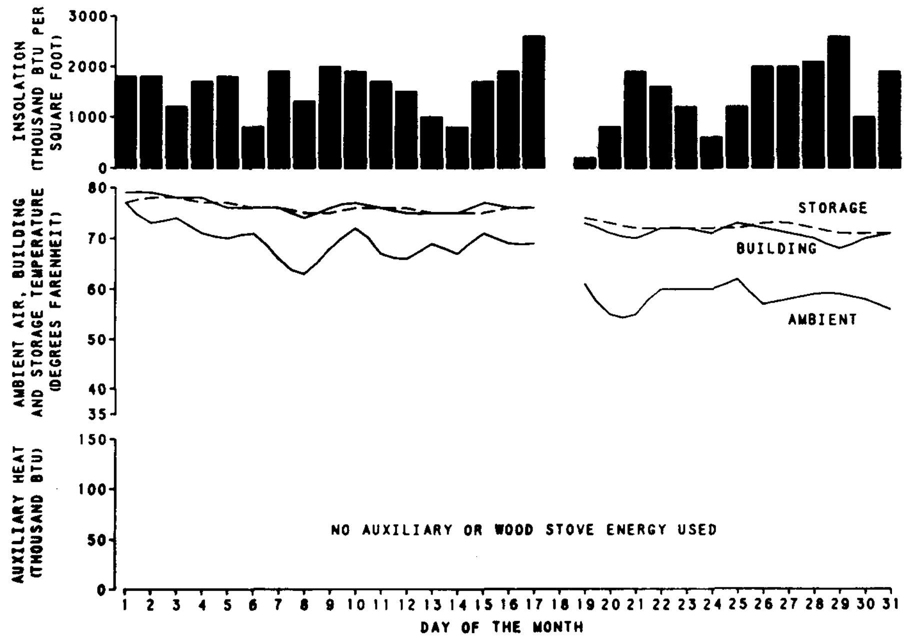

Figure 3. Monthly Summary Graphs for October 1979
Insolation Versus Building, Storage, and Ambient Temperatures
Versus Auxiliary Energy Used
Living Systems

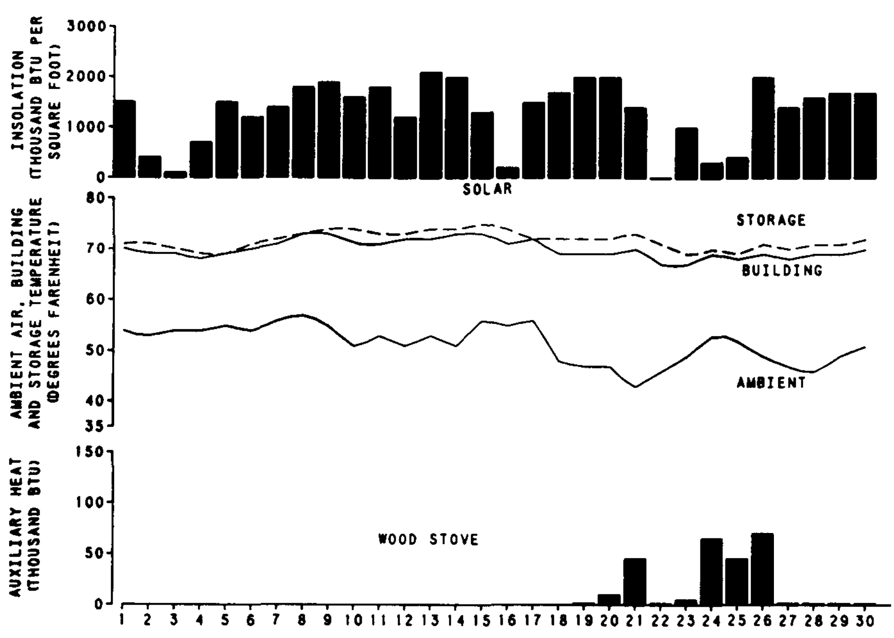

Figure 4. Monthly Summary Graphs for November 1979
Insolation Versus Building, Storage, and Ambient Temperatures
Versus Auxiliary Energy Used
Living Systems

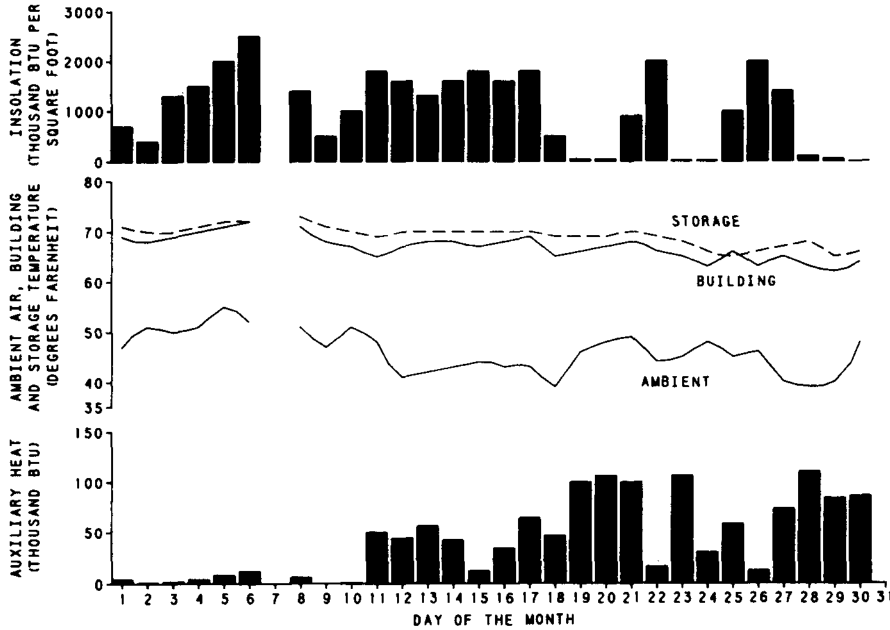

Figure 5. Monthly Summary Graphs for December 1979
Insolation Versus Building, Storage, and Ambient Temperatures
Versus Auxiliary Energy Used
Living Systems

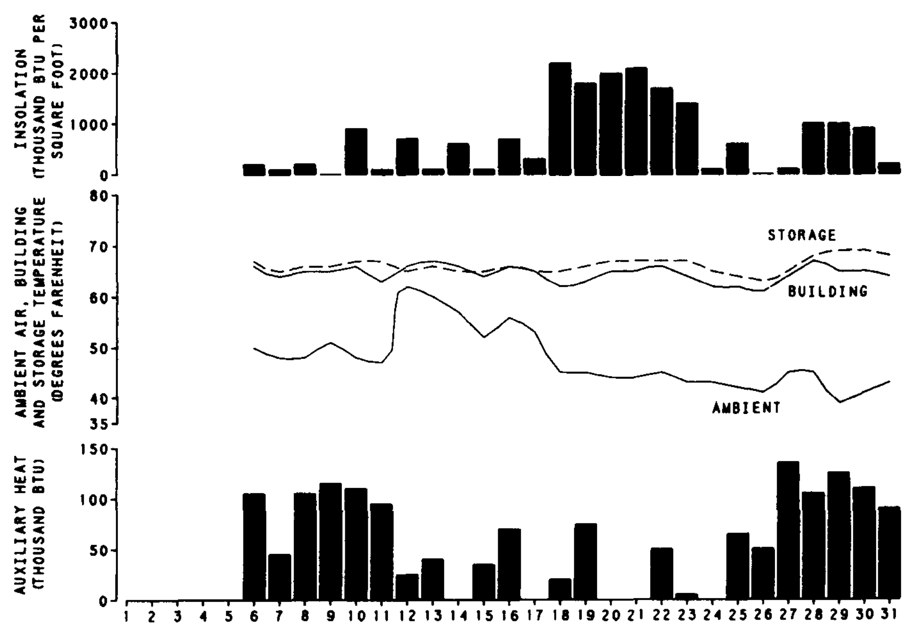

Figure 5. Monthly Summary Graphs for January 1980
Insolation Versus Building, Storage, and Ambient Temperatures
Versus Auxiliary Energy Used
Living Systems

