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Short Duration Winter-Time Performances of Different Passive Solar Systems

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

The thermal performance of three full-sized adjoining rooms, each with a different south-facing passive feature, were monitored for two short periods during January-February and February-March, 1984. These rooms are a Trombe wall cell, a control cell, and a direct gain cell in the NBS Passive Solar Test facility. During the experiments data from 436 sensors were collected. The data include: auxiliary energy supplied, continuous air infiltration, temperatures, solar radiation, and wind speed and direction. This report briefly describes the test facility, instrumentation, data acquisition system and procedures and test conditions for the experiments. The report presents representative data and results of a preliminary analysis of the data. It compares the performance of the three test cells, and the values of average, centroidal, maximum and minimum air temperatures in the direct gain and Trombe wall cells. Results indicate that regardless of the magnitude of the stratification the temperature recorded by the sensor placed in the vicinity of the centroid of the cell was nearly equal to the average value of the cell air temperature.

The report also compares measured data with the predicted values of (1) the ratios of various solar radiation quantities; and (2) the auxiliary energy required to maintain the fixed value of the lower bound temperature in the test cells. The data and predicted values show good agreement suggesting that the procedures outlined in the "Passive Solar Design Handbook Volume Three" for predicting these quantities are valid.

NOMENCLATURE

AUXM	Measured value of auxiliary energy supplied (kWh)
AUXP	Predicted value of auxiliary energy requirement (kWh)
C_p	Specific heat of air (J/kgK)
H_h	Total solar irradiation on a horizontal surface (W/m^2)
H_v	Total solar irradiation on a south vertical surface (W/m^2)
H_t	Total solar irradiation transmitted through a glazing on a south vertical surface (W/m^2)
H_g	Ground reflected irradiation on an inverted horizontal plane (W/m^2)
H_b	Direct normal beam irradiation (W/m^2)
LC	Heat loss coefficient for a cell, not including the passive solar aperture and air infiltration (W/K) [LC = UA - loss coefficient for the solar aperture]
$\dot{m}$	Air infiltration mass flow rate (kg/hr)
QNET	Calculated value of the net reference load or the energy required to maintain the nonsolar portion of a cell at the set temperature (kWh) [QNET = QREQ - Energy loss from the solar aperture]
QREQ	Calculated value of energy required to maintain a cell at the set temperature (kWh)
SSF	Solar saving fraction
Ta	Ambient (outside) air temperature (°C)
TAVE	Average of all air temperatures measured in a cell (°C)
TCEN	Air temperature at the centroid of the cell volume (°C)
TMAX	Maximum measured air temperature in a cell (°C)
TMIN	Minimum measured air temperature in a cell (°C)
UA	Overall heat loss coefficient for a cell, not including air infiltration (W/K)

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1. INTRODUCTION

1.1 BRIEF HISTORY OF THE PROJECT

In 1980, the U.S. Department of Energy (DOE) established a Program Area Plan for the systematic performance evaluation of passive/hybrid heating and cooling systems [1]. This program area plan defines three levels of performance monitoring procedures which, in decreasing order of sophistication, have been designated as Class A, B, and C. Both class A and class B level monitoring involves fixed instrumentation and data acquisition equipment, while class C level monitoring involves simple hand-recorded measurements and surveys of occupant reactions.

Class B level monitoring provides limited detailed data (about 20 sensors per building) from occupied buildings for field testing and statistical evaluation of passive systems and buildings. Class A level monitoring provides carefully measured detailed data (at least 200 sensors per building) under controlled conditions for use in (1) detailed building energy analysis and model/algorithm validation; and (2) performance characterization of various passive subsystems.

The National Bureau of Standards (NBS) passive solar test facility, constructed under the sponsorship of DOE, has four full size adjoining rooms. The first room (cell #1) houses the data acquisition system and the other three rooms (cells #2, #3, and #4) are the test cells. The test facility contains several types of generic passive solar features such as a direct gain system, a collector storage wall (Trombe wall), and clerestory windows. The NBS test facility was constructed as a part of the DOE's Experimental Systems Research Program and is used for acquiring and distributing to paticipating researchers class A level performance data for various passive subsystems under different experimental conditions.

The test facility was made operational in October of 1981, with the direct gain cell completely instrumented and the other cells minimally instrumented. A handbook describing the NBS test facility, thermophysical properties of construction materials, and sensor locations was published and distributed [2]. During FY82 performance data from the direct gain cell, under three different experimental conditions, were collected and distributed to the participating researchers. A technical paper containing the representative results from these data was presented at the ASME Passive Solar Division Sixth Annual Technical Conference in April 1983 [3].

In FY83 instrumentation of the Trombe wall cell was completed. A new data acquisition system (DAS) and a multichannel continuous air infiltration monitoring system (CAIMS) were procured and installed at the test facility. During FY83 some experiments were conducted to monitor the performance of the direct gain and Trombe wall cells, and to measure the thermocirculation characteristics of the Trombe wall. A paper containing a brief description of the new DAS and CAIMS, and some representative results from the FY83 experimental work was presented at the Passive and Hybrid Solar Energy Update meeting in September 1984 [4]. The data tape containing the hourly average data sets was distributed to the participating researchers.

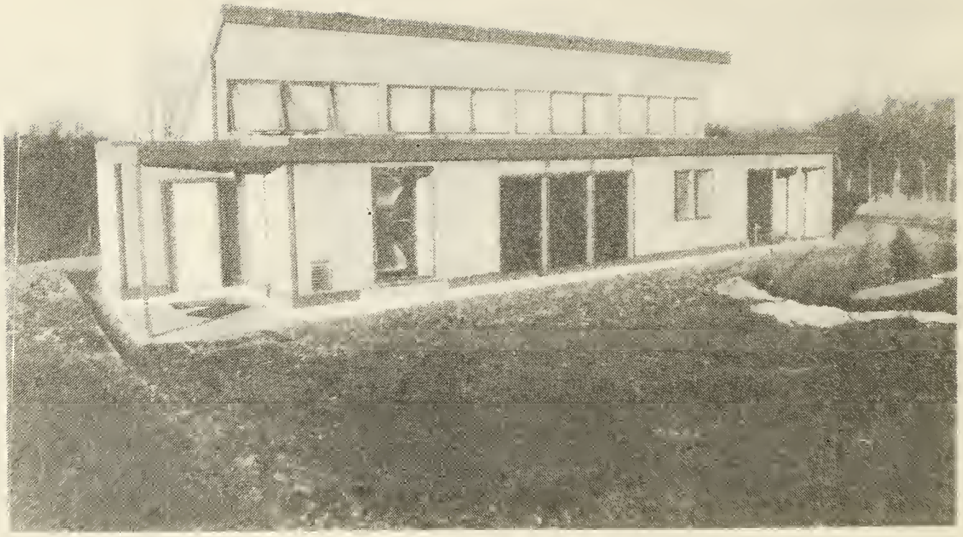
In FY84 some additional sensors were installed in the control cell (cell #3) in order to measure the floor surface temperatures. A comprehensive instrumentation and site handbook describing the test building, data acquisition system and procedures, and containing a directory of the sensors installed in and around the building was published and distributed [5]. The thermal performance of the three test cells (a control cell, a direct gain cell, and a Trombe wall cell) were monitored for two short duration experiments, the first for the period of January 16 to February 13, 1984; and the second for the period of February 17 to March 12, 1984. The data tape containing the hourly average data sets from these experiments and copies of the data documentation were distributed to various researchers. A preliminary analysis of these data were performed in order to: (1) characterize the performance of the different passive solar systems, (2) compare the values of the average and centroidal tempertures in the trombe wall cell and the direct gain cell; and (3) compare the measured data with the predicted values of the ratios of various solar irradiation quantities and energy requirements.

