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*Passive Test Cell Data
for the Solar Laboratory
Winter 1980-81*

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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**Passive-Test-Cell Data
for the Solar Laboratory,
Winter 1980-81**

R. D. McFarland

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CONTENTS

ABSTRACT	1
I. TEST CELL PHYSICAL DESCRIPTION AND CONFIGURATIONS.	2
A. Location and Climate of the Los Alamos Solar Laboratory.	2
B. Passive Test Buildings	2
C. Test Cell Configurations for 1980-81 Winter.	6
D. Summary.	25
E. Measured Test Cell Load Coefficients	26
F. Forced Ventilation	29
II. DATA SYSTEM, INSTRUMENTATION, AND CHANNEL LIST	30
A. Data Channels - Cell Data Sensors.	30
B. Auxiliary Heating.	31
C. Temperature Sensors.	34
D. Weather Data	35
E. Channel Listing.	36
III. DATA RESULTS AND COMPARISONS	45
A. Weather Data	45
B. Cell Data.	45
C. Cell Totals and Calculated Performance	47
D. Comparisons of Efficiency and Discomfort Index	56
E. Flat Black vs Selective Absorber	57
F. Other Comparisons.	60
IV. CONCLUSIONS.	60
ACKNOWLEDGEMENTS	61
REFERENCES	62
APPENDIX	63

PASSIVE TEST CELL DATA FOR THE SOLAR LABORATORY WINTER 1980-81

by

R. D. McFarland

ABSTRACT

Testing was done during the 1980-81 winter in 400 ft³ test cells at the Los Alamos National Laboratory Solar Lab. This testing was done primarily to determine the relative efficiency of various passive solar heating concepts and to obtain data that could be used to validate computer simulation programs. The passive solar systems tested were Trombe wall with and without selective absorber, water wall, phase-change wall, direct gain, a heat-pipe collector, and two sunspace geometries. The heating load coefficient of these cells was roughly 26 Btu/h °F and the collector area was 23.4 ft², giving a load collector ratio of approximately 27 Btu/°F day ft².

The test cell configurations and instrumentation are detailed herein, and the resulting data and cell efficiencies are discussed. The full set of data from December 7, 1980, through March 31, 1981, is available on request in any of several forms from

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Los Alamos, NM 87545
(505) 667-2620

I. TEST CELL PHYSICAL DESCRIPTION AND CONFIGURATIONS

A. Location and Climate of the Los Alamos Solar Laboratory

The Los Alamos National Laboratory Solar Lab is located at Tech Area (TA) 46 on Pajarito Road between Los Alamos and White Rock, New Mexico, at 106.3° west longitude, 35.8° north latitude, at an altitude of 7080 ft. The average annual heating season in Los Alamos is 6500 °F days.

The winters are generally sunny, with occasional periods of one or two cloudy days during snow storms. Average annual snowfall for Los Alamos is 50 in. Winds are generally light with occasional gusty periods, especially in the spring.

The 1980-81 heating season was mild with less than 10 in. of snow before March of which 7 in. came on December 8. March was relatively cloudy with 29 in. of snow. There were 3450 °F days for the period December 1980 through March 1981, compared with a long-term average of 3950 °F days.

B. Passive Test Buildings

The passive test buildings shown in Fig. 1 are roughly 30 ft north of the edge of a pine-covered arroyo. The buildings face true south to within 0.5°. The data monitoring and recording equipment is in a building about 120 ft north of the test buildings. Experiments have been conducted in these buildings for four winters including 1980-81. Hyde (Ref. 1) has written a report covering the testing for the winter of 1979-80.

There are seven passive test buildings, each with two side-by-side test "cells," as shown in Fig. 2. Each test cell is approximately 120 in. high, 86 in. deep, and 62 in. wide (east-west) inside. The north-south partition between cells is constructed of 2-by-4 studs on 16-in. centers with 3-1/2-in. insulation* between studs and 1-in.-thick extruded styrofoam on each side. The east, west, and north walls of the buildings are also 2-by-4 studs on 16-in. centers, with 1-in.-thick extruded styrofoam on the inside and 5/8-in.

*3-1/2-in. insulation is nominally rated at R-11, that is, a thermal resistance of 11 ft² h °F/Btu.

Fig. 1. View of passive test buildings. Cells are numbered 1 through 14 from right to left. Each building contains two cells.

Fig. 2. Basic test cell for 1980-81 winter.

plywood on the outside. Seams in the plywood and between styrofoam sheets were caulked from the inside. A 2-ft-wide by 9-ft-high door is provided on both the east and west sides for access to the cells. This door is insulated with about 4 in. of styrofoam and is held tightly closed most of the time.

Test cell floors consist of 2-by-6 joists running east-west on 16-in. centers, except for the front (south) four joists, which are on 6-in. centers to bear the load of thermal storage walls. The floor is insulated with two layers of 3-1/2-in. insulation between joists and is covered with plywood. The ceiling is also constructed of 2-by-6 joists on 16-in. centers with two layers of 3-1/2-in. insulation and covered on the underside with corrugated metal. The removable roof is about 10 in. above the ceiling and is constructed of 5/8-in. plywood on 2-by-4 studs overlaid with one layer of 30-lb felt and one layer of 90-lb rolled roofing.

The basic test buildings originally had no south wall. The whole south wall was glazed when the passive solar system was installed. A partial south wall was added at the beginning of the 1980-81 heating season to decrease the glazing area and increase the heating load collector ratio (LCR). The open part of the test cell south wall, before passive systems are added, is referred to as the "solar aperture" and is the same on all cells (except cells 9, 10, and 13).

The heating load of the test buildings (BLC), excluding the solar aperture, is calculated to be 26 Btu/h $^{\circ}\text{F}$ per test cell, including an infiltration rate of three air changes per hour, the nominal value for most test cells during the 1980-81 winter. At one air change per hour, the theoretical load coefficient is 16 Btu/h $^{\circ}\text{F}$. This BLC does not include heat transfer across the partition between adjacent cells in the same building. This heat transfer path has a coefficient of 3.5 Btu/h $^{\circ}\text{F}$ and is treated separately because the driving temperature difference is usually much smaller.

Experiments were conducted during the 1980-81 winter and spring to measure the BLC of most of the test cells by covering the solar aperture with a thick wall of insulation. The results are presented below.

C. Test Cell Configurations for 1980-81 Winter

Prior to the 1980-81 heating season, the test cells were modified to reduce the solar aperture area to 23.4 ft^2 . The standard south wall opening after the modifications was 45 in. wide by 75 in. high (Fig. 2). The remainder of the south wall was insulated with 3-1/2 in. of extruded styrofoam between 2-by-4 studs with 1 in. of styrofoam inside the studs and covered with 5/8-in. plywood on the outside.

All test cells (except cells 9, 10, and 13) were initially double glazed with Thermopane® sealed units obtained from Brother Sun in Santa Fe, New Mexico. These units had 3/16-in.-thick panes of standard glass separated by a 1/2-in. air gap. The measured overall solar transmission was 0.69 at normal incidence. A minor amount of condensation was noted in one of the 13 Thermopane® units used during the winter.

Through April 3, 1981, all test cells (except cells 9, 10, and 12) had a nominal lower setpoint of 65°F . This was maintained by supplying auxiliary heat from six 100-W light bulbs in each cell. Until February 5, 1981, the auxiliary heating had been controlled by thermostats, and some of the minimum globe temperatures drifted significantly. After February 5, the auxiliary was controlled by the on-line computer using measured globe temperatures.

The test cell configurations are shown schematically in Fig. 3; Table I gives a summary of the physical properties of the test cell solar systems.

The test cell configurations included three unvented Trombe walls, one water wall, one direct gain, a phase-change wall, two "double-wide" sunspaces, a reference cell, and a heat-pipe collector that was not in operation until the end of January. Two other test cells (cells 9 and 10) were part of a separate project to study sun-tempered buildings; Wray (Ref. 2) has reported the results of those experiments. One of the unvented Trombe wall cells (cell 12) was left unheated and without forced ventilation at the request of the Committee for the Challenges of Modern Society.

All of the cells except 9, 10, and 12 had a forced ventilation rate of three air changes per hour* throughout the winter with some exceptions. The

*These are nominal values. One nominal air change per hour is actually 4.7 SCFM , which translates to about $375 \text{ ft}^3/\text{h}$ at 7000 ft altitude.

Fig. 3. Test cell configurations for 1980-81 winter.

TABLE I

TEST CELL PROPERTIES

Cell	Storage Volume (ft ³)	Storage Mass (lbm)	Storage C _p M (Btu/°F)	Solar Aperture (ft ²)	Total Glazing Area (ft ²)
1 (Trombe wall)	36.6	5,275	952	23.4	23.4
2 (Trombe wall)	36.6	5,275	952	23.4	23.4
3 (Mass wall)	28.5 ^a	4,080	741	23.4	----
after 2/11/81	20.4 ^a	2,915	529	23.4	----
4 (Mass wall)	36.6 ^a	5,275	952	23.4	----
3/4 (Sunspace floor)	30.7 ^a	4,422	798	----	54.2
after 2/11/81	18.2 ^b	1,136	1,136	----	54.2
after 3/9/81	36.4 ^b	2,272	2,272	----	54.2
3/4 Total	95.8	13,777	2,491	46.8	54.2
after 2/11/81	105.9	13,748	3,415	46.8	54.2
after 3/9/81	124.1	14,884	4,551	46.8	54.2
5 (Water wall)	23.6	1,471	1,471	23.2	23.2
6 (Phase change)	6.67	580	-----	23.4	23.4
7 (Mass wall)	28.5 ^a	4,080	741	23.4	----
8 (Mass wall)	36.6 ^a	5,275	952	23.4	----
7/8 (Sunspace floor)	12.2 ^a	1,758	317	----	62.4
after 2/5/81	12.2 ^a	1,758	317	----	100.8
7/8 Total	77.3	11,113	2,010	46.8	62.4/100.8
11 (Direct gain)					
east wall	18.1	2,611	470	----	----
west wall	22.6	3,250	585	----	----
north wall	10.4	1,492	269	----	----
floor	13.1 ^c	1,883	339	----	----
Total	64.2	9,236	1,663	23.4	23.4
12 (Trombe wall)	See Cell 1.				
13	0	0	0	0	0
14	17.2 ^d	1,076	1,076	23.4	23.4

^a Neglecting seven blocks of sunspace floor under mass wall.

