SOLAR/1046-79/14
Distribution Category UC-59

SOLAR/1046--79/14

DE83 008828

# SOLAR-ENERGY-SYSTEM PERFORMANCE EVALUATION

LIVING SYSTEMS, 6
DAVIS, CALIFORNIA

OCTOBER 1978 THROUGH MARCH 1979

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OFFICE OF ASSISTANT SECRETARY FOR
CONSERVATION AND SOLAR APPLICATION
UNDER CONTRACT EG-77-C-01-4049
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TABLE OF CONTENTS

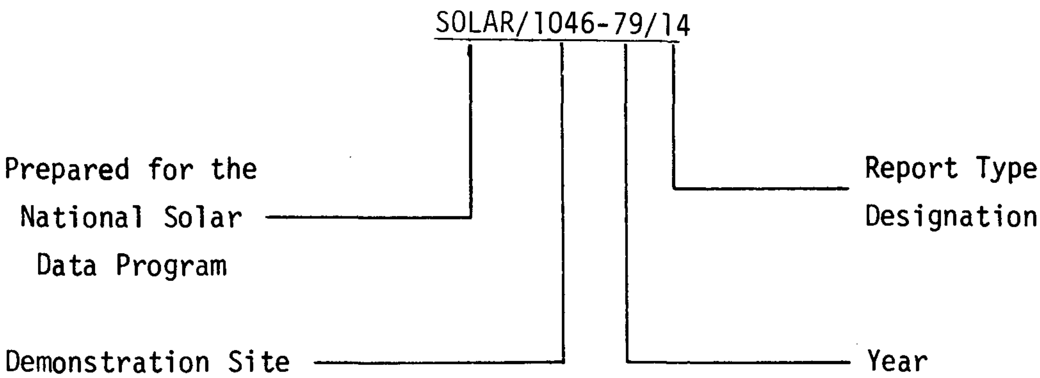
## LIST OF ILLUSTRATIONS



## LIST OF TABLES

NATIONAL SOLAR DATA PROGRAM REPORTS

Reports prepared for the National Solar Data Program are numbered under specific format. For example, this report for the Living Systems project site is designated as SOLAR/1046-79/14. The elements of this designation are explained in the following illustration.




- o Demonstration Site Number:

  Each project site has its own discrete number - 1000 through 1999 for residential sites and 2000 through 2999 for commercial sites.

- o Report Type Designation:

  This number identifies the type of report, e.g.,

  - Monthly Performance Reports are designated by the numbers 01 (for January) through 12 (for December).

  - Solar Energy System Performance Evaluations are designated by the number 14.

- Solar Project Descriptions are designated by the number 50.

- Solar Project Cost Reports are designated by the number 60.

These reports are disseminated through the U. S. Department of Energy Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830.

# 1. FOREWORD

The National Program for Solar Heating and Cooling is being conducted by the Department of Energy under the Solar Heating and Cooling Demonstration Act of 1974. The overall goal of this activity is to accelerate the establishment of a viable solar energy industry and to stimulate its growth in order to achieve a substantial reduction in nonrenewable energy resource consumption through widespread applications of solar heating and cooling technology.

Information gathered through the Demonstration Program is disseminated in a series of site-specific reports. These reports are issued as appropriate and may include such topics as:

- Solar Project Description
- Design/Construction Report
- Project Costs
- Maintenance and Reliability
- Operational Experience
- Monthly Performance
- System Performance Evaluation

The International Business Machines Corporation is contributing to the overall goal of the Demonstration Act by monitoring, analyzing, and reporting the thermal performance of solar energy systems through analysis of measurements obtained by the National Solar Data Program.

The Solar Energy System Performance Evaluation Report is a product of the National Solar Data Program. Reports are issued periodically to document the results of analysis of specific solar energy system operational performance. This report includes system description, operational characteristics and capabilities, and an evaluation of actual versus expected performance. The Monthly Performance Report, which is the basis for the Solar Energy System Performance Evaluation Report, is published on a regular basis. Each parameter presented in these reports as characteristic of system performance represents over 8,000 discrete measurements obtained each month by the National Solar

Data Network (NSDN). Documents referenced in this report are listed in Section 6, "References." Numbers shown in brackets refer to reference numbers in Section 6.

This Solar Energy System Performance Evaluation Report presents the results of a thermal performance analysis of the Living Systems solar energy system. The analysis covers operation of the system from October 1978 through March 1979. Living Systems solar energy system provides space heating, and domestic hot water to a single-family dwelling located in Davis, California. However, only the space heating subsystem will be discussed in this report. Section 2 presents a summary of the overall system results. A system description is contained in Section 3. Analysis of the system thermal performance was accomplished using a system energy balance technique described in Section 4. Section 5 presents a detailed assessment of the individual subsystems applicable to the site.

The measurement data for the reporting period were collected by the NSDN [1]. System performance data are provided through the NSDN via an IBM-developed Central Data Processing System (CDPS) [2]. The CDPS supports the collection and analysis of solar data acquired from instrumented systems located throughout the country. These data are processed daily and summarized into monthly performance reports. These monthly reports form a common basis for system evaluation and are the source of the performance data used in this report.

Acknowledgments are extended to those individuals involved in the operation of the Living Systems solar energy system: Johnathan Hammond, James Plumb, Brian and Catrina Tarkinson. Their insight and cooperation in the resolution of various on-site problems during the reporting period were invaluable.

# 2. SUMMARY AND CONCLUSIONS

This section provides a summary of the performance of the solar energy system installed at Living Systems, located in Davis, California for the period October 1978 through March 1979. This solar energy system is designed to support the active preheating of domestic hot water and passive space heating loads; however, only passive space heating is covered in this report. A detailed description of the Living Systems solar energy system operation is presented in Section 3.

## 2.1 Performance Summary

The solar energy site was occupied 5 months of the season from November 1978 through March 1979 and the solar energy system operated continuously during the entire reporting period. The total incident solar energy was 54.41 million Btu, of which 21.80 million Btu was collected by the solar energy system. Wood, another renewable resource, provided 4.65 million Btu toward the space heating load. Solar energy satisfied 79 percent of the space heating requirements. The solar energy system provided fossil fuel savings of 37.18 million Btu.

This performance level is reasonably close to the expected design performance; the differences in expected and actual performance can be accounted for by both the severe winter weather conditions encountered and by facets of owner interaction with the operation of the system. Some minor items are expected to be completed before next winter, after which the house should exceed its previous performance.

Comfort levels in the major portions of the building were acceptable all season, but early morning chill was occasionally experienced in the bedrooms. The relative humidity was very stable from day to day.

## 2.2 Conclusions

The Living Systems site has proven the concepts and received enthusiastic acceptance from the owners. The site was an early model. Subsequent systems developed by the designers use passive hot water preheat systems, slab edge insulation and alternate methods for water tube anchoring. The primary backup heat system was a small, natural convection, natural gas heater; it was not used after February 18, 1979. For this reason, solar energy replaced 79 percent of the heat that would have been required from natural gas, a nonrenewable resource. In addition, the owners bought two cords of wood for the wood stove, but used only one third of a cord. Weather-stripping the two rear doors and completing the anchoring of the insulating curtains should provide better performance next year.

## 3. SYSTEM DESCRIPTION

The Living Systems site is a single-family residence in Davis, California. The home has approximately 1700 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 and no insolation, the controller drains the water from the collectors. When water in the collector is sufficiently warmer than the water in the preheat storage tank, the controller starts the circulation between the preheat tank and the collector. 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 system is shown schematically in Figure 3-1.

The passive solar space heating system is of the direct-gain type illustrated schematically in Figure 3-2. Incident solar energy is admitted to the building through both the large south-facing vertical windows (approximately 200 square feet) and the overhead skylight (approximately 80 square feet with a tilt of 60 degrees to the horizontal). Manually-operated insulating curtains provide insulation during the night and sunless days for the south-facing collector windows. Manually-operated insulating shutters also provide night insulation for the skylight glazing and are aluminum-coated to provide reflection to the space below when open. Solar energy is stored in steel tubes that contain approximately 3600 gallons of water. The tubes are painted blue and placed near the south window wall and under the skylight. Additional storage is provided by the 6-inch-thick concrete slab floor of the building which is covered by brown ceramic tile. Collected solar energy is distributed

