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SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION

KALWALL CORPORATION
Manchester, New Hampshire
October 1979 through April 1980
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U.S. DEPARTMENT OF ENERGY
NATIONAL SOLAR DATA PROGRAM

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KALWALL CORPORATION
MANCHESTER, NEW HAMPSHIRE
SOLAR ENERGY SYSTEM PERFORMANCE EVALUATION
OCTOBER 1979 THROUGH MAY 1980

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The National Solar Data Network
Department of Energy Contract Number DE-AC01-79CS30027
Contract Management by:
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FOREWORD

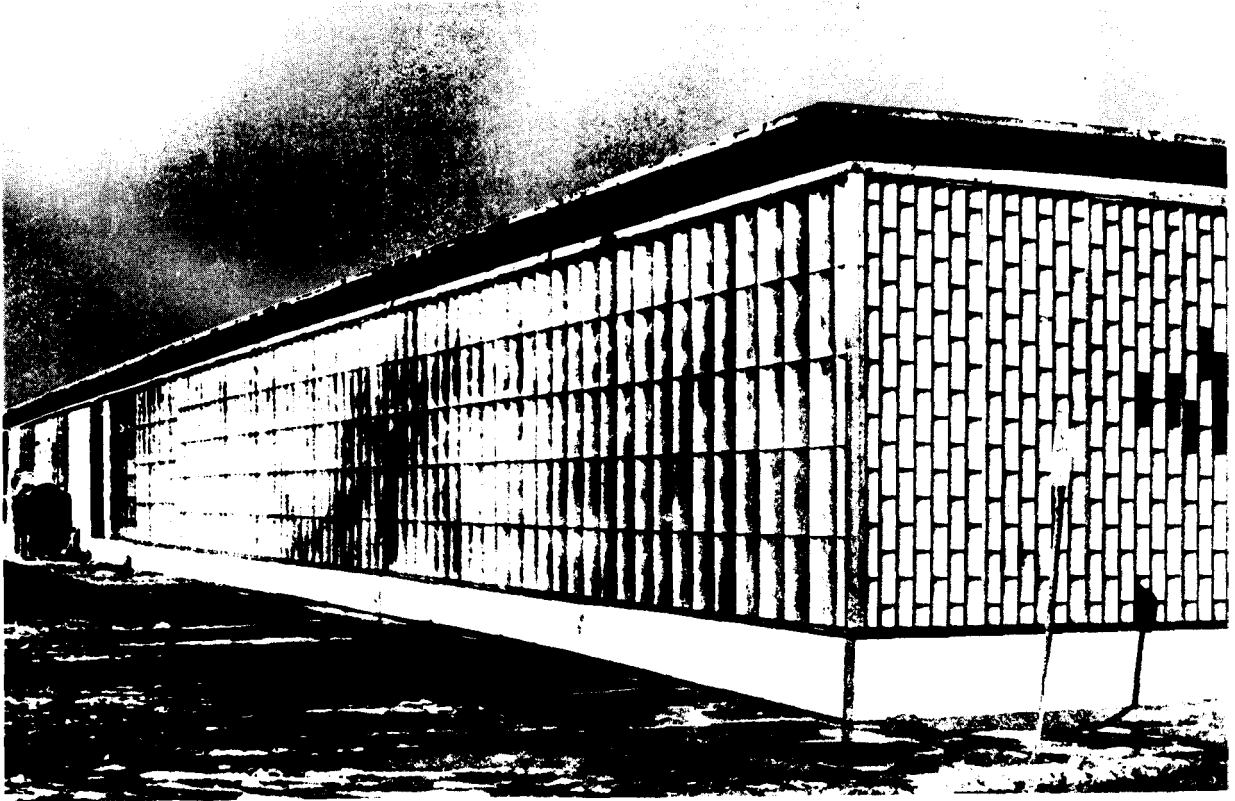
This report is one of a series which describes the performance of solar energy systems in the National Solar Data Network (NSDN) for the entire heating or cooling season. Domestic hot water is also included, if there is a solar contribution. Some NSDN installations are used solely for heating domestic hot water and annual performance reports are issued for such sites. In addition, Monthly Performance Reports are available for the solar systems in the network.

The National Solar Data Network consists of instrumented solar energy systems in buildings selected from among the 5,000 installations built (since early 1977) as part of the National Solar Heating and Cooling Demonstration Program. The overall purpose of this program is to reduce the use of nonrenewable fuels by encouraging the application of solar energy for heating, cooling, and domestic hot water. Vitro Laboratories Division operates the NSDN, under contract with the Department of Energy, to collect daily data from the sites, analyze the data, and disseminate information to interested users.

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

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

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



KALWALL CORPORATION

KALWALL CORPORATION

The Kalwall Corporation is a commercial warehouse located in Manchester, New Hampshire. The direct-gain passive solar energy system was designed to supply approximately 50% of the annual space heating demand. The addition of roof insulation has resulted in system performance which exceeds these design projections.

The structure is equipped with 1,750 ft² of vertical south-facing glazing and 850 ft² of vertical east-facing glazing. The storage system consists of 817,000 pounds of dark-colored concrete in the eight-inch floor slab. Additional storage is in the materials stored in the warehouse. Auxiliary space heating is provided by two liquid-to-air heat exchangers supplied by the building boiler.

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SECTION 1

SOLAR SYSTEM PERFORMANCE

KALWALL CORPORATION
OCTOBER 1979 THROUGH APRIL 1980

Solar Fraction¹ 79%
Conventional Fuel Savings² 1,843 gallons of No. 2 oil

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

| | <u>Total Load</u> | <u>Solar Contribution</u> | <u>% Solar</u> |
|---------|-------------------|---------------------------|----------------|
| Heating | 226.52 | 179.36 | 79 |

Environmental Data

| | <u>Measured Total</u> | <u>Long-Term Seasonal Average</u> |
|-------------------------------------|---------------------------|---|
| Heating degree-days | 5,741 | 6,744 |
| Average daily incident solar energy | 804 BTU/ft ² | 803 BTU/ft ² |

1. Solar Fraction = $\frac{\text{Solar Energy Supplied to Loads}}{\text{Total Load}}$
2. Conventional Fuel Savings = Solar Energy Used x 0.6/140,000 (BTU per gallon)

1.1 SUMMARY AND CONCLUSIONS

The Kalwall solar energy system supplied 79% of the space heating for this building during the heating season of October 1979 through April 1980.

The overall performance of the solar system was above expectations during this season. The system was designed to satisfy approximately 50% of the annual space heating demand. However, the design performance projections were made before additional insulation was added to the building roof. Consequently, revised design performance projections would be expected to predict a solar contribution of greater than 50%.

The performance of the passive collector south wall was very good. The average transmittance for the south wall glazing listed by the manufacturer is 73% at 30° angle of incidence. The collector efficiency (incident solar/solar used) was 73% for December. This means 100% of the transmitted solar energy went to the load.

The storage temperatures decreased through January and began to increase from February through April. The average storage temperature remained within 1°F to 2°F of room temperature throughout the heating season.

1.2 OVERALL SYSTEM PERFORMANCE

The flow of solar energy through the Kalwall site for the seven-month period from October 1979 through April 1980 is presented in Figure 1. This Energy Flow Diagram shows the amount of energy collected, transported, stored, consumed, or lost at each point in the system.

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

TABLE 1. SOLAR SYSTEM THERMAL PERFORMANCE
KALWALL CORPORATION
OCTOBER 1979 THROUGH APRIL 1980
(All values in million BTU, unless otherwise indicated)

| MONTH | EMPIRICAL HEATING DEGREE- DAYS | BUILDING HEAT LOAD | UA Δt | INFIL LOSSES | AUX THERMAL USED | SOLAR ENERGY COLLECTED | SOLAR ENERGY USED | EQUIP HEAT LOAD | SOLAR FRACTION EQUIP HEAT LOAD (PERCENT) |
|---------|---|--------------------------|---------|-----------------|------------------------|------------------------------|-------------------------|-----------------------|--|
| OCT | 456 | 24.50 | 22.47 E | 2.03 E | 1.15 | 24.18 | 23.36 | 24.50 | 95 |
| NOV | 585 | 30.76 | 28.30 E | 2.46 E | 8.77 | 21.91 | 21.98 | 30.76 | 71 |
| DEC | 1,005 | 39.96 | 37.15 | 2.81 | 5.79 | 33.74 | 34.17 | 39.96 | 86 |
| JAN | 1,209 | 42.45 | 39.30 | 3.15 | 8.18 | 33.65 | 34.28 | 42.45 | 81 |
| FEB | 1,130 | 42.72 | 39.43 | 3.29 | 11.35 | 31.80 | 31.37 | 42.72 | 73 |
| MAR | 844 | 29.29 | 26.38 | 2.91 | 7.60 | 21.02 | 21.69 | 29.29 | 74 |
| APR | 512 | 16.84 | 15.55 | 1.29 | 4.33 | 12.80 | 12.57 | 16.84 | 74 |
| TOTAL | 5,741 | 226.52 | 208.58 | 17.94 | 47.17 | 179.10 | 179.35 | 226.52 | - |
| AVERAGE | - | 32.36 | 29.80 | 2.56 | 6.74 | 25.59 | 25.62 | 32.36 | 79 |

E DENOTES ESTIMATED VALUE.

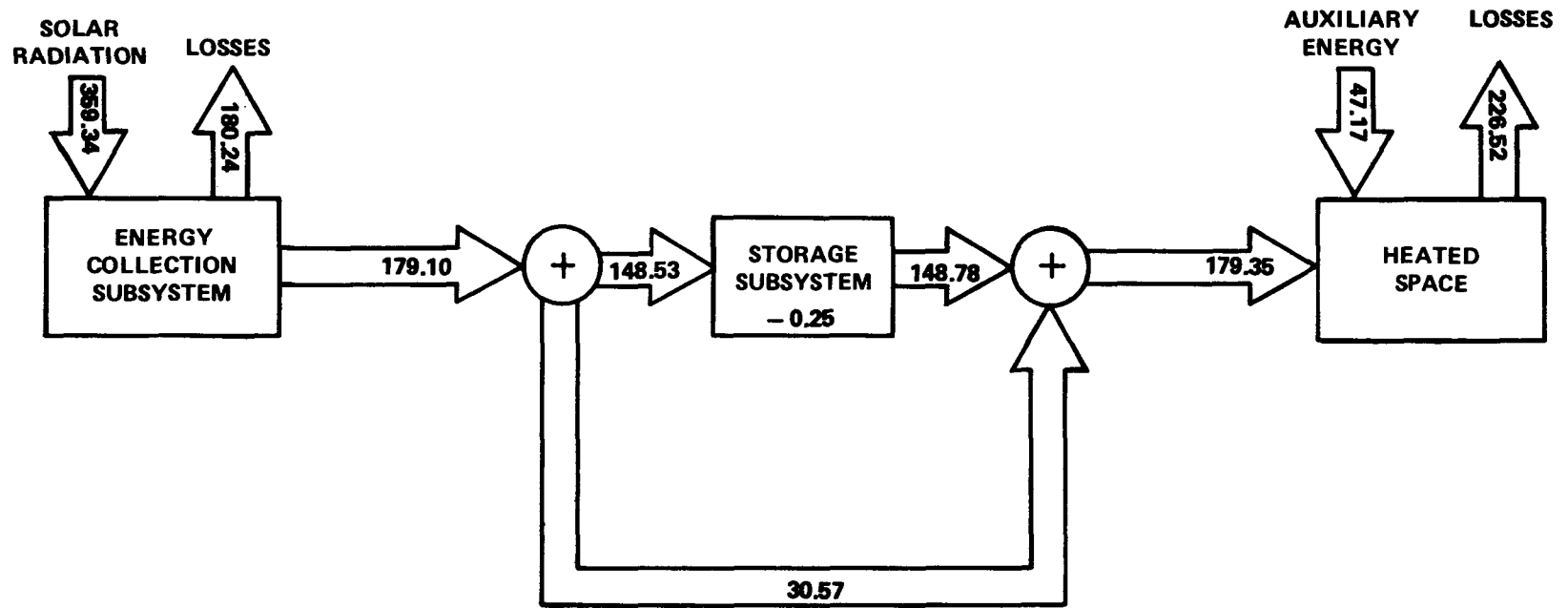


Figure 1. Energy Flow Diagram for Kalwall Corporation Passive System
October 1979 through April 1980
(Figures in million BTU)

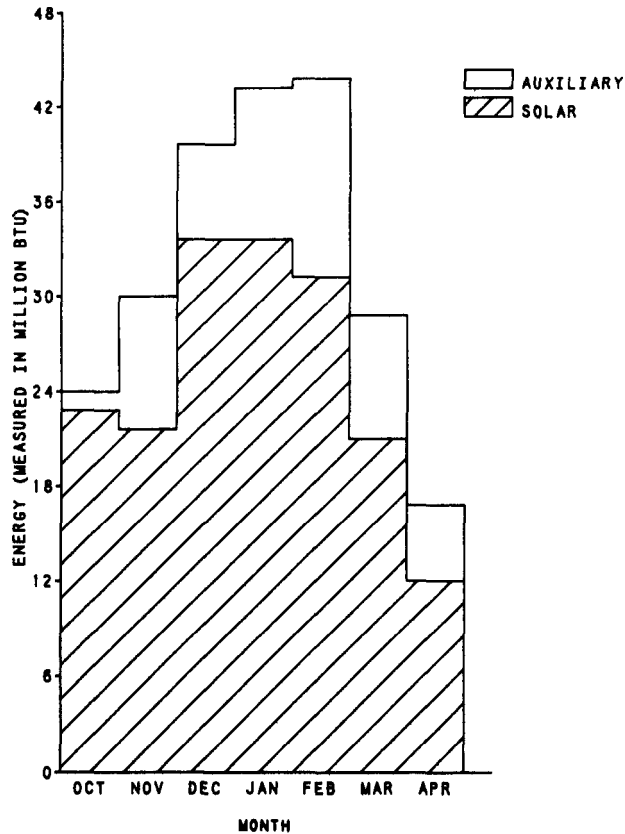


Figure 2. System Thermal Performance
Kalwall Corporation
October 1979 through April 1980

Figures 3 through 9 show the overall system performance for each month of the heating season. Solar energy available, average building temperature, average storage temperature, average ambient temperature, and auxiliary energy used are plotted for each day of the month. These graphs depict the relationship of solar, ambient temperature, and auxiliary energy to building and storage temperatures. The auxiliary energy used parameter shows that the auxiliary system was turned down on the weekends. Building temperatures and storage temperatures stayed within 2°F to 3°F of each other and fluctuated with the ambient temperature and solar radiation.