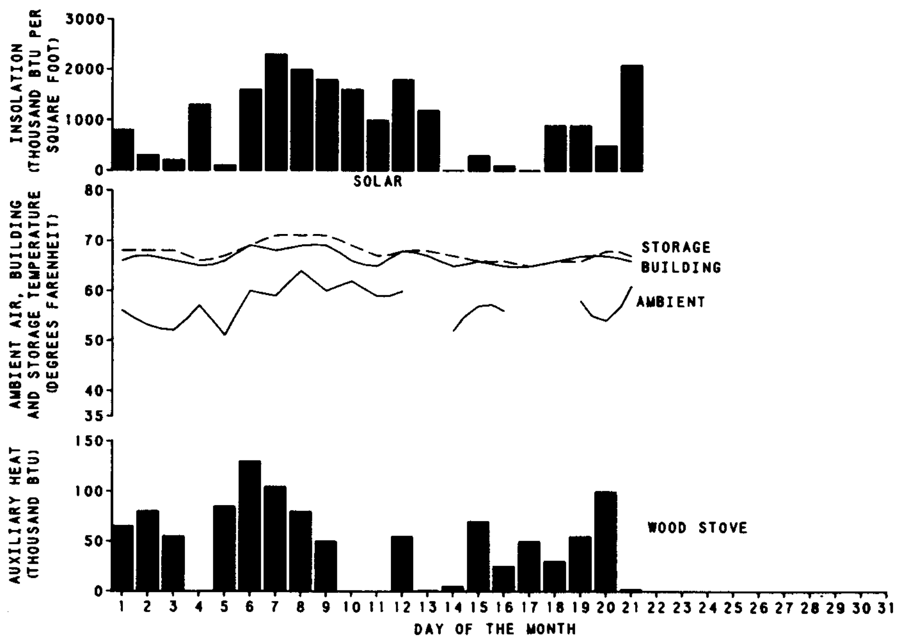

Figure 7. Monthly Summary Graphs for February 1980
Insolation Versus Building, Storage, and Ambient Temperatures
Versus Auxiliary Energy Used
Living Systems

1.3 ENERGY SAVINGS

Energy savings for this site for the reporting period, October 1979 through February 1980, are presented in Table 2 and shown graphically in Figure 8. For this five-month period, the total fossil fuel savings were 32.32 million BTU, for a monthly average of 6.46 million BTU. This is approximately 215.90 gallons of oil, or 31,811 cubic feet of natural gas, or 5,686 kwh of electricity.

The system saved $114.00 worth of natural gas for the season at $0.36 per therm.

Solar energy system savings are realized whenever energy provided by the solar energy system is used to meet system demands which would otherwise be met by auxiliary energy sources. The wood stove was used as the primary auxiliary heating system. A greater savings from solar would have been realized if the wood stove had not been used as often or at times when it was not needed.

The auxiliary source at the Living Systems site consists of a gas heater and a wood stove. The gas unit is considered to be 60% efficient for computational purposes.

Table 2. ENERGY SAVINGS

LIVING SYSTEMS
OCTOBER 1979 THROUGH FEBRUARY 1980

(All values in million BTU)

MONTH	SOLAR ENERGY USED	SOLAR ENERGY SAVINGS ATTRIBUTED TO SPACE HEATING FOSSIL FUEL	**ENERGY SAVINGS** FOSSIL FUEL
OCT	2.34	3.89	3.89
NOV	5.92	9.87	9.87
DEC	5.71	9.52	9.52
JAN	2.85	4.74	4.74
FEB	2.58	4.30	4.30
TOTAL	19.40	32.32	32.32
AVERAGE	3.88	6.46	6.46

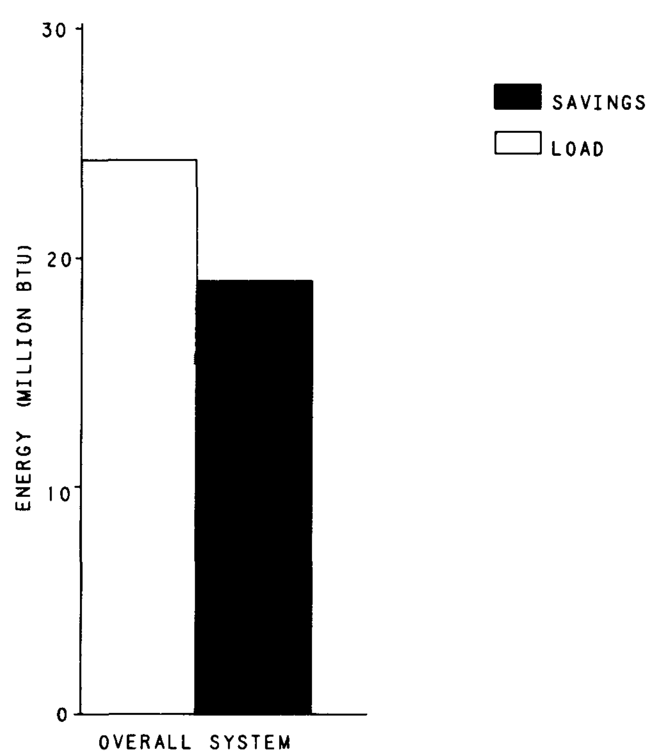

Figure 8. Combined Thermal Energy Savings Compared to Load
Living Systems
October 1979 through February 1980

1.4 SOLAR SYSTEM AVAILABILITY

The insulating curtain and the clerestory insulating panels were used regularly by the owner to reduce the heat loss from the windows at night and on days with no sun. The operation of the movable insulation reduced the average heat loss from the windows from 136.50 BTU/F°/hr to 67.90 BTU/F°/hr. This represents an average reduction in heat loss from the windows of 50% for the season from October 1979 through February 1980.

The incident solar energy on the glazing for the season was 49.23 million BTU. The operational incident solar energy, or the incident solar energy when the curtains and shutters were open, was 26.86 million BTU. This represents 56% of the available incident solar energy.

The net savings from using the movable insulation for the season were 3.38 million BTU, but, because the shutters and curtains were only open to collect 56% of the available solar energy, 15.44 million BTU of solar energy were lost or not collected (based on average collection efficiency of 69%). Therefore, in this system the performance would seem to be much better if the movable insulation was left open all the time rather than dependent on occupant operation.

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The passive collector system consists of 192 square feet of vertical south-facing windows and 81 square feet of clerestory windows at a 60° slope from the horizontal. The glazing is double-pane glass with site-built movable insulation. The vertical wall has an insulated curtain that is manually operated and sealed with velcro at the edges. The clerestory has ridged foam panels that hinge open with aluminum foil reflectors on the inside to provide reflection to the space below when open.

The collector subsystem performance is presented in Table 3.

For the period from October 1979 to February 1980, the solar energy incident on the collectors was 49.23 million BTU. The operational incident solar energy was 26.86 million BTU or 56% of the available incident energy. The solar energy collected was 18.54 million BTU. The overall collector subsystem efficiency was 38% and the operational collector subsystem efficiency was 69%. The operational efficiency is very good, but the overall efficiency is low due to the operation of the window insulation.

The collector efficiency was lowest in October and February, due to the high angle of incidence during these months. The collector efficiency was greatest in December, when the angle of incidence on the collectors was the lowest.

The manual operation of the curtains and shutters was less than optimal for the reporting period. Only 56% of the 49.23 million BTU incident on the collectors was available when the shutters and curtains were open. This represents a loss of 15.44 million BTU of solar energy assuming an average collector efficiency of 69%.

The solar energy delivered directly to the equipment heat load for the report period was 15.61 million BTU, and 2.93 million BTU were delivered to storage.

Table 3. COLLECTOR SUBSYSTEM PERFORMANCE

LIVING SYSTEMS
OCTOBER 1979 THROUGH FEBRUARY 1980

(All values in million BTU, unless otherwise indicated)

MONTH	INCIDENT SOLAR RADIATION	COLLECTED SOLAR ENERGY	COLLECTOR SUBSYSTEM EFFICIENCY (%)	OPERATIONAL INCIDENT ENERGY	OPERATIONAL COLLECTOR EFFICIENCY (%)	SOLAR ENERGY DIRECTLY TO LOADS	SOLAR ENERGY TO STORAGE	DAYTIME AMBIENT TEMPERATURE (°F)
OCT	13.39	1.95	15	4.12	47	1.59	0.36	75
NOV	11.08	5.88	53	7.75	76	5.28	0.60	59
DEC	9.43	5.21	55	6.65	78	4.61	0.60	53
JAN	7.22	2.99	41	4.08	73	2.26	0.73	52
FEB	8.11	2.51	31	4.26	59	1.87	0.64	57
TOTAL	49.23	18.54	-	26.86	-	15.61	8.33	-
AVERAGE	9.85	3.71	38	5.37	69	3.12	1.67	59

2.2 STORAGE

Solar energy is stored in two sets of steel culverts filled with water. The first set is behind the vertical south wall and consists of five tubes three and one-half feet tall, two feet in diameter, painted flat blue, containing 411 gallons of water. The second set of eight water tubes is located behind the clerestory and is 10 feet tall, and contains 2,932 gallons of water. The total water storage is 3,343 gallons. Additional storage is in the six-inch-thick concrete slab floor that covers the entire 1,700 square feet of the house. The tubes and floor receive solar energy by direct radiation and deliver their heat back to the room by radiation.

Storage performance data for the site for the reporting period are shown in Table 4.