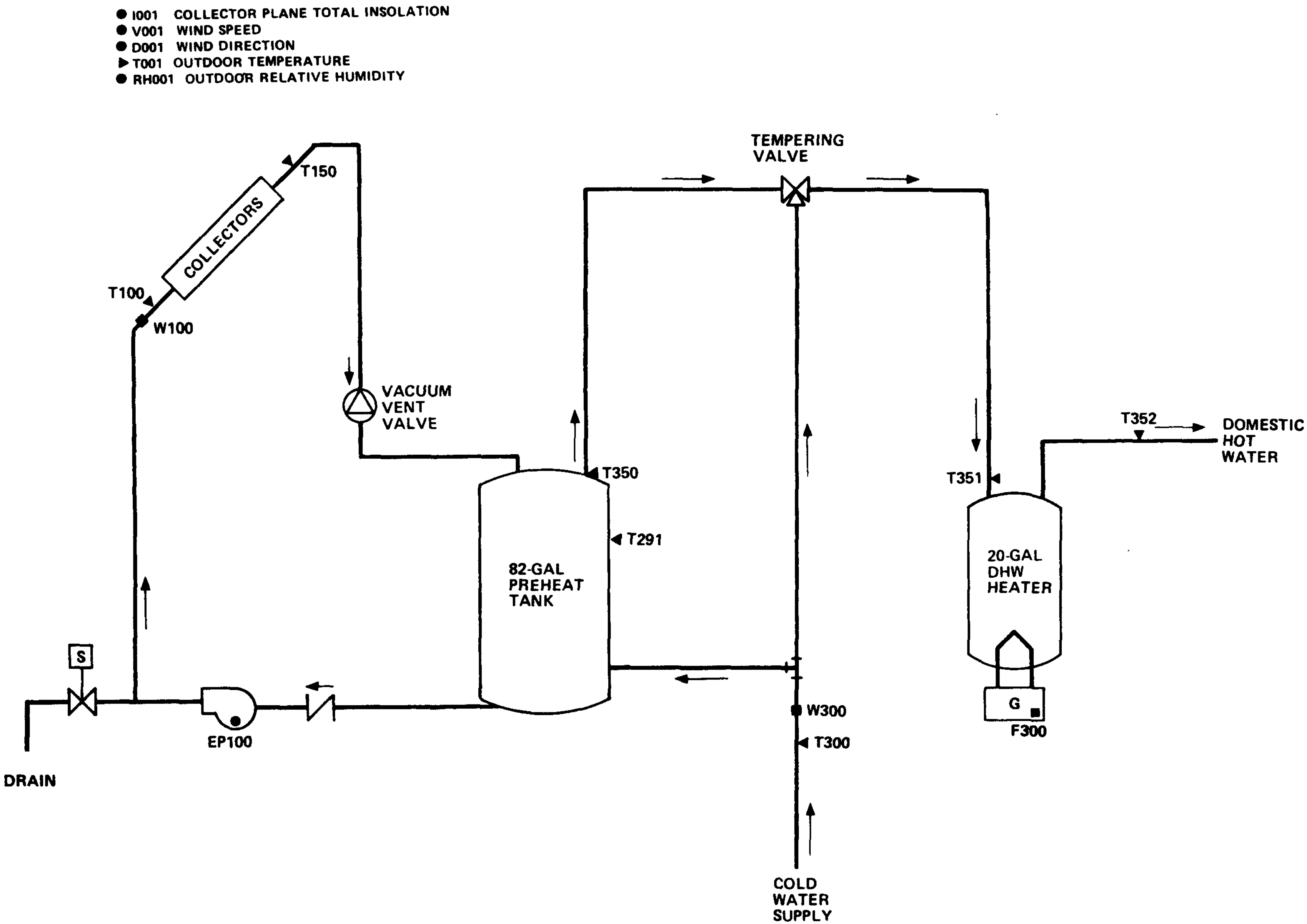



*Figure 3-1. ACTIVE SOLAR DOMESTIC HOT WATER SYSTEM SCHEMATIC*

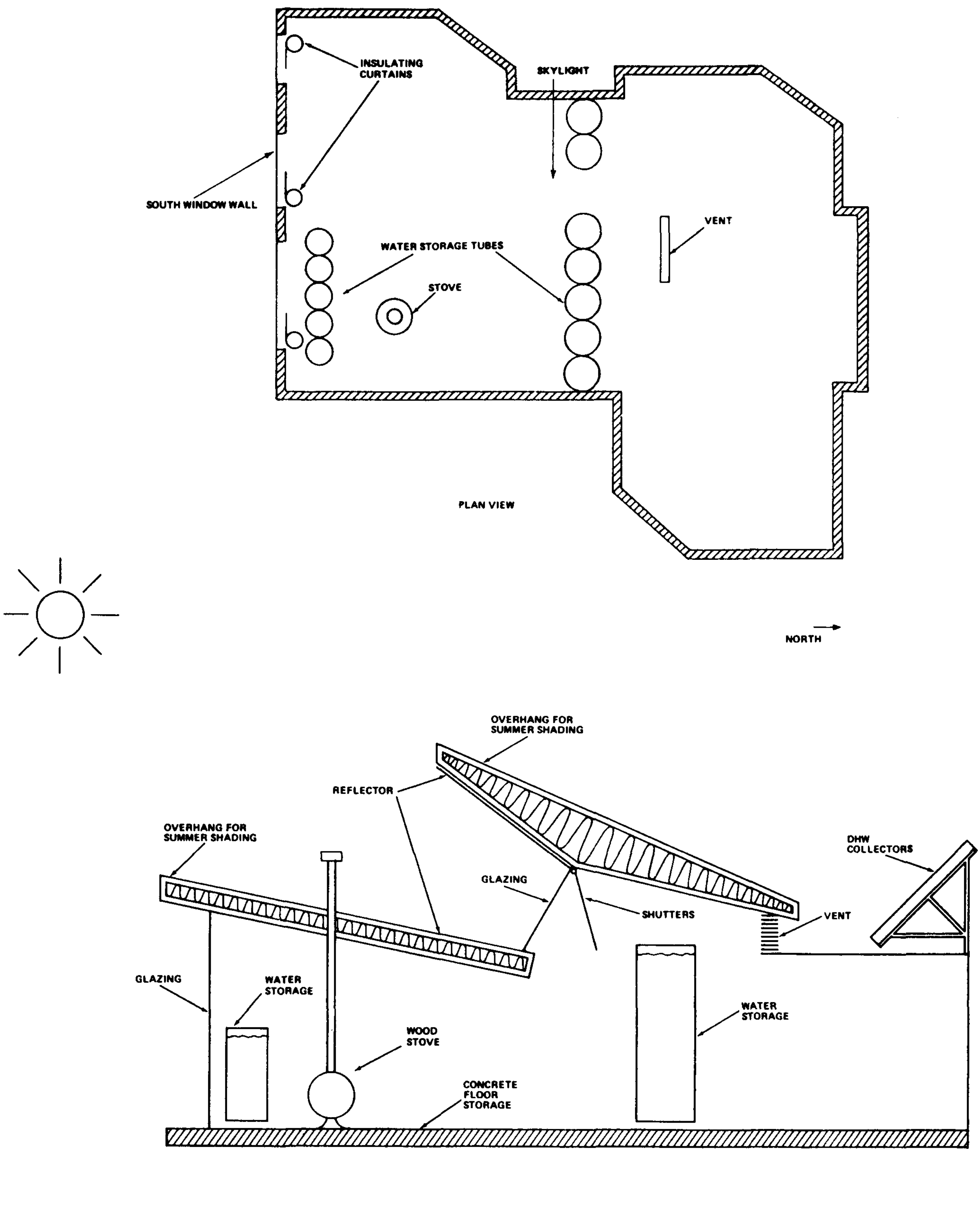



*Figure 3-2.* ***PASSIVE SPACE HEATING SYSTEM***

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 double-glazed with minimum window area in nonsouth-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.

# 4. 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 proposed in the intergovernmental agency report "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program" [3]. These performance factors quantify the thermal performance of the system by measuring the amount of energies that are being transferred between the components of the system. The performance of the system can then be evaluated based on the efficiency of the system in transferring these energies. A list of all performance factors and their definitions are listed in Appendix A.

Data from monitoring instrumentation located at key points within the solar energy system are collected by the National Solar Data Network. This data is first formed into factors showing the hourly performance of each system component, either by summation or averaging techniques, as appropriate. The hourly factors then serve as a basis for the calculation of the daily and monthly performance of each component subsystem. The analysis technique used is outlined in the report, "Performance Evaluation Reporting for Passive Systems" [4]. The performance factor equations for this site are listed in Appendix B.

Each month, as appropriate, a summary of overall performance of the Living Systems site and a detailed subsystem analysis is published. These monthly reports for the period covered by this Solar Energy System Performance Evaluation (October 1978 through March 1979) are available from the Technical Information Center, Oak Ridge, Tennessee 37830.

In the tables and figures in this report, an asterisk indicates that the value is not available for that month; N.A. indicates that the value is not applicable for this site.

# 5. PERFORMANCE ASSESSMENT

The performance of the Living Systems solar energy system has been evaluated for the October 1978 through March 1979 time period. Two perspectives were taken in this assessment: The first views the overall system in which the total solar energy collected, the system load, the measured values for solar energy used, and system solar fraction are presented. The second examines (in Section 5.4) the equivalent energy savings contributed by the solar energy system.

The performance assessment of any solar energy system is highly dependent on the prevailing weather conditions at the site during the period of performance. The original design of the system is generally based on the long-term averages for available insolation and temperature. Deviations from these long-term averages can significantly affect the performance of the system. Therefore, before beginning the discussion of actual system performance, a presentation of the measured and long-term averages for critical weather parameters has been provided.

## 5.1 Weather Conditions

Monthly values of the total solar energy incident in the plane of the collector array and the average outdoor temperature measured at the Living Systems site during the reporting period are presented in Table 5-1. Also presented in Table 5-1 are the corresponding long-term average monthly values of the measured weather parameters. These data are taken from Reference Monthly Environmental Data for Systems in the National Solar Data Network [4]. A complete yearly listing of these values for the site is given in Appendix C.