October began the heating season for Kalwall with 456 heating degree-days and an average ambient temperature of 51°F. The system performed very well for October, providing 95% of the space heating requirements in spite of the fact that there was only about 50% of the long-term average solar energy available for the month. Building and storage temperatures remained within 2°F to 3°F of each other. The temperatures fluctuated from a low of approximately 65°F on October 10 to a high of 76°F on October 22. On October 10, the average ambient temperature dropped to 35°F and there was no sun. On October 22, the average ambient temperature rose to 72°F and there was good solar energy available.

November had 585 heating degree-days and an average ambient temperature of 45°F. The storage temperatures were usually 2°F below building temperatures except for the first five days of the month. Then, the average storage temperatures were a few degrees above average building temperatures. This happens when the outside temperature goes down for a few days and at the same time there is good solar energy available. This can be seen on November 1, 4, 10, and 30. Auxiliary energy use was high and solar provided 71% of the load for November. The high auxiliary use was due to the warehouse temperature being kept between 65°F and 70°F for the month (67°F average) and only 66% of the long-term solar energy being available for the month.

December brought colder average temperatures (33°F), 1,005 heating degree-days, and 85% of the long-term average solar energy available. The building temperatures were allowed to swing from about 65°F to 52°F (61°F average). By allowing greater swings in the building temperatures, the auxiliary energy consumption was 5.79 million BTU and the solar fraction was 86%. Energy was also conserved by turning off the heat on the weekends.

In January, the building and storage temperatures remained between 55°F and 65°F (60°F average). There were 1,209 heating degree-days and the average ambient temperature was 26°F. The solar radiation was 79% of the long-term average and the solar fraction for January was 81%. The grantee continued to turn the heat off on the weekends and let the building temperature swing.

February showed an increase in auxiliary energy consumption over January with less heating degree-days (1,130 heating degree-days). The average ambient temperature was 25°F and more solar energy was available. The increase of auxiliary energy use was caused by maintaining the building at a higher temperature than the previous month. The average building temperature was 60°F in January and 63°F in February. The loss of data on February 15 was due to communications problems.

March began a warming trend with 844 heating degree-days and 38°F average ambient temperature. The solar energy available was 50% of the long-term average. The solar fraction was 74% and the auxiliary requirement was high (7.60 million BTU). The high auxiliary was due again to maintaining a higher than normal building temperature of 64°F.

In April, the building was maintained at an average of 67°F and the auxiliary was high (4.33 million BTU) for 512 heating degree-days. The storage continued to increase this month and the average storage temperature for April was 65°F. The average ambient temperature was 48°F. The solar energy available for April was only 34% of the long-term average and the solar fraction for April was 74%.

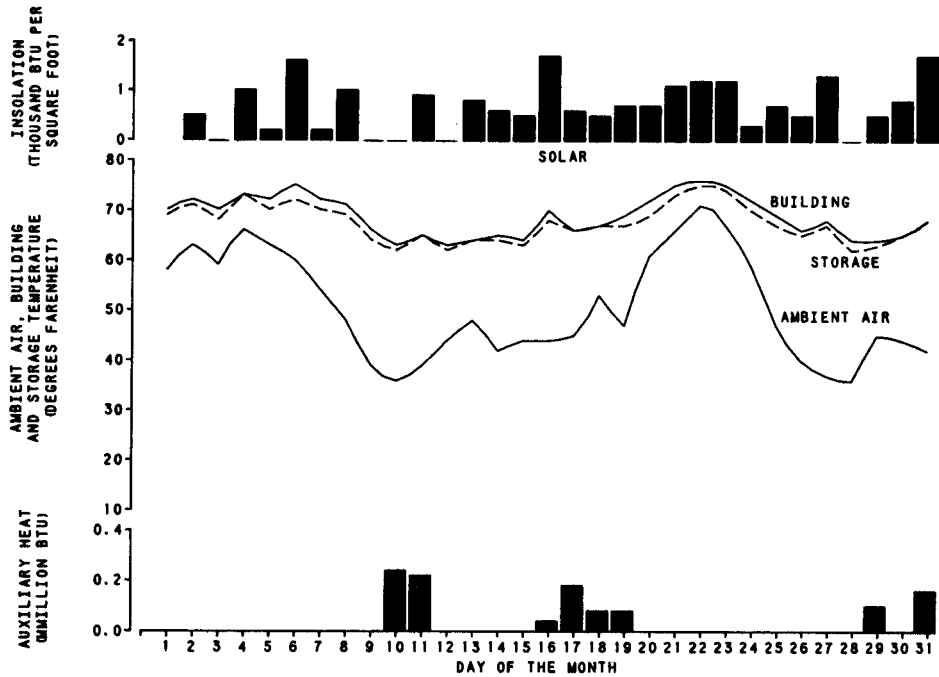


Figure 3. Monthly Summary Graphs for October 1979
 Insolation Versus Building, Storage, and Ambient Temperatures
 Versus Auxiliary Energy Used
 Kalwall Corporation

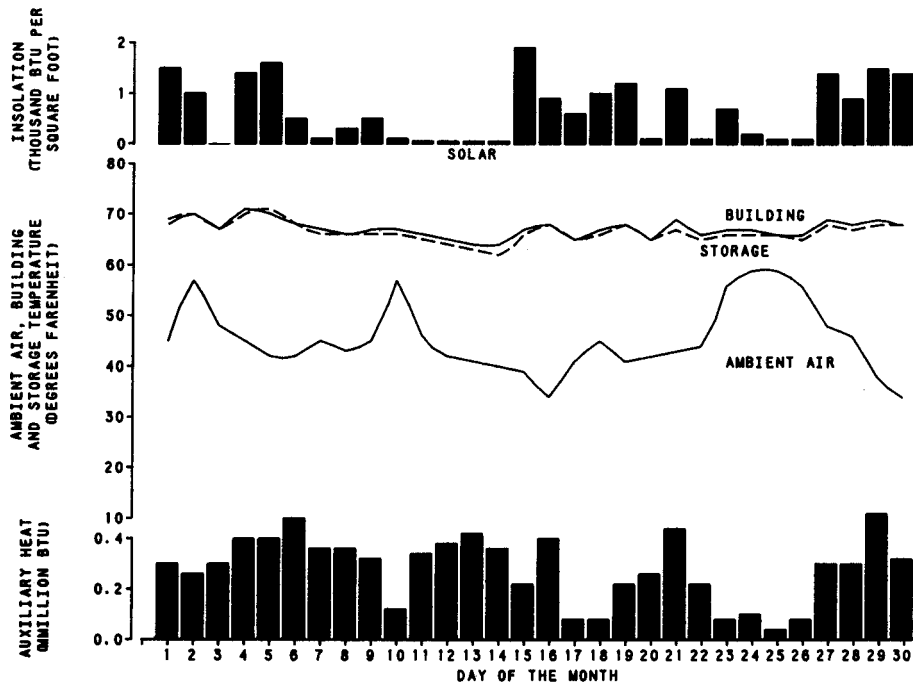


Figure 4. Monthly Summary Graphs for November 1979
 Insolation Versus Building, Storage, and Ambient Temperatures
 Versus Auxiliary Energy Used
 Kalwall Corporation

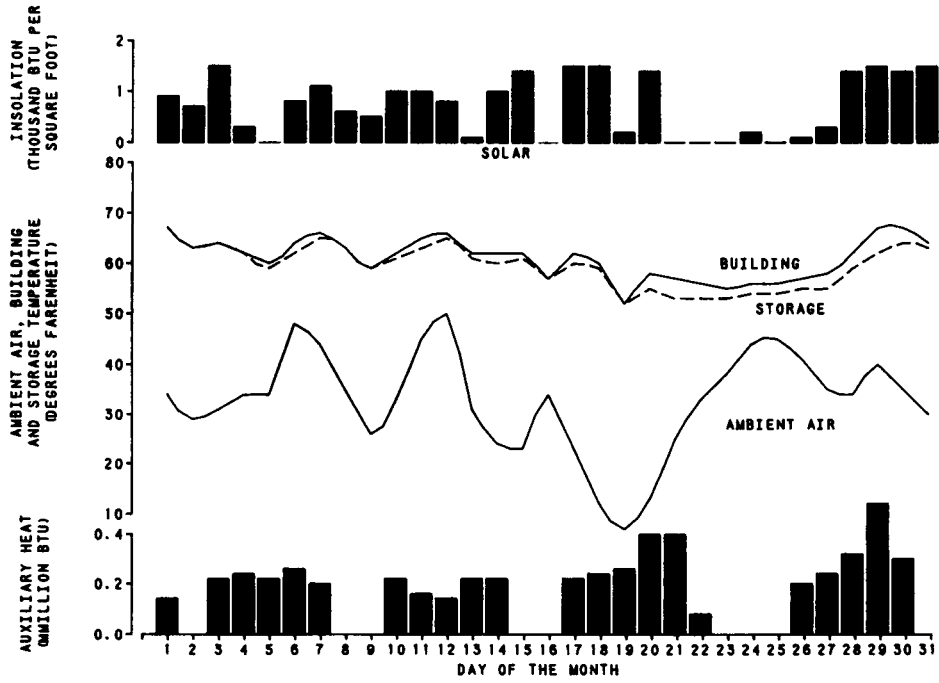


Figure 5. Monthly Summary Graphs for December 1979
 Insolation Versus Building, Storage, and Ambient Temperatures
 Versus Auxiliary Energy Used
 Kalwall Corporation

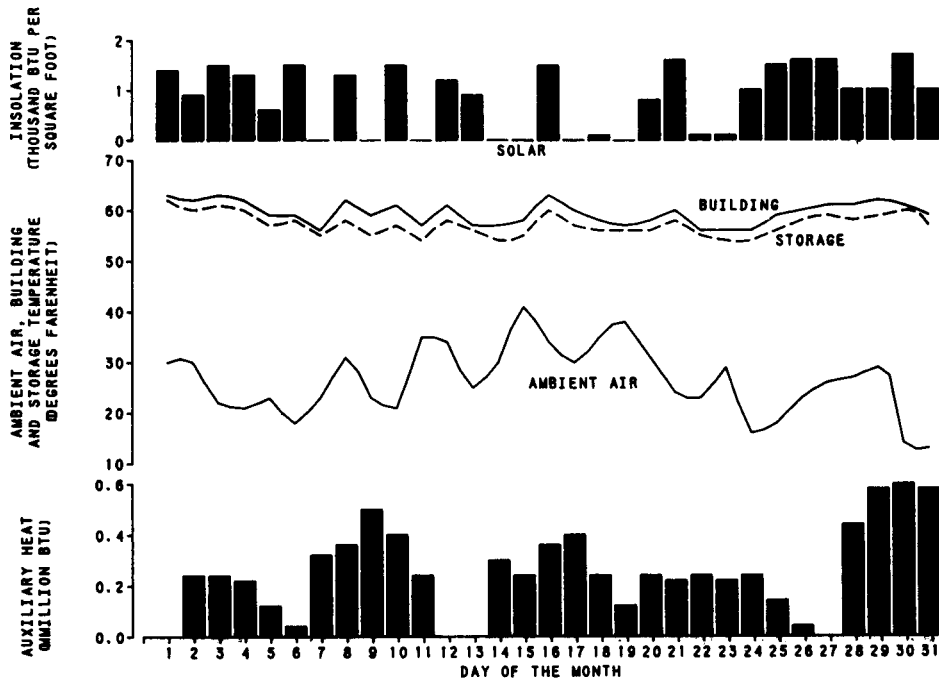


Figure 5. Monthly Summary Graphs for January 1979
 Insolation Versus Building, Storage, and Ambient Temperatures
 Versus Auxiliary Energy Used
 Kalwall Corporation