^b Water only.

^c Neglecting floor blocks under mass walls.

^d 5-1/2 tanks.

direct gain cell (cell 11) was inadvertently set to one air change per hour from January 8 to January 13, and the air-change rate of the reference cell (cell 13) was purposely varied from December 18 through January 15.

The following is a cell-by-cell description of the solar systems tested for the 1980-81 heating season.

1. Cells 1 and 2 (Figs. 4 and 5). These side-by-side cells were initially identical, unvented Trombe wall cells, except for the absorber surface on the south side of the Trombe wall. In cell 1, the absorber surface was painted with a flat black paint having an estimated solar absorptivity of 0.95 and infrared emissivity of approximately 0.9. In cell 2, a selective absorber foil was applied to the south side of the Trombe wall. This was a commercial copper foil with black chrome plating manufactured by Berry Solar Products. The preseason measurements of the optical properties of a single sample of this foil showed a solar absorptivity of 0.92 and an infrared emissivity of 0.07; these are very close to the advertised values.

Fig. 4. View of south side of cell 2 (with selective absorber foil) and part of cell 1 (flat-black-painted) Trombe wall.

Fig. 5. View of inside (north) surface of typical Trombe wall.

Postseason inspection revealed some problems with the selective absorber installation. The adhesive used to bond the foil to the concrete block wall was found to have shrunk drastically after application, with the result that much of the foil was not in good contact with the wall. The very porous surface of the concrete blocks contributed to the poor bond.

Measurements of the optical properties of four patches of foil taken from cell 2 after the heating season resulted in emissivity values of 0.06 to 0.07, as before. The measured absorptivity values from the four quadrants of the wall, however, were 0.92 and 0.92 at the top and 0.88 and 0.82* at the bottom. The wall was covered with three different pieces of foil. The bottom piece had a distinctly different appearance both when installed and throughout the winter. A postseason visual inspection was made by a representative of Berry Solar Products, who thought the lower section of foil had come from the end of a roll and had been sent to Los Alamos by mistake.

Other than the absorber surface, cells 1 and 2 were identical at the beginning of the heating season. Each had an unvented Trombe wall 15-5/8-in. thick, consisting of 99 "standard" concrete blocks** with a total surface area of 29.8 ft². The blocks, oriented 7-5/8 in. vertically by 5-5/8 in. horizontally in an east-west direction, were in 11 horizontal rows of 9 blocks each. As noted above, the solar aperture is only 23.4 ft²; the mass wall extends beyond the aperture on all sides. The Trombe wall was insulated on the top, east, and west sides with 3 to 4 in. of styrofoam to approach one-dimensional heat flow through the wall.

Modifications were made to the glazing systems of these two cells during the heating season. From December 13, 1980, when cell 2 was finished, to January 5, 1981, both cells 1 and 2 were double glazed with no night insulation. From January 5 to February 3, 1981, R-10*** night insulation was applied to cell 1

*These are total solar-spectrum values obtained using a Gier-Dunkle Solar Reflectometer. Later measurements using a Beckman Spectrophotometer resulted in values about 2% higher.

**The standard concrete block used in cells 1, 2, 3, 4, 7, 8, 11, and 12 is a solid, high-density block measuring 5-5/8 in. by 7-5/8 in. by 15-5/8 in. and weighing 53 lb. The estimated volumetric heat capacity and thermal conductivity of the concrete are 26 Btu/ft³ °F and 1.0 Btu/ft h °F.

***See Ref. 3 for an indication of the true night-insulation thermal resistance.

but not to cell 2. Both cells were still double glazed. From February 4 to March 5, 1981, both cells were single glazed with night insulation continuing on cell 1 only, and from March 5 both cells were single glazed with no night insulation on either.

Night insulation, when used, was put on at approximately 4:30 p.m. MST and removed at about 8:00 a.m. MST. Night insulation consisted of a 2-in.-thick piece of extruded styrofoam cut to the exact size of the glazing aperture and backed by plywood. The styrofoam was held tightly against the outside of the glazing with two 2-by-4s in retainers. The single glazing was one piece of 3/16-in. standard glass obtained from the local paint and glass store. The measured normal solar transmission of this glass was 0.82.

On March 5, 1981, horizontal aluminum-foil reflectors were in place in front of cells 1, 2, and 5. These each measured 45-1/2 in. wide (east-west) and 60 in. long (north-south). During a significant fraction of early March, the reflectors were covered with snow. The foil wrinkled somewhat after installation so that the reflection was not strictly specular. The reflectance was never measured, but other measurements on aluminum foil have resulted in 85% reflectance.

Other pertinent factors are the following:

- (1) December 11, 1980 (11:30 a.m.), to December 12 (2:00 p.m.), cell 1 was partially shaded by a temporary structure in front of cell 2;
- (b) January 11, 1981 (8:00 a.m.), a burned-out light bulb was found in cell 1;
- (c) January 31 (6:50 p.m.) night insulation was installed;
- (d) March 4 (3:00 p.m.) platform built for reflectors; and
- (e) March 5 (9:30 a.m.) platform painted white.

2. Cells 3 and 4 (Figs. 6-9). These cells were combined by cutting a door through the common wall and putting a single sunspace across the entire south side of the building containing cells 3 and 4. Masonry walls 15-1/2 in. thick, similar to the Trombe walls in cells 1 and 2, were installed between each cell and the sunspace. A sunspace doorway was provided on the cell-3 (east) side to provide a thermocirculation path from the sunspace into the cell. Circulation of heated sunspace air to the cell-4 (west) side was provided via cell 3 through the door between the cells. The sunspace doorway

Fig. 6. View through sunspace doorway of cell 3/4 after doorway was widened and water drums were added.

Fig. 8. Six of 10 water drums in cell 3/4 sunspace after February 5.

Fig. 7. South view of double-wide sunspace cell 3/4 before conversion to water-drum storage. The two dark areas are flat black masonry walls.

Fig. 9. Interior of cell 3/4 sunspace looking west.

was 11 in. wide by 75 in. high, reducing the east-side mass-wall portion of the aperture from 23.4 ft² to 17.9 ft². (In the case of the sunspace cells, the aperture and glazing areas are not the same.)

The east portion of the mass wall (between cell 3 and the sunspace) had 84 standard concrete blocks, including 7 at the bottom, which formed a continuation of the sunspace floor beneath the mass wall. Likewise, the west portion of the mass wall between cell 4 and the sunspace had 106 blocks, including 7 at the bottom.

The sunspace was 89 in. deep by 113 in. wide at the floor and was 4 ft deep at the ceiling. Two Thermopane units 45 in. wide by 89 in. high and tilted 60° from horizontal formed the south wall of the sunspace. The east and west ends and the ceiling of the sunspace were insulated with 4 in. of extruded styrofoam and covered with plywood on the outside. Thermal storage in the sunspace floor consisted of 83 standard concrete blocks with the 5-5/8-in. dimension in the vertical direction. The blocks were laid on a plywood platform insulated with 3-1/2 in. of extruded styrofoam on the underside.

The doorway between cells 3 and 4 was 15 in. wide by 75 in. high and was always open during the reported time period. At times during the winter, the doorway between the sunspace and cell 3 ("sunspace doorway") was closed and sealed at night to prevent reverse thermocirculation. This was done at approximately 4:30 p.m. MST, and the door was opened at approximately 8:00 a.m. MST. Until December 20, 1980, this door was left closed during weekends. From December 20, 1980, to January 4, 1981, the door was kept closed at all times. From January 4 to February 22, 1981, the door was closed each night and opened each morning. From February 22 to the end of the heating season, the door was open at all times. Each night from January 5 to March 5, 1981, night insulation similar to that on cell 1 was put on the outside of the sunspace glazing (again, from approximately 4:30 p.m. to 8:00 a.m.).

On February 10-11, 1981, a major change was made to the sunspace configuration. The mass wall was insulated from the sunspace with 4 in. of extruded styrofoam, and a single row of five water-filled drums was placed on the sunspace floor along its north wall with a gap at the doorway. Each of these drums held 27.2 gal. (227 lbm) of water and measured roughly 18 in.

in diameter by 28 in. high. On March 9, 1981, five more water-filled drums were added on top of the original five. At the time the original drums were installed (February 10), the sunspace doorway was widened from 11 in. to 22 in. by removing two columns of blocks.

The sunspace floor and mass wall were painted flat black ($\alpha = 0.95$, $\epsilon = 0.9$), as were the water drums. The extruded styrofoam insulation on the sunspace ceiling and end walls was left unpainted and had an absorptivity of 0.3. When the mass wall was insulated, the south side of the insulation was painted dark brown ($\alpha = 0.87$). Sunspace "air temperature" measurements referred to in the instrumentation section were obtained with suspended thermocouples shielded from solar radiation with two concentric 10-in.-long phenolic tubes. The inside tube was 3/4 in. outside diameter and the outside tube 1-1/4 in. outside diameter. Both tubes were covered on the outside with aluminum foil.

Other pertinent factors are the following:

- (a) January 9, 1981, a burned-out light bulb was found on the cell 4 side;*
- (b) January 19, 1981, the sunspace door was not closed the night before; and
- (c) April 2, 1981, a burned-out light bulb was found on the cell 3 side.

3. Cell 5 (Figs. 10 and 11). A Crimsco Corporation Heat Wall[®] water wall was installed in the solar aperture of cell 5. This unit was a steel tank consisting of five rectangular sections 11-5/8 in. thick (north-south) by 9.2 in. wide (east-west) by 76.4 in. high. The total tank width was 48 in. On the south side were provisions to mount glazings. The south surface of the tank was covered with the same type of selective absorber foil as was used on cell 2. The plastic-lined tank was filled with water and insulated at the east and west edges and at the top.