During October 1978 through March 1979, the average daily total incident solar energy on the collector window was 1095 Btu per square foot per day. This is below the estimated average daily solar radiation for this geographical area during the reporting period of 1176 Btu per square foot per day for a south-facing plane with a tilt of 60 degrees to the horizontal. The average ambient

## TABLE 5-1. WEATHER CONDITIONS

### LIVING SYSTEMS

| MONTH | DAILY INCIDENT SOLAR ENERGY PER UNIT AREA * (Btu/Ft$^2$) | | AMBIENT TEMPERATURE (°F) | | HEATING DEGREE-DAYS | | WIND SPEED (mph) | RELATIVE HUMIDITY (%) |
|---|---|---|---|---|---|---|---|---|
| | MEASURED | LONG-TERM AVERAGE | MEASURED | LONG-TERM AVERAGE | MEASURED | LONG-TERM AVERAGE | MEASURED | MEASURED |
| OCT | 1713 | 1564 | 66 | 63 | 217 | 101 | 4 | 47 |
| NOV | 1132 | 1216 | 51 | 53 | 512 | 360 | 6 | 60 |
| DEC | 633 | 897 | 38 | 46 | 779 | 595 | 3 | 91 |
| JAN | 842 | 921 | 44 | 45 | 601 | 617 | 6 | 85 |
| FEB | 1056 | 1165 | 48 | 50 | 466 | 426 | 5 | 82 |
| MAR | 1194 | 1295 | 54 | 53 | 403 | 372 | 5 | 78 |
| TOTAL | X | X | X | X | 2978 | 2471 | X | X |
| AVERAGE | 1095 | 1176 | 50 | 52 | 496 | 412 | 5 | 74 |

*In collector array plane and azimuth, unless otherwise indicated in Section 5.1.

temperature from October 1978 through March 1979 was 50°F as compared with the long-term average of 52°F from October through March. The number of heating degree-days for the same period (based on a 65°F reference) was 2978, as compared with the long-term average of 2471.

Monthly values of heating degree-days are derived from daily values of ambient temperature and are useful indications of the system heating loads. Heating degree-days are computed as the difference between daily average temperature and 65°F. For example, if a day's average temperature was 60°F, then five heating degree-days are accumulated. The total number of heating degree-days is summed monthly.

Daily analysis of wind speeds for the period shows that frequent peaks occurred which exceeded a 10 mph daily average with one peak at 18 and another at 22 mph. Similar analysis of outdoor relative humidities indicated that "cold-dry" days are almost nonexistent in Davis, California. Only during the warmer days of October were there days with low humidity.

Analysis of the weather conditions for the months November 1978 through March 1979 shows that winter was more severe than the long-term average: the incident solar energy was less, the temperature was lower and the resultant heating degree-days higher.

## 5.2 System Thermal Performance

The thermal performance of a solar energy system is a function of the total solar energy collected and applied to the system load. The total system load is the sum of the solar and auxiliary thermal energies delivered to the loads (excluding losses in the system). The portion of the total load supported by solar energy is defined as the solar fraction of the load.

The thermal performance of the Living Systems solar energy system is presented in Table 5-2. This performance assessment is based on the 6-month period from October 1978 to March 1979. During the reporting period, a total of

| MONTH | BUILDING HEATING LOAD (Million Btu) | SOLAR ENERGY USED (Million Btu) | SOLAR FRACTION OF BUILDING LOAD (%) | BUILDING TEMPERATURE (°F) | OUTSIDE AMBIENT TEMPERATURE (°F) |
|---|---|---|---|---|---|
| OCT | 0 | 0 | N.A. | 71 | 66 |
| NOV | 5.96 | 4.57 | 77 | 68 | 51 |
| DEC | 8.05 | 4.40 | 55 | 63 | 38 |
| JAN | 5.87 | 5.00 | 85 | 63 | 44 |
| FEB | 4.39 | 4.35 | 99 | 65 | 48 |
| MAR | 4.03 | 4.01 | 99 | 67 | 54 |
| SEASON | 28.30 | 22.33 | 79 | 66 | 50 |

N.A. - Denotes not applicable data.

21.80 million Btu of solar energy was collected, a total of 22.33 million Btu of solar energy was used, and the total system load for space heating was 28.30 million Btu. The discrepancy between solar energy used and solar energy collected is the excess heat available in storage at the beginning of November 1978. The measured system solar fraction was 79 percent as compared to an expected value of 88 percent for the winter season.

In Table 5-1, note that the number of heating degree-days for November and December considerably exceeded the long-term average, but January had fewer heating degree-days than the long-term average. In Table 5-2, the heating load was highest in December rather than in January (as suggested by the long-term heating degree-day column in Table 5-1). The December weather was colder than January; the December insolation was also considerably lower than expected. Over the Christmas holidays, the relatively new wood stove overheated, causing the occupants to open windows and vent, and to operate the fan for several hours. Unfortunately, the vent remained open for several days, increasing the space heating load considerably. This emphasizes the cooperation required of the occupants of a passive home. By late January, the new owners (since November 1) were using minimum auxiliary, nonrenewable fossil fuel for heat. The last time fossil fuel was used was on February 18; the pilot light was turned off on March 4 to save energy.

Table 5-3 contains additional information on thermal performance: The wood stove, using a renewable resource, reduced the apparent space heating load of the home. In October, the house was sometimes in the summer mode and sometimes heated by a part-time caretaker. In December, the wood stove was not used as often as in the other cold months and aggravated the severe weather load on the home.

A total of 4.65 million Btu of auxiliary thermal energy was derived from use of the wood stove during the winter. According to the occupants, approximately one third of a cord of wood was used during the winter. Assuming a heat content of 30 million Btu per cord of wood, the wood stove provided energy at an average efficiency level of 47 percent. However, the sample size was too small to put much credence in this figure. The wood stove was used primarily

TABLE 5-3. SYSTEM THERMAL PERFORMANCE

LIVING SYSTEMS

| MONTH | WOOD STOVE ENERGY (Million Btu) | ADJUSTED BUILDING LOAD (Million Btu) | SOLAR ENERGY TO SPACE HEATING LOAD (Million Btu) | SOLAR FRACTION OF LOAD (%) | AVERAGE INTERNAL RELATIVE HUMIDITY (%) | AVERAGE BUILDING TEMPERATURE (°F) | AVERAGE AMBIENT TEMPERATURE (°F) |
|---|---|---|---|---|---|---|---|
| OCT | 0.17 | 0 | 0 | N.A. | 36 | 71 | 66 |
| NOV | 1.00 | 5.96 | 4.57 | 77 | 30 | 68 | 51 |
| DEC | 0.24 | 8.05 | 4.40 | 55 | 32 | 63 | 38 |
| JAN | 2.00 | 5.87 | 5.00 | 85 | 36 | 63 | 44 |
| FEB | 1.00 | 4.39 | 4.35 | 99 | 38 | 65 | 48 |
| MAR | 0.24 | 4.03 | 4.01 | 99 | 44 | 67 | 54 |
| TOTAL | 4.65 | 28.30 | 22.33 | | | | |
| AVERAGE | 0.78 | 4.72 | 3.72 | 79 | 36 | 66 | 50 |

N.A. - Denotes not applicable data.

to maintain a lower bound to the building temperature and interior comfort level. Therefore, the wood stove was used mostly at night and through the early morning and on cloudy days.

In order to satisfy the building load, additional energy was derived from electric lights, appliances, etc. External lights for the yard, entryways, and garage did not contribute.

For reporting purposes, the reported load is an equivalent equipment demand. As illustrated in Table 5-3, this space heating equipment demand is the difference between the building load and the wood energy gains. This demand is the amount of energy which would be required to maintain the measured building environmental conditions. Approximately 79 percent of this space heating subsystem demand was satisfied by collected solar energy. Only 5.97 million Btu of auxiliary fossil fuel (natural gas) was used over the entire heating season.

One more observation should be made from this table: While the external relative humidity was rather high, the internal relative humidity was stable near the bottom of the comfort zone. The occupants, however, have indicated complete comfort with this low relative humidity.

The primary collection of incident solar energy at the Living Systems site occurs through the south-facing windows and skylight and goes directly to the water tube and concrete storage. Energy stored in the form of heated water or heated concrete is transferred to the air in the house by conduction and convection. This is shown graphically in Figure 5-1. The solar energy collection efficiency reaches a maximum near the coldest part of the year (mid-winter) and drops off rapidly in the fall and spring when there is relaxation of the rigid schedule of opening and closing insulating shutters and curtains, and when shading and venting to control overheating reduces the efficiency of energy collection. It is of particular interest to compare the conversion efficiencies of January, February, and March 1979: 70 percent, 54 percent, and 40 percent, respectively. It should be noted that the value