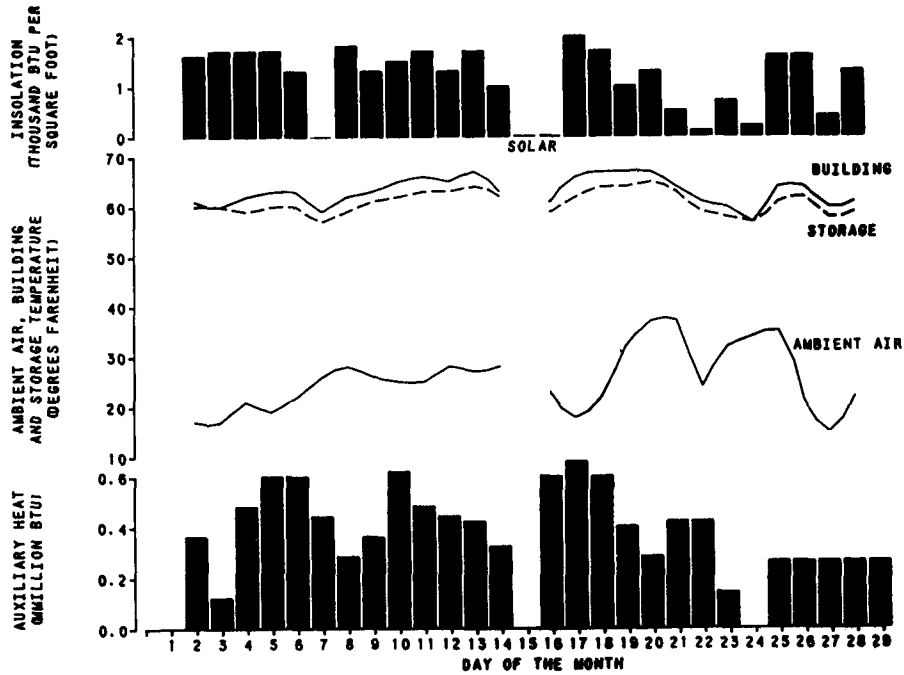


Figure 7. Monthly Summary Graphs for February 1979
 Insolation Versus Building, Storage, and Ambient Temperatures
 Versus Auxiliary Energy Used
 Kalwall Corporation

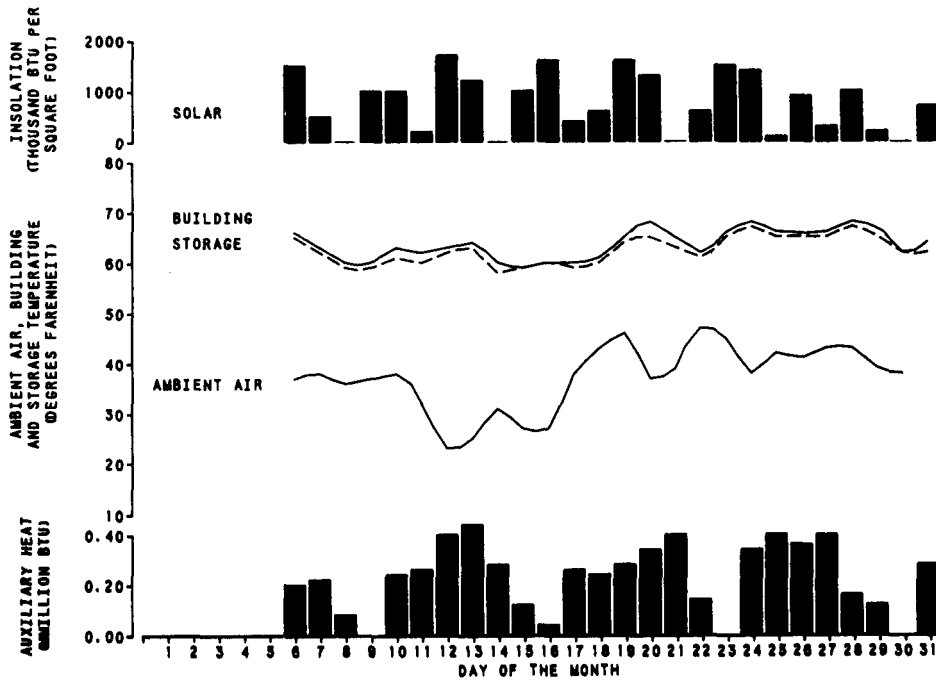


Figure 8. Monthly Summary Graphs for March 1979
 Insolation Versus Building, Storage, and Ambient Temperatures
 Versus Auxiliary Energy Used
 Kalwall Corporation

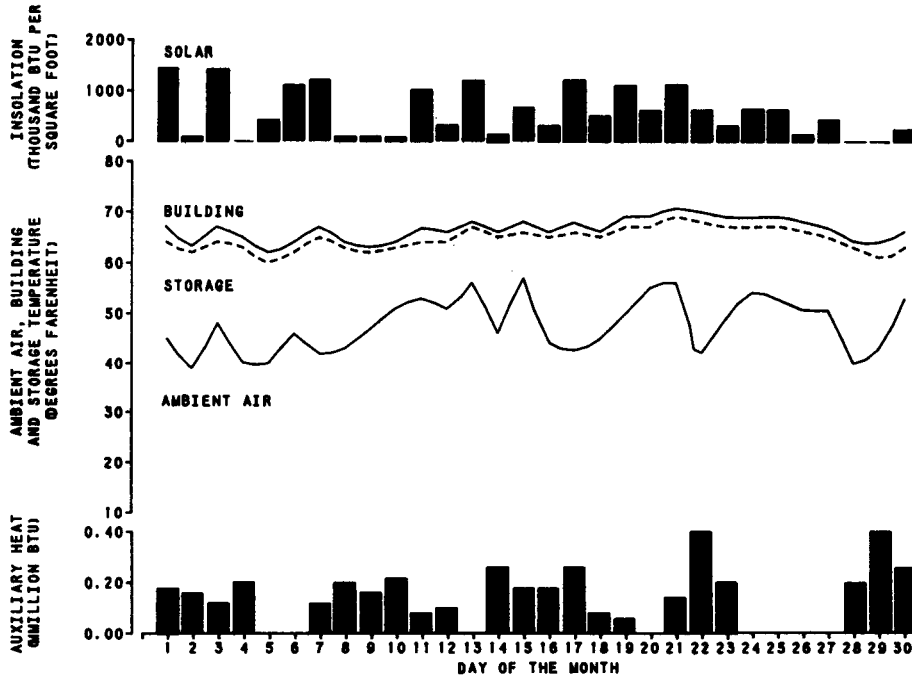


Figure 9. Monthly Summary Graphs for April 1979
 Insolation Versus Building, Storage, and Ambient Temperatures
 Versus Auxiliary Energy Used
 Kalwall Corporation

1.3 ENERGY SAVINGS

Energy savings for this site for the reporting period, October 1979 through May 1980, are presented in Table 2. For this seven-month period, the total savings were 179.35 million BTU, for a monthly average of 25.62 million BTU. This is approximately 1,843 gallons of oil, or 229,948 cubic feet of natural gas, or 52,552 kwh of electricity.

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. Auxiliary energy is provided by two liquid-to-air heat exchangers supplied by the building boiler. The control thermostat for the auxiliary system was set at approximately 60°F.

Table 2. ENERGY SAVINGS

KALWALL CORPORATION
OCTOBER 1979 THROUGH APRIL 1980

(All values in million (BTU))

| MONTH | SOLAR ENERGY USED | SOLAR ENERGY SAVINGS ATTRIBUTED TO SPACE HEATING | |
|----------------|----------------------|---|--------------------------------------|
| | | FOSSIL FUEL | <u>ENERGY SAVINGS</u> FOSSIL FUEL |
| OCT | 23.36 | 38.93 | 38.93 |
| NOV | 21.98 | 36.64 | 36.64 |
| DEC | 34.17 | 56.94 | 56.94 |
| JAN | 34.28 | 57.13 | 57.13 |
| FEB | 31.37 | 52.28 | 52.28 |
| MAR | 21.69 | 36.15 | 36.15 |
| APR | 12.51 | 20.85 | 20.85 |
| TOTAL | 179.36 | 298.92 | 298.92 |
| AVERAGE | 25.62 | 42.70 | 42.70 |

The energy savings are summarized in Figure 10.

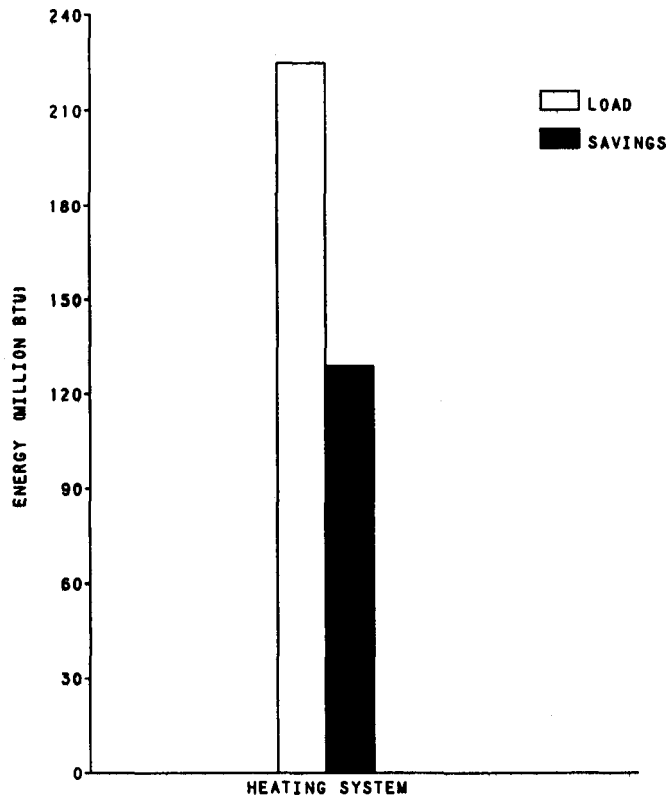


Figure 10. Combined Thermal Energy Savings Compared to Load
 Kalwall Corporation
 October 1979 through April 1980

1.4 SOLAR SYSTEM AVAILABILITY

The solar system was operational during the entire heating season. Kalwall is a passive system with no nighttime insulation. Thus, the system collected solar energy whenever it was available.

SECTION 2

SUBSYSTEM PERFORMANCE

2.1 COLLECTOR

The Kalwall collector is composed of 1,750 square feet of south-facing vertical wall and 850 square feet of east-facing vertical wall. The glazing consists of two layers of Kalwall "Sun-Lite" fiberglass. The collector subsystem is direct gain into the building.

For the period from October 1979 through April 1980, the incident solar energy was 359.34 million BTU for an average of 51.33 million BTU per month. The system collected 179.15 million BTU, or an average of 25.58 million BTU per month. The overall collector efficiency for the season was 50%. The collector efficiency was highest in December (73%) when the sun is the lowest and the angle of incidence is lower. The collector efficiency was lowest in April when the sun is higher and the effect of shading from the overhang reduces the amount of solar radiation striking the collector. This effect is illustrated in Figure 11.