1.2 SCOPE OF THIS REPORT

This report briefly describe the test building, instrumentation, data acquisition system and procedures, and test conditions for the two performance monitoring experiments. The report contains representative data from the two performance monitoring experiments and results from a preliminary analysis of the data, and compares the performance of the three test cells. The data presented include: solar radiation; wind speed and air infiltration; ambient and room air temperatures; average, centroidal, maximum and minimum room air temperatures in the direct gain and Trombe wall cells; cell floor surface temperatures; and auxiliary energy supplied. The report also contains predicted values of the ratios of various irradiation quantities and the auxiliary energy required to maintain the cells at 20°C, and compares the predicted values with the measured data.

2. BRIEF DESCRIPTION OF THE TEST FACILITY

The NBS Passive Solar Test Facility is located in Gaithersburg, Maryland (latitude 39°N, longitude 77.3°W) on an open area with no shading from the surroundings. The building is a rectangular one-story slab on grade, frame structure, with the long axis running from east to west. The building is especially designed to be reconfigurable so that passive solar features can be installed with minimum cost and effort. The current configuration provides four test cells of equal area. Each cell has a floor area of 30.1 m^2 and contains a different south-facing passive feature. Cell #1 houses the data acquisition system, continuous air infiltration monitoring system, and component-testing calorimeter; cell #2 contains a south facing Trombe wall; cell #3 contains a normal-sized double-pane casement window; cell #4 contains a south facing direct gain fenestration. Figure 1 shows the south elevation of the building, and Figure 2 shows the floor plan. A complete description of the test building, including wall cross sections, physical properties of the construction material used, and sensor locations is available in reference 5.



Photograph of NBS Passive Solar Test Building.

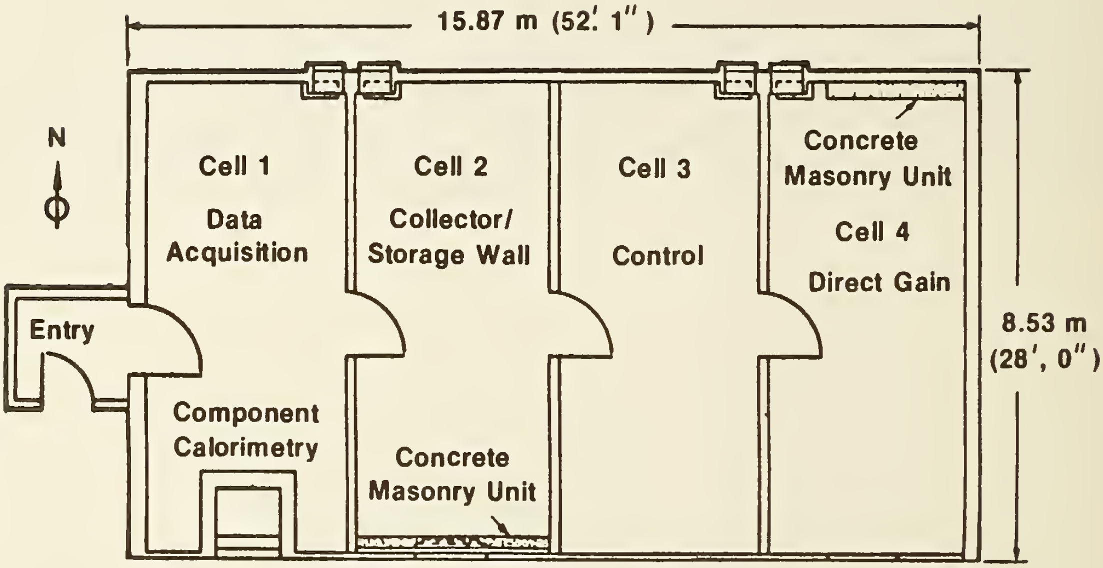


Figure 2. Floor Plan of the NBS Passive Solar Test Building.

3. INSTRUMENTATION AND DATA ACQUISITION

3.1 SENSORS

A total of 457 sensors are installed in and around the test building. Of these, 26 sensors are outside the building; and 6, 173, 26, and 226 respectively are in cells #1, #2, #3, and #4. The sensors include flow meters, heat flux meters, pyranometers, resistance thermometers, themocouples, watt-hour meters, and weather sensors. The general location of these sensors is summarized in Table 1.

3.2 DATA ACQUISITION SYSTEM

The data acquisition system, used for monitoring the sensors, consists of a desktop computer with 575K bytes of memory, real-time clock, and a scanner with an intergrated digital voltmeter having 1 microvolt resolution. The system has two cassette drives and a magnetic tape drive for data and software storage.

A completely separate system is used to monitor the air infiltration continuously in three test cells. The multi-zone automated air infiltration monitoring system, which uses the tracer gas decay method, was designed by Dr. Richard Grot of NBS. A brief description of this system is available in reference 5 and a detailed description of the system may be found in reference 6.

3.3 DATA ACQUISITION AND DISTRIBUTION

The solar radiation and weather data are taken at 1 minute intervals, auxiliary energy data are taken at 1-hour intervals, and all other data are taken at 10-minute intervals. The data are converted to engineering units and stored on magnetic tape. Air infiltration data are stored separately on a floppy disk. These data are later numerically integrated and averaged to create hourly average data sets. The hourly average data sets, including air infiltration data, are recorded onto a magnetic tape. A documentation file containing the test conditions and an index to the data records is also recorded on the data tape. The data tape along with a print-out of the documentation is distributed to the participating researchers. The hourly average data sets are also archived at the National Bureau of Standards where they are available upon request to interested parties.