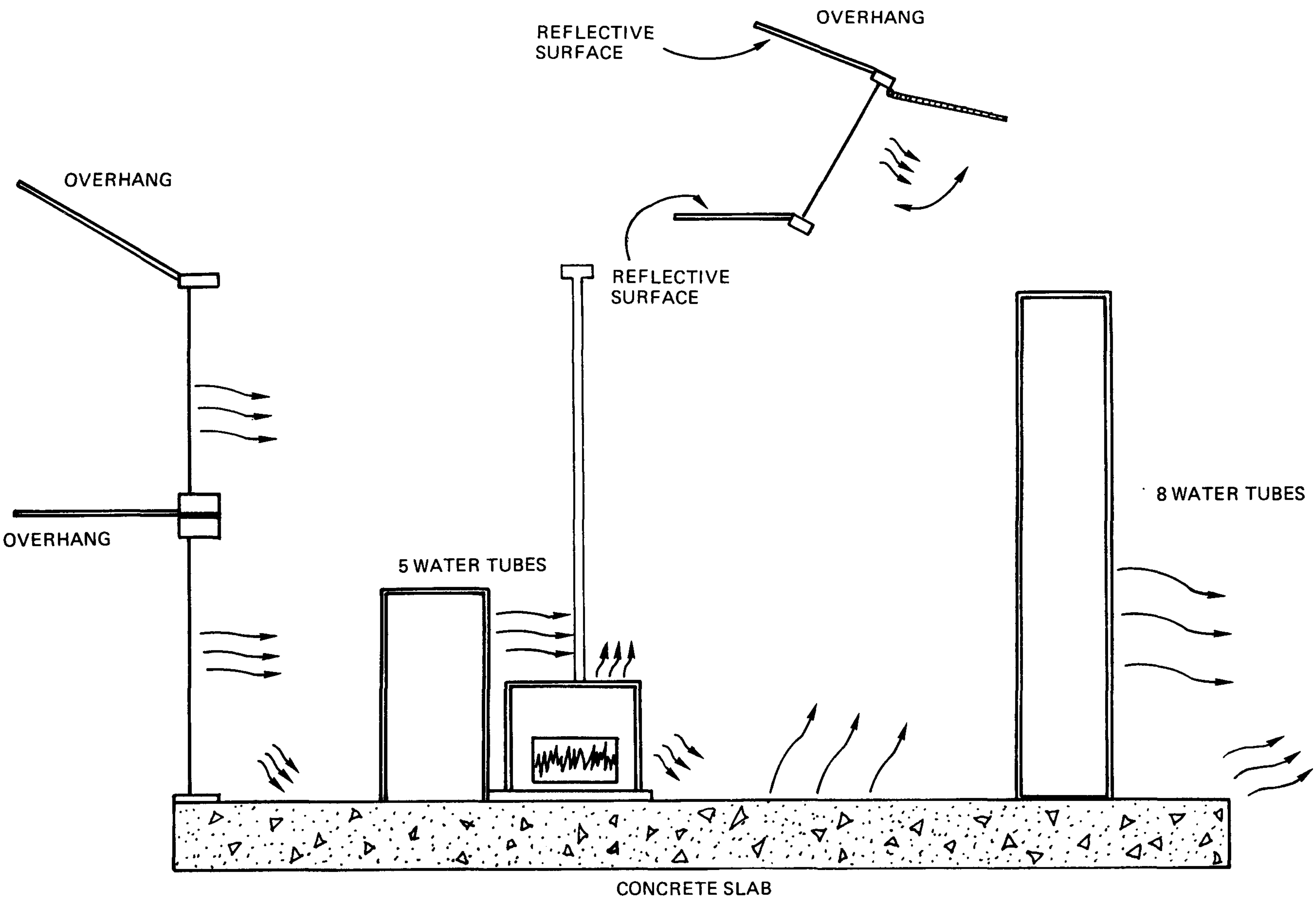



*Figure 5-1. ENERGY FLOW*

of collection efficiency does not directly compare to the collection efficiencies presented for active solar energy systems, because the thermal losses that occur through the passive system glazing are a part of the building load instead of a part of the collection efficiency.

## 5.3 Storage Performance

Primary storage of collected solar energy at the Living Systems site is provided by the concrete slab floors of the building and the south and central water tubes. Evidence indicates that the gravel and earth below the slab provide additional storage (about twice the size of the slab). This storage would be even larger if the early version of the Living Systems homes had been constructed with slab-edge insulation as are the newer models.

To compare the effectiveness of three storage areas, two contrasting days in January were selected: one with no insolation and one with very high insolation. In Table 5-4, on January 7, 1979, when the sun did not shine, the central and south water tubes experienced about the same temperature drop. However, the slab was the primary source of heating for the rear bedrooms. The conclusion is that the slab and sub-slab have large storage capacity and are more stable. On January 22, 1979, when the sun was at its hottest, the central water tubes had the largest temperature rise and the slab actually lost temperature. This loss reflects the continued drain from earlier days. The conclusion is that the water tubes are better collectors, while the slab is more involved in satisfying the space heating distribution. For this reason, as well as the problem with edge insulation, the average slab temperature remains considerably below the water tube temperature. The seasonal view is shown in Figure 5-2. The water tube temperature is always several degrees above the slab temperature with the average temperature somewhere between them. In this plot, the three storage areas are averaged equally. Had weighted averaging based on the thermal capacity been used, the building storage temperature would be somewhat lower.

Notice also that except in March when some very warm days were experienced, the average building temperature was always below the storage temperature.

TABLE 5-4. STORAGE PERFORMANCE, TWO SAMPLE DAYS

LIVING SYSTEMS

| DATE | INSOLATION ($Btu/Ft^2$) | SPACE HEATING LOAD (Million Btu) | CHANGE IN STORAGE (Million Btu) | CHANGE IN STORAGE TEMPERATURE (°F) | | | STORAGE TEMPERATURE (°F) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | SOUTH TUBES | CENTRAL TUBES | SLAB | SOUTH TUBES | CENTRAL TUBES | SLAB |
| JAN 7 | 0.00 | .137 | -.121 | -2.1 | -2.0 | -1.4 | 67.9 | 70.0 | 64.8 |
| JAN 22 | 1668 | .263 | +.057 | +0.19 | +0.73 | -0.002 | 72.6 | 72.8 | 65.7 |

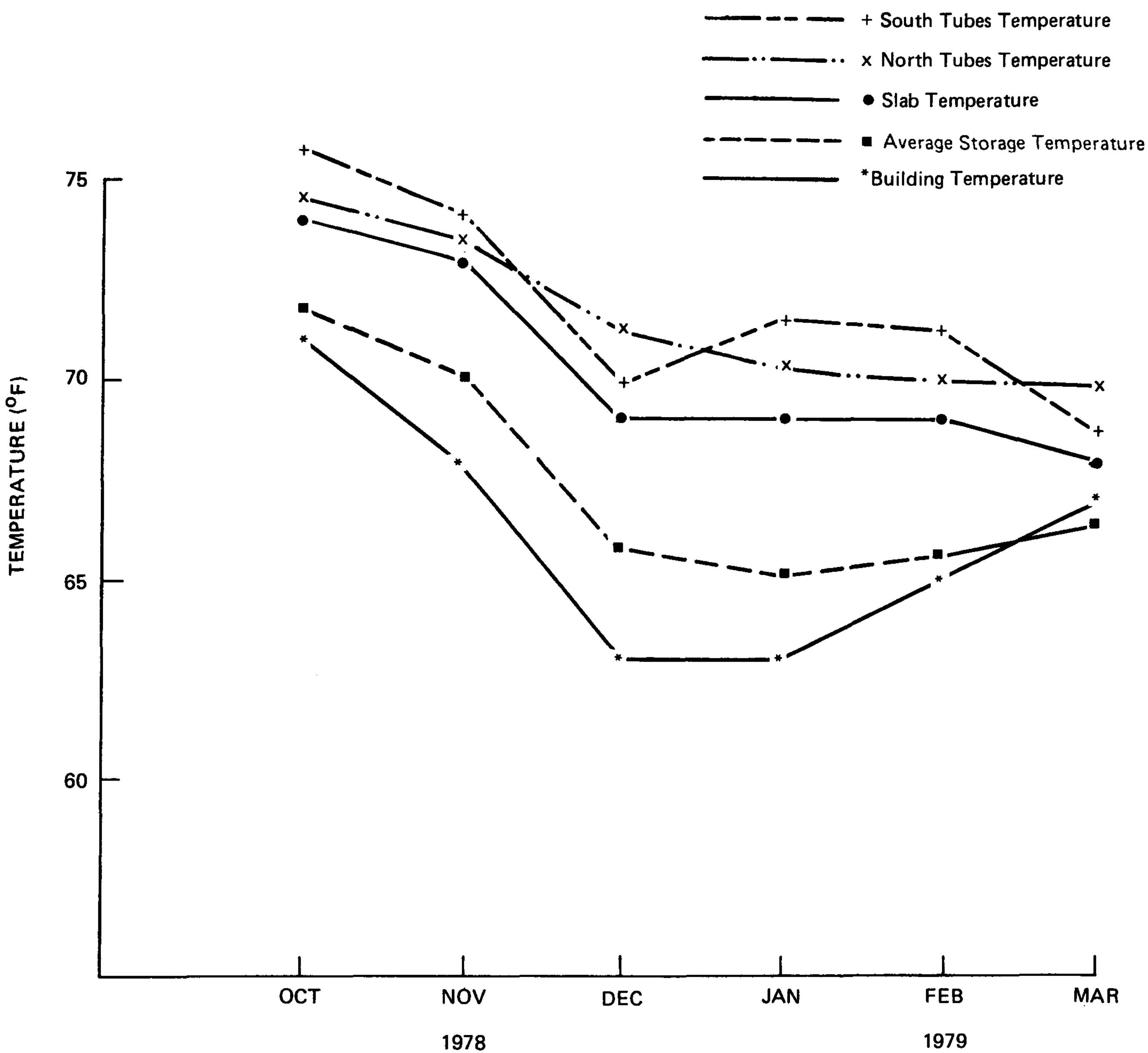



*Figure 5-2. AVERAGE MONTHLY STORAGE TEMPERATURES*

LIVING SYSTEMS

Fresh air enters this building primarily through infiltration. The cool outside air is heated by the energy stored in the water tubes and slab. Thus, the building temperature stays below the average storage temperature all winter. A clearer picture of this is apparent in Figure 5-3. Note that calculated comfort levels in zone 1, the front half of the building, and in zone 2, the bedrooms and master bath, are always higher than the building temperature.