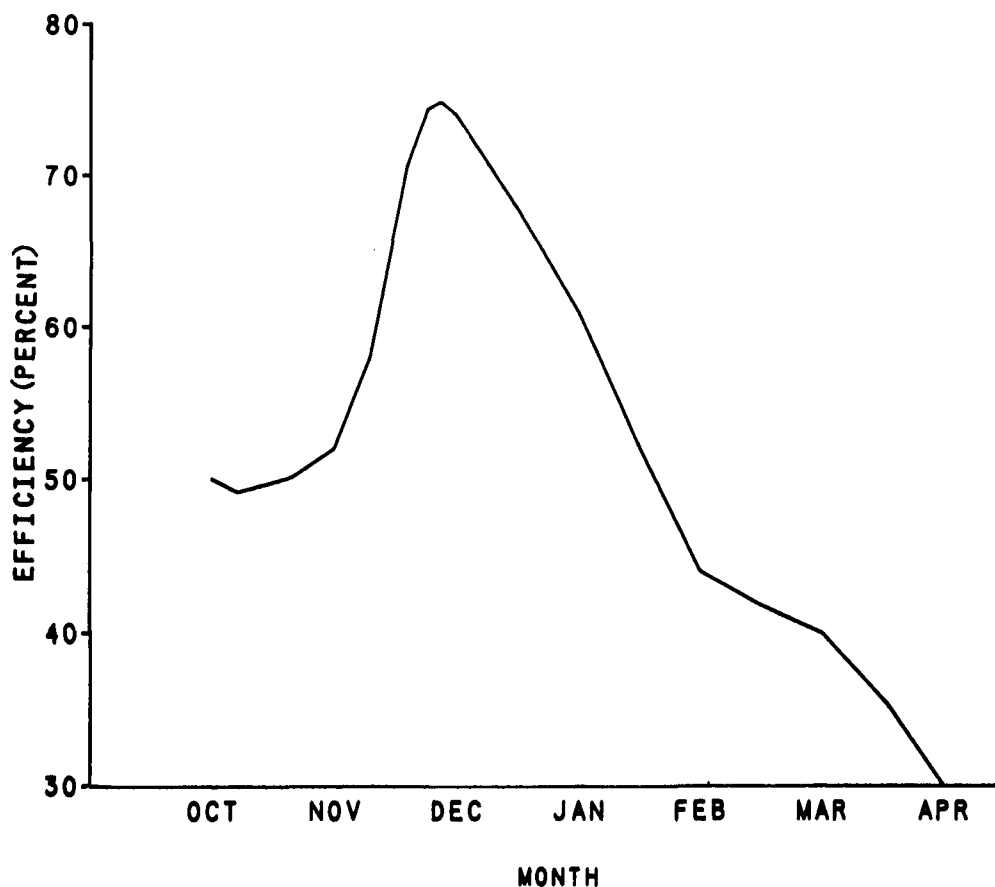


Figure 11. Collector Subsystem Efficiency
Kalwall Corporation
October 1979 through April 1980

The solar transmission of the Kalwall "Sun-Lite" panels is listed by the manufacturer as 77% at a zero degree angle of incidence and 73% at a 30 degree angle of incidence. When compared to the collector efficiency of 73% for December, the system uses up to 100% of the transmitted solar energy through the glazing.

The collector subsystem performance is summarized in Table 3.

Table 3. COLLECTOR SUBSYSTEM PERFORMANCE

KALWALL CORPORATION
OCTOBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

| MONTH | INCIDENT SOLAR RADIATION | COLLECTED SOLAR ENERGY | COLLECTOR SUBSYSTEM EFFICIENCY (%) | DAYTIME AMBIENT TEMPERATURE (°F) |
|---------|--------------------------|------------------------|------------------------------------|----------------------------------|
| OCT | 46.71 | 24.18 | 52 | 58 |
| NOV | 41.91 | 21.91 | 52 | 52 |
| DEC | 46.28 | 33.74 | 73 | 38 |
| JAN | 56.23 | 33.65 | 61 | 33 |
| FEB | 72.10 | 31.80 | 44 | 35 |
| MAR | 54.04 | 21.02 | 39 | 44 |
| APR | 42.07 | 12.80 | 30 | 56 |
| TOTAL | 359.34 | 179.10 | - | - |
| AVERAGE | 51.33 | 25.59 | 50 | 45 |

2.2 STORAGE

The storage subsystem consists of a dark colored eight-inch concrete slab which receives direct radiation from the south and east walls. Additional storage is in the material stored in the warehouse.

Storage system performance summarized in Table 4.

Table 4. STORAGE PERFORMANCE

KALWALL CORPORATION
OCTOBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

| MONTH | ENERGY TO STORAGE | ENERGY FROM STORAGE | CHANGE IN STORED ENERGY | AVERAGE STORAGE TEMP. (°F) | AVERAGE BUILDING TEMP. (°F) |
|---------|-------------------|---------------------|-------------------------|----------------------------|-----------------------------|
| OCT | 20.54 | 19.72 | 0.82 | 69 | 68 |
| NOV | 20.45 | 20.52 | -0.07 | 67 | 67 |
| DEC | 23.21 | 23.64 | -0.43 | 59 | 61 |
| JAN | 23.37 | 24.00 | -0.63 | 57 | 60 |
| FEB | 26.78 | 26.35 | 0.43 | 61 | 63 |
| MAR | 20.41 | 21.07 | -0.66 | 62 | 64 |
| APR | 13.77 | 13.48 | 0.29 | 65 | 67 |
| TOTAL | 148.53 | 148.78 | -0.25 | - | - |
| AVERAGE | 21.22 | 21.25 | -0.03 | 63 | 64 |

During the reporting period, the energy delivered to storage was 148.53 million BTU. The energy from storage to the space heating load was 148.78 million BTU.

The average storage temperature in October was 69°F. Stored energy increased 0.82 million BTU during the month. The storage released energy to the space each month until January 1980. This is shown by the negative change in stored energy for these months and the decrease in average storage temperature. In February, the combination of 11.35 million BTU of auxiliary energy and higher than normal 72.10 million BTU of solar energy brought the average storage temperature up from a low of 57°F to 61°F. From January through April, the storage temperature increased and kept within 3°F of the building temperature. This effect is illustrated in Figure 12.

A three-day system discharging cycle as represented by Figure 13 shows how closely the storage temperatures coincide with the building temperatures. The storage is adequately sized to store enough energy for approximately a day and a half after one good day of solar radiation.

During a system charging cycle, as illustrated in Figure 14, there is approximately a two-hour time lag between peak insolation and peak storage temperature. The building temperature increases rapidly with respect to solar insolation. This is primarily caused by the lighter mass objects in the warehouse absorbing and radiating the heat into the space. The clear skies that bring large amounts of solar radiation during the day also create plummeting outdoor temperatures at night. This can be seen in the evenings of January 20 and 21 (see Figure 14). As a result of the lower nighttime temperatures and large glazed areas with no nighttime insulation, the building losses were high enough to drop indoor ambient temperatures below those of the storage temperatures.

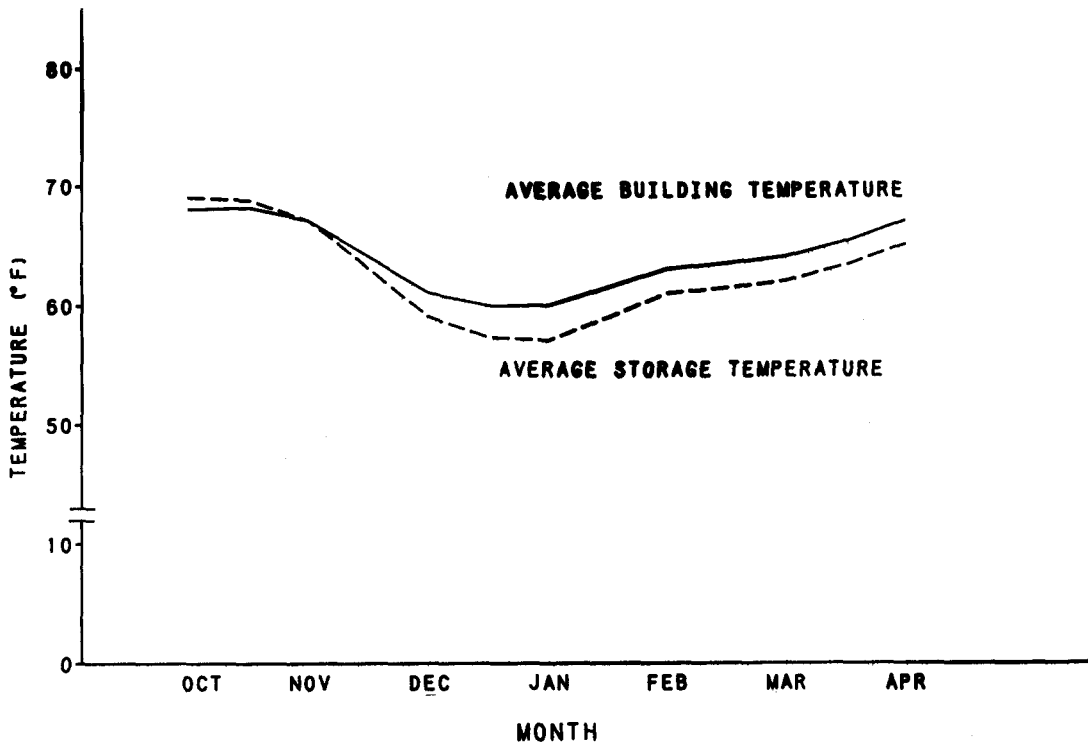


Figure 12. Building Temperatures Versus Storage Temperatures
Kalwall Corporation
October 1979 through April 1980

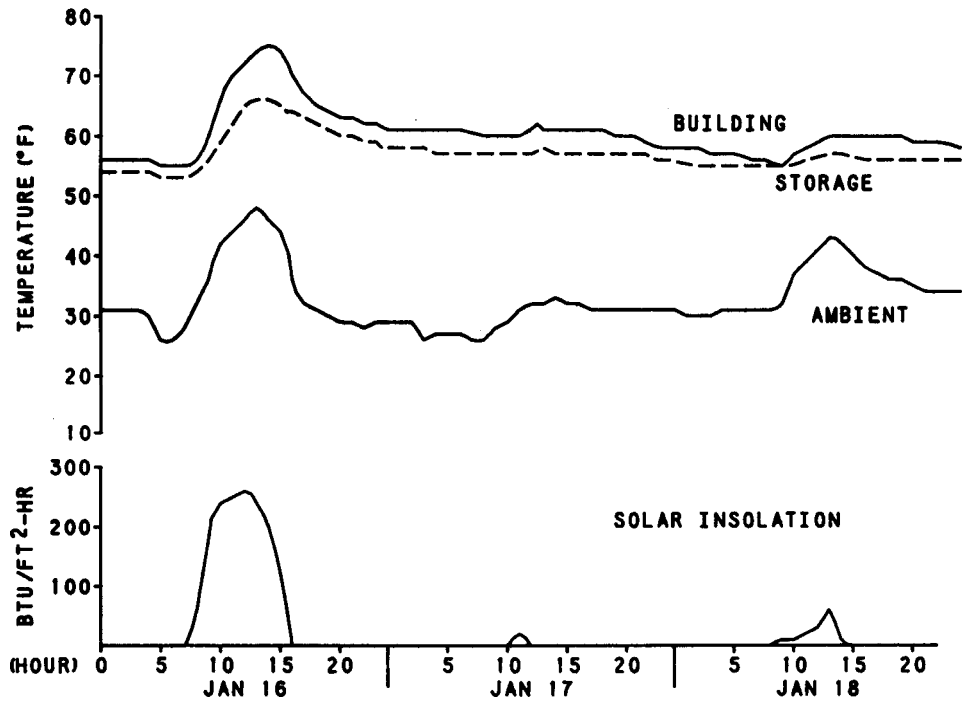


Figure 13. System Discharging Cycle
 Kalwall Corporation
 January 16, 17, and 18, 1980

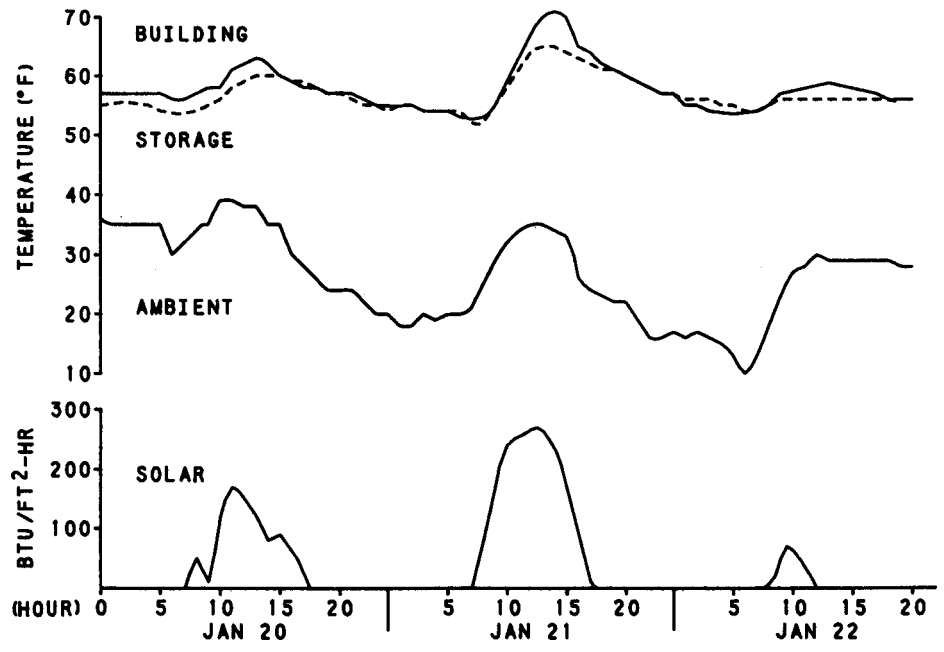


Figure 14. System Charging Cycle
 Kalwall Corporation
 January 20, 21, and 22, 1980

2.3 SPACE HEATING

Auxiliary energy is provided by two liquid-to-air heat exchangers supplied by the building boiler. Control thermostats for the auxiliary system are set at approximately 60°F. Figure 15 presents a schematic of the Kalwall system.