During the reporting period, total solar energy delivered to storage was 2.93 million BTU. There were 3.79 million BTU delivered from storage to the space heating subsystem.

Table 4. STORAGE PERFORMANCE

LIVING SYSTEMS
OCTOBER 1979 THROUGH FEBRUARY 1980

(All values in million BTU, unless otherwise indicated)

MONTH	ENERGY TO STORAGE	ENERGY FROM STORAGE	CHANGE IN STORED ENERGY	AVERAGE STORAGE TEMP. (°F)
OCT	0.36	0.74	-0.38	75
NOV	0.60	0.64	-0.04	72
DEC	0.60	1.11	-0.51	69
JAN	0.73	0.59	0.14	66
FEB	0.64	0.71	-0.07	68
TOTAL	2.93	3.79	-0.86	-
AVERAGE	0.59	0.76	-0.17	70

The average storage temperature is made up of temperature readings from the south water tubes, the north water tubes, and the area of the slab that receives direct solar radiation. When the temperature in the storage mass increases, it is charging with energy, and, when the temperature drops, it is discharging the stored energy to the living space. In looking at the charging and discharging cycles of the primary storage masses (the rest of the house mass is secondary storage), these three storage masses respond differently to the surrounding internal and external conditions. As can be seen in Figure 9, the north tubes and the slab respond with approximately the same temperature time lag to the daily radiation. The north tube temperature is 3°F higher than the slab and 2°F higher than the lower mass south tubes at the beginning of the three-day discharging cycle. The 61°F building temperature reached at 7:00 A.M. on January 22 prompted the occupants to start a fire in the wood-burning stove, thus affecting overall building temperature and the average storage temperature of the south water tubes. The wood-burning stove is within a few feet of the south wall; thus, the stove is effectively heating the south water walls above what the sun alone would do. This has the advantage of storing additional heat for later use. At the end of a three-day discharging cycle, the average north water wall temperature and the average slab temperature were within one degree of each other.

During the three days represented in Figure 10, both renewable energy and solar energy were used to charge the system. On the afternoon of January 26, building temperatures leveled at 59°F with the average storage temperature staying 3°F above that of the building temperature. The wood stove was fired up that evening, allowed to burn all night, and continued to be used until the end of January 28. Due to the wood stove and one day of solar energy, the south water tube temperature rose a total of 13°F over the three-day period while the north water tubes and slab temperatures rose 4°F. The combination of lower mass and close proximity of the wood stove to the south wall caused the 10°F difference in storage temperatures. With this combination of renewable energy and solar energy, the building temperature was brought back up to the 65°F to 70°F range.

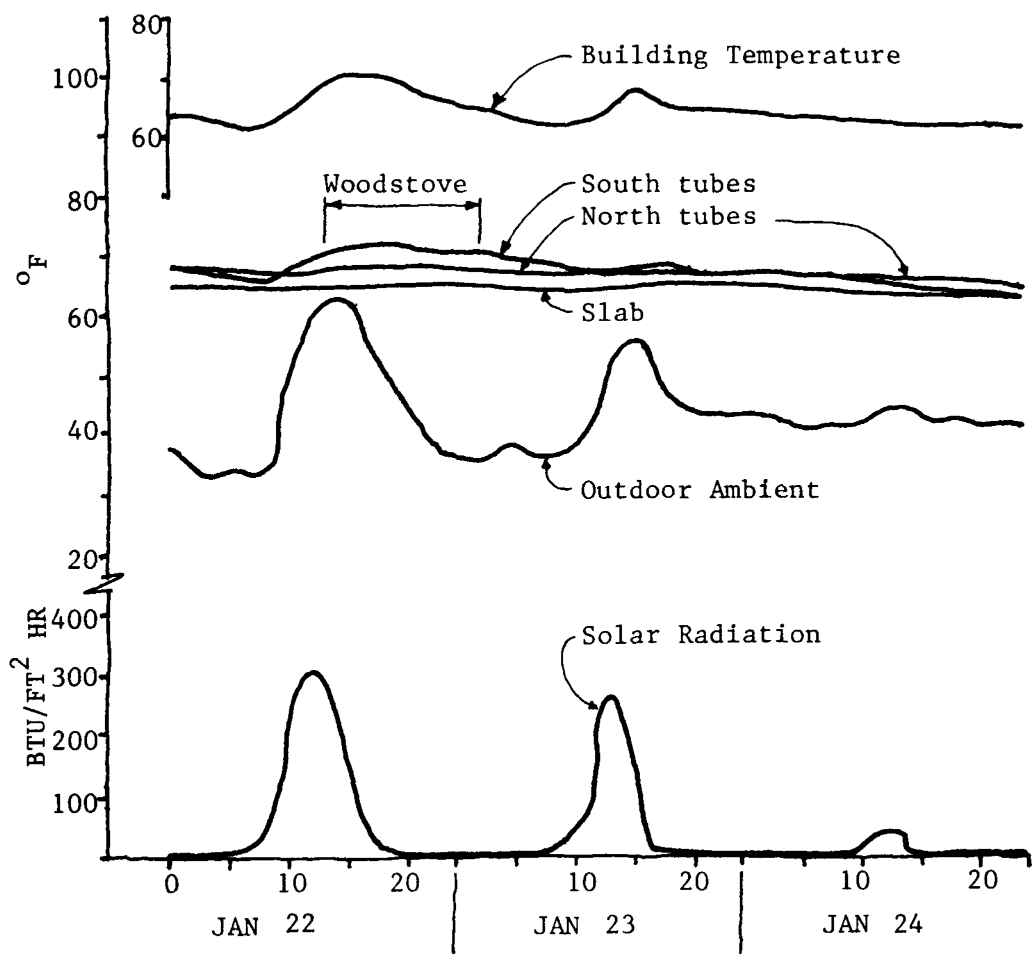

Figure 9. Charging Cycle
Living Systems
January 22, 23, and 24, 1980

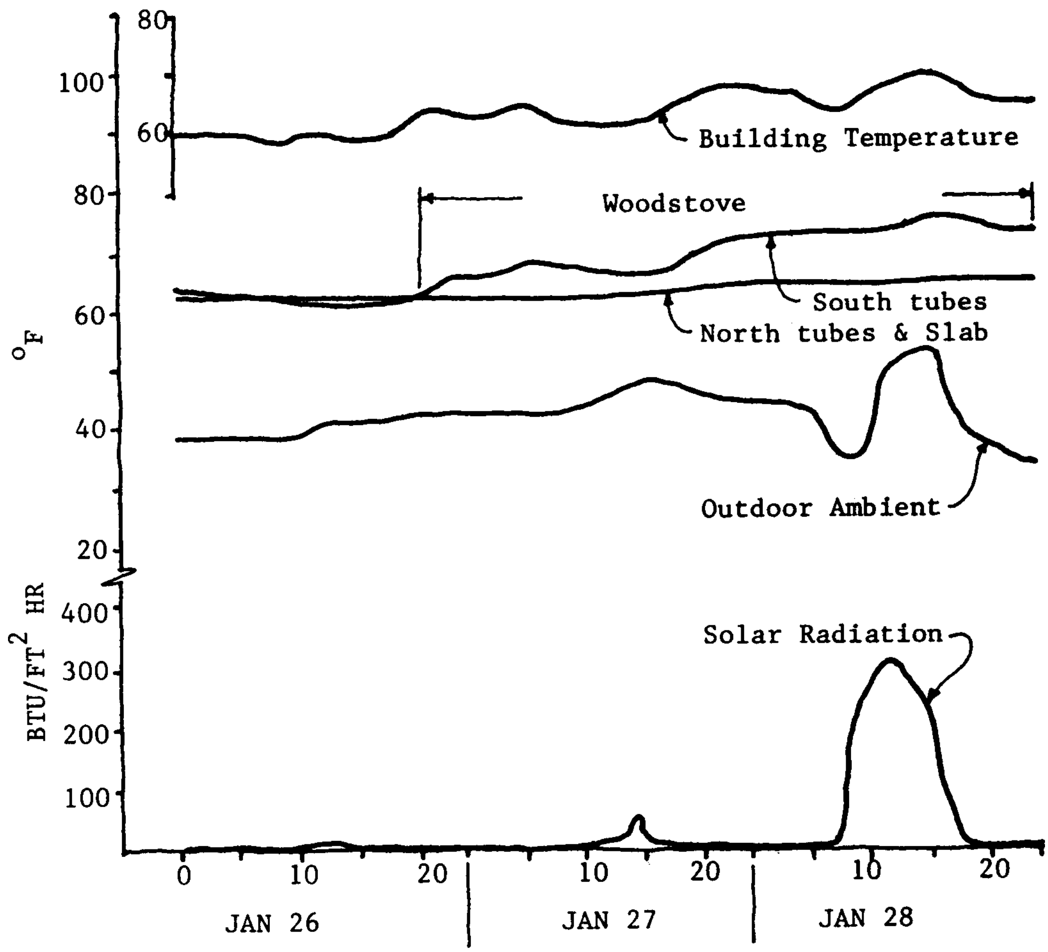

Figure 10. Discharging Cycle
Living Systems
January 26, 27, and 28, 1980

2.3 SPACE HEATING

The space heating subsystem consists of a gas hot-air furnace designed to deliver 35,000 BTU/hr. A wood stove is also used for auxiliary heat. The wood stove is custom-made by Living Systems from a surplus marine buoy. It is estimated to produce 30,000 BTU/hr output.