The comfort index used in this analysis is the operative temperature, which is defined as the average of the space dry bulb and mean radiant temperatures. For this analysis, the space mean radiant temperature is defined as the average surface temperature of all radiating surfaces bordering the space, except for the wood stove, since a surface temperature measurement of the wood stove was available for only a small portion of the season. The building is divided into two comfort zones: Zone 1 is the south part of the building, while zone 2 is the north part of the building. While relative humidity does play an important part in the perception of comfort, it is not presently included in the comfort index. Comfort levels in zone 2 were occasionally below those that would be acceptable for some individuals, but the owners are conservation conscious and accepted them. Comfort levels in zone 1 were normally acceptable. The occupants verified these observations.

The earth around cellars can be used to keep them cool because the earth remains at 52 to 57°F year-round. However, when a warm surface such as a slab is placed on top of the earth, the thermal lag of the earth prevents rapid dissipation of the heat to the cooler subsurface. A volume of the earth under the slab acts as additional storage, moderating the heat of the house. In the Living Systems site, two sets of three sensors each were positioned to measure the temperature gradient across the slab storage: one sensor was placed one inch below the slab surface, one at six inches below the top of the slab and another at 11 inches below the top of the slab into the earth below the gravel. Figure 5-4 shows the plotted temperature values at these three locations together with a plot of the insolation values on a sunny January day. With sensors of this type, absolute values should not be considered; the shapes of the curves are of interest. As the sun came out,

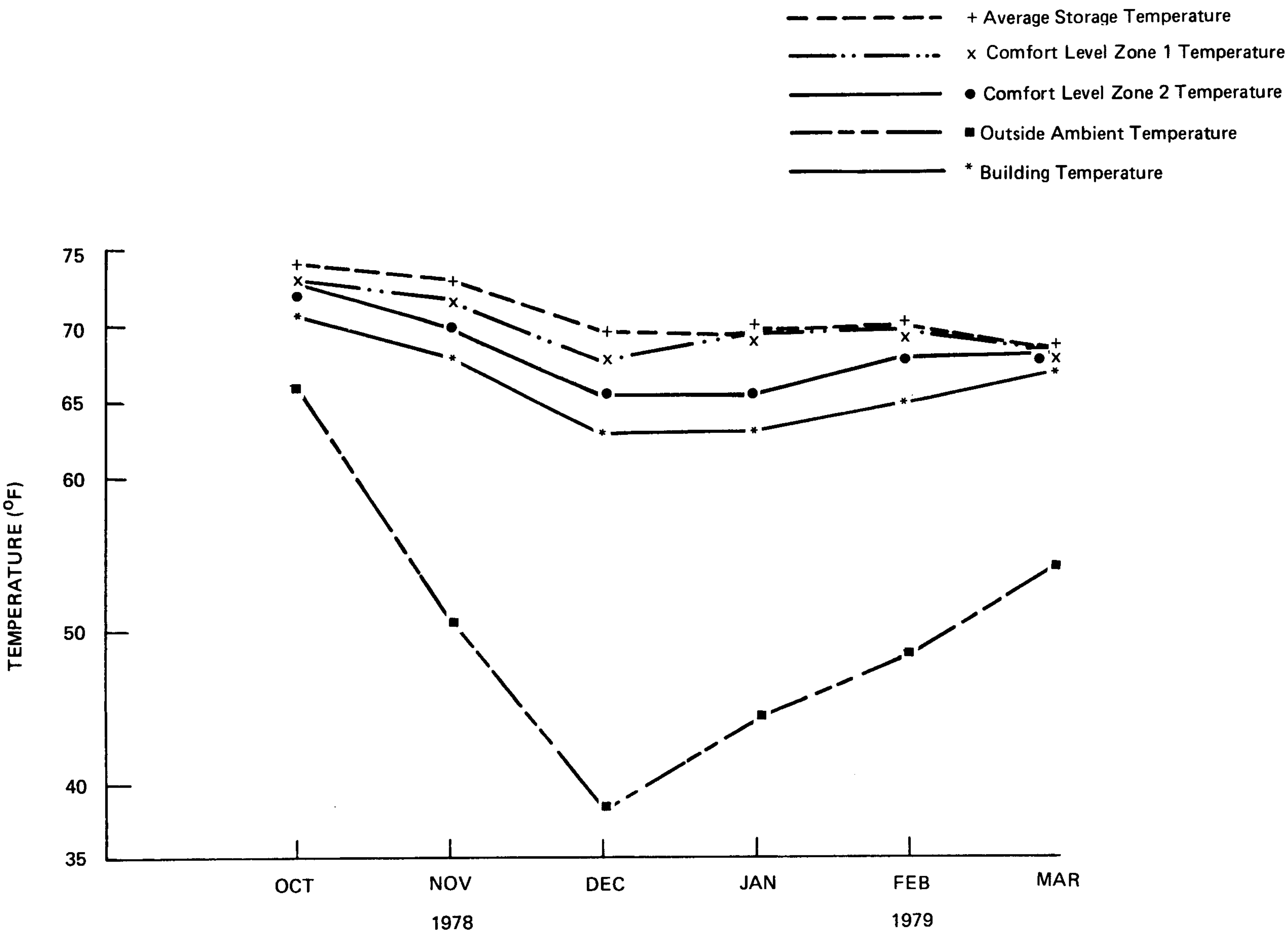



*Figure 5-3.* ***AVERAGE SEASONAL COMFORT LEVELS***

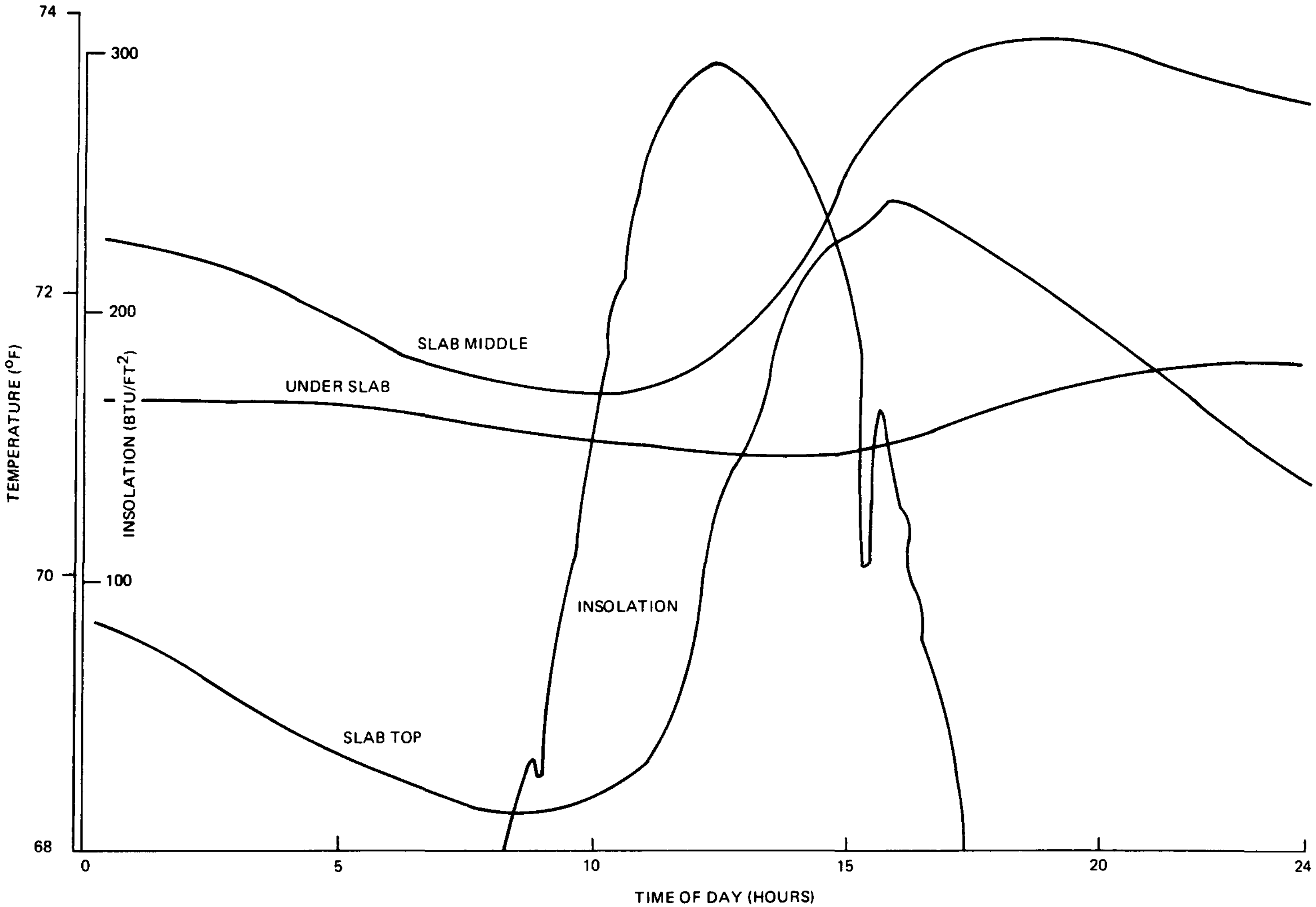



*Figure 5-4.* ***SLAB STORAGE GRADIENT VERSUS INSULATION JANUARY 22, 1979***

the slab surface started to heat almost immediately, the middle was delayed about two hours and the bottom was delayed about six hours. Although none of the areas of the slab were in the uncomfortable range at any time, the temperature swing on the top surface was about 5°F; whereas the temperature swing in the earth was only about 0.8°F.