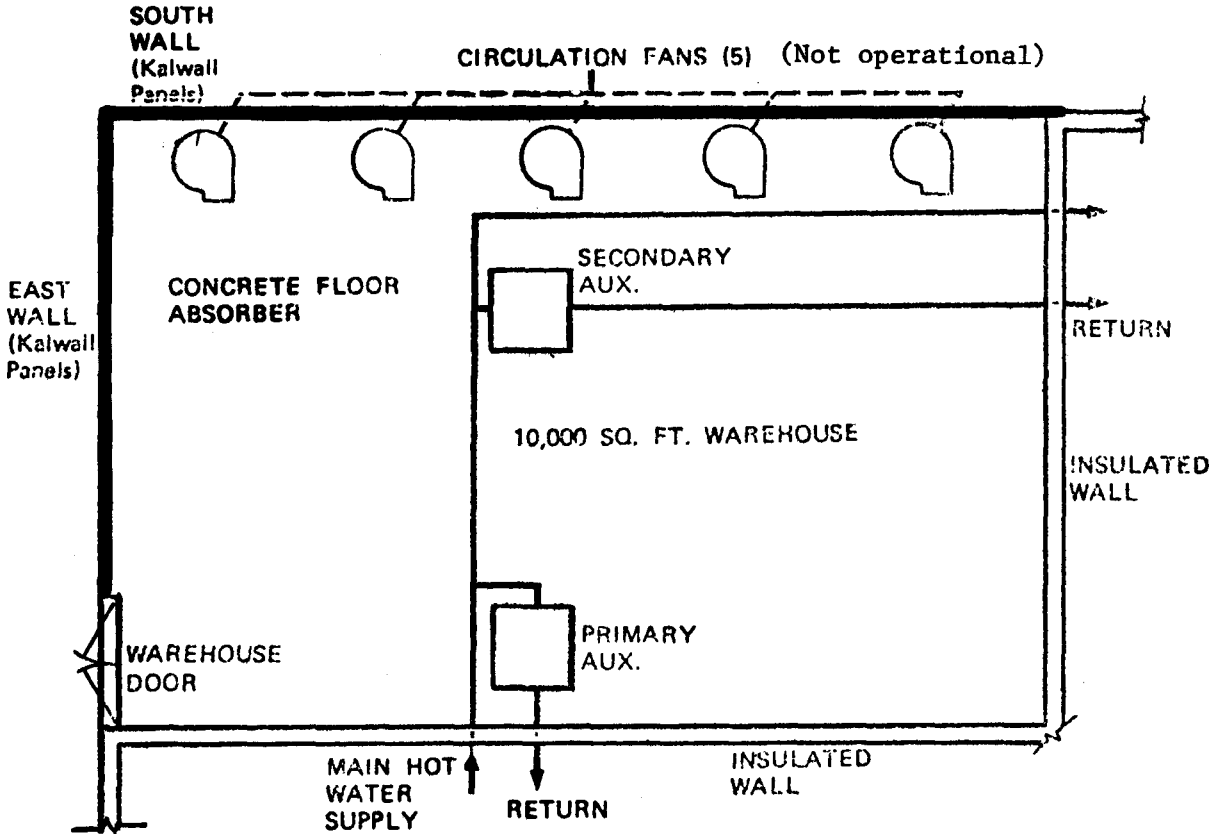


Figure 15. Kalwall Corporation System Schematic

The space heating performance for the Kalwall site for the reporting period is shown in Table 5 and presented graphically in Figure 16.

The space heating load of 226.52 million BTU was satisfied by 179.35 million BTU of solar energy and 47.61 million BTU of auxiliary energy. The solar fraction of this load was 79%.

The fossil fuel energy savings were 298.92 million BTU. The average building temperature for the season was 64°F.

Table 5. SPACE HEATING SUBSYSTEM

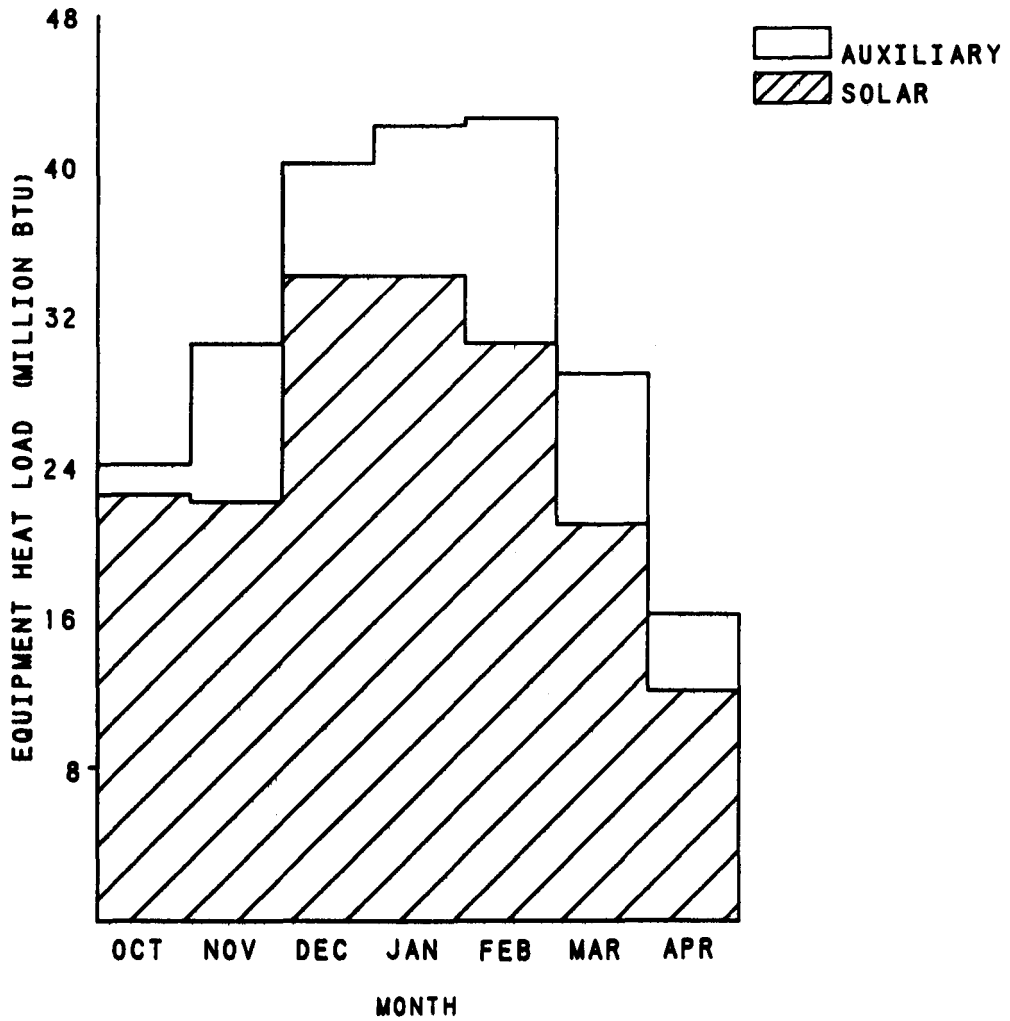
KALWALL CORPORATION
OCTOBER 1979 THROUGH APRIL 1980

(All values in million BTU, unless otherwise indicated)

| MONTH | SPACE HEATING LOAD | SOLAR | ENERGY CONSUMED | | SOLAR FRACTION (%) |
|---------|-----------------------|--------|-------------------|--|-----------------------|
| | | | AUXILIARY THERMAL | | |
| OCT | 24.50 | 23.36 | 1.15 | | 95 |
| NOV | 30.76 | 21.98 | 8.77 | | 71 |
| DEC | 39.96 | 34.17 | 5.79 | | 86 |
| JAN | 42.45 | 34.28 | 8.62 | | 81 |
| FEB | 42.72 | 31.37 | 11.35 | | 73 |
| MAR | 29.29 | 21.69 | 7.60 | | 74 |
| APR | 16.84 | 12.51 | 4.33 | | 74 |
| TOTAL | 226.52 | 179.35 | 47.61 | | - |
| AVERAGE | 32.36 | 25.62 | 6.98 | | 79 |

The auxiliary system heat exchanger fans were turned off for the entire season. Therefore, all auxiliary energy used was derived from uncontrolled heat exchanges from the main hot water supply line to the air in the building. This uncontrolled energy transfer was approximately 20,000 BTU per hour when the building boiler was on.

An effect of turning off the heat exchanger fans was to increase the amount of energy transferred to and from the rest of the building through the common concrete slab floor. Instrumentation is not sufficient to determine the amount of energy transferred but the effect is apparent on days when the floor temperatures reach the local maximum or minimum. Since energy flow through the slab is both into and out of the demonstration area, the long-term effect over the month is small.



**Figure 16. Space Heating Performance
Kalwall Corporation
October 1979 through April 1980**

SECTION 3

WEATHER CONDITIONS

The Kalwall Corporation site is located in Manchester, New Hampshire, at 43 degrees N latitude and 71 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

| KALWALL CORPORATION OCTOBER 1979 THROUGH APRIL 1980 | | | | | | |
|--|--|----------------------|--------------------------|----------------------|---------------------|----------------------|
| MONTH | DAILY INCIDENT SOLAR ENERGY PER UNIT AREA (BTU/FT ² -DAY) | | AMBIENT TEMPERATURE (°F) | | HEATING DEGREE-DAYS | |
| | MEASURED | LONG-TERM AVERAGE | MEASURED | LONG-TERM AVERAGE | MEASURED | LONG-TERM AVERAGE |
| OCT | 710 | 1,567 | 51 | 49 | 456 | 487 |
| NOV | 690 | 1,045 | 45 | 38 | 585 | 810 |
| DEC | 765 | 896 | 33 | 34 | 1,005 | 1,246 |
| JAN | 902 | 1,138 | 26 | 21 | 1,209 | 1,376 |
| FEB | 1,198 | 1,394 | 25 | 23 | 1,130 | 1,187 |
| MAR | 792 | 1,570 | 38 | 32 | 844 | 1,014 |
| APR | 573 | 1,703 | 48 | 44 | 512 | 624 |
| TOTAL | - | - | - | - | 5,741 | 6,744 |
| AVERAGE | 804 | 1,330 | 38 | 34 | 820 | 963 |

During the period from October 1979 through April 1980, the average daily total incident solar radiation on the collector array was 804 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 1,330 BTU per square foot per day for south- and east-facing planes with a tilt of 90 degrees to the horizontal. During the period, the highest monthly average insolation was 1,198 BTU per square foot per day during February. The average ambient temperature during the reporting period was 38°F as compared with the long-term average of 34°F. The highest monthly average ambient temperature

was 51°F during October and the lowest monthly average ambient temperature was 25°F during February. The number of heating degree-days for the period (based on a 65°F reference) was 5,741 as compared with the long-term average of 6,744. The range of heating degree-days was from a high of 1,209 during January to a low of 456 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, Kalwall Corporation, October 1979, SOLAR/2015-79/10, IBM, Huntsville, Alabama.
- *8. Monthly Performance Report, Kalwall Corporation, November 1979, SOLAR/2015-79/11, IBM, Huntsville, Alabama.
- *9. Monthly Performance Report, Kalwall Corporation, December 1979, SOLAR/2015-79/12, Vitro Laboratories, Silver Spring, Maryland.

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

**Note. Reference [6] only used if the heat transfer coefficient discussion in Section 5.3.1.2 applies.

- *10. Monthly Performance Report, Kalwall Corporation, January 1980, SOLAR/2015-80/01, Vitro Laboratories, Silver Spring, Maryland.
- *11. Monthly Performance Report, Kalwall Corporation, February 1980, SOLAR/2015-80/02, Vitro Laboratories, Silver Spring, Maryland.
- *12. Monthly Performance Report, Kalwall Corporation, March 1980, SOLAR/2015-80/03, Vitro Laboratories, Silver Spring, Maryland.
- *13. Monthly Performance Report, Kalwall Corporation, April 1980, SOLAR/2015-80/04, Vitro Laboratories, Silver Spring, Maryland.

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

APPENDIX A
SYSTEM DESCRIPTION

APPENDIX A

SYSTEM DESCRIPTION

The Kalwall Corporation solar energy system is a direct gain passive space heating system. The system heats a 10,000 square-foot portion of a commercial warehouse in Manchester, New Hampshire. (See Figure A-1, system schematics.) The south and east walls are covered with vertical double glazed Kalwall panels. The major collection area on the south wall is 1,750 square feet of double glazed Kalwall "Sunwall." The panels are made of two layers of fiber-glass reinforced plastic sheet, heat and pressure bonded to an aluminum grid core with a two and one-half inch air space. The overall transmittance of the glazing is 77% at a zero degree angle of incidence.