The water wall was initially double glazed with Thermopane[®]. On February 4 and 5, 1981, the double glazing was removed, and a single sheet of 3/16-in. glass (as in cells 1 and 2) was installed. Because of the physical constraints of the manufactured unit, the final solar aperture of cell 5 was slightly smaller than that of the other cells. On March 9 a reflector similar to

*When a light bulb burns out, it may not be detected for up to 24 hours, or 72 hours over a weekend.

Fig. 10. Cell 5 water wall from the south showing selective absorber.

Fig. 11. Cell 5 with aluminum foil reflector in front. Note reflector above glazing. Also shown is vertical pyranometer mounting.

those on cells 1 and 2 was placed in front of cell 5. Neither a reflector nor a reflector platform was put in front of adjacent cell 6.

Another pertinent factor is that on December 31, 1980, water level was found to be down about 10 in. The tank was refilled and sealed.

4. Cell 6 (Figs. 12 and 13). This cell had a phase-change wall in the solar aperture consisting of 116 cans of a calcium-chloride-based phase-change solution. Each can, manufactured by Texus, Inc., was 4-1/4 in. in diameter, 7 in. high, and was covered on one side with the same type of selective absorber foil that was used in cells 2 and 5. These cans were stacked in 10 rows of 11 cans each with a top row of 6 cans laid on their sides. The rows were separated by thin plywood strips, and the whole wall was sealed with foam rubber strips and caulking to prevent air circulation from the glazing side to the room side of the cans. This cell was double glazed with Thermopane® throughout the heating season. No configuration changes were made to this cell during the heating season, but the addition, in early March, of a platform and reflector in front of adjacent cell 5 would have had some effect on the performance of cell 6.

According to Texus literature, the phase-change cans (Texus Heat Cells®) have the following properties

diameter of can	4.26 in.
height of can	6.94 in.
melting point	$81 \pm 2^{\circ}\text{F}$
latent heat of fusion	$345 \pm 3 \text{ Btu/can}$
mass of salt	4.2 lbm/can
total mass	4.54 lbm/can
specific heat of solid	$1.52 \text{ Btu/}^{\circ}\text{F/can}$

The trade name of the salt is BISOL II®. Additional data found in the literature for $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ are

$$\text{specific heat of liquid} = 0.8 \frac{\text{Btu}}{\text{lbm } ^{\circ}\text{F}}$$

and

$$\text{thermal conductivity} = 0.1 - 0.3 \text{ Btu/h } ^{\circ}\text{F ft.}$$

Fig. 12. South side of phase-change wall with selective absorber in cell 6.

Fig. 13. Interior of phase-change wall in cell 6.

Another pertinent factor is that on March 16, 1981, small salt leaks were noted on about 12 cans. These leaks were never significant, but corrosion was noted at the end seals of many cans when the wall was disassembled in November 1981.

5. Cells 7 and 8 (Figs. 14-17). Cells 7 and 8 were combined to form a "double-wide" sunspace cell (cell 7/8) in the same manner as cell 3/4. Cell 7/8 was essentially the same as cell 3/4, except for the sunspace itself and some operational procedures.

The sunspace of cell 7/8 was 108 in. wide (east-west) by 51 in. deep (north-south) on the outside. The vertical south wall of the sunspace was 62-1/2 in. high and almost entirely glazed. The sunspace "roof" was at an angle of 30° from the horizontal and ran from the sunspace south wall (62-1/2 in. high) to the test cell at a height of 87 in. The "roof" was also almost entirely glazed. At the start of the heating season, the east and west ends of the sunspace were insulated with 4 in. of extruded styrofoam. On February 4, 1981, the east and west ends were glazed with two layers of 1/8-in. Plexiglas-K[®] with a 1/2-in. separation; the total glazed area on each of the ends was 19.2 ft² or roughly 72% of the available area.

The vertical south wall was glazed with two Thermopane[®] units, each with open area dimensions of 44-3/4 in. wide by 50-3/4 in. high, for a total area of 31.5 ft². The 30° sloping roof was also glazed with two Thermopane[®] units having the same open area dimensions.

The sunspace floor was covered with 33 flat-black-painted standard concrete blocks with the 5-5/8-in. dimension perpendicular to the floor. The sunspace was on a platform that extended 46 in. in front of and 17 in. on each side of the sunspace. This platform was initially painted flat black but was repainted white on January 22, 1981.

The sunspace door of cell 7/8 was closed and opened at the same times as that of cell 3/4, except that it was closed nightly until March 5, after which it was left open permanently.

Other pertinent factors are the following:

- (1) December 9, 1980, first noted condensation between glazings of top Thermopane[®], west side that persisted all winter but was never serious;
- (2) January 19, 1981, found light bulb out on east side (cell 7);

Fig. 14. Cell 7/8 sunspace in early part of winter with insulated east and west ends.

Fig. 15. Cell 7/8 sunspace in latter part of winter with glazed ends.

Fig. 16. Cell 7/8 sunspace floor doorway.

Fig. 17. Interior view of from double-wide sunspace cell 7/8 showing part of east-side masonry wall and sunspace doorway on left and doorway between cells on right. Typical also of cell 3/4 in early winter.

- (3) February 2, 1981, found door between cells 7 and 8 closed (the door had probably been closed for the previous two nights);
- (4) February 6 and 7, 1981 one light bulb on cell 8 side worked only intermittently; and
- (5) February 17, 1981, found light bulb on cell 8 side burned out (could have happened any time from the morning of February 13 to the morning of February 17).

6. Cell 11 (Figs. 18-20). This was a direct gain cell with mass in the floor and part way up the east, west, and north walls. A 45-in. by 75-in. Thermopane® unit was used for the solar aperture throughout the heating season. Night insulation similar to that used on cells 1 and 3/4 was installed from January 5 to March 5, 1981, from approximately 4:30 p.m. to 8:00 a.m. MST.

The thermal mass consisted of 44 standard concrete blocks on the floor, 49 blocks on the east wall, 61 blocks on the west wall, and 28 blocks on the north wall. The blocks were all oriented with the 5-5/8-in. dimension perpendicular to the wall surface. The open floor area was 79 in. deep by 52 in. wide (east-west). A 5-5/8-in. strip of the floor was covered by the wall mass, except at the door (at the north end of the east wall). The top of the floor blocks was about 2 in. above the bottom of the glazing, and there was a gap of about 5 in. between the glazing and the mass floor.

Blocks on the east wall extended 54-1/2 in. from 5 in., behind the glazing to the door, and were stacked 109 in. high. The west mass wall was 71 in. long (north-south) by 109 in. high, with two blocks out of the middle for the thermostat. The north mass wall was approximately 53 in. high by 62-1/2 in. wide (east-west) with two extra blocks on the floor nearby.

The concrete blocks were initially left unpainted ($\alpha = 0.7$), but the exposed surfaces of the blocks were painted dark brown ($\alpha = 0.87$) on February 12-13, 1981.

Other pertinent factors are the following:

- (1) January 8-13, 1981, forced ventilation at 1 ac/h;
- (2) January 12, 1981, working in cell most of the day;
- (3) January 21, 1981, night insulation not installed on previous night;
- (4) February 12/13, 1981, working in cell, and
- (5) total auxiliary power in cell 11 is 1000 W rather than the 600 W in the other cells.

Fig. 18. Direct gain cell before the masonry blocks were painted.

Fig. 19. Floor and lower west wall of cell 11 after being painted dark brown.

Fig. 20. Upper west wall of cell 11 after painting.

7. Cell 12. This was an unvented Trombe wall with flat black paint and double glazing (Thermopane®), identical to the initial configuration of cell 1. This cell was part of an SSEA/CCMS* project. It had no auxiliary heat and no forced ventilation. There were no configuration changes on this cell, and only the globe temperature was recorded.

8. Cell 13 (Fig. 21). Cell 13 was a reference cell in which the entire south wall was insulated with 4 in. of extruded styrofoam and covered with plywood painted white on the outside. The cell had no mass other than that of the structure. Except for the experiments with forced ventilation listed below, there were no changes during the heating season. This cell did have auxiliary heating and the same nominal setpoint (65°F) as the other cells.

Other pertinent factors are the following:

- (1) until December 18, 1980, forced ventilation set at 3 ac/h;
- (2) December 18-29, 1980, no forced ventilation;
- (3) December 29, 1980-January 15, 1981, forced ventilation set at 1 ac/h;
- (4) January 5, 1981, forced ventilation set at 3 ac/h;
- (5) January 7, 1981, burned-out relay caused loss of auxiliary power; and
- (6) January 7-19, 1981, styrofoam cover in place on south side of cells 13 and 14 for load measurement.

9. Cell 14 (Figs. 21 and 22). This cell was not completed until January 30, 1981. The solar system for cell 14 was a heat-pipe collector with waterstorage wall built at Battelle Memorial Institute in Columbus, Ohio, and shipped to Los Alamos. The unit consisted of six water heat pipes bonded to a flat black, flat plate collector with six rectangular water-storage tanks stacked vertically and insulated from the collector plate. Each heat pipe slanted upward from west to east. At the east edge of the collector, the pipe is bent around the insulation to the condenser end that was in the water tank. (The water working fluid in the heat pipe was entirely separate from the water in the storage tank.) At night or in cloudy weather, the water drained to the lower end of the heat pipe (away from the storage tank), creating a thermal diode effect. See Ref. 4 for a more complete description of the system.

*Systems Simulation and Economic Analysis Working Group was an informal working cooperation among several U.S. laboratories and research organizations. The Committee for Challenges of Modern Society was a similar international cooperative effort.

Fig. 21. South side of cells 13 and 14. Heat pipes can be seen in cell 14.

Fig. 22. Water-storage tanks in cell 14 showing heat pipe connection.

Since the six-heat-pipe unit was taller than the standard aperture, only five heat pipes could have been fully effective. One of the heat pipes was inoperative when the unit was received and was therefore put on top. Before testing was initiated, however, another of the heat pipes (the third from the top) failed, and the testing was done with four pipes operating. The bottom five thermal storage tanks and half of the top one were filled with water. John Corliss of Battelle suggested that the heat-pipe failures were caused by freeze-thaw cycling of the water in the heat pipes while the unit was not in use.

The standard glazing Thermopane® unit was used on this cell.

Another pertinent factor is that some time between February 9 and February 14, 1981, forced ventilation increased to 3-1/2 ac/h; on February 14 it was reset to 3 ac/h.