A statement of measurement uncertainty is available in reference 5. The maximum overall uncertainty: in temperature measurements using type-T thermocouples is estimated to be $\pm$ 0.5°C; in air infiltration measurements is estimated to be about $\pm$ 10 percent [7]; and in other measurements is estimated to be $\pm$ 5 percent.

TABLE 1

Various Sensors Installed at the NBS Passive Solar Test Facility

Item #	Sensor Type	Outside	Cell #1	Cell #2	Cell #3	Cell #4	
1	Flow meters (chiller fluid)*			1	1	1	3
2	Heat flux meters					11	11
3	Resistance thermometers			2	2	3	7
4	Radiation Sensors						
4.1	Direct normal beam	1					1
4.2	Ground reflected	1					1
4.3	Infrared sky radiation	1					1
4.4	Total Horizontal	1					1
4.5	Total on a south vertical surface	1				1	2
5	Type-T thermocouples						
5.1	Air	4		23	3	25	55
5.2	Black globe			3		5	8
5.3	Ceiling surface			12		12	24
5.4	East wall surface	2		3		13	18
5.5	Floor surface			12	20	12	44
5.6	Foundation			18*		54	72
5.7	Ground	12		11		46	69
5.8	Heat flux meter Surface					11	11
5.9	Heater discharge					1	1
5.10	North wall	1		3		16	20
5.11	Pink globe					2	2
5.12	Trombe wall			82			82
5.13	West wall			3		13	16
6	Watt-hour meters		6				6
7	Weather sensors						
7.1	Wind direction	1					1
7.2	Wind speed	1					1
	TOTAL	26	6	173	26	226	457

*CURRENTLY NOT MONITORED

4. TEST CONDITIONS

Two short duration performance monitoring experiments were conducted: the first for the period of January 16 to February 13, 1984; and the second for the period of February 17 to March 12, 1984. During the first experiment clerestory window shutters were closed in all test cells. During the second experiment clerestory window shutters were open in cells #2 and #4 and closed in cell #3.

During both of the experiments, the room air temperature in the cells was allowed to float upward without restriction since no auxiliary cooling was provided. The lower bound room air temperature in the cells was fixed at 20°C by the thermostat, and auxiliary heat was supplied as needed. The actual lower bound temperature in the cells fluctuated between 19.5 and 20.5°C due to thermostat hysteresis.

During both of the experiments, the north wall window shutters and the doors between the cells were closed. The Trombe wall in cell #2 is a vented Trombe wall; however, for these experiments vents of the Trombe wall were blocked. No night insulation was provided for the glazings on the lower level south wall. The fan coil unit fans were kept on in the test cells for the duration of the experiment. Two destratifying fans, placed near the center of the floor, were used in the direct gain cell (i.e. cell #4). One fan took the room air from the floor level and discharged it at the sloped ceiling level near the clerestory window; the other fan did the reverse. The combined action of the two fans mixed the room air to reduce thermal stratification. Air infiltration for the three cells and all of the sensors listed in Table 1 were monitored during the experiments.

5. DISCUSSION OF REPRESENTATIVE RESULTS

Representative results from the hourly average data sets for a period of 13 days (0.0 a.m., January 24 to 0.0 a.m. February 5, 1984) from the first experiment and for a period of 24 days (3.0 p.m. February 17 to 3.0 p.m. March 12, 1984) from the second experiment are presented below. These results show data for solar radiation, wind speed and air infiltration, ambient and room air temperatures, floor surface temperatures, and the auxiliary energy supplied. The results also show comparison data with the predicted values of various solar radiation quantities, and with the auxiliary energy required to maintain the test cells at the 20°C lower bound temperature.

5.1 SOLAR RADIATION

Measured data on solar radiation include: total on a horizontal surface, total on a south facing vertical surface; total transmitted through a glazing on a south facing vertical surface; ground reflected radiation on an inverted horizontal plane; and direct normal beam radiation. Figures 3 and 4 show the variation of the total horizontal irradiance for the first and second periods respectively. The thirteen days in the first period included six completely sunny, four partial sunny, and three cloudy days. The twenty four days in the second period include twelve completely sunny, eight partial sunny, and four cloudy days. The solar radiation data was summed over the duration of the periods and the resulting irradiation values are shown in Table 2.

Table 2. Solar Irradiation Data for the Two Periods

Quantity		January 24 to February 5, 1984	February 17 to March 12, 1984
H_h	(kWh/m^2)	29.1	77.5
H_v	(kWh/m^2)	42.1	78.3
H_f	(kWh/m^2)	26.3	46.5
H_g	(kWh/m^2)	8.2	18.5
H_b	(kWh/m^2)	35.3	65.3

5.2 WIND SPEED AND AIR INFILTRATION

Figures 5 and 6 show the wind speed measured at a distance of about 50 m southwest of the test building for the two experiments. Figures 7 and 8 show, for the two experiments, the net air infiltration rates computed from the measured values of the tracer gas concentration in the test cells. Figures 7a and 8a, 7b and 8b, and 7c and 8c are respectively for cells #2, #3, and #4. Although the use of one tracer gas precludes determination of intercell infiltration rates, the effects of any such infiltration must be very small because the cell temperatures and pressures were nearly the same. The data in Figures 5 to 8 indicates that the wind speed did have some effect on the infiltration rate, this effect, however, cannot be quantified at this time.