The absorber consists of the floor slab and the inventory in the warehouse. The floor is painted with flat black paint with an absorbency of 95% and emissivity of 95%. Storage is also in the concrete slab floor, which is eight inches thick, and in the inventory. The slab and inventory absorb the solar energy and reradiate back to the space at night.

Summer overheat protection is provided by both an overhang on the south roof edge and by natural ventilation. Auxiliary energy is provided by two liquid-to-air heat exchangers supplied by the building boiler. Control thermostats for the auxiliary system are set at approximately 60°F. Five thermostatically-controlled circulating fans located along the south wall were initially designed to assist in distribution of the collected solar energy by operating when the temperature near the fan falls below 60°F or rises above approximately 90°F.

During the 1977-1978 heating season, it was realized that the operation of the circulating fans provided very little benefit to the solar system during the heating season. Therefore, they were turned off and not used during the 1979-1980 heating season.

The system was designed to satisfy approximately 50% of the annual space heating demand. However, the design performance projections were made before additional insulation was added to the building roof. Consequently, revised design performance projections would be expected to predict a solar contribution of greater than 50%. Results of previous performance analysis for the near-average winter of 1977-1978 have shown that the system does perform above these design projections.

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

APPENDIX B

PERFORMANCE EVALUATION TECHNIQUES

The performance of the Kalwall Construction 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.

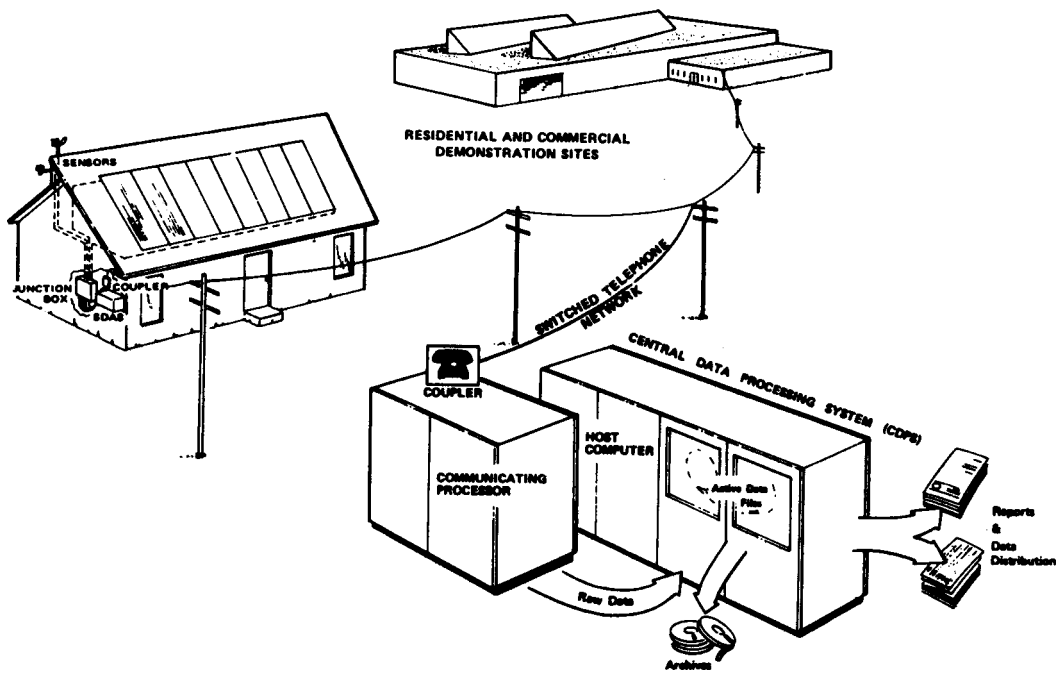


Figure B-1. The National Solar Data Network

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

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

OTHER DATA REPORTS ON THIS SITE*

Monthly Performance Reports

November 1977, SOLAR/2015-77/11
December 1977, SOLAR/2015-77/12
January 1978, SOLAR/2015-78/01
February 1978, SOLAR/2015-78/02
March 1978, SOLAR/2015-78/03
April 1978, SOLAR/2015-78/04
May 1978, SOLAR/2015-78/05
June 1978, SOLAR/2015-78/06
July 1978, SOLAR/2015-78/07
August 1978, SOLAR/2015-78/08
September 1978, SOLAR/2015-78/09
October 1978, SOLAR/2015-78/10
November 1978, SOLAR/2015-78/11
December 1978, SOLAR/2015-78/12
January 1979, SOLAR/2015-79/01
February 1979, SOLAR/2015-79/02
March 1979, SOLAR/2015-79/03
April 1979, SOLAR/2015-79/04
May 1979, SOLAR/2015-79/05
June 1979, SOLAR/2015-79/06
July 1979, SOLAR/2015-79/07
August 1979, SOLAR/2015-79/08
September 1979, SOLAR/2015-79/09
October 1979, SOLAR/2015-79/10
November 1979, SOLAR/2015-79/11
December 1979, SOLAR/2019-79/11
January 1980, SOLAR/2015-80/01
February 1980, SOLAR/2015-80/02
March 1980, SOLAR/2015-80/03
April 1980, SOLAR/2015-80/04
May 1980, SOLAR/2015-80/05
June 1980, SOLAR/2015-80/06
August 1980, SOLAR/2015-80/08

Performance Evaluation: July 1978, SOLAR/2015-78/14

Solar Project Description: May 1978, SOLAR/2015-78/50

Solar Project Cost Report: May 1978, SOLAR/2015-78/60

Thermal Performance of Kalwall Corporation Warehouse Passive Solar Energy
Space Heating System: November 1978, SOLAR/2015-78/39

* 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

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
- Section 2. Solar Terminology
- Section 3. Abbreviations

SECTION 1. PERFORMANCE FACTOR DEFINITIONS

| <u>SYMBOL</u> | <u>NAME</u> | <u>DEFINITION</u> |
|---------------|--|--|
| 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

| <u>SYMBOL</u> | <u>NAME</u> | <u>DEFINITION</u> |
|---------------|---|--|
| 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

| <u>SYMBOL</u> | <u>NAME</u> | <u>DEFINITION</u> |
|---------------|--------------------------------------|--|
| 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

| <u>SYMBOL</u> | <u>NAME</u> | <u>DEFINITION</u> |
|---------------|-----------------------------------|--|
| 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

| <u>SYMBOL</u> | <u>NAME</u> | <u>DEFINITION</u> |
|---------------|----------------------------------|---|
| * 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

| <u>SYMBOL</u> | <u>NAME</u> | <u>DEFINITION</u> |
|---------------|---|---|
| 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

| <u>SYMBOL</u> | <u>NAME</u> | <u>DEFINITION</u> |
|---------------|----------------|-------------------------------------|
| 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.

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

Fixed Collector

A solar collector that is fixed in position and cannot be rotated to follow the sun daily or seasonably.

Flat Plate Collector

A solar energy collecting device consisting of a relatively thin panel of absorbing material. A container with insulated bottom and sides and covered with one or more covers transparent to visible solar energy and relatively opaque to infrared energy. Visible energy from the sun enters through the transparent cover and raises the temperature of the absorbing panel. The infrared energy re-radiated from the panel is trapped within the collector because it cannot pass through the cover. Glass is an effective cover material (see Selective Surface).

Focusing Collector

A concentrating type collector using parabolic mirrors or optical lenses to focus the energy from a large area onto a small absorbing area.

Fossil Fuel

Petroleum, coal, and natural gas derived fuels.

| | |
|--------------------------------|---|
| Glazing | In solar/energy technology, the transparent covers used to reduce energy losses from a collector panel. |
| Heat Exchanger | A device used to transfer energy from one heat transfer fluid to another while maintaining physical segregation of the fluids. Normally used in systems to provide an interface between two different heat transfer fluids. |
| Heat Transfer Fluid | The fluid circulated through a heat source (solar collector) or heat exchanger that transports the thermal energy by virtue of its temperature. |
| Heating Degree Days | The sum over a specified period of time of the number of degrees the average daily temperature is <u>below</u> 65°F. |
| Instantaneous Efficiency | The efficiency of a solar collector at one operating point, $\frac{T_i - T_a}{I}$, under steady state conditions (see Operating Point). |
| Instantaneous Efficiency Curve | A plot of solar collector efficiency against operating point, $\frac{T_i - T_a}{I}$ (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: |
| | $\frac{T_i - T_a}{I} \quad \frac{^{\circ}\text{F} \times \text{hr.} \times \text{sq. ft.}}{\text{BTU}}$ |
| Operational Collector Efficiency | Ratio of collected solar energy to incident solar energy <u>only during the time the collector fluid is being circulated with the intention of delivering solar-source energy to the system.</u> |
| 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 thermal 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 parameter 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

APPENDIX D

PERFORMANCE EQUATIONS

KALWALL CORPORATION

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

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

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

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

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 \bar{C}_p is the average specific heat, in $\text{BTU}/\text{lb}_m\text{-}^\circ\text{F}$, of the heat transfer fluid and ΔT , in $^\circ\text{F}$, is the temperature differential across the heat exchanging component.

* See Appendix B.

For an air system ΔH is generally given by

$$\Delta H = H_a(T_{out}) - H_a(T_{in})$$

where $H_a(T)$ is the enthalpy, in BTU/lb_m, of the transport air evaluated at the inlet and outlet temperatures of the heat exchanging component.

$H_a(T)$ can have various forms, depending on whether or not the humidity ratio of the transport air remains constant as it passes through the heat exchanging component.

For electrical power, a general example is

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

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

AMBIENT TEMPERATURE (°F)

$$T_A = T_{001}$$

AVERAGE BUILDING TEMPERATURE (°F)

$$T_B = T_{625} + T_{618} + T_{619} + T_{621} + T_{622} + T_{624} + T_{623/7}$$

DAYTIME AVERAGE AMBIENT TEMPERATURE (°F)

$$T_{DA} = T_{001}$$

for ± three hours from solar noon

TIME OF DAY BUILDING TEMPERATURES (ONCE PER DAY)

$$T_{MID} = T_B$$

at 12 hours from local solar noon

$$T_{6AM} = T_B$$

at six hours before local solar noon

$$T_{NOON} = T_B$$

at local solar noon

$$T6PM = TB$$

at six hours past local solar noon

INCIDENT SOLAR ENERGY (BTU/FT²)

$$SE = I001 \text{ (south wall)}$$

$$SEE = I002 \text{ (east wall)}$$

INCIDENT SOLAR ENERGY (BTU)

$$SEA = SE \times 1,750 + SEE \times 850$$

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.

WIND

WIND NORTH - SOUTH COMPONENT

$$WNS = V001 \times \text{COSD} (D001)$$

WIND EAST - WEST COMPONENT

$$WEW = V001 \times \text{SIND} (D001)$$

WIND VELOCITY

$$WIND = V001$$

AVERAGE STORAGE TEMPERATURE

$$TST = T102 + T103 + 2 \times T104 + T602 + T605 + 2 \times T105/8$$

HEAT LOSS (UA)

$$\text{(WALL)} \quad HL1 = (T620 + T621 + T624 + T625/4) - T600 \times UA1$$

$$\text{(WALL)} \quad HL2 = (T618 + T619 + T622/3) - T001 \times UA2$$

$$\text{(WALL)} \quad HL3 = (T622 + T623 + T624 + T625/4) - T601 \times UA3$$

$$\text{(SOUTH)} \quad HL4 = (T618 + T619 + T620 + T621/4) - T001 \times UA4$$

$$\text{(FLOOR)} \quad HL5 = (T602 + T102 + T605/3) - (T104 + T105/2) \times UA5$$

$$\text{(ROOF)} \quad HL6 = (T606 + T607 + T608 + T609/4) - T100 \times UA6$$

INFILTRATION

$$H1 = \text{Volume} \times 0.07216 \times \text{HRF} \times (\text{TB} - \text{TA}) \times \text{Hinf}$$

where Hinf = air changes per hour adjusted for wind speed and door opening.