D. Summary

Table II gives a brief summary of the major test cell configuration changes.

TABLE II
CONFIGURATION CHANGES

<u>Date</u>	<u>Change</u>
December 13, 1980	Cell 2 finished.
December 20- January 4, 1981	Sunspace doors closed day and night (cells 3/4 and 7/8).
January 5	Started night insulation on cells 1, 3/4, and 11 (7 nights/week).
January 6	Started opening sunspace doors in cells 3/4, and 7/8 daily (7 days/week).
January 22	Painted cell 7/8 platform white.
February 3-5	Single glazed cells 1, 2, and 5; glazed east and west ends of cell 7/8.
February 5	Computer-controlled globe temperatures in cells 1, 2, 3/4, 5, 7/8, and 11.
February 10-11	Insulated south side of mass wall in cell 3/4; put 5 water drums in sunspace.
February 13	Painted inside of cell 11 dark brown.
February 22	Started leaving sunspace door of cell 3/4 open at all times.
March 5	Stopped night insulation (cells 1, 3/4, and 11); stopped closing sunspace door in cell 7/8.
March 5-9	Installed reflectors in front of cells 1, 2, and 5;
March 9	Five more water drums added to cell 3/4 sunspace.

E. Measured Test Cell Load Coefficients

The BLC is merely the total daily required heating energy divided by the 24-hour integral of the difference between cell globe temperature and outside dry bulb temperature. Ideally, this quantity should be measured when there is just enough solar gain through the solar aperture portion of the south wall to offset losses, with negligible solar gain through any other surfaces. The reference cell (cell 13) is assumed to approximate these conditions at all times. Another way of approximating a net adiabatic condition for the solar aperture is to cover it with a heavy layer of insulation. This was done to all of the flat-fronted cells (cells 1, 2, 5, 6, 11, 12, and 14, and, as a check, to 13). A 1-ft-thick cover of extruded styrofoam was sealed to the front of each flat-fronted unit (see Fig. 23) for about a week at a time. This cover should not be confused with the night insulation systems.

Figure 24 shows the BLC of cell 13 during variation of configuration. Initially, cell 13 had the nominal three air changes per hour, and the BLC was fluctuating around the theoretical value of 26 Btu/h °F. On December 18, the ventilation fan was turned off and sealed. The BLC dropped to 18-19 and stayed there when the fan was turned on at the rate of one air change per hour. This indicates that the natural infiltration rate is approximately one air change per hour. When the ventilation fan is on, the cell is positively pressurized so that the forced ventilation should supplant the natural ventilation rather than add to it.

Because of a temperature-controller malfunction, there was no auxiliary heating, and, consequently, no BLC data for January 1-7. During the remainder of the one-air-change period, the BLC was in the range 17-19, slightly higher than the theoretical value of 16. During the latter part of this period (January 6-15), the 1-ft-thick insulation cover was put on cells 13 and 14, and a slight decrease in BLC was detected.

On January 15, the ventilation rate was set back to three air changes per hour, with the insulation cover still in place, and the BLC increased to 25 Btu/h °F. When the insulation was removed on January 19, the BLC increased to the original 26-27. This indicates that the south wall of cell 13 normally has a slight net heat loss.

Figures 25-28 show the BLC results of the other cells with the 1-ft-thick styrofoam cover applied and the normal ventilation rate of three

Fig. 23. Cells 1 and 2 with one-foot-thick insulation cover on south side to measure heating load.

Fig. 24. Measured load coefficient of the reference cell.

Fig. 25. Measured load coefficients of cell 1 and 2 compared to the reference cell.

Fig. 26. Measured load coefficients of cells 5 and 6 compared to the reference cell.

Fig. 27. Measured load coefficients of cell 11 compared with the reference cell.

Fig. 28. Measured load coefficients of cell 14 compared with the reference cell.

air changes per hour. The BLC of cell 13 is shown for comparison. The plots start with the third day after the styrofoam cover was installed and end with the day before it was taken off.

Some large variations are seen among the BLC values of different cells. In comparison with data from cell 13, which appear on all the plots, these seem to be mostly variations with time. The only significant deviation from the BLC of cell 13 is that of cell 6, which seems to be about 15% lower than that of cell 13 during the time the insulation cover was on. Probably a more extensive study should be made of the BLCs using insulation on all cells at the same time.

F. Forced Ventilation

Forced ventilation of test cells was accomplished using a small centrifugal blower on the outside of each cell, blowing air into the cell through a flow-straightening section and a flow nozzle. A deflector plate was placed at the exit of the flow nozzle to diffuse the air coming into the cell. The flow rate was set and checked weekly by connecting the pressure taps of the flow nozzle to an inclined manometer. Adjustments to the flow rate were made by throttling the blower inlet.

II. DATA SYSTEM, INSTRUMENTATION, AND CHANNEL LIST

The data system consisted of sensors, a reference junction unit for thermocouples, data lines to the data room, a pair of scanners, and an HP-9845 on-line data processing and recording computer.

The reference junction unit employs electronic compensation to maintain an effective 150⁰F reference temperature for thermocouple channels. The data lines go through a small tunnel to the data room, where the line voltages are sampled by a pair of 80-channel scanners at the rate of 180 times per hour. The digitized voltage data are fed to the HP-9845 on-line computer where they are processed (including conversion to engineering units and averaging), stored, and recorded once an hour on magnetic cartridge tapes. The on-line computer can also be used to display selected data channels in graphic or tabular form. This can be done either in real time or over some past time period for which data are available on the current tape. While past data are being displayed, however, no scanner information is processed or stored.

Tapes were changed once a week, usually on Wednesday morning, and taken to the Solar Group offices. There the data were stored on a hard disc unit connected to another HP-9845 computer and an X-Y plotter. A complete set of plots of the data was produced each week and reviewed for bad channels and missing data, possible channel changes, and any problems that might have arisen. These plots are on file.

During this reporting period, the data were also transmitted to the Los Alamos Central Computing Facility, where files were created on a mass storage system accessible to the Laboratory's CDC 6600 and 7600 computers. This is the data base used in Sec. III of this report.

A. Data Channels - Cell Data Sensors

A block of 10 data channels was allotted to each of the 14 test cells (including two blocks for each of the double-wide sunspace test cells). The first nine channels in each block were used for temperature measurements, and the 10th channel was used for auxiliary power indications. These blocks were allotted in the order of test cell numbering so that the auxiliary power channel number of each test cell was always 10 times the cell number. The ninth temperature in each block was always the cell globe temperature.

B. Auxiliary Heating

The auxiliary power was not directly measured. When there was indication that a cell was receiving auxiliary heat, the on-line data reduction program added a value of 600 W (1000 W for cell 11) to the cell-auxiliary sum. At the end of the recording period (1 hour), the accumulated cell-auxiliary sum was divided by the number of scans during that hour to obtain the average auxiliary power, and these values were recorded in the cell-auxiliary channel. At the end of each hour, the cell auxiliary sums were zeroed. This procedure was used because it was felt that the manufacturer's power ratings on the light bulbs were more precise than our ability to measure the power with reasonably priced instrumentation. This assumption was checked earlier by measuring the power consumption of about a dozen 100-W light bulbs with a very precise instrument. It was found that the bulbs were within about 2% of the rated value at the rated voltage (125 V). Line voltage at the test cells was within about 2% of the rated value.*

This method of power measurement, however, assumes that one knows when the auxiliary is on and that all of the light bulbs are working. As indicated in Sec. I, there were very few light bulb failures. No corrections were made to the data when burned-out light bulbs were found.

There were two different methods of determining when the cells were receiving auxiliary heat. During the first part of the heating season (until February 5, 1981), the auxiliary power was controlled by thermostats and relays in the test cells. Triplet® clamp-on ammeters were used to measure the current to the light bulbs via the auxiliary power channels. When the output of the current meters was above a threshold value, it was assumed that the auxiliary was on and the corresponding power value was added to the auxiliary sum.

In midwinter it was observed that the thermostats were not holding the cell globe temperatures sufficiently close to the desired minimum setpoint. On February 5, all cells except 6, 13, and 14 were changed so that the auxiliary power was controlled by the on-line data reduction program. Thereafter, when the measured globe temperature dropped below 65°F, the data program demanded auxiliary heat via a multichannel controller/relay box

*Line voltage was not continuously monitored.

("multiprogrammer") in the data room, the auxiliary power channel, and relays in the cells. At the same time, the corresponding power value was added into the auxiliary power sum. This method precisely controlled the globe temperature lower limit but had the disadvantage of involving no actual power measurement. When the computer demanded auxiliary, it added auxiliary to the data sum whether or not the auxiliary power was actually on. Although there was no evidence that any significant problem was caused by this, it would probably be safer to use a second data channel in each cell to provide the computer with a direct indication of power.

In cells 6, 13, and 14, individual controllers in the cells were used after February 5, 1981, because of a lack of channels on the multiprogrammer. These individual controllers were set up to control globe temperature also. The controllers, however, had to be set by trial and error, so that the actual setpoint was often something other than 65°F. The on-line computer sensed that auxiliary power was being used by way of clamp-on current meters as described above for the original setup.

Controllers such as these were, in fact, used in cells 13 and 14 throughout the heating season, in cell 5 until February 5, in cell 6 from February 5 on, and in cells 1 and 4 from January 22 to February 5.

The accumulated energy into each cell was also measured with a conventional direct-read watt-hour meter on the side of the cell. Due to a 1-kWh resolution limit, these meters are good only for long-term comparisons. Table III shows a comparison of the meter readings with the data system sums for several time periods. There are some significant discrepancies in which the power meter indications were different from those of the data system. Most of the larger percentage errors occurred in cases where the total energy usage was small, and the precise comparison between data system and watt-hour meters was, therefore, not reliable. The biggest overall difference was in cell 1, just under 8%. The other cells were within 6% on the overall comparison. The weighted RMS deviation in overall energy was 3.4% for 11 cells. For the measuring systems used, the author considers this to be good agreement. At this time there is no indication of which energy measurement method is more accurate. One of the watt-hour meters got stuck, as indicated in Table III, but this is not necessarily an indication of overall unreliability. For convenience, the data system energy measurements were used with no corrections.