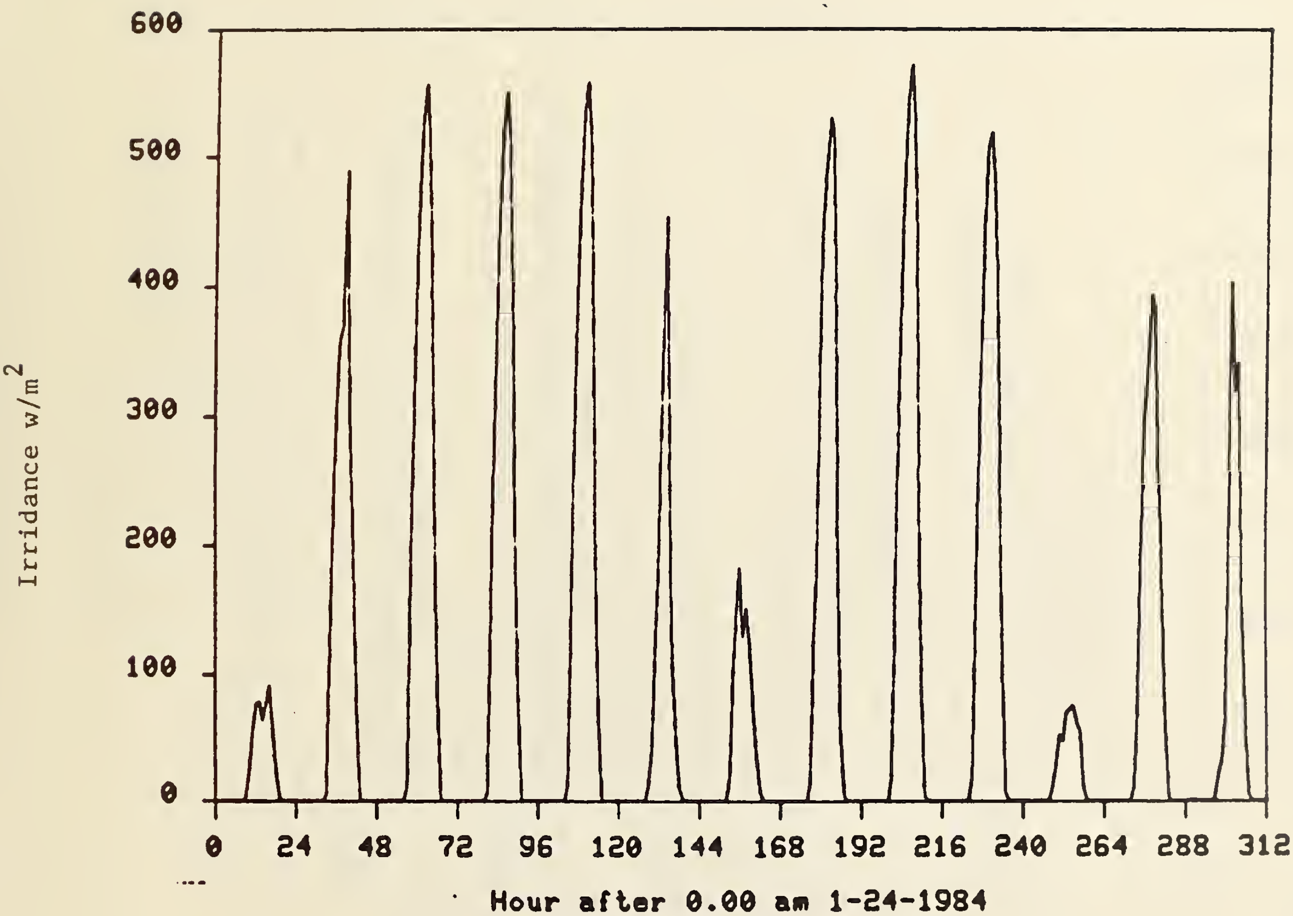


Figure 3. Total horizontal irradiance during 2/17 - 3/12/84.

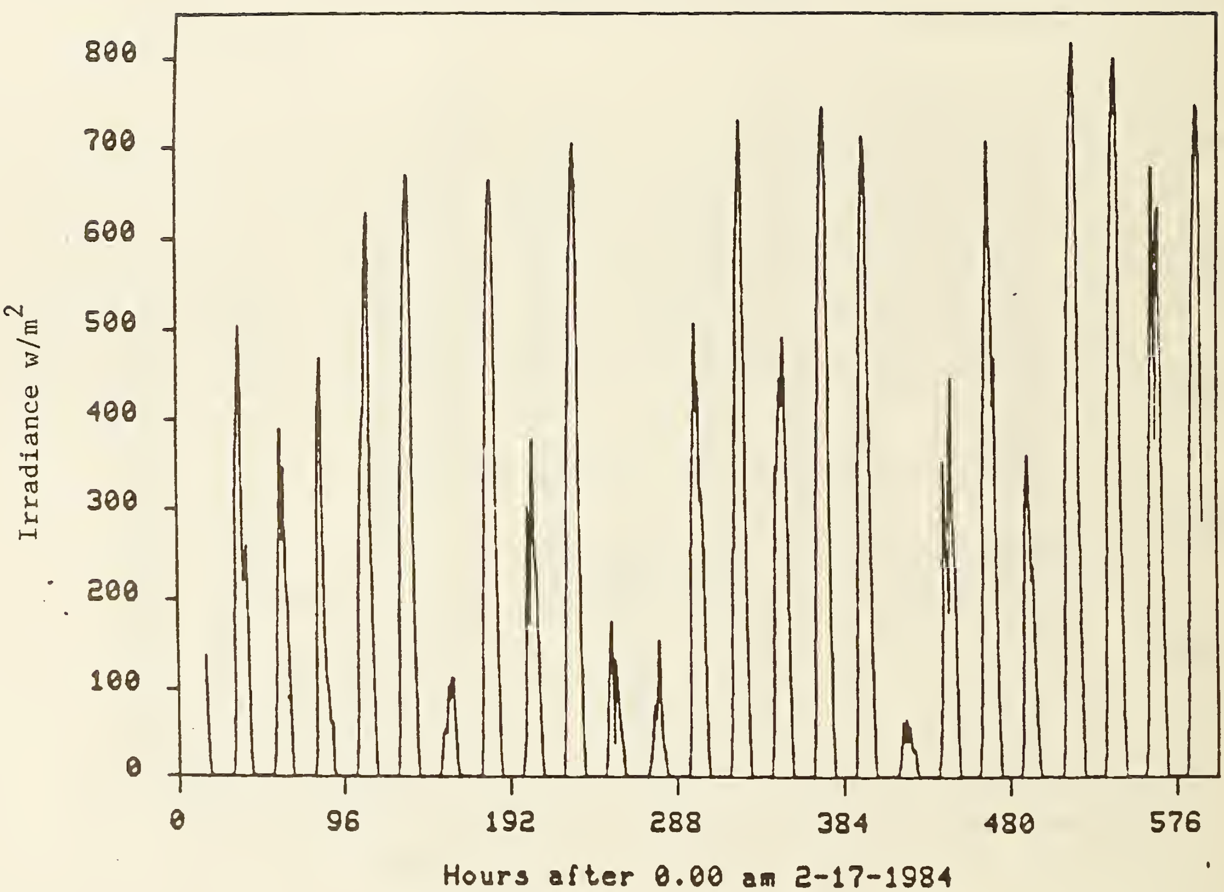


Figure 4. Total horizontal irradiance during 2/17 - 3/12/84.