The space heating performance for the Living Systems site for the reporting period is shown in Table 5 and presented graphically in Figure 11. The equipment heat load is the load on the heating system to maintain the thermostat setting. This is the building heat loss minus the internal gains from appliances and electric lights. The equipment heat load was met by 80% solar and 20% from the wood stove. The total building load, that is, the heat loss plus infiltration, was 30.24 million BTU. This was met by 64% solar, 20% internal gains, and 16% from the wood stove.

Table 5. SPACE HEATING SUBSYSTEM

LIVING SYSTEMS
OCTOBER 1979 THROUGH FEBRUARY 1980

(All values in million BTU, unless otherwise indicated)

MONTH	EQUIPMENT SPACE HEATING LOAD	SOLAR	ENERGY CONSUMED FURNACE	ENERGY CONSUMED INTERNAL GAINS	ENERGY CONSUMED WOOD STOVE	SOLAR FRACTION (%)	BUILDING LOAD
OCT	2.34	2.34	0.00	0.70	0.00	100	3.04
NOV	6.16	5.92	0.00	0.74	0.24	96	6.90
DEC	7.04	5.71	0.00	0.93	1.33	81	7.97
JAN	4.71	2.85	0.00	1.92	1.86	60	6.63
FEB	4.03	2.58	0.00	1.67	1.45	64	5.70
TOTAL	24.28	19.40	0.00	5.96	4.88	-	30.24
AVERAGE	4.86	3.88	0.00	1.19	0.98	80	6.05

The internal gains provide a significant amount of energy to the building load during the heating season. It ranges from 11% in November to 29% in January and February. The internal gains provided more energy to the space than the wood stove. The wood stove provided 28% of the building load in January and 25% in February.

The space heating equipment load of 24.28 million BTU (loss - internal gains) was satisfied by 19.40 million BTU of solar energy and 4.88 million BTU of auxiliary energy. The solar fraction of this load was 80%.

The fossil fuel energy savings were 32.32 million BTU or $114.00 worth of natural gas at $0.36 per therm. The average building temperature for the season was 68°F.

The gas furnace was not used during the heating season and all the auxiliary heating was provided by a wood stove. The energy supplied by the wood stove was 4.88 million BTU for the season. This represents 22% of a cord of wood.

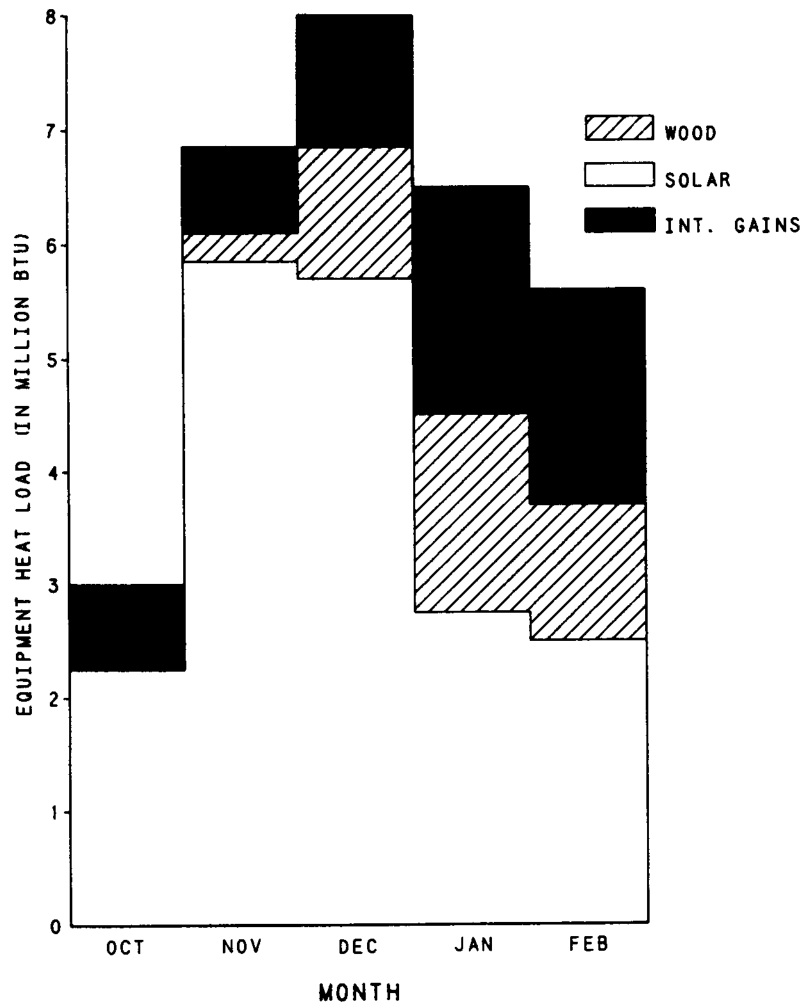

Figure 11. Space Heating Performance
Living Systems
October 1979 through February 1980

In January and February, the electrical consumption at Living Systems showed a significant increase. In October and November, the electrical consumption was near the long-term average of 0.70 million BTU; in December, it rose slightly to 0.90 million BTU; but, in January, it jumped to 1.92 million BTU and in February to 1.67 million BTU. This increase in internal gains contributed 29% of the space heating load in January and February, 11% in December, and less than one percent in October and November. The increase in internal gains also affected the solar fraction by reducing the equipment heat load. The solar fraction decreased from 81% in December to 60% in January and 64% in February.

The system is sized very well for this house and climate. The storage prevented large temperature swings and only a small amount of wood was burned to maintain comfortable conditions in this house in Davis, California.

SECTION 3

WEATHER CONDITIONS

The Living Systems site is located in Davis, California, at 39 degrees N latitude and 122 degrees W longitude.

Monthly values of the total solar energy incident in the plane of the collector array and the average outdoor temperature measured at the site during the reporting period are presented in Table 6. 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 6. WEATHER CONDITIONS

LIVING SYSTEMS
OCTOBER 1979 THROUGH FEBRUARY 1980

	DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT^2-DAY)		AMBIENT TEMPERATURE (°F)		HEATING DEGREE-DAYS	
MONTH	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE	MEASURED	LONG-TERM AVERAGE
OCT	1,652	1,912	65	63	88	101
NOV	1,334	1,322	51	53	405	360
DEC	1,114	943	46	46	586	595
JAN	848	995	47	45	558	617
FEB	1,041	1,378	51	50	415	426
TOTAL	-	-	-	-	2,052	2,099
AVERAGE	1,198	1,310	52	51	410	420

During the period from October 1979 through February 1980, the average daily total incident solar radiation on the collector array was 1,198 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 1,310 BTU per square foot per day for south-facing plane with a tilt of 45 degrees to the horizontal. During the period, the highest monthly average insolation was 1,652 BTU per square foot per day during October. The average ambient temperature during the reporting period was 52°F as compared with the long-term average for the five months of 51°F. The highest monthly average ambient temperature was 65°F during October and the lowest monthly average ambient temperature was 46°F during December. The number of heating degree-days for the period (based on a 65°F reference) was 2,052 as compared with the long-term average of 2,099. The range of heating degree-days was from a high of 586 during December to a low of 88 during October.

SECTION 4

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, Living Systems, October 1979, SOLAR/1046-79/10, IBM, Huntsville, Alabama.

*8. Monthly Performance Report, Living Systems, November 1979, SOLAR/1046-79/11, Vitro Laboratories, Silver Spring, Maryland.

*9. Monthly Performance Report, Living Systems, December 1979, SOLAR/1046-79/12, 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, Living Systems, January 1980, SOLAR/1046-80/01, Vitro Laboratories, Silver Spring, Maryland.

*11. Monthly Performance Report, Living Systems, February 1980, SOLAR/1046-80/02, 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 Living Systems site is a single family residence in Davis, California. The home has approximately 1,700 square feet of conditioned space. The solar energy system consists of two independently controlled systems: an active system for preheating domestic hot water (DHW) and a passive system for space heating the home.