TABLE III
COMPARISON OF AUXILIARY ENERGY USED (kwh)
(Sums at Approximately 8:00 a.m.)

Cell	12/9/80-12/31/80			12/31/80-1/30/81			1/30/81-2/28/81			2/28/81-3/31/81			Overall		
	A	B	C(%)	A	B	C(%)	A	B	C(%)	A	B	C(%)	A	B	C(%)
1	42.5	39	+9.0	53.9	55	-2.1	39.0	35	+11.4	98.6	88	+12.1	234	217	+7.8
2	17.7 ^a	20 ^a	-11.5 ^a	55.5	54	+2.8	47.4	49	- 3.3	72.8	75	- 2.9	193	198	-1.3
3	40.1	40	+ 0.3	35.2	33	+6.5	46.3	47	- 1.5	58.8	59	- 0.3	180	179	+0.8
4	64.1	65	- 1.4	79.6	79	+0.7	47.6	44	+ 8.2	87.7	86	+ 2.0	279	274	+1.8
5	25.1	27	- 3.3	29.5	28	+4.9	30.3	30	+ 1.0	59.3	58	+ 2.2	145	143	+1.5
6	26.0	23	+13.0	30.0	30	+0.1	31.9	33	- 3.3	65.9	67	- 1.6	154	153	+0.5
7	53.3	56	- 4.8	66.6	64	+3.9	68.9	70	- 1.6	86.2	87	- 0.9	275	277	-0.7
8	33.9	32	+ 5.9	37.8	36	+5.0	50.1	47	+ 6.6	37.9 ^c	37 ^c	+ 2.4 ^c	160	152	+5.1
9	111.5	110	+ 1.4	217.6	215	+1.1	212.6	201	+ 5.8	182.4	176	+ 3.6	724	702	+3.1
10	123.3	120	+ 2.8	211.5	206	+2.6	221.6	207	+ 7.1	259.8	248	+ 4.8	816	781	+4.5
11	31.5	31	+ 1.6	23.5	23	+1.2	26.9	27	- 0.4	95.4	97	- 1.6	177	178	-0.4
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
13	128.5	127	+ 1.2	130.0	128	+1.5	150.8	149	+ 1.2	157.3	157	+ 0.2	567	561	+1.0
14							36.9 ^b	37 ^b	- 0.3 ^b	74.5	81	- 8.0	111	118	-5.6

A = Data System

B = Watt-Hour Meters

C = (A-B)/B x 100 (deviation)

^a12/15/80 to 12/31/80.

^b2/2/81 to 2/28/81.

^c3/11/81 to 3/31/81 (meter stuck through 3/10).

C. Temperature Sensors

All temperature sensors used were type K thermocouples. For globe temperature measurements, the thermocouple was inserted into a black-painted toilet-bowl float and suspended about 6 ft above the floor, roughly in the center of the cell. In some cases it was necessary to measure the air temperature in places that would be exposed to solar radiation; in most of these cases the thermocouples were shielded, as described in Sec. I.

Thermocouples used to measure various concrete-block wall temperatures were run perpendicular to the surface from the inside of the cell to the desired depth, and then parallel to the surface for about 2-3 in. This was done to reduce stem-conduction errors. Surface-temperature measurements were made by grooving the surface of the blocks and "potting-in" the thermocouples flush with the surface.

The concrete-block walls of cells 1, 2, 3, 4, 7, 8, and 12 each had three instrumented blocks. The blocks were in the middle (east-west) of the solar apertures at three different heights (first, fifth, and ninth rows from the bottom). These blocks were each instrumented with five thermocouples spaced at about 0, 2.0, 7.8, 13.6, and 15.6 in. from the south surface.

In addition to these sensors, the sunspace cells had thermocouples in the sunspace floors and shielded thermocouples to measure sunspace air temperatures. Each sunspace floor had two concrete blocks with thermocouples embedded in the top and bottom surfaces. These blocks were roughly in the middle of the east and west halves of the sunspace floor. Cell 7/8 had a vertical rake of three shielded thermocouples in the center of the sunspace. Cell 3/4 had two such rakes, one in each of the east and west halves of the sunspace, until February 11, when one rake was removed and the other put in the center. In each rake the top sensor was about 1 ft from the ceiling, the bottom one about 1 ft from the floor, and the third in the middle.

The sunspace cells also had temperature sensors about 6 in. from the top and bottom of the sunspace doorways. These were bare thermocouples; bare thermocouples were also used to measure air temperatures about 6 in. from the wall at various locations inside the cell rooms to compare with globe temperature measurements.

Cell 5 had a vertical rake of seven thermocouples in the center water-tank segment. These were spaced 1 ft apart from top to bottom of the tank.

Cell 6 had four sensors inserted into three phase-change cans and the cans were resealed. Four more thermocouples were later attached to the back (north) surface of the cans. These had small patches of insulation placed over them in an attempt to isolate them from the room air.

Cell 11 had two instrumented floor blocks with thermocouples in the top, middle, and bottom surfaces. The blocks were placed near the south end of the floor and halfway to the north end. In addition, there were shielded air temperature sensors about 2 ft above the center of the floor and about 6 ft above the floor. The latter sensor was next to the globe temperature sensor and was never in direct sunlight.

Cell 14 had thermocouples placed inside the first, third, and fifth water tanks from the top and on the back surface of the other three tanks. The last three were covered with patches of insulation. All but the top heat pipe had thermocouples attached to the surface on the room side where the heat pipe entered the water tank.

D. Weather Data

Besides the cell data, which comprised the first 140 channels of data, there were two blocks of data allotted to weather data. Channels 141-160 were allotted to instantaneous measurements of outside ambient dry bulb temperature, dew point temperature, wind velocity, wind direction, and several solar radiation measurements. The values of channels 141-160 from each scan were accumulated, averaged at the end of the hour, and recorded as channels 161-180, respectively.

High-quality Eppley PSP pyranometers were used to measure total insolation on a vertical, south-facing surface just in front and to the west of cell 6 and total insolation on a horizontal surface on top of the data room. The latter pyranometer channel was defective until December 9. A medium-quality Eppley 8-48 "Black and White" pyranometer was placed on the upper west portion of the cell 3/4 sunspace to measure total insolation on a south-facing, 60° tilted surface.

Dry bulb and dew point temperatures were measured using a commercial weather unit about 50 ft to the north of the test cells and about 10 ft above the ground. Wind velocity and direction were measured on top of the data room.

E. Channel Listing

As mentioned above, the ninth channel in each block of 10 was the globe temperature (channel 9 was globe temperature for cell 1, channel 19 for cell 2, etc.). Since there were more than eight other temperature sensors in most test cells, some data channels were switched from one sensor to another at various times during the winter. Table IV shows the location of each data channel from December 7, 1980, through March 31, 1981. The thermocouples in the concrete-wall instrumented blocks were numbered from 1 on the south surface to 5 on the north surface. In cell 2, the adhesive and selective absorber foils were applied over the #1 thermocouple so that this did not produce a true surface-temperature measurement. Water drums in the sunspace of cell 3/4 were numbered from 1 on the west end to 5 on the east end of the bottom row, and 6 on the west end to 10 on the east end of the top row.

TABLE IV

CHANNEL LISTING

Cell Data. All temperature data are in $^{\circ}\text{F}$ except auxiliary power, which is in watts (average over the previous hour). Some abbreviations used in the table are:

E = east side W = west side N = north side S = south side

Lower-case letters refer to notes at the end of the table.

<u>Channel</u>	<u>Sensor Location</u>	<u>Dates</u>
<u>Cell 1</u>		
1	Trombe wall, top, #1 Trombe wall, mid height, #2	12/7-12/23 1/15-3/31(a)
2	Trombe wall, top, #3 Trombe wall, bottom, #4	12/7-12/23 12/23-3/18(b)
3	Trombe wall, top, #5 Trombe wall, bottom, #3	12/7-12/23 12/23-3/31
4	Trombe wall, midheight, #1	a11
5	Trombe wall, midheight, #3	a11
6	Trombe wall, midheight, #5	a11
7	Trombe wall, bottom, #1	a11
8	Trombe wall, bottom, #5	a11(c)
9	Cell 1 globe temperature	a11
10	Cell 1 auxiliary power	a11
<u>Cell 2</u>		
11	Trombe wall, top, #1 Trombe wall, midheight, #2	12/12-12/23 12/23-3/23(d)
12	Trombe wall, top, #3 Trombe wall, bottom, #5	12/12-12/23 12/23-3/25(e)

TABLE IV (cont)

<u>Channel</u>	<u>Sensor Location</u>	<u>Dates</u>
<u>Cell 2 (cont)</u>		
13	Trombe wall, top, #5	see note ^(f)
14	Trombe wall, midheight, #1	all
15	Trombe wall, midheight, #3	all
16	Trombe wall, midheight, #5	all
17	Trombe wall, bottom, #5 Trombe wall, bottom, #1	12/12-12/23 12/23-3/31 ^(g)
18	Trombe wall, bottom, #3	all
19	Cell 2 globe temperature	all
20	Cell 2 auxiliary power	all
<u>Cell 3/4 (Combined)</u>		
21	E masonry wall, midheight, #1 Water drum #5 (bottom, E)	12/7-2/11 2/11-3/31
22	E masonry wall, midheight, #3	12/16-3/31 ^(h)
23	E masonry wall, midheight, #5 Water drum #4	12/7-2/11 2/11-3/31
24	Sunspace floor, E, top	all
25	Sunspace floor, E, bottom Water drum #6 (top, W)	12/15-3/13 ^(h) 3/13-3/31
26	Sunspace air, E, top Sunspace air, center, top	12/7-2/11 2/11-3/31
27	Sunspace air, E, midheight Sunspace doorway, bottom Sunspace air, center, midheight Water drum #8	12/7-1/22 1/22-2/11 2/11-3/13 3/13-3/31
28	Sunspace air, E, bottom Sunspace air, center, bottom	12/16-2/11 ^(h)
29	E room globe temperature	all

TABLE IV (cont)