HEAT LOAD

$$\text{HL} = \text{HL1} + \text{HL2} + \text{HL3} + \text{HL4} + \text{HL5} + \text{HL6} + \text{H1}$$

SYSTEM OPERATING ENERGY

$$\text{HOPE} = \text{EP100} + \text{EP400} \times \text{FANRATE}$$

HEAT EXCHANGER DELTA TEMPERATURES

$$\text{DTPRI} = \text{T450} - \text{T400}$$

$$\text{DTSEC} = \text{T450} - \text{T401}$$

$$\text{DTMAIN} = \text{T450} - \text{T403}$$

AUXILIARY THERMAL ENERGY

$$\text{HAT} = \text{W400} \times \text{RHO} (\text{T400}) \times \text{CP} (\text{T400}) \times \text{DTPRI} + \text{W401} \times \text{RHO} (\text{T401}) \times \text{CP} (\text{T401}) \times \text{DTSEC} + \text{W402} \times \text{RHO} (\text{T403}) \times \text{CP} (\text{T403}) \times \text{DTMAIN}$$

ELECTRICAL ENERGY SAVINGS

$$\text{HSVE} = -56.8833 \times \text{EP100}$$

CHANGE IN STORED ENERGY

$$\text{STECH} = \text{STOMASS} \times (\text{TST} - \text{DCDTST})$$

ENERGY INTO STORAGE

$$\text{if STECH} > 0 \text{ then STE1} = \text{STECH}$$

ENERGY FROM STORAGE

$$\text{if STECH} < 0 \text{ then STE0} = - \text{STECH}$$

SOLAR ENERGY TO LOAD

$$\text{SEL} = \text{HL} - \text{HAT}$$

SOLAR ENERGY USED

$$\text{HSE} = \text{SEL}$$

AUXILIARY THERMAL

$$\text{AXT} = \text{HAT}$$

SOLAR FRACTION

$$\text{HSFR} = (\text{HSE}/\text{HL}) + 100$$

FOSSIL ENERGY SAVINGS

$$\text{HSVF} = \text{HSE}/0.6$$

SYSTEM PERFORMANCE FACTOR

$$\text{SYSPF} = \text{HL}/(\text{SEL}/0.8 + \text{AXT})$$

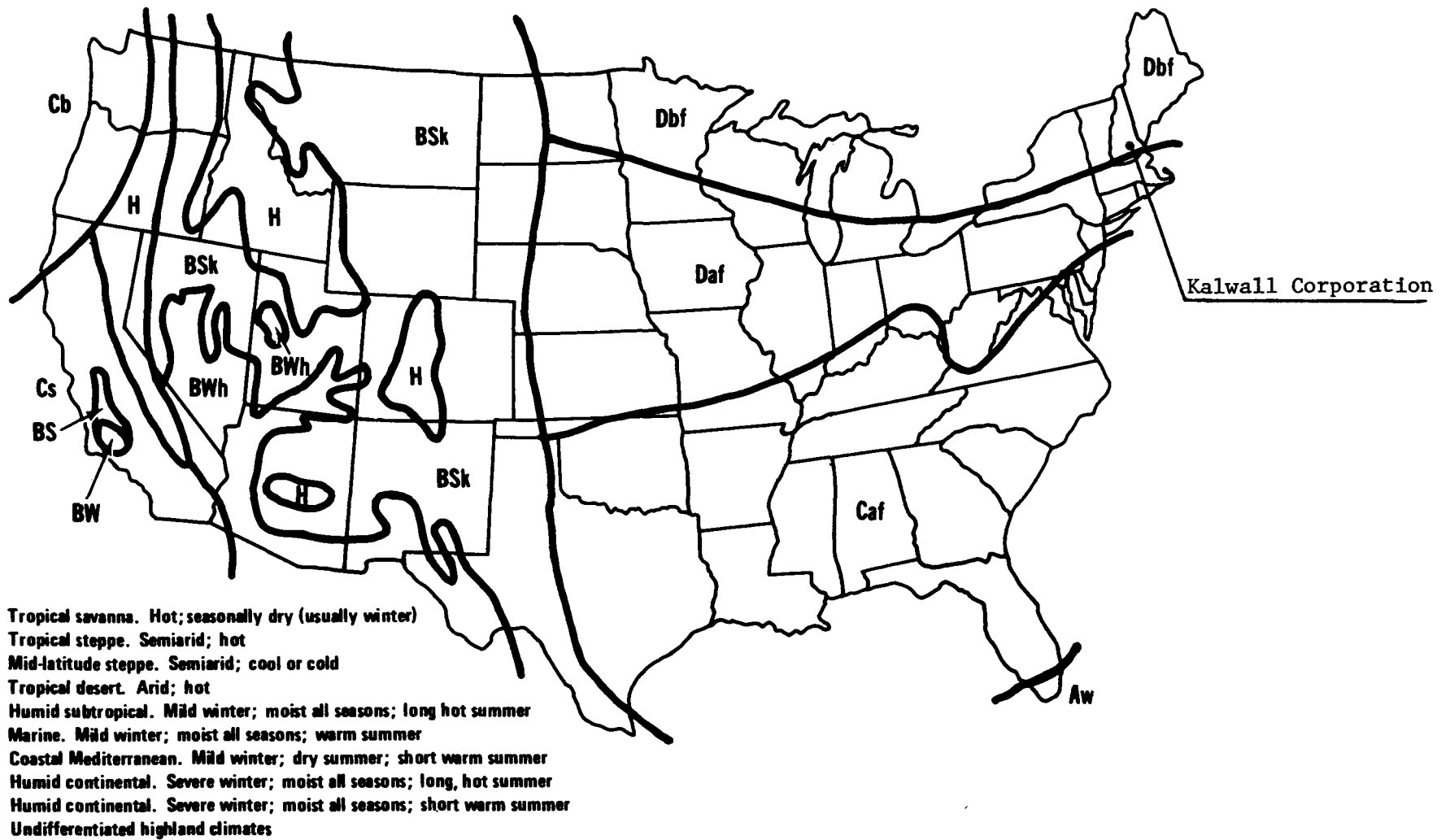
SOLAR ENERGY COLLECTED (BTU)

$$\text{SECA} = \text{HSE} + \text{STECH}$$

SOLAR ENERGY COLLECTED (BTU/FT²)

$$\text{SEC} = \text{SECA}/1,750$$

APPENDIX E
METEOROLOGICAL CONDITIONS



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

Figure E-1. Meteorological Map of the United States Showing Kalwall Corporation Location

KALWALL CORPORATION LONG-TERM WEATHER DATA

COLLECTOR TILT: 90 DEGREES
 LATITUDE: 43 DEGREES

LOCATION: MANCHESTER, NEW HAMPSHIRE
 COLLECTOR AZIMUTH: 0 DEGREES

| MONTH | HOBAR | HBAR | KBAR | RBAR | SBAR | HDD | CDD | TBAR |
|-------|-------|-------|---------|-------|------|-------|-----|------|
| OCT | 1,846 | 819 | 0.44328 | 1.172 | 960 | 487 | 0 | 49 |
| NOV | 1,302 | 465 | 0.35691 | 1.487 | 691 | 810 | 0 | 38 |
| DEC | 1,065 | 361 | 0.33922 | 1.700 | 614 | 1,246 | 0 | 25 |
| JAN | 1,192 | 461 | 0.38658 | 1.682 | 775 | 1,376 | 0 | 21 |
| FEB | 1,665 | 686 | 0.41182 | 1.283 | 880 | 1,187 | 0 | 23 |
| MAR | 2,291 | 973 | 0.42493 | 0.904 | 880 | 1,014 | 0 | 32 |
| APR | 2,958 | 1,316 | 0.44496 | 0.621 | 818 | 624 | 0 | 44 |

LEGEND:

HOBAR - Monthly average daily extraterrestrial radiation (on a horizontal plane) 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 x HBAR) in BTU/day-Ft².

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: KALWALL CORPORATION
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 | WIND DIRECTION DEGREES (N115) | WIND SPEED M.P.H. (N114) |
|--------------------------------|---|---|----------------------------------|--|-----------------------------------|
| 1 | 78 | 58 | 61 | 0 | 1 |
| 2 | 652 | 63 | 68 | 0 | 0 |
| 3 | 9 | 59 | 62 | 0 | 1 |
| 4 | 1131 | 66 | 75 | 0 | 1 |
| 5 | 191 | 63 | 68 | 0 | 1 |
| 6 | 1570 | 60 | 66 | 227 | 5 |
| 7 | 226 | 54 | 61 | 278 | 2 |
| 8 | 1078 | 48 | 55 | 289 | 8 |
| 9 | 0 | 39 | 39 | 0 | 2 |
| 10 | 5 | 36 | 40 | 0 | 0 |
| 11 | 906 | 39 | 44 | 0 | 1 |
| 12 | 3 | 44 | 46 | 0 | 0 |
| 13 | 773 | 49 | 54 | 277 | 3 |
| 14 | 660 | 42 | 51 | 314 | 3 |
| 15 | 559 | 44 | 51 | 259 | 3 |
| 16 | 1753 | 44 | 55 | 322 | 2 |
| 17 | 645 | 45 | 53 | 0 | 1 |
| 18 | 568 | 53 | 64 | 0 | 1 |
| 19 | 777 | 47 | 57 | 0 | 1 |
| 20 | 796 | 61 | 70 | 0 | 2 |
| 21 | 1175 | 66 | 79 | 0 | 1 |
| 22 | 1232 | 71 | 88 | 0 | 0 |
| 23 | 1235 | 67 | 77 | 0 | 2 |
| 24 | 273 | 59 | 62 | 290 | 4 |
| 25 | 706 | 47 | 53 | 283 | 5 |
| 26 | 626 | 40 | 47 | 300 | 3 |
| 27 | 1290 | 37 | 49 | 0 | 2 |
| 28 | 0 | 35 | 37 | 0 | 1 |
| 29 | 523 | 46 | 54 | 0 | 2 |
| 30 | 850 | 44 | 55 | 329 | 2 |
| 31 | 1729 | 42 | 57 | 0 | 0 |
| SUM | 22918 | - | - | - | - |
| AVG | 719 | 51 | 58 | 0 | 2 |

DE-3

**MONTHLY REPORT: KALWALL CORPORATION
NOVEMBER 1979
ENVIRONMENTAL SUMMARY**

| DAY OF MONTH (NBS ID) | TOTAL INSOLATION BTU/SQ. FT (Q001) | AMBIENT TEMPERATURE DEG F (N113) | DAYTIME AMBIENT TEMP DEG F | WIND DIRECTION DEGREES (N115) | WIND SPEED M.P.H. (N114) |
|--------------------------------|---|---|----------------------------------|--|-----------------------------------|
| 1 | 1513 | 45 | 57 | 0 | 1 |
| 2 | 1012 | 57 | 68 | 0 | 2 |
| 3 | 0 | 48 | 47 | 327 | 3 |
| 4 | 1416 | 45 | 57 | 317 | 2 |
| 5 | 1605 | 42 | 57 | 0 | 0 |
| 6 | 552 | 41 | 47 | 0 | 1 |
| 7 | 123 | 45 | 50 | 0 | 0 |
| 8 | 376 | 43 | 48 | 0 | 1 |
| 9 | 580 | 47 | 53 | 0 | 1 |
| 10 | 100 | 57 | 63 | 242 | 3 |
| 11 | 54 | 46 | 49 | 0 | 1 |
| 12 | 0 | 42 | 44 | 0 | 1 |
| 13 | 0 | 41 | 42 | 0 | 1 |
| 14 | 23 | 41 | 44 | 320 | 3 |
| 15 | 1703 | 39 | 46 | 290 | 4 |
| 16 | 1426 | 34 | 36 | 301 | 7 |
| 17 | 669 | 41 | 47 | 278 | 4 |
| 18 | 1014 | 45 | 53 | 0 | 2 |
| 19 | 1230 | 41 | 49 | 0 | 0 |
| 20 | 82 | 42 | 46 | 0 | 0 |
| 21 | 1164 | 43 | 57 | 0 | 1 |
| 22 | 26 | 44 | 47 | 0 | 0 |
| 23 | 722 | 56 | 63 | 0 | 1 |
| 24 | 126 | 59 | 60 | 0 | 1 |
| 25 | 67 | 59 | 63 | 0 | 1 |
| 26 | 0 | 56 | 55 | * | 3 |
| 27 | 1414 | 48 | 58 | 273 | 5 |
| 28 | 897 | 46 | 62 | 261 | 4 |
| 29 | 1463 | 38 | 45 | 277 | 6 |
| 30 | 1339 | 34 | 41 | 271 | 4 |
| SUM | 20694 | - | - | - | - |
| AVG | 690 | 45 | 52 | 305 | 2 |

*DEMOTES UNAVAILABLE DATA.