Taking another viewpoint, the Living Systems site is instrumented so that temperatures on a north-south slice through the house can be measured. Figure 5-5 shows temperatures one inch below the slab surface at 0800 (8 a.m.) and 1600 (4 p.m.) on the same day as the previous figure. The small water tanks moderate the edge temperature in the front, but also shade the front area of the slab. The large and small water tubes and front slab keep the largest part of the house warm. However, behind the partition, the temperature drops rapidly toward the back wall. During this period, the rear center room shown on this chart was the coldest bedroom because of an open ceiling access. However, adjacent room slabs were almost only a few degrees warmer. As mentioned earlier, these homes now have edge insulation and this drop should be considerably less.

With the aid of Figure 5-6, one can review typical operation of the Living Systems home over a two-day, January period; one day was sunny, the other mostly cloudy. In the early hours of January 29, 1979, the outside temperature was below freezing and dropping. Storage and inside temperatures were also dropping with inside temperature somewhat chilly. Around 5 a.m. the gas heater came on and the building temperature started to rise. As the sun came up, the occupants opened the insulating shutters and curtains. The ceiling Casablanca fan was turned on for a little over an hour. During winter use, this fan distributes hot air which has risen, both naturally and from the heater; the fan also abstracts some heated air from the large water tubes. During the day, both storage and building temperatures rose. As the sun went down, the shutters and curtains were manually closed and the fan was turned on for almost an hour. The gas heater operated for short bursts through the evening and night and for two hours in the early morning. The shutters and curtains were opened during the short period when the sun was shining and

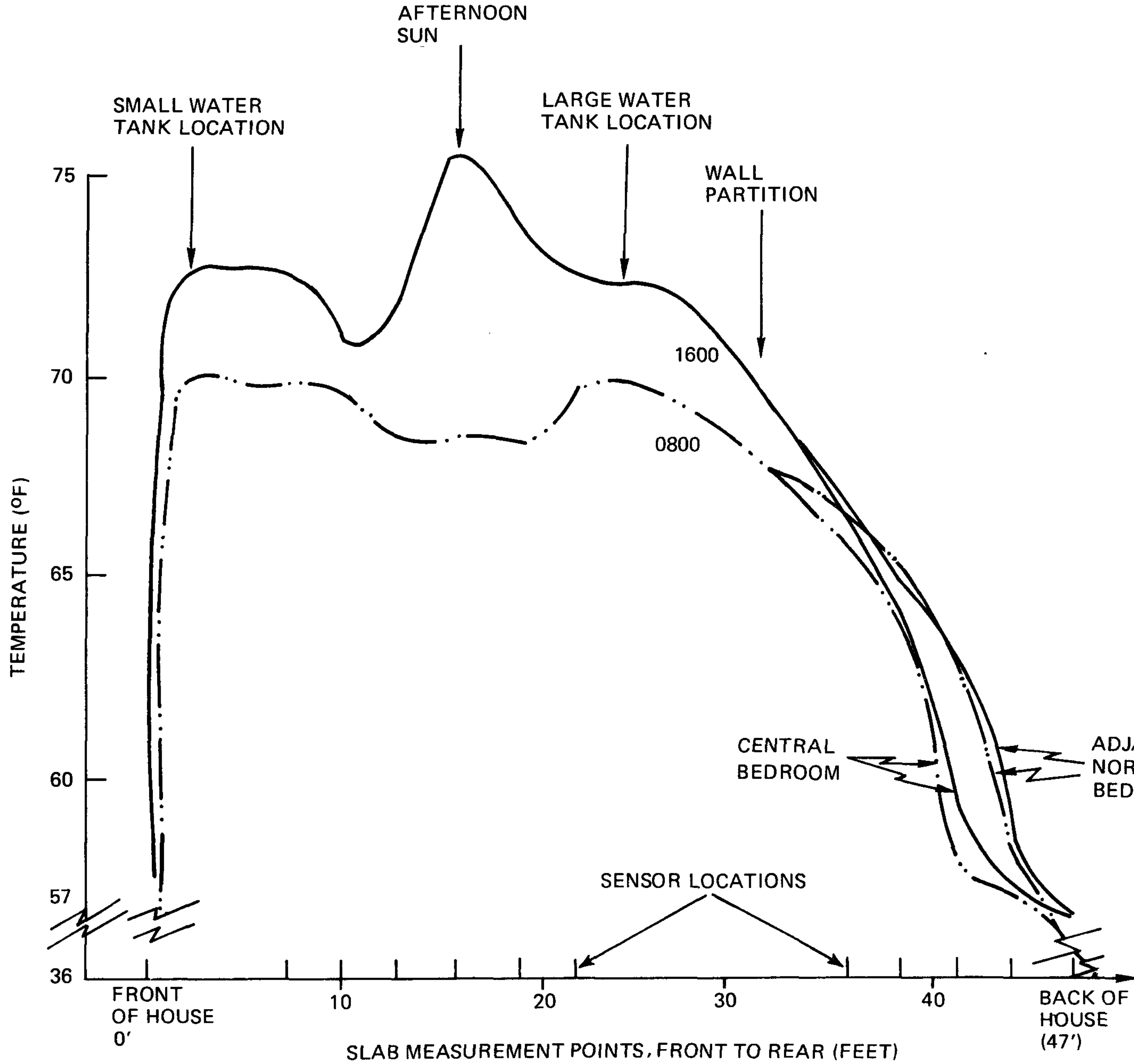



*Figure 5-5. SLAB TEMPERATURES ON A NORTH-SOUTH SLICE THROUGH THE HOUSE*

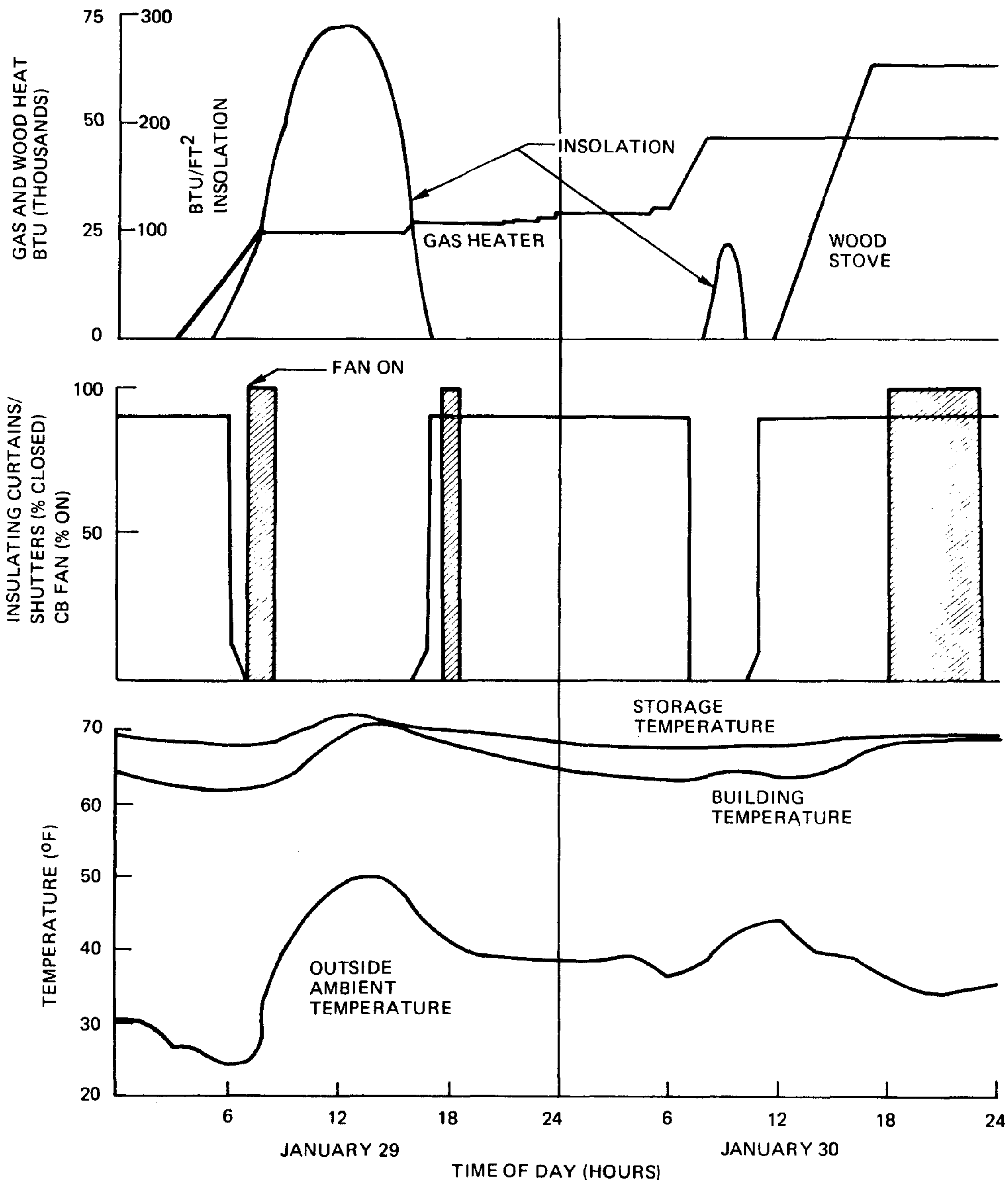



*Figure 5-6. SYSTEM PERFORMANCE – JANUARY 29-30, 1979*

some heat was gained. The wood stove was fired up from about noon until 5 p.m. and the fan was subsequently turned on. The storage and building temperatures were both higher at the end of the two-day period. Shutters, curtains, fan, wood stove and possibly the thermostat (not instrumented) were operated manually during the two-day period.