The active solar DHW system has an array of flat-plate collectors with a gross area of 46 square feet. The array faces south at an angle of 45 degrees to the horizontal. Potable city water is the transfer medium used throughout the system. In the event of freezing temperatures and no insolation, the controller drains the water from the collectors. When water in the collectors is sufficiently warmer than the water in the preheat storage tank, the controller starts the circulation between the preheat tank and the collectors. The preheat tank holds 82 gallons of water which is supplied, on demand, to a conventional 20-gallon DHW tank. When the water preheated by solar energy is not hot enough to satisfy the hot water load, a natural gas burner in the DHW tank provides auxiliary energy for water heating. The DHW system was damaged by freezing in December 1979 and did not operate for the remainder of the season. Therefore, its performance is not included in this report.

The passive solar space heating system is of the direct-gain type illustrated schematically. Incident solar energy is admitted to the building through both the large south-facing vertical windows (approximately 200 square feet) and the clerestory (approximately 80 square feet with a tilt of 60 degrees to the horizontal). Manually-operated insulating curtains provide insulation during the night and on sunless days for the south-facing collector windows. Manually-operated insulating shutters also provide night insulation for the clerestory glazing and are aluminum-coated to provide reflection to the space below when open. Solar energy is stored in steel tubes that contain approximately 3,600 gallons of water. The tubes are painted blue and placed near the south window wall and under the clerestory. Additional storage is provided by the six-inch-thick concrete slab floor of the building which is covered by brown ceramic tile. Collected solar energy is distributed by natural convection, by conduction through the slab floor, and by radiation. Floor covering is minimal: linoleum in the kitchen and eating area, and white shag rugs in two bedrooms. The building envelope is well insulated in order to ensure energy conservation, with R-19 insulation in the walls and R-30 insulation in the roof. The effective R-values of the windows are in the range of R-2 to R-10 (uncovered and covered with curtains and shutters). All glass surfaces are doubled-glazed with minimum window area in non-south-facing walls. Auxiliary space heating is provided by a gas-fired wall furnace which distributes the energy by natural convection. Additional auxiliary energy can be supplied from a wood-burning stove.

The building has summer overheat protection which is provided by several means: roof overhangs over the south-facing glazed areas provide shading;

operable windows in the south wall and a vent in the north wall provide cross-ventilation of the house at night, cooling the solar storage mass and moderating daytime building temperatures; the curtains and shutters over the windows prevent collection of incident solar energy during the day; and a ceiling fan assists the heat distribution and the nocturnal venting process.

PASSIVE HEATING SUBSYSTEMS

Collector

The passive collector subsystem consists of 192 square feet of vertical south-facing windows and 81 square feet of clerestory windows at a 60° slope from the horizontal. The glazing is double-pane glass with movable insulation. The vertical wall has an insulated curtain that is manually operated and sealed with velcro at the edges. The clerestory has ridged foam panels that hinge open with aluminum foil reflectors on the inside to provide reflection to the space below when open.

Storage

Solar energy is stored in two sets of steel culverts filled with water. The first set is behind the vertical south wall and consists of five tubes three and one-half feet tall, two feet in diameter, painted flat blue, containing 411 gallons of water. The second set of eight water tubes is located behind the clerestory and is 10 feet tall, containing 2,932 gallons of water. The total water storage is 3,343 gallons. Additional storage is in the six-inch-thick concrete slab floor that covers the entire 1,700 square feet of the house. The tubes and floor receive solar energy by direct radiation and deliver their heat back to the room by radiation.

Space Heating

The space heating subsystem consists of a gas hot-air furnace designed to deliver 35,000 BTU/hr. The furnace is a Westwood Model 5BOD. A wood stove is also used for auxiliary heat. The wood stove is custom-made by Living Systems from a surplus marine buoy. It is estimated to produce 30,000 BTU/hr output.

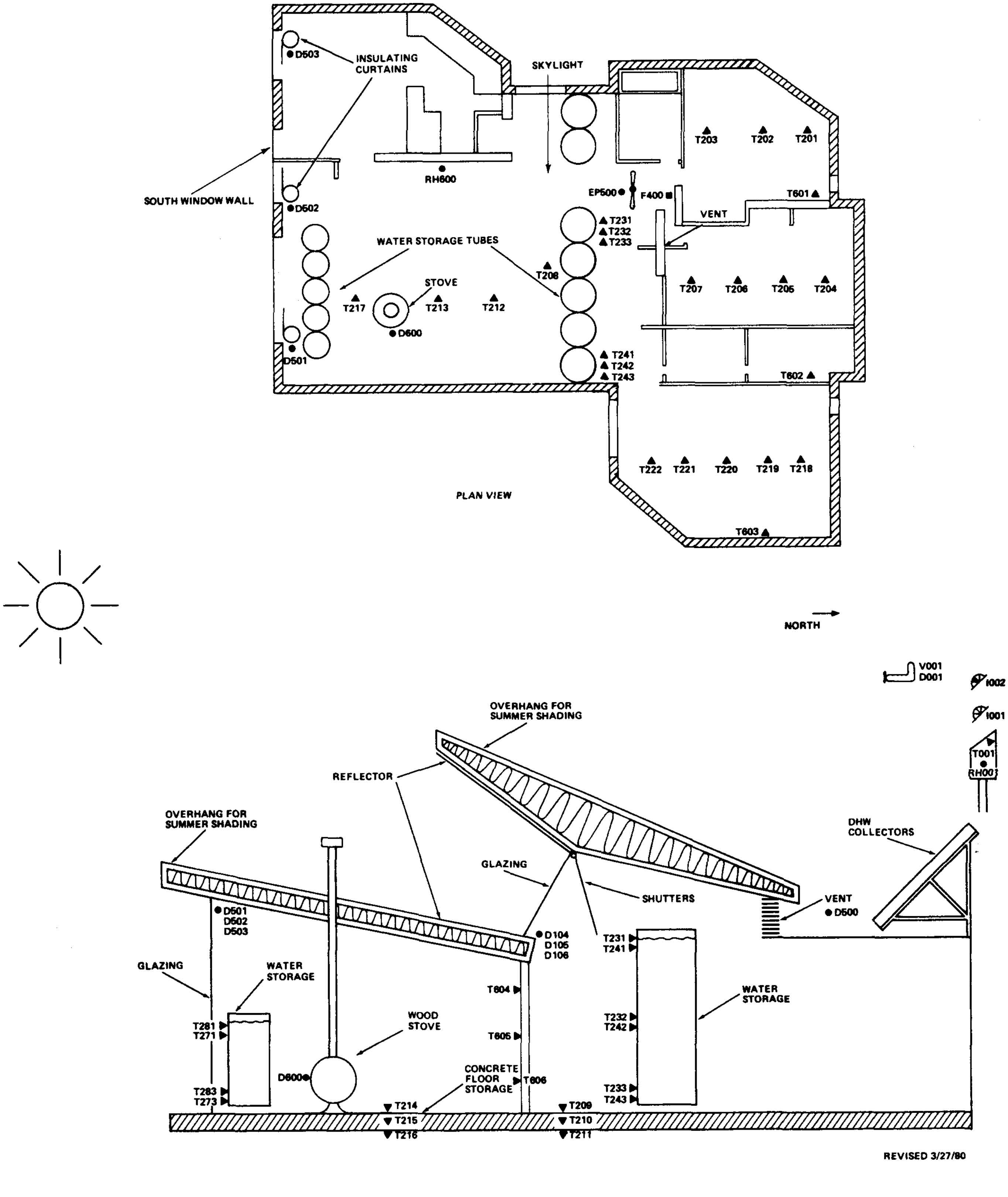

Figure A-1. Living Systems Passive Space Heating System Schematics

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Living Systems 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.