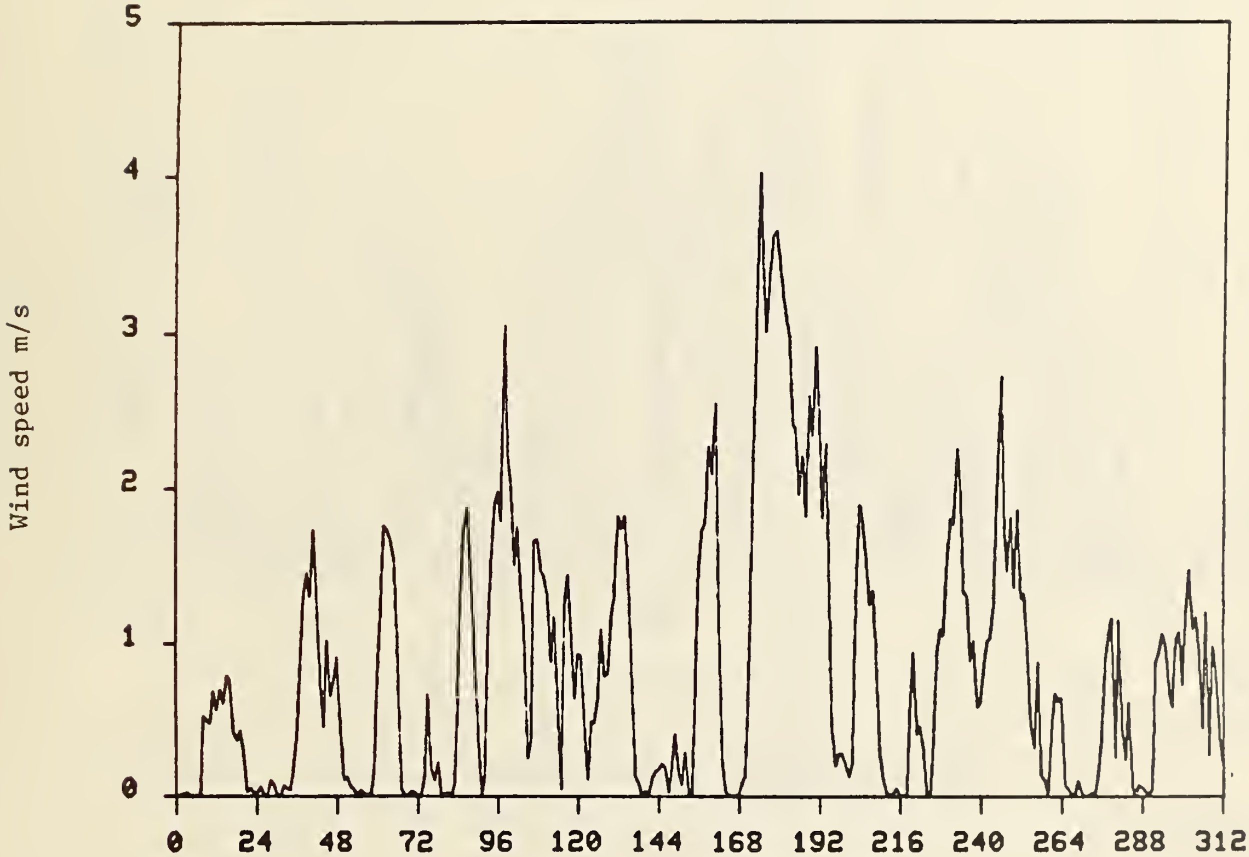


Figure 5. Wind speed measured at a height of 5 m and a distance of 5 m southwest of the building during 1/24-2/5/84

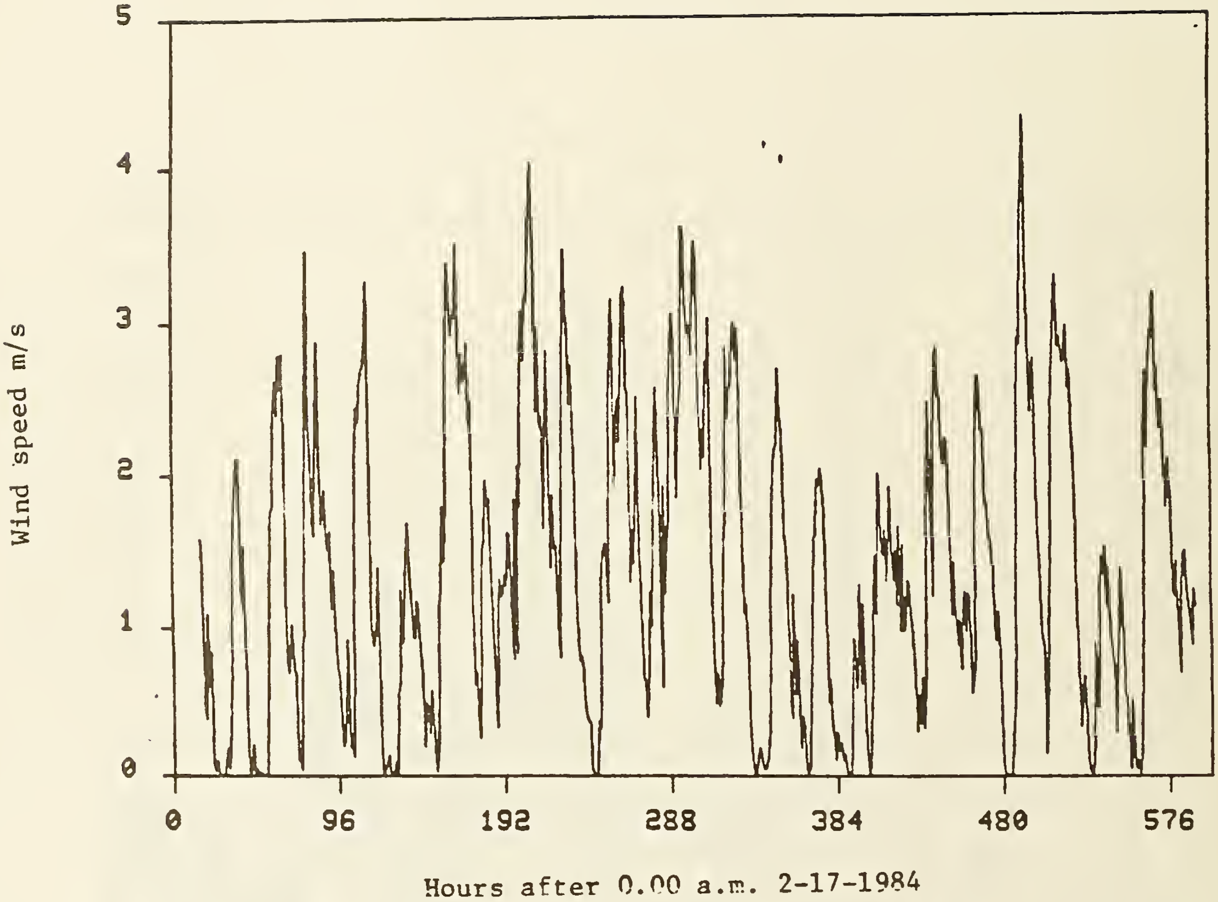


Figure 6. Wind speed measured at a height of 5 m and a distance of 50 m southwest of the building during 2/17 - 3/12/84