MONTHLY REPORT: KALWALL CORPORATION
 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 | WIND DIRECTION DEGREES (N115) | WIND SPEED M.P.H. (N114) |
|-----------------------|------------------------------------|----------------------------------|----------------------------|-------------------------------|--------------------------|
| 1 | 957 | 34 | 41 | 0 | 1 |
| 2 | 738 | 29 | 36 | 326 | 4 |
| 3 | 1587 | 31 | 41 | 302 | 5 |
| 4 | 318 | 34 | 40 | 274 | 4 |
| 5 | 17 | 34 | 34 | 0 | 2 |
| 6 | 830 | 48 | 55 | 186 | 2 |
| 7 | 1124 | 44 | 51 | 307 | 3 |
| 8 | 648 | 35 | 44 | 292 | 9 |
| 9 | 504 | 26 | 29 | 251 | 4 |
| 10 | 1028 | 33 | 41 | 0 | 1 |
| 11 | 1069 | 45 | 52 | 0 | 1 |
| 12 | 877 | 50 | 62 | 260 | 2 |
| 13 | 0 | 31 | 33 | 1 | 3 |
| 14 | 1061 | 24 | 29 | 323 | 3 |
| 15 | 1463 | 23 | 32 | 0 | 1 |
| 16 | 0 | 34 | 35 | 0 | 0 |
| 17 | 1570 | 23 | 21 | 320 | 9 |
| 18 | 1548 | 12 | 23 | 312 | 4 |
| 19 | 95 | 7 | 12 | 0 | 1 |
| 20 | 1476 | 13 | 25 | 0 | 1 |
| 21 | 11 | 25 | 29 | 0 | 1 |
| 22 | 0 | 33 | 35 | 0 | 0 |
| 23 | 35 | 38 | 41 | 0 | 0 |
| 24 | 245 | 44 | 51 | 0 | 0 |
| 25 | 0 | 45 | 47 | 0 | 1 |
| 26 | 148 | 41 | 45 | 326 | 4 |
| 27 | 372 | 35 | 40 | 322 | 9 |
| 28 | 1486 | 34 | 38 | 320 | 10 |
| 29 | 1532 | 40 | 48 | 315 | 7 |
| 30 | 1413 | 35 | 43 | 316 | 6 |
| 31 | 1557 | 30 | 39 | 322 | 5 |
| SUM | 23708 | - | - | - | - |
| AVG | 765 | 33 | 38 | 315 | 3 |

MONTHLY REPORT: KALWALL CORPORATION
 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 | WIND DIRECTION DEGREES (N115) | WIND SPEED M.P.H. (N114) |
|-----------------------|------------------------------------|----------------------------------|----------------------------|-------------------------------|--------------------------|
| 1 | 1434 | 30 | 41 | 0 | 0 |
| 2 | 902 | 30 | 40 | 0 | 1 |
| 3 | 1548 | 23 | 32 | 331 | 4 |
| 4 | 1353 | 21 | 31 | 322 | 2 |
| 5 | 649 | 23 | 29 | 4 | 2 |
| 6 | 1575 | 18 | 30 | 0 | 1 |
| 7 | 0 | 23 | 30 | 0 | 1 |
| 8 | 1386 | 32 | 37 | 281 | 6 |
| 9 | 52 | 23 | 27 | 0 | 1 |
| 10 | 1493 | 21 | 31 | 0 | 1 |
| 11 | 2 | 36 | 33 | 0 | 2 |
| 12 | 1263 | 34 | 33 | 276 | 12 |
| 13 | 973 | 25 | 32 | 0 | 1 |
| 14 | 43 | 30 | 35 | 0 | 1 |
| 15 | 3 | 41 | 47 | 0 | 3 |
| 16 | 1586 | 34 | 44 | 10 | 3 |
| 17 | 24 | 30 | 31 | 0 | 2 |
| 18 | 145 | 35 | 39 | 0 | 0 |
| 19 | 46 | 38 | * | 311 | 4 |
| 20 | 817 | 32 | 38 | 302 | 8 |
| 21 | 1656 | 24 | 33 | 296 | 8 |
| 22 | 157 | 23 | 28 | 0 | 1 |
| 23 | 112 | 29 | 32 | 0 | 1 |
| 24 | 988 | 16 | 18 | 274 | 9 |
| 25 | 1588 | 18 | 26 | 291 | 5 |
| 26 | 1687 | 23 | 33 | 303 | 7 |
| 27 | 1677 | 26 | 38 | 314 | 5 |
| 28 | 1021 | 26 | 34 | 303 | 5 |
| 29 | 1010 | 24 | 33 | 295 | 5 |
| 30 | 1724 | 14 | 22 | 314 | 8 |
| 31 | 1049 | 13 | 20 | 322 | 5 |
| SUM | 27965 | - | - | - | - |
| AVG | 902 | 26 | 33 | 309 | 4 |

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: KALWALL CORPORATION
 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 | WIND DIRECTION DEGREES (N115) | WIND SPEED M.P.H. (N114) |
|-----------------------|------------------------------------|----------------------------------|----------------------------|-------------------------------|--------------------------|
| 1 | * | * | * | * | * |
| 2 | 1611 | 17 | 26 | 319 | 8 |
| 3 | 1721 | 17 | 27 | 319 | 7 |
| 4 | 1694 | 21 | 34 | 325 | 3 |
| 5 | 1694 | 19 | 31 | 325 | 3 |
| 6 | 1329 | 22 | 33 | 0 | 1 |
| 7 | 4 | 26 | 29 | 355 | 2 |
| 8 | 1755 | 28 | 41 | 329 | 5 |
| 9 | 1366 | 26 | 38 | 0 | 2 |
| 10 | 1568 | 25 | 37 | 334 | 2 |
| 11 | 1732 | 25 | 38 | 0 | 1 |
| 12 | 1315 | 28 | 41 | 311 | 3 |
| 13 | 1702 | 27 | 40 | 300 | 3 |
| 14 | 1020 | 28 | 38 | 289 | 3 |
| 15 | * | * | * | * | * |
| 16 | 47 | 23 | 25 | 330 | 3 |
| 17 | 1972 | 18 | 26 | 298 | 6 |
| 18 | 1766 | 21 | 31 | 250 | 2 |
| 19 | 1073 | 32 | 43 | 0 | 2 |
| 20 | 1383 | 37 | 50 | 0 | 0 |
| 21 | 478 | 37 | 47 | 326 | 3 |
| 22 | 26 | 24 | 26 | 0 | 1 |
| 23 | 710 | 32 | 39 | 328 | 2 |
| 24 | 199 | 34 | 36 | 0 | 1 |
| 25 | 1640 | 35 | 47 | 0 | 2 |
| 26 | 1597 | 21 | 29 | 326 | 6 |
| 27 | 458 | 15 | 20 | 0 | 1 |
| 28 | 1293 | 22 | 30 | 295 | 5 |
| 29 | * | * | * | * | * |
| SUM | 34748 | - | - | - | - |
| AVG | 1198 | 25 | 35 | 322 | 3 |

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: KALWALL CORPORATION
 MARCH 1980
 ENVIRONMENTAL SUMMARY

| DAY OF MONTH (NBS ID) | TOTAL INSOLATION BTU/SQ. FT (Q001) | AMBIENT TEMPERATURE DEG F (N113) | DAYTIME AMBIENT TEMP DEG F | WIND DIRECTION DEGREES (N115) | WIND SPEED M.P.H. (N114) |
|-----------------------|------------------------------------|----------------------------------|----------------------------|-------------------------------|--------------------------|
| 1 | * | * | * | * | * |
| 2 | * | * | * | * | * |
| 3 | * | * | * | * | * |
| 4 | * | * | * | * | * |
| 5 | * | * | * | * | * |
| 6 | 1575 | 37 | * | 300 | 5 |
| 7 | 560 | 38 | 43 | 0 | 1 |
| 8 | 0 | 36 | 37 | 0 | 1 |
| 9 | 938 | 37 | 43 | 310 | 5 |
| 10 | 1139 | 38 | 47 | 0 | 2 |
| 11 | 363 | 33 | 33 | 286 | 9 |
| 12 | 1748 | 24 | 30 | 297 | 11 |
| 13 | 1204 | 26 | 36 | 41 | 2 |
| 14 | 11 | 31 | 35 | 336 | 6 |
| 15 | 1043 | 28 | 33 | 301 | 13 |
| 16 | 1651 | 28 | 35 | 315 | 5 |
| 17 | 431 | 39 | 48 | 0 | 1 |
| 18 | 585 | 44 | 47 | 292 | 9 |
| 19 | 1624 | 39 | 49 | 295 | 6 |
| 20 | 1310 | 46 | 57 | 0 | 1 |
| 21 | 0 | 38 | 41 | 59 | 5 |
| 22 | 651 | 40 | 40 | 28 | 7 |
| 23 | 1578 | 48 | 60 | 333 | 3 |
| 24 | 1428 | 46 | 60 | 0 | 2 |
| 25 | 131 | 39 | 41 | 29 | 2 |
| 26 | 430 | 42 | 48 | 333 | 3 |
| 27 | 293 | 42 | 49 | 0 | 1 |
| 28 | 1015 | 44 | 55 | 0 | 0 |
| 29 | 122 | 44 | 48 | 0 | 1 |
| 30 | 58 | 40 | 44 | 0 | 2 |
| 31 | 703 | 38 | 48 | 55 | 2 |
| SUM | 24550 | - | - | - | - |
| AVG | 792 | 38 | 44 | 324 | 4 |

* DENOTES UNAVAILABLE DATA.

MONTHLY REPORT: KALWALL CORPORATION
APRIL 1980
ENVIRONMENTAL SUMMARY

| DAY OF MONTH (NBS ID) | TOTAL INSOLATION BTU/SQ. FT (Q001) | AMBIENT TEMPERATURE DEG F (W113) | DAYTIME AMBIENT TEMP DEG F | WIND DIRECTION DEGREES (W115) | WIND SPEED M. P. H. (W114) |
|--------------------------------|---|---|----------------------------------|--|-------------------------------------|
| 1 | 1439 | 45 | 60 | 0 | 1 |
| 2 | 82 | 39 | 46 | 0 | 1 |
| 3 | 1402 | 48 | 59 | 311 | 2 |
| 4 | 0 | 40 | 42 | 0 | 1 |
| 5 | 248 | 40 | 46 | 299 | 5 |
| 6 | 1181 | 46 | 61 | 318 | 2 |
| 7 | 1278 | 42 | 55 | 93 | 2 |
| 8 | 43 | 44 | 48 | 0 | 1 |
| 9 | 51 | 47 | 52 | 79 | 2 |
| 10 | 6 | 52 | 53 | 0 | 2 |
| 11 | 920 | 53 | 60 | 298 | 3 |
| 12 | 367 | 51 | 56 | 0 | 2 |
| 13 | 1270 | 56 | 63 | 294 | 7 |
| 14 | 166 | 46 | 50 | * | 2 |
| 15 | 749 | 56 | 65 | 261 | 4 |
| 16 | 342 | 44 | 53 | 319 | 5 |
| 17 | 1232 | 43 | 53 | 324 | 6 |
| 18 | 586 | 45 | 57 | 299 | 2 |
| 19 | 1184 | 51 | 66 | 0 | 2 |
| 20 | 695 | 56 | 70 | 243 | 3 |
| 21 | 1150 | 57 | 70 | 319 | 4 |
| 22 | 567 | 42 | 49 | 343 | 3 |
| 23 | 339 | 50 | 54 | 356 | 3 |
| 24 | 678 | 54 | 60 | 0 | 1 |
| 25 | 624 | 53 | 61 | 0 | 1 |
| 26 | 120 | 51 | 53 | 0 | 0 |
| 27 | 415 | 51 | 64 | 0 | 2 |
| 28 | 0 | 40 | 40 | 39 | 5 |
| 29 | 11 | 43 | 44 | 24 | 4 |
| 30 | 183 | 53 | 57 | 0 | 0 |
| SUM | 17325 | - | - | - | - |
| AVG | 578 | 48 | 56 | 332 | 3 |

* DENOTES UNAVAILABLE DATA.

APPENDIX F

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

APPENDIX F

SITE HISTORY, PROBLEMS, CHANGES IN SOLAR SYSTEM

Kalwall Corporation was occupied for all of the reporting period. During this time, the solar system operated the full time. This system has been in operation since November 1977. Since being put into operation, there have not been any major operational problems.

APPENDIX G
CONVERSION FACTORS

APPENDIX G
CONVERSION FACTORS

Energy Conversion Factors¹

| <u>Fuel Type</u> | <u>Energy Content</u> | <u>Fuel Source Conversion Factor</u> |
|----------------------------------|-------------------------|--|
| 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 | 979.43×10^{-6} cubic feet/ BTU |
| Electricity | 3,413 BTU/kilowatt-hour | 293.08×10^{-6} kwh/BTU |

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

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

³No. 5 and No. 6 fuel oils

APPENDIX H
SENSOR TECHNOLOGY

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 shadow-band 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/ft²-hr.

The addition of a shadow band 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 shadow band 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 wave/length of about 285 to 2,800 nanometers. The temperature dependence is $\pm 1\%$ over the range of -4°F to 104°F . It has a response time of one second and a linearity of $\pm 5\%$ over the range of the instrument.

Flow Sensors

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

Power Sensors

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

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

The resultant measurements of the wattmeter are summarized below:

1. Output is directly proportional to the flux in the magnetic core which in turn is directly proportional to the load current (I).
2. Output is directly proportional to the load voltage (E).
3. Final output is directly proportional to the vector product of E, I, and $\cos \phi$ (power factor angle). This output is read into the SDAS as an electrical power in watts.