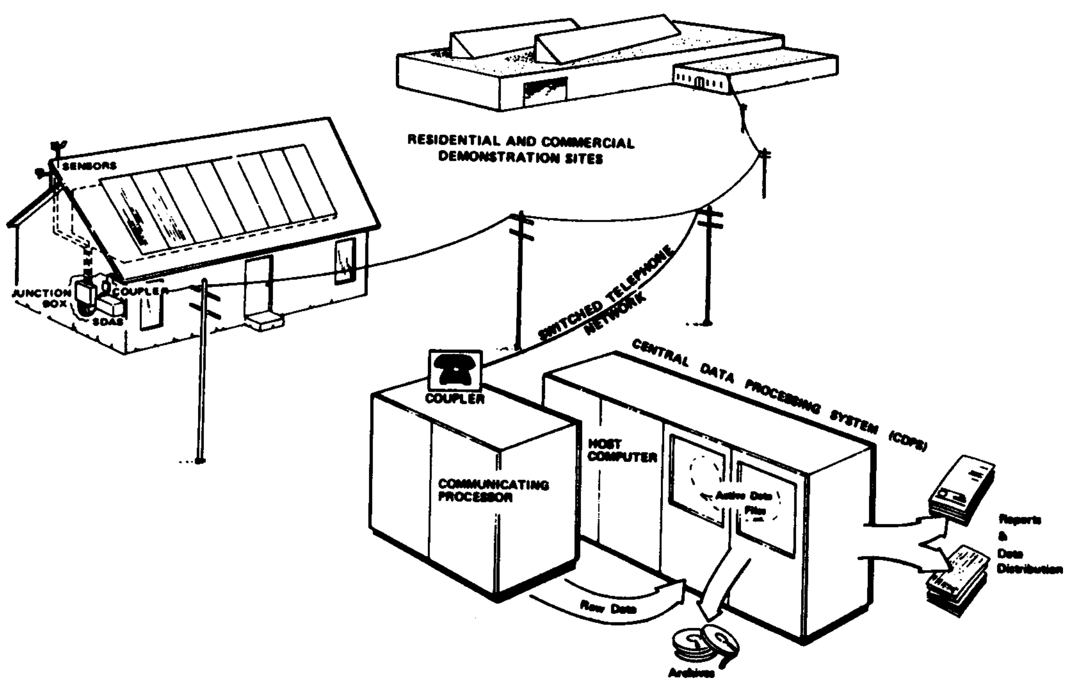

Figure B-1. The National Solar Data Network

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 Living Systems solar energy system from October 1979 through February 1980 was analyzed during the heating season, and Monthly Performance Reports were published for the months when sufficient valid data were available. See the following page for a list of these reports.

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

OTHER DATA REPORTS ON THIS SITE*

Monthly Performance Reports:

August 1978, SOLAR/1046-78/08
September 1978, SOLAR/1046-78/09
October 1978, SOLAR/1046-78/10
November 1978, SOLAR/1046-78/11
December 1978, SOLAR/1046-78/12
January 1979, SOLAR/1046-79/01
February 1979, SOLAR/1046-79/02
March 1979, SOLAR/1046-79/03
April 1979, SOLAR/1046-79/04
May 1979, SOLAR/1046-79/05
June 1979, SOLAR/1046-79/06
July 1979, SOLAR/1046-79/07
August 1979, SOLAR/1046-79/08
September 1979, SOLAR/1046-79/09
October 1979, SOLAR/1046-79/10
November 1979, SOLAR/1046-79/11
December 1979, SOLAR/1046-79/12
January 1980, SOLAR/1046-80/01
February 1980, SOLAR/1046-80/02
May 1980, SOLAR/1046-80/05
June 1980, SOLAR/1046-80/06
July 1980, SOLAR/1046-80/07
August 1980, SOLAR/1046-80/08

Solar Energy System Performance Evaluation:

SOLAR/1046-79/14

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

APPENDIX C

PERFORMANCE FACTORS AND SOLAR TERMS

The performance factors identified in the site equations (Appendix D) by the use of acronyms or symbols are defined in this Appendix in Section 1. Appendix C includes the symbol, 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 abbreviations used in this report.

SECTION 1. PERFORMANCE FACTOR DEFINITIONS

SYMBOL	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.
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.
CSE	Solar Energy to SCS	Amount of solar energy delivered to the SCS.

* Primary Performance Factors

SYMBOL	NAME	DEFINITION
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

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

* Primary Performance Factors

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

* Primary Performance Factors

SYMBOL	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

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

* Primary Performance Factors

SYMBOL	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 <u>above</u> 65°F.
Cooling Tower	A heat exchanger that transfers waste heat to outside ambient air.
Diffuse Radiation	Solar Radiation which is scattered by air molecules, dust, or water droplets and incapable of being focused.
Drain Down	An arrangement of sensors, valves and actuators to automatically drain the solar collectors and collector piping to prevent freezing in the event of cold weather.
Duct Heating Coil	A liquid-to-air heat exchanger in the duct distribution system.
Effective Heat Transfer Coefficient	The heat transfer coefficient, per unit plate area of a collector, which is a measure of the total heat losses per unit area from all sides, top, back, and edges.
Energy Gain	The thermal energy gained by the collector transfer fluid. The thermal energy output of the collector.

Energy Savings	The estimated difference between the fossil and/or electrical energy requirements of an assumed conventional system (carrying the full measured load) and the actual electrical and/or fossil energy requirements of the installed solar-assisted system.
Expansion Tank	A tank with a confined volume of air (or gas) whose inlet port is open to the system heat transfer fluid. The pressure and volume of the confined air varies as to the system heat transfer fluid expands and contracts to prevent excessive pressure from developing and causing damage.
F-Curve	The collector instantaneous efficiency curve. Used in the "F-curve" procedure for collector analysis (see Instantaneous Efficiency).
Figure of Merit, FMS	A calculated number showing the relative net fraction of the system load supplied from solar energy.

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

Fixed Collector	A solar collector that is fixed in position and cannot be rotated to follow the sun daily or seasonably.
Flat Plate Collector	A solar energy collecting device consisting of a relatively thin panel of absorbing material. A container with insulated bottom and sides and covered with one or more covers transparent to visible solar energy and relatively opaque to infrared energy. Visible energy from the sun enters through the transparent cover and raises the temperature of the absorbing panel. The infrared energy re-radiated from the panel is trapped within the collector because it cannot pass through the cover. Glass is an effective cover material (see Selective Surface).
Focusing Collector	A concentrating type collector using parabolic mirrors or optical lenses to focus the energy from a large area onto a small absorbing area.
Fossil Fuel	Petroleum, coal, and natural gas derived fuels.

Glazing	In solar/energy technology, the transparent covers used to reduce energy losses from a collector panel.
Heat Exchanger	A device used to transfer energy from one heat transfer fluid to another while maintaining physical segregation of the fluids. Normally used in systems to provide an interface between two different heat transfer fluids.
Heat Transfer Fluid	The fluid circulated through a heat source (solar collector) or heat exchanger that transports the thermal energy by virtue of its temperature.
Heating Degree Days	The sum over a specified period of time of the number of degrees the average daily temperature is <u>below</u> 65°F.
Instantaneous Efficiency	The efficiency of a solar collector at one operating point, $\frac{Ti-Ta}{I}$, 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 which uses architectural components of the building to collect, distribute and store solar energy.
Pebble Bed (Rock Bed)	A space filled with uniform-sized pebbles to store solar-source energy by raising the temperature of the pebbles.
Reflected Radiation	Insolation reflected from a surface, such as the ground or a reflecting element onto the solar collector.
Rejected Energy	Energy intentionally rejected, dissipated, or dumped from the solar system.
Retrofit	The addition of a solar energy system to an existing structure.
Selective Surface	A surface that has the ability to readily absorb solar radiation, but re-radiates little of it as thermal radiation.

Sensor	A device used to monitor a physical 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.
Trombe Wall	A masonry wall which absorbs solar energy on its outer face and transfers this energy to the other face by conduction.

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. ABBREVIATIONS

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

LIVING SYSTEMS

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	=	Specific Heat
D	=	Direction or Position
EE	=	Electric Energy
EP	=	Electric Power
F	=	Fuel Flow Rate
I	=	Incident Solar Flux (Insolation)
N	=	Performance Parameter
P	=	Pressure
PD	=	Differential Pressure
Q	=	Thermal Energy
T	=	Temperature
TD	=	Differential Temperature
V	=	Velocity
W	=	Heat Transport Medium Mass Flow Rate
TI	=	Time

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

NOTE: Sensor identification (measurement) numbers reference system schematic, Figure A-1.

AVERAGE AMBIENT TEMPERATURE (°F)

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

AVERAGE BUILDING TEMPERATURE (°F)

$$TB = (1/60) \times \Sigma \; [(T600 + T601 + T602 + T603)/4]$$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

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

for ± three hours from solar noon

TIME OF DAY BUILDING TEMPERATURES (ONCE PER DAY)

$$TMID = TB$$

at 12 hours from local solar noon

$$T6AM = TB$$

at six hours before local solar noon

$$TNOON = TB$$

at local solar noon

$$T6PM = TB$$

at six hours past local solar noon

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

$$SE = (1/60) \times \Sigma \; I002$$

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

$$SEOP = (1/60) \times \Sigma \; [I002 \times (192 \times (D101 + D102 + D103) + 81 \; (D104 + D105 + D106))/3]$$

HUMIDITY RATIO FUNCTION (BTU/lb_m-°F)

HRF = 0.24 + 0.444 x HR

where 0.24 is the specific heat and HR is the humidity ratio of the transport air. This function is used whenever the humidity ratio will remain constant as the transport air flows through a heat exchanging device or as in infiltration

AVERAGE FLOOR STORAGE TEMPERATURE

TSTSLAB = (1/1200) x Σ (T201 + T202 + T203 + T204 + T205 + T206 + T207 + T208 + T209 + T210 + T212 + T213 + T214 + T215 + T217 + T218 + T219 + T220 + T221 + T222)