<u>Channel</u>	<u>Sensor Location</u>	<u>Dates</u>
<u>Cell 3/4 (cont)</u>		
30	E room auxiliary power	all
31	W masonry wall, midheight, #1 Water drum #1 (bottom, W)	12/7-2/11 2/11-3/31
32	W masonry wall, midheight, #3	all
33	W masonry wall, midheight, #5 Water drum #3 (bottom, middle)	12/7-2/11 2/11-3/31
34	Sunspace floor, W, top W room air, W wall, 6 ft up Water drum #10 (top, E)	12/7-1/7 1/7-3/13 3/13-3/31
35	Sunspace floor, W, bottom W room air, W wall, 3 ft up Sunspace doorway, top	12/7-1/7 1/7-1/23 1/23-3/31
36	Sunspace air, W, top W room air, N wall, 6 ft up	12/7-1/7 1/7-3/31
37	Sunspace air, W, bottom W room air, N wall, 3 ft up	12/7-1/7 1/7-3/31
38	Sunspace air, W, midheight Sunspace doorway, bottom	12/7-2/11 2/11-3/31
39	W room globe temperature	all
40	W room auxiliary power	all
<u>Cell 5</u>		
41	Water, top of tank	all
42	Water, 1 ft from top	all
43	Water, 2 ft from top	all
44	Water, 3 ft from top	all
45	Water, 4 ft from top	all
46	Water, 5 ft from top	all

TABLE IV (cont)

<u>Channel</u>	<u>Sensor Location</u>	<u>Dates</u>
<u>Cell 5 (cont)</u>		
47	Water, 6 ft from top (bottom)	all
48	open	all
49	Cell 5 globe temperature	all
50	Cell 5 auxiliary power	all
<u>Cell 6</u>		
51	Top row, center, center of can (inside)	all
52	Seventh row, center, center of can (inside)	all
53	Fifth row, center, south side of can (inside)	all
54	Fifth row, center, north side of can (inside)	all
55	Ninth row, center, north surface	all
56	Sixth row, center, north surface	all
57	Third row, center, north surface	See note ⁽ⁱ⁾
58	First row, center, north surface	all
59	Cell 6 globe temperature	all
60	Cell 6 auxiliary power	all
<u>Cell 7/8 (Combined)</u>		
61	E masonry wall, top, #1	12/7-12/23
	E masonry wall, midheight, #1	12/23-3/31
62	E masonry wall, top, #3	12/7-12/23
	E masonry wall, midheight, #3	12/23-3/31
63	E masonry wall, top, #5	12/7-12/23
	E masonry wall, midheight, #5	12/23-3/31
64	E masonry wall, midheight, #1	12/7-12/23
	E masonry wall, bottom, #1	12/23-2/19
	E room air, N wall, 3 ft up	2/19-3/31

TABLE IV (cont)

<u>Channel</u>	<u>Sensor Location</u>	<u>Dates</u>
<u>Cell 7/8 (cont)</u>		
65	E masonry wall, midheight, #5 E masonry wall, bottom, #3 E room air, N wall, 6 ft up	12/7-12/23 12/23-2/19 2/19-3/31
66	Sunspace floor, E, top E masonry wall, bottom, #5 Sunspace doorway, bottom	12/7-12/23 12/23-2/19 2/19-3/31
67	Sunspace floor, E, bottom	all
68	Sunspace doorway, top	all
69	E room globe temperature	all
70	E room auxiliary power	all
71	W masonry wall, midheight, #1	12/7-3/22(j)
72	W masonry wall, midheight, #3	all
73	W masonry wall, midheight, #5	all
74	Sunspace floor, W, bottom	all
75	Sunspace floor, W, top	12/17-3/31(k)
76	Sunspace air, center, top	all
77	Sunspace air, center, midheight	all
78	Sunspace air, center, bottom	all
79	W room globe temperature	all
80	W room auxiliary power	all
<u>Cell 11</u>		
101	Floor block, S, top surface	all
102	Floor block, S, midheight	all
103	Floor block, S, bottom surface	all

TABLE IV (cont)

<u>Channel</u>	<u>Sensor Location</u>	<u>Dates</u>
<u>Cell 11 (cont)</u>		
104	Floor block, center, top surface	all
105	Floor block, center, midheight	all
106	Floor block, center, bottom surface	all
107	Room air, 6 ft above floor	all
108	Room air, 2 ft above floor	all
109	Cell 11 globe temperature	all
110	Cell 11 auxiliary power	all
<u>Cell 12(1)</u>		
119	Globe temperature	all
<u>Cell 13 (m,n)</u>		
129	Globe temperature	all
130	Auxiliary power	all
<u>Cell 14(n)</u>		
125	Water tank #1 (top), surface	2/9-3/31
126	Water tank #3, surface	2/9-3/31
127	Water tank #5, surface	2/9-3/31
131	Heat pipe #2, surface	"
132	Heat pipe #3, surface	"
133	Heat pipe #4, surface	"
134	Heat pipe #5, surface	"
135	Heat pipe #6, surface	"
136	Water tank #2, inside	"

TABLE IV (cont)

<u>Channel</u>	<u>Sensor Location</u>	<u>Dates</u>
	<u>Cell 14⁽ⁿ⁾</u>	
137	Water tank #4, inside	2/9-3/31
138	Water tank #6, inside	"
139	Globe temperature	"
140	Auxiliary power	"
	<u>Weather Channels^(o)</u>	
<u>Channel</u>	<u>(Second channel is average over preceding hour)</u>	
141, 161	Vertical surface insolation (in front of cell 6); Eppley PSP (Btu/ft ² h) ^(p)	
146, 166	60° surface insolation (on cell 3/4, west side); Eppley 8-48 (Btu/ft ² h) ^(q)	
147, 167	36° surface insolation; Eppley PSP (Btu/ft ² h)	
150, 170	Dry bulb temperature (°F)	
152, 172	Horizontal surface insolation; Eppley PSP (Btu/ft ² h)	
156, 176	45° surface insolation; Eppley PSP (Btu/ft ² h)	
157, 177	Wind speed (mph)	
158, 178	Wind direction (degrees from north)	
159, 179	Dew-point temperature (°F)	

Footnotes for Table IV

-
- (a) Channel 1 defective 2/6 to 2/12.
 - (b) Channel 2 used for back-up power measurement 3/18 to 3/31.
 - (c) Channel 8 questionable during many periods.
 - (c) Channel 11 defective 3/23-3/31.
 - (e) Channel 12 used for back-up power measurement 3/25-3/31.
Questionable during many periods prior to this.
 - (f) Channel 13 defective throughout.
 - (g) Channel 17 defective 2/11 - 2/20.
 - (h) Channels 22, 25, and 28 defective until 12/16.
 - (i) Channel 57 intermittent during most of winter.
 - (j) Channel 71 intermittent from 3/22.
 - (k) Channel 75 defective until 12/16.
 - (l) Channels 111 through 118 were used for experiments not related to the passive test cells.
 - (m) Channels 121 through 124 were used for experiments not related to the passive test cells.
 - (n) Channels 125 through 127 were used for cell 14.
 - (o) Starting 2/11/81, channel 143/163 was used to monitor a second PSP used to check 141/161.
 - (p) Channel 141/161 erratic during week ending 2/5.
 - (q) Channel 146/166 defective 3/15 to 3/19.

III. DATA RESULTS AND COMPARISONS

All of the passive test cell data for the 1980-81 heating season reported here (December 7, 1980, through March 31, 1981) are available on request. This would usually be in the form of a magnetic tape file, but other forms are possible. These data are attached to the back of this report in the form of a microfiche listing.

Care should be taken in using the data, because some bad data periods may not have been detected or detailed; the data should be plotted and reviewed before using. Some noteworthy periods of bad or missing data are detailed below.

On February 18 at 5:00 p.m., the Solar Laboratory experienced a power outage that lasted until about noon on February 19. The data for this time period were patched in using the data from the same time period of February 17-18. On February 19 at 3:00 p.m., a scanner block was broken, causing the data for cells 1 and 2 (channels 1 through 20) to be bad until February 20 at 9:00 a.m. The same time period of February 18-19 was used, most of which was already patched as discussed above.

On January 15, the first scanner (channels 1 through 80) was accidentally turned off from 10:00 a.m. to 3:00 p.m.; these data were patched in.

The reporting period starts on December 7, 1980, rather than earlier because there was an extensive data loss period through December 6.

A. Weather Data

Weather data (vertical insolation and dry bulb temperature) are plotted as a function of time for the entire reporting period in Figs. 29 and 30.

B. Cell Data

Selected cell data channels are plotted as a function of time in the Appendix. Data are plotted for each cell for each of four 2-week time periods selected to represent the various test-cell configurations. In addition, overall performance indices have been computed for the four time periods, and comparisons are made among the test cells. The four time periods chosen were

Fig. 29. Vertical solar radiation at the passive test cells.

Fig. 30. Ambient air temperature at the passive test cells.

- (1) December 20, 1980, through January 2, 1981,
- (2) January 6 through 19, 1981,
- (3) February 14 through 27, 1981, and
- (4) March 15 through 28, 1981.

Some of the cells had different configurations throughout the heating season as shown earlier. Configuration changes were usually made just after the first of the month. The four time periods were chosen to include as many of the configurations as possible while minimizing the number of changes that took place during the time period.

A brief recap of the configurations of each cell during the four time periods is given in Table V. Cells 12 and 13 were not changed; cell 12 was an unvented Trombe wall with flat black paint, double glazed, with no night insulation, no forced venting, and no auxiliary heat. Only globe temperature was recorded. Cell 13 was the reference cell with an opaque, insulated south wall.

Table VI shows the daily average weather data for each time period.