## 5.4 Energy Savings

Energy savings for the reporting period are presented in Table 5-5. The total savings were 37.18 million Btu, for a monthly average of 6.20 million Btu.

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.

TABLE 5-5 ENERGY SAVINGS

LIVING SYSTEMS

| MONTH | SPACE HEATING LOAD (Million Btu) | SOLAR ENERGY USED (Million Btu) | SOLAR FRACTION (%) | ENERGY SAVINGS (Million Btu) FOSSIL FUEL |
|---|---|---|---|---|
| OCT | 0 | 0 | N.A. | 0 |
| NOV | 5.96 | 4.57 | 77 | 7.61 |
| DEC | 8.05 | 4.40 | 55 | 7.32 |
| JAN | 5.87 | 5.00 | 85 | 8.33 |
| FEB | 4.39 | 4.35 | 99 | 7.24 |
| MAR | 4.03 | 4.01 | 99 | 6.68 |
| TOTAL | 28.30 | 22.33 | | 37.18 |
| AVERAGE | 4.72 | 3.72 | 79 | 6.20 |

N.A. - Denotes not applicable data.

# 6. REFERENCES


1. U.S. Department of Energy, National Solar Data Network, prepared under contract number EG-77-C-4049 by IBM Corporation, December 1977.

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. "Performance Evaluation Reporting for Passive Systems", April 17, 1979, SOLAR/0018-79/35.

5. "A Thermal Performance Analysis Technique for Passive Solar Space Heating Systems" proceedings of the 3rd National Passive Solar Conference, January 11-13, 1979, San Jose, California.

6. 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.

7.# Monthly Performance Report, Living Systems, SOLAR/1024-78/10, Washington, D.C., Department of Energy (October 1978).

8.# Monthly Performance Report, Living Systems, SOLAR/1046-78/11, Washington, D.C., Department of Energy (November 1978).

9.# Monthly Performance Report, Living Systems, SOLAR/1046-78/12, Washington, D.C., Department of Energy (December 1978).

10.# Monthly Performance Report, Living Systems, SOLAR/1046-79/01, Washington, D.C., Department of Energy (January 1979).

11.# Monthly Performance Report, Living Systems, SOLAR/1046-79/02, Washington, D.C., Department of Energy (February 1979).

12.# Monthly Performance Report, Living Systems, SOLAR/1046-79/03, Washington, D.C., Department of Energy (March 1979).

13.# "Users' Guide to the Monthly Performance Report of the National Solar Data Program," February 28, 1978, SOLAR/0004-78/18.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#Copies of these reports may be obtained from Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830.

APPENDIX A

DEFINITIONS OF PERFORMANCE FACTORS AND SOLAR TERMS

COLLECTOR ARRAY PERFORMANCE

The collector array performance is characterized by the amount of solar energy collected with respect to the energy available to be collected.

- INCIDENT SOLAR ENERGY (SEA) is the total insolation available on the gross collector array area. This is the area of the collector array energy-receiving aperture, including the framework which is an integral part of the collector structure.

- OPERATIONAL INCIDENT ENERGY (SEOP) is the amount of solar energy incident on the collector array during the time that the collector loop is active (attempting to collect energy).

- COLLECTED SOLAR ENERGY (SECA) is the thermal energy removed from the collector array by the energy transport medium.

- COLLECTOR ARRAY EFFICIENCY (CAREF) is the ratio of the energy collected to the total solar energy incident on the collector array. It should be emphasized that this efficiency factor is for the collector array, and available energy includes the energy incident on the array when the collector loop is inactive. This efficiency must not be confused with the more common collector efficiency figures which are determined from instantaneous test data obtained during steady-state operation of a single collector unit. These efficiency figures are often provided by collector manufacturers or presented in technical journals to characterize the functional capability of a particular collector design. In general, the collector panel maximum efficiency factor will be significantly higher than the collector array efficiency reported here.

STORAGE PERFORMANCE

The storage performance is characterized by the relationships among the energy delivered to storage, removed from storage, and the subsequent change in the amount of stored energy.

- ENERGY TO STORAGE (STEI) is the amount of energy, both solar and auxiliary, delivered to the primary storage medium.

- ENERGY FROM STORAGE (STEO) is the amount of energy extracted by the load subsystems from the primary storage medium.

- CHANGE IN STORED ENERGY (STECH) is the difference in the estimated stored energy during the specified reporting period, as indicated by the relative temperature of the storage medium (either positive or negative value).

- STORAGE AVERAGE TEMPERATURE (TST) is the mass-weighted average temperature of the primary storage medium.

- STORAGE EFFICIENCY (STEFF) is the ratio of the sum of the energy removed from storage and the change in stored energy to the energy delivered to storage.

ENERGY COLLECTION AND STORAGE SUBSYSTEM

The Energy Collection and Storage Subsystem (ECSS) is composed of the collector array, the primary storage medium, the transport loops between these, and other components in the system design which are necessary to mechanize the collector and storage equipment.

- INCIDENT SOLAR ENERGY (SEA) is the total insolation available on the gross collector array area. This is the area of the collector array energy-receiving aperture, including the framework which is an integral part of the collector structure.

- AMBIENT TEMPERATURE (TA) is the average temperature of the outdoor environment at the site.

- ENERGY TO LOADS (SEL) is the total thermal energy transported from the ECSS to all load subsystems.

- AUXILIARY THERMAL ENERGY TO ECSS (CSAUX) is the total auxiliary energy supplied to the ECSS, including auxiliary energy added to the storage tank, heating devices on the collectors for freeze-protection, etc.

- ECSS OPERATING ENERGY (CSOPE) is the critical operating energy required to support the ECSS heat transfer loops.

HOT WATER SUBSYSTEM

The hot water subsystem is characterized by a complete accounting of the energy flow into and from the subsystem, as well as an accounting of internal energy. The energy into the subsystem is composed of auxiliary fossil fuel, and electrical auxiliary thermal energy, and the operating energy for the subsystem.

- HOT WATER LOAD (HWL) is the amount of energy required to heat the amount of hot water demanded at the site from the incoming temperature to the desired outlet temperature.

- SOLAR FRACTION OF LOAD (HWSFR) is the percentage of the load demand which is supported by solar energy

- SOLAR ENERGY USED (HWSE) is the amount of solar energy supplied to the hot water subsystem.

- OPERATING ENERGY (HWOPE) is the amount of electrical energy required to support the subsystem, (e.g., fans, pumps, etc.) and which is not intended to directly affect the thermal state of the subsystem.

- AUXILIARY THERMAL USED (HWAT) is the amount of energy supplied to the major components of the subsystem in the form of thermal energy in a heat transfer fluid, or its equivalent. This term also includes the converted electrical and fossil fuel energy supplied to the subsystem.

- AUXILIARY FOSSIL FUEL (HWAF) is the amount of fossil fuel energy supplied directly to the subsystem.

- ELECTRICAL ENERGY SAVINGS (HWSVE) is the estimated difference between the electrical energy requirements of an alternative conventional system (carrying the full load) and the actual electrical energy required by the subsystem.

- FOSSIL FUEL SAVINGS (HWSVF) is the estimated difference between the fossil fuel energy requirements of the alternative conventional system (carrying the full load) and the actual fossil fuel energy requirements of the subsystem.

SPACE HEATING SUBSYSTEM

The space heating subsystem is characterized by performance factors accounting for the complete energy flow into the subsystem. The average building temperature is tabulated to indicate the relative performance of the subsystem in satisfying the space heating load and in controlling the temperature of the conditioned space.

- SPACE HEATING LOAD (HL) is the sensible energy added to the air in the building.

- SOLAR FRACTION OF LOAD (HSFR) is the fraction of the sensible energy added to the air in the building derived from the solar energy system.

- SOLAR ENERGY USED (HSE) is the amount of solar energy supplied to the space heating subsystem.

- OPERATING ENERGY (HOPE) is the amount of electrical energy required to support the subsystem, (e.g., fans, pumps, etc.) and which is not intended to directly affect the thermal state of the system.

- AUXILIARY THERMAL USED (HAT) is the amount of energy supplied to the major components of the subsystem in the form of thermal energy in a heat transfer fluid or its equivalent. This term also includes the converted electrical and fossil fuel energy supplied to the subsystem.

- AUXILIARY ELECTRICAL FUEL (HAE) is the amount of electrical energy supplied directly to the subsystem.

- ELECTRICAL ENERGY SAVINGS (HSVE) is the estimated difference between the electrical energy requirements of an alternative conventional system (carrying the full load) and the actual electrical energy required by the subsystem.