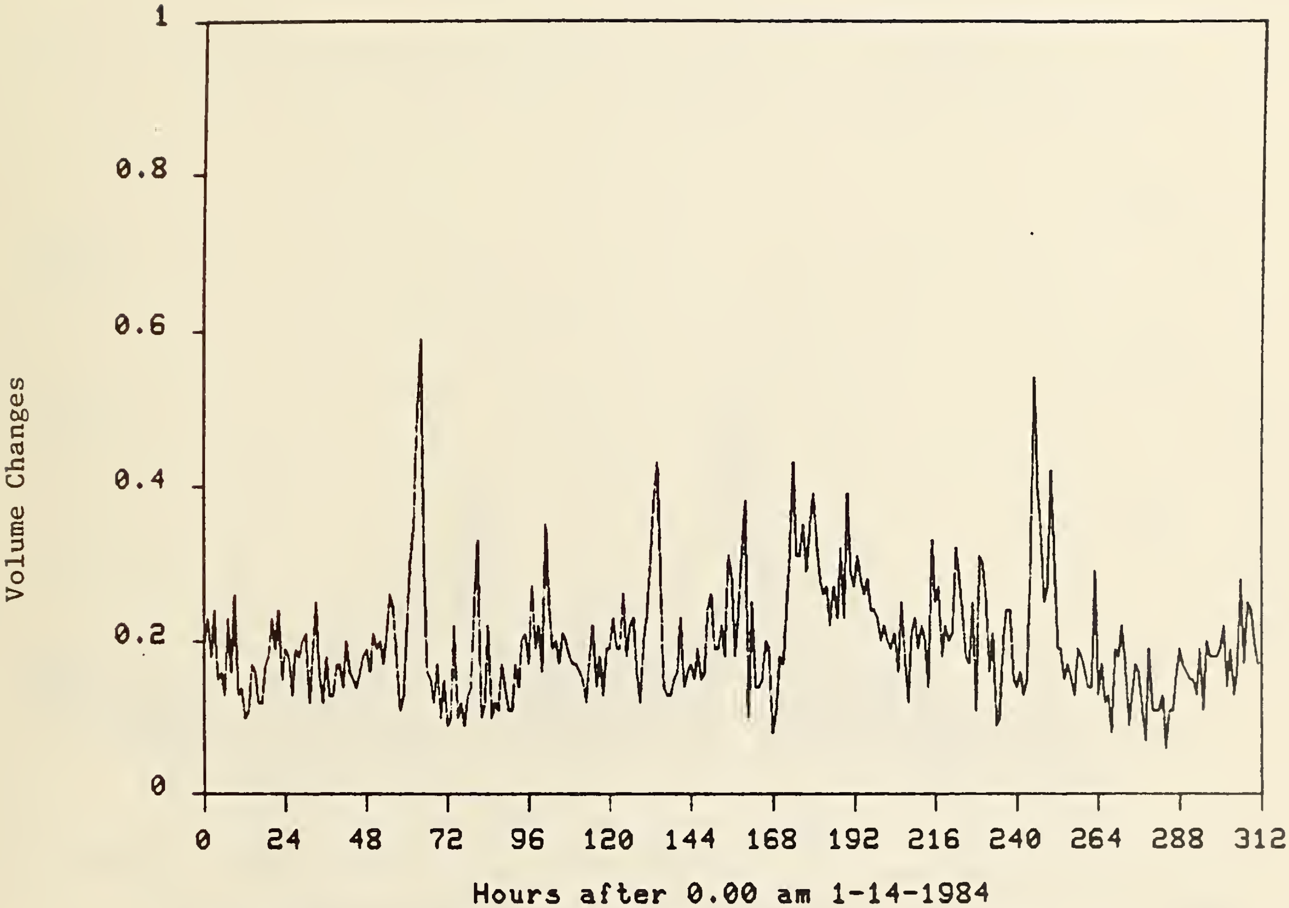


Figure 7a. Air infiltration rates in cell #2 during 1/24 - 2/5/84

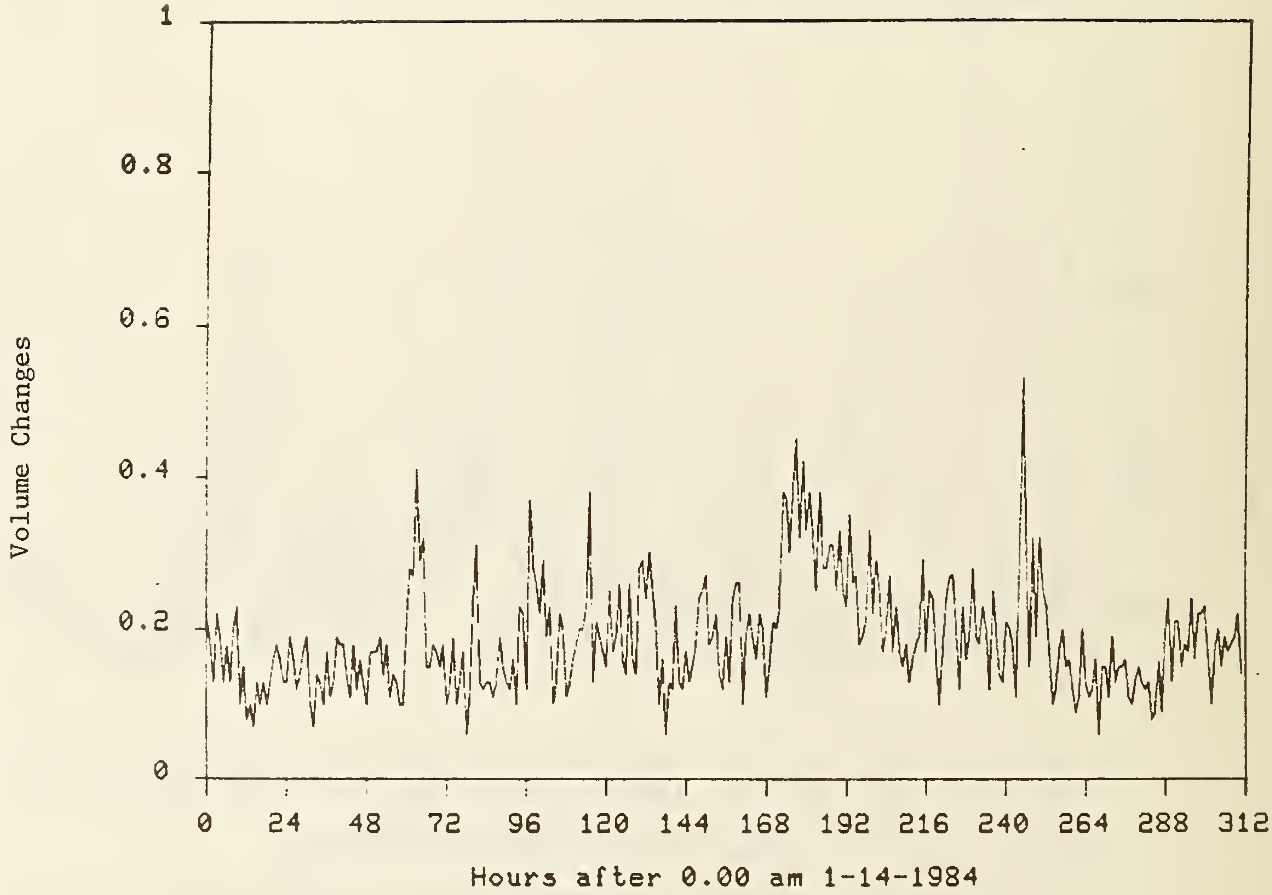


Figure 7b. Air infiltration rates