AVERAGE WATER STORAGE TEMPERATURE

TSTST012 = (1/720) x Σ (T271 + T281 + T272 + T282 + T273 + T283 + T231 + T241 + T232 + T242 + T233 + T243)

SUM OF CONDUCTION LOSSES (U X A)

LOSSES = HTN + HTS + HTW + HTE + HFL + HRF + EDGE LOSS + HSTECH

ELECTRICAL HEAT INCIDENTLY APPLIED TO SPACE HEATING

HAE = 56.8833 x (EP600 - OUTSIDE LIGHTS - EP100)

SPACE HEATING SUBSYSTEM AUXILIARY NATURAL GAS FUEL ENERGY (BTU)

HAF = 1000 x F400

SPACE HEATING SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

HAT = 0.52 x HAF

SPACE HEATING SUBSYSTEM LOAD (BTU)

HL = LOSSES + HI - HAE - HFIRE

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

SEA = CLAREA x SE

COLLECTED SOLAR ENERGY (BTU)

SEC = SECA/CLAREA

COLLECTOR ARRAY EFFICIENCY

CAREF = SECA/SEA

CHANGE IN STORED ENERGY (BTU)

$$STECH = WATERMASS \times (TSTS012 - TSTST012_p) + 0.2 \times SLABMASS \times (TSTSLAB - TSTSLAB_p)$$

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

SOLAR ENERGY TO LOAD SUBSYSTEMS (BTU)

SEL = HSE

SPACE HEATING SUBSYSTEM SOLAR FRACTION (PERCENT)

HSFR = 100 x HSE/HL

EXTERIOR RELATIVE HUMIDITY

RELH = RH001/60

INTERIOR RELATIVE HUMIDITY

RHIN = RH600/60

WIND NORTH - SOUTH COMPONENT

WNS = V001 x COSD (D001)/60

WIND EAST - WEST COMPONENT

WEW = V001 x SIND (D001)/60

WIND VELOCITY

WIND = V001/60

AVERAGE TEMPERATURE OF STORAGE (°F)

$$TST = (1/60) \times \Sigma\ (TSTSLAB + TSTST012)/2$$

SOLAR ENERGY TO SPACE HEATING SUBSYSTEM (BTU)

HSE = HL - HAT

HEAT OF INFILTRATION

HI = VOLUME x 0.07216 x HRF x (TB - TA) x HINF

where HINF = air changes per hour

SPACE HEATING SUBSYSTEM FOSSIL ENERGY SAVINGS (BTU)

HSVF = HSE/0.6

SYSTEM LOAD (BTU)

SYSL = HL

SOLAR FRACTION OF SYSTEM LOAD (PERCENT)

SFR = HSFR

AUXILIARY THERMAL ENERGY TO LOADS (BTU)

AXT = HAT

AUXILIARY ELECTRICAL ENERGY TO LOADS (BTU)

AXE = N.A.

SYSTEM OPERATING ENERGY (BTU)

SYSOPE = N.A.

SYSTEM AUXILIARY FOSSIL ENERGY (BTU)

AXF = HAF

TOTAL FOSSIL ENERGY SAVINGS (BTU)

TSVF = HSVF

COMFORT INDEX ZONE 1

COM1 = [(TSTSLAB + TSTST01)/2 + (T604 + T605 + T606)/3]/2

COMFORT INDEX ZONE 2

COM2 = [TSTST02 + (T601 + T602 + T603)/3]/2

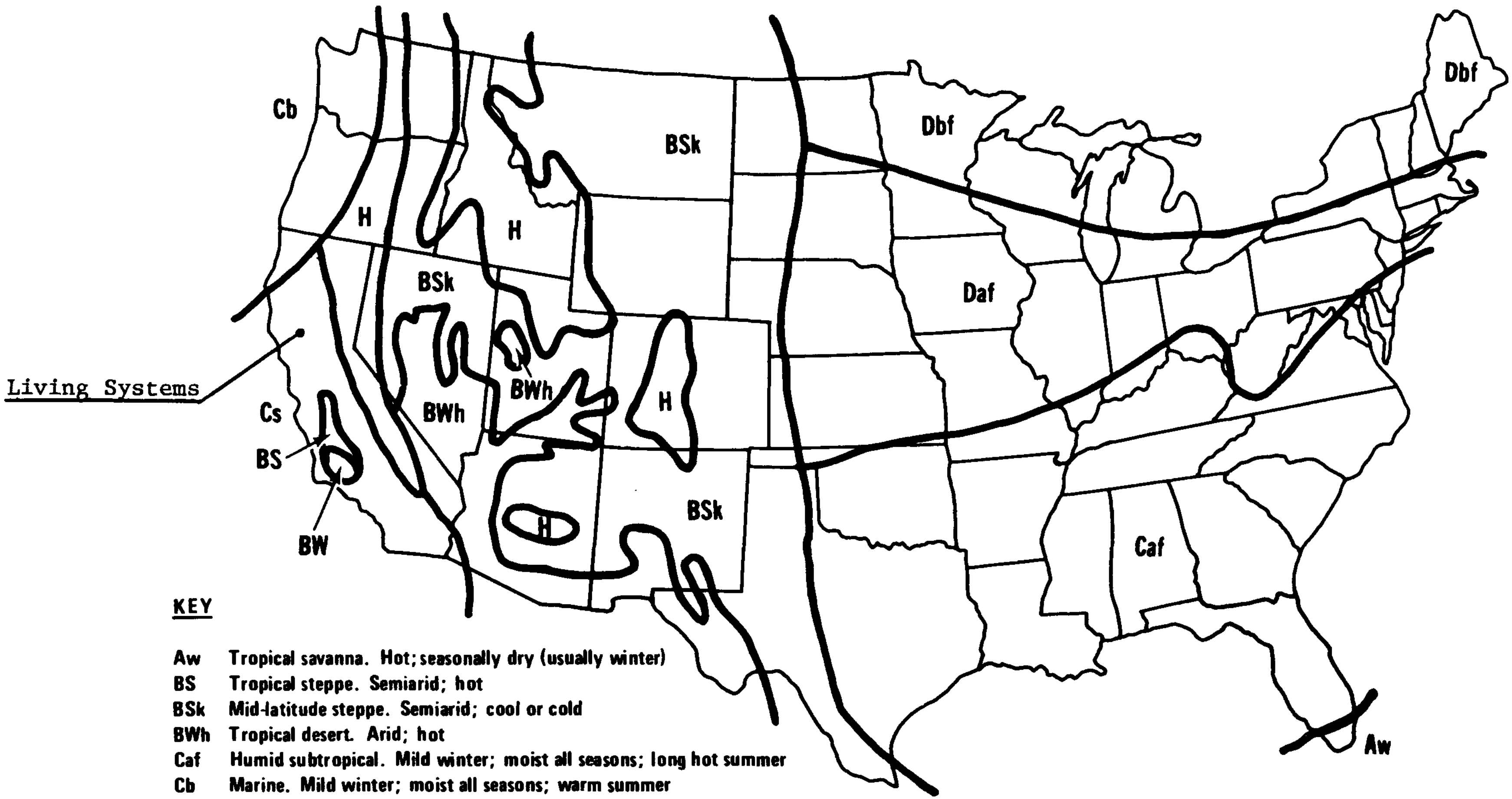
WIND DIRECTION

WDR = ATAN (WEW, WNS)

add or substract 360 to get between 0 and 360°

APPENDIX E

METEOROLOGICAL CONDITIONS



KEY

Aw	Tropical savanna. Hot; seasonally dry (usually winter)
BS	Tropical steppe. Semiarid; hot
BSk	Mid-latitude steppe. Semiarid; cool or cold
BWh	Tropical desert. Arid; hot
Caf	Humid subtropical. Mild winter; moist all seasons; long hot summer
Cb	Marine. Mild winter; moist all seasons; warm summer
Cs	Coastal Mediterranean. Mild winter; dry summer; short warm summer
Daf	Humid continental. Severe winter; moist all seasons; long, hot summer
Dbf	Humid continental. Severe winter; moist all seasons; short warm summer
H	Undifferentiated highland climates

Trewartha, G.T. The Earth's Problem Climates. University Wisconsin Press, Madison, WI, 1961.