C. Cell Totals and Calculated Performance

Table VII shows the useful efficiency of each cell for each selected time period, and Table VIII shows the discomfort index. The useful efficiency was defined as the useful solar contribution to the cell heating load divided by the solar radiation on the vertical collection area (solar aperture):

$$\eta_u = S / (I_v A_c) \quad .$$

Collection area (A_c) was the same (23.4 ft^2) for all test cells, including each side of the double sunspace cells, regardless of glazing area. The solar flux on a vertical surface (I_v) was obtained from the vertical PSP pyranometer (channel 161). Useful solar contribution (S) is given by

TABLE V

CELL CONFIGURATIONS DURING SELECTED TIME PERIODS

Cell	NGL	NI	Other
<u>Period 1: December 20, 1980-January 2, 1981</u>			
1	2	no	Unvented Trombe wall, flat black.
2	2	no	Unvented Trombe wall, selective absorber.
3/4	2	no	Sunspace with masonry wall, sunspace doors always closed.
5	2	no	Water wall, selective absorber.
6	2	no	Phase-change cans.
7/8	2	no	Sunspace with opaque end walls, sunspace door always closed.
11	2	no	Direct gain unpainted.
14	--	--	Not operational.
<u>Period 2: January 6-19, 1981</u>			
1	2	yes	Same as Period 1.
2	2	no	Same as Period 1.
3/4	2	yes	Same as Period 1, except sunspace door opened daily.
5	2	no	Same as Period 1.
6	2	no	Same as Period 1.
7/8	2	no	Same as Period 1, except sunspace door opened daily.
11	2	yes	Same as Period 1.
14	--	--	Not operational.
<u>Period 3: February 14-27, 1981</u>			
1	1	yes	Same as Period 1.
2	1	no	Same as Period 1.
3/4	2	yes	Sunspace with insulated wall, five water drums for storage. Sunspace door opened daily until February 22, open at all times after February 22.
5	1	no	Same as Period 1.
6	2	no	Same as Period 1.
7/8	2	no	Sunspace with glazed end walls. Sunspace door opened daily.
11	2	yes	Direct gain painted dark brown.
14	2	no	Heat-pipe collector/water storage.

TABLE V (cont)

Cell	NGL ^a	NI ^b	Other
<u>Period 4: March 15-28, 1981</u>			
1	1	no	Same as Period 1, but with reflector.
2	1	no	Same as Period 1, but with reflector.
3/4	2	no	Same as Period 3 except with 10 water drums.
5	1	no	Same as Period 1, but with reflector.
6	2	no	Same as Period 1.
7/8	2	no	Same as Period 3 except sunspace door open at all times.
11	2	no	Same as Period 3.
14	2	no	Same as Period 3.

(a) NGL = number of glazing layers

(b) NI = night insulation

TABLE VI

AVERAGE DAILY WEATHER DATA FOR SELECTED PERIODS

Period	Av Temp (°F)	Min Temp (°F)	Max Temp (°F)	Vertical Insolation (Btu/ ft ²)	Horizontal Insolation (Btu/ ft ²)	Wind Velocity (mph)
1. Dec. 20-Jan. 2	38.3	28.0	51.1	1895	938	3.4
2. Jan. 6-Jan. 19	31.4	22.9	42.8	1464	864	3.5
3. Feb. 14-Feb. 27	41.7	27.4	54.6	1610	1355	4.6
4. Mar. 15-Mar. 28	39.5	28.4	50.4	1305	1708	6.7

TABLE VII

AVERAGE USEFUL EFFICIENCY (%)

Cell	Period 1	Period 2	Period 3	Period 4
1	30	39	31	27
2	33	34	29	38
3/4	26	36	28	40
5	36	41	31	45
6	32	45	33	36
7/8	30	30	28	39
11	36	39	36	30
12	(25) ^a	(31)	(22)	(29)
13	(5)	(10)	(2)	(0)
14	--	--	31	36

^aNumbers in parentheses indicate cells that are not comparable to the others.

TABLE VIII

AVERAGE DAILY DISCOMFORT INDEX, BASE 22.5C
(C² h/day)

<u>Cell</u>	<u>Period 1</u>	<u>Period 2</u>	<u>Period 3</u>	<u>Period 4</u>
1	5	7	3	4
2	4	8	3	3
3/4	7/4	17/9	54/23	7/3
5	7	5	11	4
6	36	15	28	2
7/8	6/10	20/17	30/14	19/7
11	10	10	14	2
12	(12)	(21)	(8)	(16)
13	(12)*	(17) ^a	(5)	(5)
14	--	--	6	2

^a These numbers are high because the temperature controller was inoperative for several days, allowing the globe temperature to drop substantially.

$$S = L + M\Delta T - A ,$$

where L is the useful heating load, $M\Delta T$ is the net energy stored in cell mass over the time period, and A is the auxiliary heat used.

Useful heating load for one hour is

$$L = BLC (T_i - T_A) + CLC (T_G - T_{GN}) ,$$

where BLC is the building-load coefficient, excluding the solar aperture and the cell-to-cell partition wall, taken to be 26.0 Btu/°F h for all* except cell 12, which is taken to be 16.0 Btu/°F h; CLC is the load coefficient of the cell-to-cell partition wall taken to be 3.5 Btu/°F h; T_G is the cell globe temperature; T_{GN} is the globe temperature of the adjacent cell; and T_A is the outside ambient dry bulb temperature.

*BLC is 16 Btu/°F h for cell 11 for the period January 8 through January 13.

The useful inside cell temperature, T_I , is either the globe temperature or 65°F , whichever is smaller. In other words, any heating of the cell over 65°F is not considered to contribute to the useful load. The limit of 65°F was used throughout, regardless of whether or not the cell minimum setpoint was actually 65°F . The useful heating load, L , was calculated hourly and summed over those hours for which $T_I - T_A$ was positive.

Only a rough estimate could be made of the stored energy. The net value of this term over 2 weeks should be small, although it could be important during periods of small heating load.

The discomfort index is a modification of one described in Ref. 5. The instantaneous discomfort index is given by

$$DI = E^2 W ,$$

where

$$E = 0.93 TG + 0.04 TA + 1.1 - PT ,$$

$$PT = 0.91 TB + 0.09 TA - DN .$$

TG and TA are the globe and ambient temperatures in $^{\circ}\text{C}$, and TB is the base temperature, which is taken here to be 22.5°C (72.5°F). For the hours from midnight through 6:00 a.m., $W = 0.5$ and $DN = 2$. For 7:00 a.m. through 11:00 p.m., $W = 1.0$ and $DN = 0$. The index is summed over the hours of each day, and the values in Table VIII are average daily values. PT is the comfort temperature, which varies slightly with ambient temperature; it is equal to the base temperature only when the ambient temperature is equal to the base temperature (in daytime). The globe temperature at which the discomfort index is zero varies from 67.6°F at $TA = -4^{\circ}\text{F}$ to 71.7°F at $TA = 72.5^{\circ}\text{F}$ (the base temp). Since the globe setpoint (65°F) is less than the zero discomfort temperature, there will usually be a nonzero discomfort index.

Table IX shows the total auxiliary heating for each cell for each time period, and Table X shows the "useful" solar heating fraction, F_u , which is calculated from

$$F_u = 1 - A/L ,$$

where A and L are the auxiliary heating and useful load of the cell as described above. During times when the minimum cell temperatures are not

equal for all cells (as during the first two time periods before the control strategy was changed), the auxiliary and F_u values from different cells cannot be compared directly. These parameters are useful mainly in determining the operating regime of the cells.

Figures 31-33 show the daily maximum cell globe temperatures for the four time periods. These can be used as another indication of comfort level. The maximum temperatures in cell 6 and in the sunspace cells (when the sunspace doors are open) are seen to be high.

TABLE IX

TOTAL AUXILIARY HEATING (kWh)

<u>Cell</u>	<u>Period 1</u>	<u>Period 2</u>	<u>Period 3</u>	<u>Period 4</u>
1	63.7	88.4	20.7	109.1
2	48.8	103.6	27.7	64.6
3/4	65.6/121.1	79.8/108.2	43.8/43.6	36.6/90.2
5	34.0	75.8	13.9	41.7
6	38.3	63.1	25.2	71.6
7/8	86.5/48.5	135.7/79.7	43.2/27.9	74.9/61.0
11	42.6	58.7	3.5	103.5
12	-	-	-	-
13	210.5	218.5	186.5	219.4
14	-	-	29.1	74.3

TABLE X

USEFUL SOLAR FRACTION

<u>Cell</u>	<u>Period 1</u>	<u>Period 2</u>	<u>Period 3</u>	<u>Period 4</u>
1	0.72	0.69	0.90	0.51
2	0.79	0.63	0.86	0.71
3/4	0.58	0.66	0.79	0.72
5	0.85	0.74	0.93	0.82
6	0.83	0.78	0.88	0.68
7/8	0.70	0.60	0.83	0.70
11	0.82	0.77	0.98	0.55
12	1.00	1.00	1.00	1.00
13	0.13	0.17	0.05	0.00
14	-	-	0.86	0.67

Fig. 31. Maximum daily globe temperatures for test cells 1, 2, 3, and 4 (cell 3 is the east-side room globe temperature and cell 4 is the west-side room globe temperature of cell 3/4).

Fig. 32. Maximum daily globe temperatures for test cells 5, 6, 7, and 8. Cell 7 is the east-side-room globe temperature and cell 8 is the west-side-room globe temperature of cell 7/8).

Fig. 33. Maximum daily globe temperatures of test cells 11, 12, and 14 (when operating).

D. Comparisons of Efficiency and Discomfort Index

One notices in Table VII that there is not much difference in efficiency among the comparable cells (all cells except 9, 10, 12, and 13). The efficiencies of the sunspace cells are relatively low during the first period because the sunspace doors were kept closed, preventing heat transfer to the cells by thermocirculation. During the last period, cell 1 had low efficiency because it was single glazed with no night insulation.

In comparing the discomfort index in Table VIII, we see that the phase-change material cell (cell 6) has high values during the first and third periods due to overheating because of the low sensible heat capacity of the melted salt. Once the sunspace doors of cells 3/4 and 7/8 were opened daily starting with the second period, the east-side rooms to which the sunspace doors opened (cells 3 and 7) tended to overheat daily because there was no provision for closing the doors when overheating started. This is reflected in high discomfort-index numbers for cells 3 and 7 (and to a lesser degree, for cells 4 and 8) during the second and third time periods. The fourth time period was a relatively cloudy period and there was little overheating of any space except cell 7.