in cell #3 during 1/24 - 2/5/84

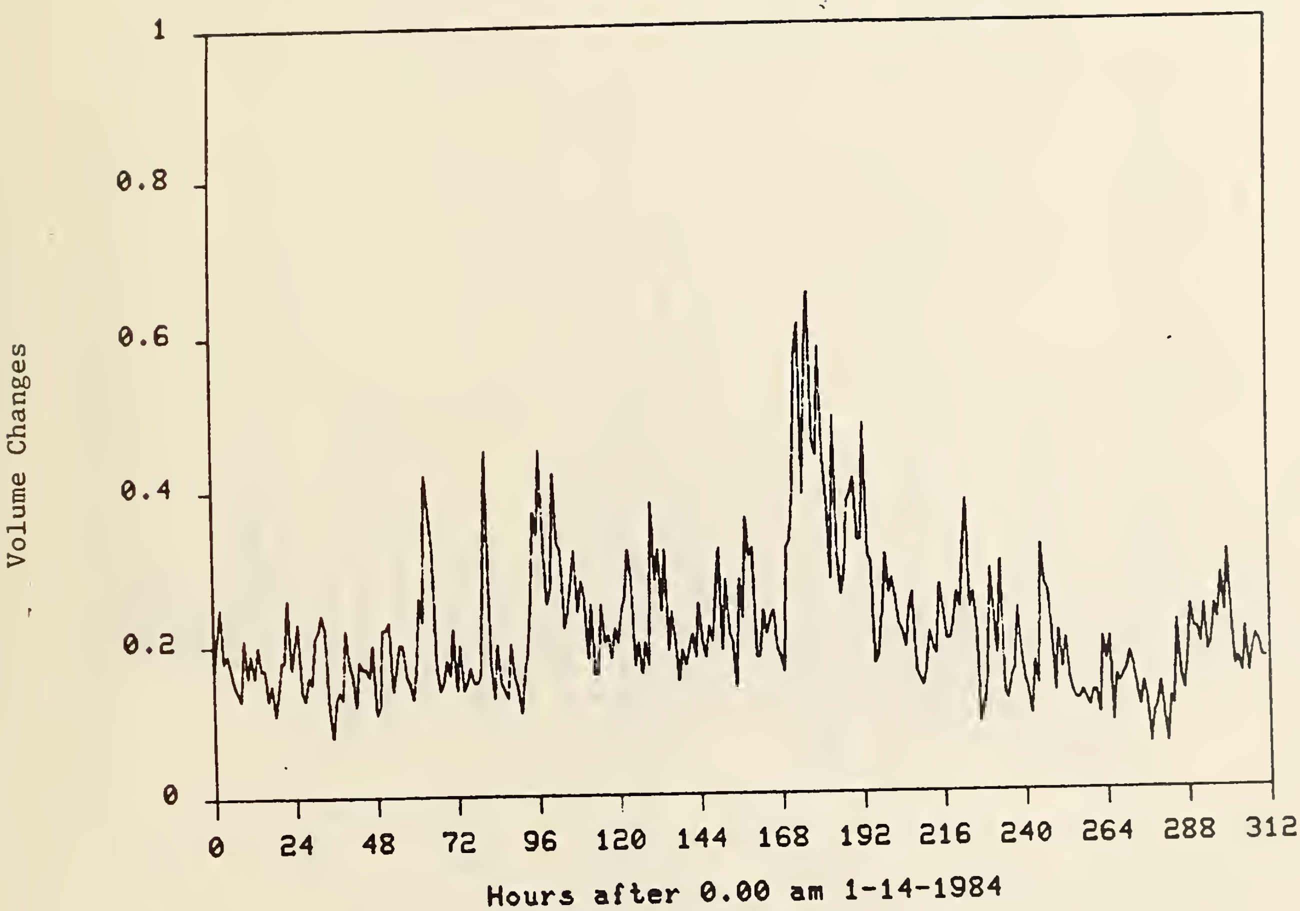


Figure 7c. Air infiltration rates in cell #4 during 1/24 - 2/5/84

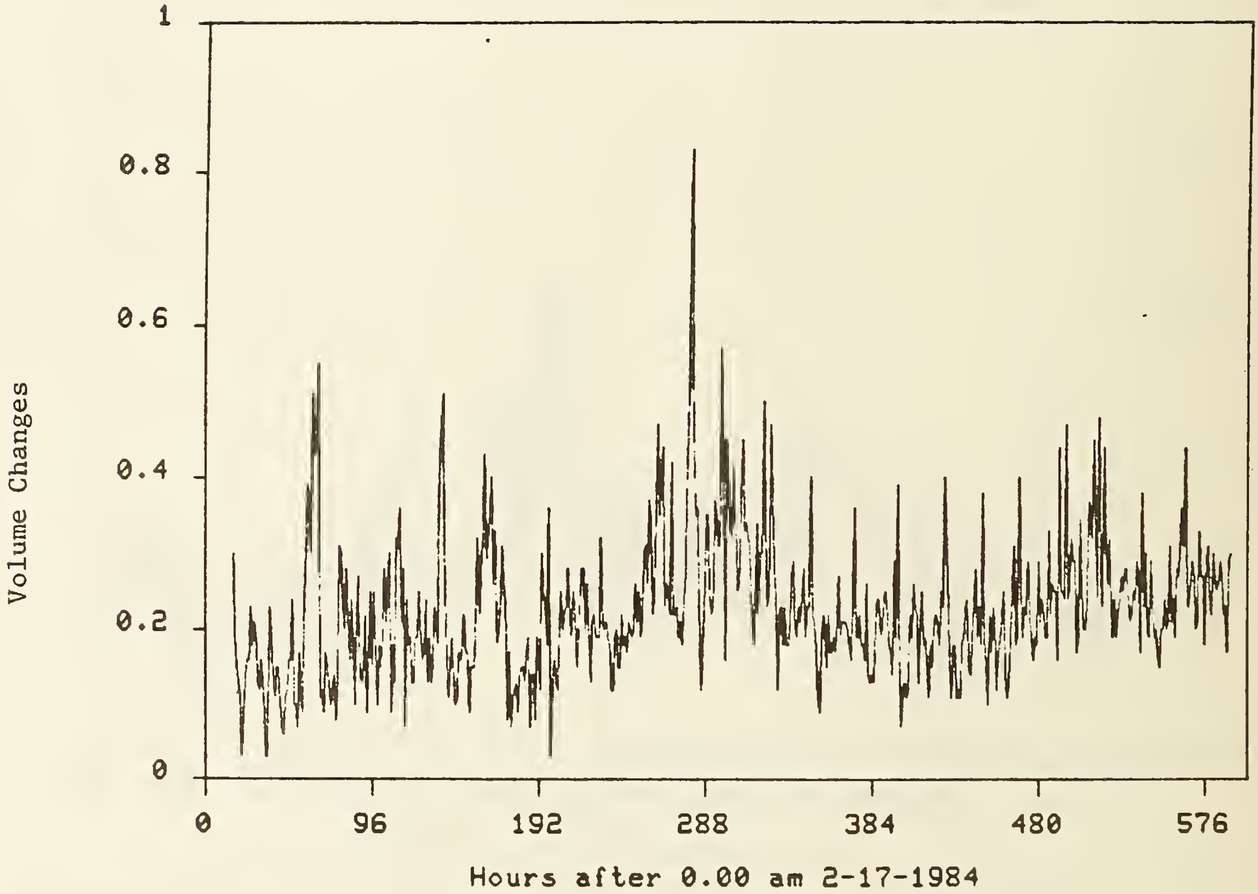