Figure E-1. Meteorological Map of the United States Showing Living Systems Location

LIVING SYSTEMS LONG-TERM WEATHER DATA

COLLECTOR TILT: 45 DEGREES
LATITUDE: 39 DEGREES

LOCATION: DAVIS, CALIFORNIA
COLLECTOR AZIMUTH: 0 DEGREES

MONTH	HOBAR	HBAR	KBAR	RBAR	SBAR	HDD	CDD	TBAR
OCT	2,033	1,316	0.64732	1.453	1,912	101	48	63
NOV	1,512	782	0.51712	1.691	1,322	360	0	53
DEC	1,280	538	0.42069	1.752	943	595	0	46
JAN	1,406	597	0.42488	1.665	995	617	0	45
FEB	1,864	940	0.50432	1.466	1,378	426	0	50

LEGEND:

HOBAR - Monthly average daily extraterrestrial radiation (on a horizontal plane) 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: LIVING SYSTEMS
OCTOBER 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	2035	77	94	33	*	5
2	2026	73	85	45	179	4
3	1400	74	83	42	0	1
4	1880	71	84	45	182	4
5	2007	70	83	47	190	3
6	933	71	82	44	184	3
7	2074	66	78	54	191	5
8	1421	63	72	67	*	3
9	2049	68	77	62	0	2
10	2043	72	85	46	206	2
11	1849	67	80	52	188	3
12	1565	66	75	56	0	2
13	975	69	*	62	207	3
14	892	67	73	75	203	3
15	1839	71	81	56	228	2
16	2031	69	81	49	335	3
17	2703	69	80	42	315	3
18	*	*	*	*	*	*
19	410	61	*	85	183	9
20	948	55	60	72	209	5
21	1989	55	*	62	357	2
22	1680	60	67	61	159	4
23	1128	60	67	75	339	6
24	620	60	63	74	178	5
25	1213	62	66	78	185	6
26	2029	57	66	75	337	4
27	1911	58	69	70	0	0
28	2139	59	69	51	329	8
29	2679	59	66	29	329	15
30	1113	57	65	42	319	3
31	1995	56	68	52	318	4
SUM	51226	-	-	-	-	-
AVG	1652	65	75	57	*	4

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: LIVING SYSTEMS
NOVEMBER 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION PASS HEATING SYS BTU/SQ. FT (Q001)	TOTAL INSOLATION DHW SYSTEM BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	1556	1583	54	63	61	0	1
2	399	440	53	58	78	0	2
3	142	164	54	55	96	181	4
4	707	740	54	59	92	180	6
5	1465	1462	55	61	86	155	4
6	1287	1270	54	*	83	166	2
7	1430	1410	56	63	86	353	3
8	1886	1867	57	66	84	0	1
9	1945	1899	55	64	88	332	3
10	1637	1581	51	60	91	0	0
11	1826	1791	53	65	87	343	2
12	1267	1257	51	*	92	0	2
13	2078	2065	53	64	80	353	3
14	2038	1984	51	65	82	0	1
15	1344	1335	56	66	81	0	1
16	257	299	55	58	100	338	5
17	1578	1552	56	63	100	*	2
18	1699	1638	48	58	95	339	3
19	2094	2022	47	56	84	325	10
20	2043	1983	47	57	74	328	8
21	1479	1424	43	53	92	0	1
22	77	102	46	48	100	160	3
23	1035	1049	49	53	100	337	6
24	377	392	53	*	100	161	7
25	421	454	52	56	99	172	7
26	2024	1946	49	55	72	322	9
27	1450	1415	47	54	60	339	5
28	1595	1549	46	57	79	359	2
29	1698	1636	49	61	78	343	2
30	1767	1708	51	63	79	*	2
SUM	40601	40017	-	-	-	-	-
AVG	1353	1334	51	59	86	302	4

* DENOTES UNAVAILABLE DATA

MONTHLY REPORT: LIVING SYSTEMS
DECEMBER 1979
ENVIRONMENTAL SUMMARY

DAY OF MONTH (NBS ID)	TOTAL INSOLATION BTU/SQ. FT (Q001)	AMBIENT TEMPERATURE DEG F (N113)	DAYTIME AMBIENT TEMP DEG F	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	732	47	54	98	0	1
2	428	51	56	96	143	2
3	1354	50	60	91	0	2
4	1544	51	62	84	0	2
5	2019	55	68	56	335	8
6	2553	52	64	68	49	2
7	*	*	*	*	*	*
8	1433	51	61	85	0	1
9	495	47	50	99	0	1
10	1045	51	56	58	328	11
11	1868	48	55	2	328	17
12	1699	41	53	47	0	1
13	1352	42	53	72	0	1
14	1662	43	56	73	0	1
15	1871	44	57	75	0	1
16	1695	43	56	80	0	2
17	1844	43	56	77	0	1
18	612	39	46	96	0	1
19	43	46	48	100	351	2
20	63	48	48	100	161	3
21	879	49	*	97	219	6
22	2017	44	53	87	333	3
23	11	45	45	100	153	13
24	0	48	48	100	158	15
25	1089	46	52	99	177	6
26	1933	46	*	90	325	13
27	1410	40	*	96	0	1
28	309	39	43	100	0	1
29	270	40	42	100	0	1
30	74	48	49	100	183	4
31	*	*	*	*	*	*
SUM	34532	-	-	-	-	-
AVG	1114	46	53	84	*	4

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: LIVING SYSTEMS
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	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	*	*	*	*	*	*
2	*	*	*	*	*	*
3	*	*	*	*	*	*
4	*	*	*	*	*	*
5	*	*	*	*	*	*
6	215	50	54	100	0	1
7	95	48	51	100	174	3
8	172	48	51	100	0	1
9	21	51	53	99	211	4
10	931	48	50	77	*	6
11	71	47	44	100	*	12
12	683	62	66	100	176	15
13	62	60	61	100	183	13
14	579	57	60	100	180	10
15	84	52	*	100	183	4
16	732	56	59	100	175	9
17	284	53	55	100	173	4
18	2228	45	49	42	326	20
19	1882	45	*	42	332	12
20	2039	44	55	74	0	1
21	2107	44	55	83	0	2
22	1781	45	57	86	0	1
23	1056	43	49	97	162	3
24	134	43	43	100	0	2
25	571	42	47	98	*	3
26	33	41	40	100	159	2
27	177	45	46	100	165	5
28	1997	44	51	77	343	2
29	2084	39	49	62	324	6
30	1886	41	*	38	342	5
31	285	43	49	72	0	2
SUM	26454	-	-	-	-	-
AVG	853	47	52	86	*	6

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: LIVING SYSTEMS
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	RELATIVE HUMIDITY PERCENT	WIND DIRECTION DEGREES (N115)	WIND SPEED M.P.H. (N114)
1	806	47	56	78	344	3
2	351	48	53	96	0	1
3	229	48	52	100	328	4
4	1332	48	57	91	*	2
5	118	48	51	100	0	1
6	1683	54	60	60	328	10
7	2346	53	59	15	329	19
8	2090	54	64	33	348	10
9	1837	48	60	70	346	2
10	1689	50	62	70	0	2
11	1016	49	59	71	0	1
12	1837	49	60	68	347	3
13	1255	50	*	60	329	5
14	60	50	52	100	*	4
15	322	55	57	100	153	12
16	179	55	56	100	146	15
17	50	56	*	100	158	18
18	892	58	*	94	179	14
19	829	55	58	90	184	12
20	574	51	54	97	158	14
21	2012	54	61	79	226	8
22	*	*	*	*	*	*
23	*	*	*	*	*	*
24	*	*	*	*	*	*
25	*	*	*	*	*	*
26	*	*	*	*	*	*
27	*	*	*	*	*	*
28	*	*	*	*	*	*
29	*	*	*	*	*	*
SUM	29695	-	-	-	-	-
AVG	1024	51	57	80	*	8

* DENOTES UNAVAILABLE DATA.

APPENDIX F

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

The Living Systems site was unoccupied for all of the reporting period. During this time, the solar system operated for the entire period. This system has been in operation since 1978. Since being put into operation, there have not been any major operational problems to the passive system.

However, there were data communications problems as follows:

Date	Event
January 1-5 1980	Data communications problems lost data
February 22-29, 1980	Data communications problems lost data

APPENDIX G

CONVERSION FACTORS

Energy Conversion Factors[1]

Fuel Type	Energy Content	Fuel Source Conversion Factor
Distillate fuel oil[2]	138,690 BTU/gallon	7.21×10^{-6} gallon/BTU
Residual fuel oil[3]	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
Wood[4]	20-25 million BTU/cord	

[1]Source information is from the Dept. of Energy "Monthly Energy Review" FEB 1980

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

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

[4]Energy content varies widely depending on the type of wood and the moisture content of the wood.

APPENDIX H

SENSOR TECHNOLOGY

Temperature Sensors

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

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

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

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

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

Wind Sensor

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

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

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

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

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

Humidity Sensors

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

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

The sensor is based upon the capacitance change of a polymer thin-film capacitor. A one-micron thick dielectric polymer layer absorbs water molecules through a thin metal electrode and causes capacitance change proportional to relative humidity. The thin polymer layer reacts very quickly and, therefore, the response time is very short (one second to 90% humidity change at 68°F).

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

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

Insolation Sensors

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

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

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

Power Sensors

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

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

The resultant measurements of the wattmeter are summarized below:

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

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

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

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