It is interesting to note the discomfort-index numbers of cells 12 and 13, even though they are not comparable to the other cells. Cell 12 was not heated, and therefore had a high discomfort index during the second (and coldest) period due to low globe temperatures. Cell 13 had a high discomfort index in the first and (especially) the second periods. This was due primarily to a failure of the temperature controller, which allowed the globe temperature to drop significantly, as shown in the Appendix. It was also due, in part, to a too-high controller setting until about January 9.

As discussed earlier, the globe temperatures drifted quite low during cloudy periods until the control scheme was changed before the third time period. This fact could affect some of the discomfort indexes and reference should be made to the globe temperature plots in the Appendix.

The direct gain cell (cell 11) did not overheat as much as might be expected. This situation could change, however, if furniture or rugs were present to shade the storage mass.

E. Flat Black vs Selective Absorber

Among the more interesting comparisons is that between the flat black Trombe wall in cell 1 and the selective absorber Trombe wall in cell 2. During period 1, when both had double glazing and no night insulation, cell 2 outperformed cell 1 by about 10%. During period 2, when cell 1 had night insulation, the situation reversed; cell 1 outperformed the selective absorber cell without night insulation by about 15%. During period 3, both cells were single glazed and cell 1 still had night insulation. The advantage of cell 1 over cell 2 decreased to an insignificant 7%. Finally, in period 4 when both cells were single glazed and neither had night insulation, the selective absorber demonstrated a large advantage: more than 40% better than flat black paint.

Figure 34 shows a comparison of south surface* temperatures from the two Trombe walls. The first time period (Fig. 34a) shows a 5° higher peak temperature in cell 2 and about 10° higher minimum. When night insulation was applied to cell 1 in period 2 (Fig. 34b), the maximum surface temperatures were about the same, but cell 1 cooled down less at night. In period 3 (Fig. 34c), the difference in minimums was about the same, but daytime maximums were again about 5° higher in cell 2, with both cells single glazed. Figure 34d shows period 4, when night insulation on cell 1 was discontinued. There was a considerably higher ($\sim 15^{\circ}$) surface temperature for cell 2 at all times.

Balcomb (Ref. 3) has used the wall-temperature measurements of cells 1 and 2 to determine surface heat fluxes and resulting nighttime U-values for the two cells. Table XI summarizes his results for U-values and Table XII shows the calculated heat-delivery ratios for the four configuration combinations. The heat-delivery results are seen to be qualitatively similar to the above efficiency results.

*Again, the measurement on cell 2 is not a true surface temperature. The true temperature should be somewhat higher at midday.

(a)

(b)

(c)

(d)

Fig. 34 (a) (b) (c) (d). Comparison of south-side surface temperatures of Trombe walls in cell 1 (flat black paint) and cell 2 (selective absorber).

TABLE XI
SUMMARY OF U-VALUE RESULTS (NIGHTTIME)
(Ref. 3)

<u>Time Period</u>	<u>Cell</u>	<u>Glazing</u>	<u>Other</u>	<u>U-Effective^c</u>	<u>No. Days Used</u>
12/15 - 1/4	1	2	--	0.46	20
1/8 - 2/2	1	2	NI ^a	0.14	23
12/17 - 1/5	2	2	SS ^b	0.30	20
1/8 - 2/2	2	2	SS ^b	0.29	22
2/6 - 4/2	2	1	SS ^b	0.37	53
2/6 - 3/4	1	1	NI ^a	0.15	23
3/6 - 4/2	1	1	--	0.70	27

^aNI = Night Insulation.

^bSS = Selective Absorber Surface.

^c= Btu/h °F ft².

TABLE XII
HEAT DELIVERY THROUGH INSIDE WALL SURFACE
RATIO OF CELL 2 (SELECTIVE ABSORBER)
TO CELL 1 (FLAT BLACK).
(Ref. 3)

<u>Month</u>	<u>NI^a</u>	<u>Glazings</u>	<u>Ratio</u>
Dec.	no	2	1.10
Jan.	yes	2	0.93
Feb.	yes	1	0.97
Mar.	no	1	1.66

^aNI = Night Insulation on Cell 1

F. Other Comparisons

Cell 5, a water wall with selective absorber, consistently outperformed the Trombe wall with selective absorber (cell 2). These two cells had the same configuration (other than mass-wall type) throughout the winter. Cell 5 was generally the best performer, although cell 6 (phase change) had better thermal performance (assuming the BLCs were the same) in period 2 (the coldest period) and period 3 (when cell 5 was single glazed and cell 6 was double glazed). Even though it was single glazed, cell 5 outperformed all other cells in period 4, the cloudiest period; this was the same period in which cells 1, 2, and 5 had specular reflectors. It should also be noted that cell 5 had considerably more thermal storage capacity than the Trombe wall cells, as shown in Table I: 1471 Btu/⁰F vs 952 Btu/⁰F. It is significant that the heat-pipe collector in cell 14 performed well even though only four of the heat pipes were working.

IV. CONCLUSIONS

All of the passive heating concepts tested during the 1980-81 winter had good thermal performance as measured by useful solar efficiency. There is a reasonably complete set of data for the test cells from December 7, 1980, through the end of March 1981. These data are available for further performance studies or for computer simulation program validation. This data set also includes the data for the sun-tempered building experiments described in Ref. 2.

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Jim Hedstrom has been responsible for the data system, particularly the on-line data reduction program. He also took care of the data manipulation and storage.

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Lee Dalton of the Solar Laboratory was responsible for the day-to-day surveillance of test cell operation and maintenance.

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APPENDIX

GRAPHICAL CELL DATA

Fig. A-1. Trombe wall temperatures in cell 1. The upper (solid) curve is the south surface at midheight (channel 4), the middle (broken) curve is the inner surface (channel 6), and the lower (dashed) curve is the globe temperature (channel 9).

Fig. A-2. Trombe wall temperatures in cell 2. The upper (solid) curve is the south surface at midheight (channel 14 under the adhesive). The middle (broken) curve is the inner surface temperature at midheight (channel 16). The lower (dashed) curve is the globe temperature (channel 19).

PASSIVE CELL 3/4
DEC 1980-JAN 1981

PASSIVE CELL 3/4
JAN 1981

PASSIVE CELL 3/4
FEB 1981

PASSIVE CELL 3/4
MAR 1981

Fig. A-3. Temperatures in sunspace cell 3/4. The upper (solid) curve is channel 26, the sunspace air at the top. The lower (dashed) curve is channel 29, the east-side globe temperature.

PASSIVE CELL 3/4
DEC 1980-JAN 1981

PASSIVE CELL 3/4
JAN 1981

PASSIVE CELL 3/4
FEB 1981

PASSIVE CELL 3/4
MAR 1981

Fig. A-4. Temperatures in sunspace cell 3/4. The lower (dashed) curve is channel 33, the inner surface of the west masonry wall in the first two periods and the bottom, middle water drum in the last two periods. The upper (solid) curve is channel 24, the east-side floor surface.

Fig. A-5. Water-wall temperatures (cell 5). The upper (solid) curve is channel 41, the water temperature at the top. The middle (broken) curve is channel 46, the water temperature one foot above the bottom. The lower (dashed) curve is the room globe temperature (channel 49).

Fig. A-6. Temperatures in test cell 6. The upper (solid) curve is channel 54, the salt temperature on the north side of the middle can in the fifth row. The lower (dashed) curve is channel 59 (the globe temperature). The salt apparently did not melt in the last period possibly because of the fact that March was a relatively cloudy month.

PASSIVE CELL 7/8
DEC 1980-JAN 1981

PASSIVE CELL 7/8
JAN 1981

PASSIVE CELL 7/8
FEB 1981

PASSIVE CELL 7/8
MAR 1981

Fig. A-7. Temperatures in sunspace cell 7/8. The upper (solid) curve is channel 77, sunspace air temperature at midheight. The lower (dashed) curve is channel 69, the east room globe temperature. The spikes in channel 77 are possibly due to shadowing from sunspace framing.

Fig. A-8. Temperatures in sunspace cell 7/8. The solid curve is channel 61, the south surface of the east masonry wall. The dashed curve is channel 74, the sunspace floor on the west-side bottom.

Fig. A-9. Temperatures in the direct gain cell (cell 11). The solid curve is channel 101, the top surface of the floor at the south end. The dashed curve is channel 109 (the globe temperature). The low globe temperature during late January is due to the use of a thermostatic control until early February.

Fig. A-10. Temperatures in cell 14, the heat-pipe collector. The upper solid curve is channel 133, the #4 heat-pipe temperature at the entrance to the water tank. The dashed curve is channel 137, the water temperature in #4 water tank. The lower solid curve is channel 139, the globe temperature.

Fig. A-11. Globe temperatures in cell 12 (unheated, unvented Trombe wall) and cell 13 (reference cell). The solid curve is cell 13 (channel 129) and the dashed curve is cell 12 (channel 119). For the period January 1 through 7, the temperature controller in cell 13 was inoperative and was not set properly until January 9.

PASSIVE CELLS 1 AND 2
DEC 1980-JAN 1981

PASSIVE CELLS 1 AND 2
JAN 1981

PASSIVE CELLS 1 AND 2
FEB 1981

PASSIVE CELLS 1 AND 2
MAR 1981

Fig. A-12. Auxiliary heat for cell 1 (solid line) and cell 2 (dashed line).

PASSIVE CELL 3/4
DEC 1980-JAN 1981

PASSIVE CELL 3/4
JAN 1981

PASSIVE CELL 3/4
FEB 1981

PASSIVE CELL 3/4
MAR 1981

Fig. A-13. Auxiliary heat for cell 3/4. Solid line is auxiliary for east room, dashed line for west room.

PASSIVE CELLS 5 AND 6
DEC 1980-JAN 1981

PASSIVE CELLS 5 AND 6
JAN 1981

PASSIVE CELLS 5 AND 6
FEB 1981

PASSIVE CELLS 5 AND 6
MAR 1981

Fig. A-14. Auxiliary heat for cell 5 (solid line) and cell 6 (dashed line).

Fig. A-15. Auxiliary heat for cell 7/8. Solid line is east room, dashed line is west room.

Fig. A-16. Auxiliary heat for cell 11 (solid line) and cell 13 (dashed line).

Fig. A-17. Auxiliary heat for test cell 14 (heat pipe collector) for periods 3 and 4.

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