- BUILDING TEMPERATURE (TB) is the average heated space dry bulb temperature.

PASSIVE SYSTEM ENVIRONMENT

In addition to the environmental summary performance factors presented earlier, additional performance factors describing the environment of a passive space heating system are presented.

- BUILDING COMFORT ZONE 1 (COM1) is an index relating to the comfort conditions on the south side of the building. The index is formed as an average of the average dry bulb and mean radiant temperatures inside the sone.

- BUILDING COMFORT ZONE 2 (COM2) is an index relating to the comfort conditions on the north side of the building and is defined similarly to the other comfort index.

- BUILDING TEMPERATURE MIDNIGHT (TMID) is the average building interior temperature at midnight local solar time.

- BUILDING TEMPERATURE 6 A.M. (T6AM) is the average building interior temperature at 6 A.M. local solar time.

- BUILDING TEMPERATURE NOON (TNOON) is the average building interior temperature at local solar noon.

- BUILDING TEMPERATURE 6 P.M. (T6PM) is the average building interior temperature at 6 P.M. local solar time.

- INTERIOR RELATIVE HUMIDITY (RELHIN) is the average relative humidity inside the building.

- AVERAGE STORAGE TEMPERATURE, (TST) is the mass weighted average temperature of all solar storage masses.

- WIND DIRECTION (WDIR) is the average direction of the prevailing wind.

- WIND SPEED (WIND) is the average wind speed measured at the site.

- DAYTIME AMBIENT TEMPERATURE (TDA) is the temperature during the period from three hours before solar noon to three hours after solar noon.

- RELATIVE HUMIDITY (RELH) is the average outside relative humidity.

## APPENDIX B

## SOLAR ENERGY SYSTEM 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 $\Delta H$ is the enthalpy change, in Btu/$lb_m$, of the fluid as it passes through the heat exchanging component.

For a liquid system $\Delta H$ is generally given by

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

where $\overline{C}_p$ is the average specific heat, in Btu/($lb_m$-°F), of the heat transfer fluid and $\Delta T$, in °F, is the temperature differential across the heat exchanging component.

For an air system $\Delta H$ 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.

These equations are comparable to those specified in "Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program." This document was prepared by an interagency committee of the Government, and presents guidelines for thermal performance evaluation.

Performance factors are computed for each hour of the day. Each integration process, therfore, is performed over a period of one hour. Since long-term performance data is desired, it is necessary to build these hourly performance factors to daily values. This is accomplished, for energy parameters, by summing the 24 hourly values. For temperatures, the hourly values are averaged. Certain special factors, such as efficiencies, require appropriate handling to properly weight each hourly sample for the daily value computation. Similar procedures are required to convert daily values to monthly values.

## EQUATIONS USED TO GENERATE MONTHLY PERFORMANCE VALUES

NOTE: SENSOR IDENTIFICATION (MEASUREMENT) NUMBERS REFERENCE SYSTEM SCHEMATIC FIGURE 3-2

AVERAGE AMBIENT TEMPERATURE (°F)

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

AVERAGE BUILDING TEMPERATURE (°F)

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

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

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

FOR $\pm$ 3 HOURS FROM SOLAR NOON

TIME OF DAY BUILDING TEMPERATURES (ONCE PER DAY)

TMID = TB

AT 12 HOURS FROM LOCAL SOLAR NOON

T6AM = TB

AT 6 HOURS BEFORE LOCAL SOLAR NOON

TNOON = TB

AT LOCAL SOLAR NOON

T6PM = TB

AT 6 HOURS PAST LOCAL SOLAR NOON

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

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

OPERATIONAL INCIDENT SOLAR ENERGY (BTU)

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

HUMIDITY RATIO FUNCTION ($BTU/lb_m$-°F)

$$HRF = 0.24 + 0.444 \times HR$$

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

$$TSTSLAB = (1/1200) \times \Sigma\,(T201 + T202 + T203 + T204 + T205 + T206 + T207 + T208 + T209 + T210 + T212 + T213 + T214 + T215 + T217 + T218 + T219 + T220 + T221 + T222) \times \Delta\tau$$

AVERAGE WATER STORAGE TEMPERATURE

$$TSTST012 = (1/720) \times \Sigma\,(T271 + T281 + T272 + T282 + T273 + T283 + T231 + T241 + T232 + T242 + T233 + T243)$$

SUM OF CONDUCTION LOSSES (U X A)

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

ELECTRICAL HEAT INCIDENTLY APPLIED TO SPACE HEATING

$$HAE = 56.8833 * (EP600 - OUTSIDE\ LIGHTS - EP100)$$

SPACE HEATING SUBSYSTEM AUXILIARY NATURAL GAS FUEL ENERGY (BTU)

$$HAF = 1000 * F400$$

SPACE HEATING SUBSYSTEM AUXILIARY THERMAL ENERGY (BTU)

$$HAT = 0.52 * HAF$$

SPACE HEATING SUBSYSTEM LOAD (BTU)

$$HL = LOSSES + HI - HAE - HFIRE$$

INCIDENT SOLAR ENERGY ON COLLECTOR ARRAY (BTU)

$$SEA = CLAREA \times SE$$

COLLECTED SOLAR ENERGY (BTU)

$$SEC = SECA/CLAREA$$

COLLECTOR ARRAY EFFICIENCY

CAREF = SECA/SEA

CHANGE IN STORED ENERGY (BTU)

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

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 x $\Delta\tau$

INTERIOR RELATIVE HUMIDITY

RHIN = RH600/60 x $\Delta\tau$

WIND NORTH - SOUTH COMPONENT

WNS = V001 * COSD (D001)/60 x $\Delta\tau$

WIND EAST - WEST COMPONENT

WEW = V001 x SIND (D001)/60 x $\Delta\tau$

WIND VELOCITY

WIND = V001/60 x $\Delta\tau$

AVERAGE TEMPERATURE OF STORAGE (°F)

TST = (1/60) x $\Sigma$ (TSTSLAB + TSTST012)/2 x $\Delta\tau$

SOLAR ENERGY TO SPACE HEATING SUBSYSTEM (BTU)

HSE = HL - HAT

HEAT OF INFILTRATION

HI = VOLUME x 0.07216 x HRF x (TB - TA) * 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 SUBTRACT 360 TO GET BETWEEN 0 AND 360°

# APPENDIX C

## LONG-TERM AVERAGE WEATHER CONDITIONS

This appendix contains a table which lists the long-term average weather conditions for each month of the year for this site.

SITE: LIVING SYSTEMS 159. LOCATION: DAVIS CA

ANALYST: G. KINNIE FDRIVE NO.: 34.

COLLECTOR TILT: 90.00 (DEGREES) COLLECTOR AZIMUTH: 0.0 (DEGREES)

LATITUDE: 38.52 (DEGREES) RUN DATE: 6/04/79

| MONTH | HOBAR | HBAR | KBAR | RBAR | SBAR | HDD | CDD | TBAR |
|---|---|---|---|---|---|---|---|---|
| JAN | 1406. | 597. | 0.42488 | 1.542 | 921. | 617 | 0 | 45. |
| FEB | 1864. | 940. | 0.50432 | 1.239 | 1165. | 426 | 0 | 50. |
| MAR | 2451. | 1460. | 0.59569 | 0.887 | 1295. | 372 | 0 | 53. |
| APR | 3053. | 2006. | 0.65689 | 0.566 | 1135. | 227 | 26 | 58. |
| MAY | 3471. | 2433. | 0.70109 | 0.387 | 943. | 120 | 98 | 64. |
| JUN | 3638. | 2684. | 0.73779 | 0.316 | 849. | 20 | 185 | 71. |
| JUL | 3549. | 2688. | 0.75741 | 0.336 | 904. | 0 | 316 | 75. |
| AUG | 3209. | 2367. | 0.73754 | 0.474 | 1123. | 0 | 286 | 74. |
| SEP | 2665. | 1906. | 0.71536 | 0.761 | 1451. | 5 | 200 | 72. |
| OCT | 2033. | 1316. | 0.64732 | 1.189 | 1564. | 101 | 48 | 63. |
| NOV | 1512. | 782. | 0.51712 | 1.555 | 1216. | 360 | 0 | 53. |
| DEC | 1280. | 538. | 0.42069 | 1.666 | 897. | 595 | 0 | 46. |

LEGEND:

HOBAR ==> MONTHLY AVERAGE DAILY EXTRATERRESTRIAL RADIATION (IDEAL) IN BTU/DAY-FT2.

HBAR ==> MONTHLY AVERAGE DAILY RADIATION (ACTUAL) IN BTU/DAY-FT2.

KBAR ==> RATIO OF HBAR TO HOBAR.

RBAR ==> RATIO OF MONTHLY AVERAGE DAILY RADIATION ON TILTED SURFACE TO THAT ON A HORIZONTAL SURFACE FOR EACH MONTH (I.E., MULTIPLIER OBTAINED BY TILTING).

SBAR ==> MONTHLY AVERAGE DAILY RADIATION ON A TILTED SURFACE (I.E., RBAR * HBAR) IN BTU/DAY-FT2.

HDD ==> NUMBER OF HEATING DEGREE DAYS PER MONTH.

CDD ==> NUMBER OF COOLING DEGREE DAYS PER MONTH.

TBAR ==> AVERAGE AMBIENT TEMPERATURE IN DEGREES FAHRENHEIT.