Figure 8a. Air infiltration rates in cells #2 during 2/17 - 3/12/84

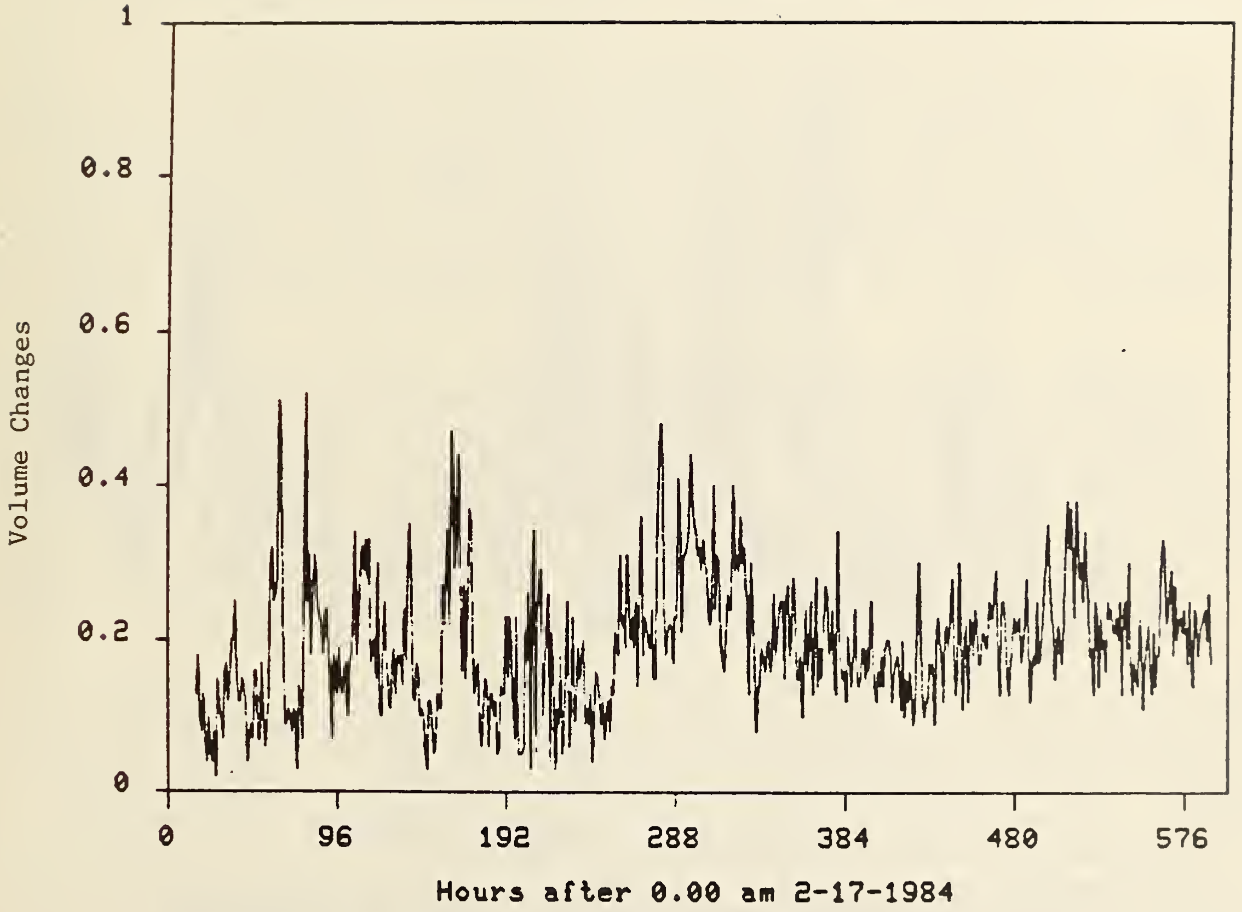


Figure 8b. Air infiltration rates in cells #3 during 2/17 - 3/12/84

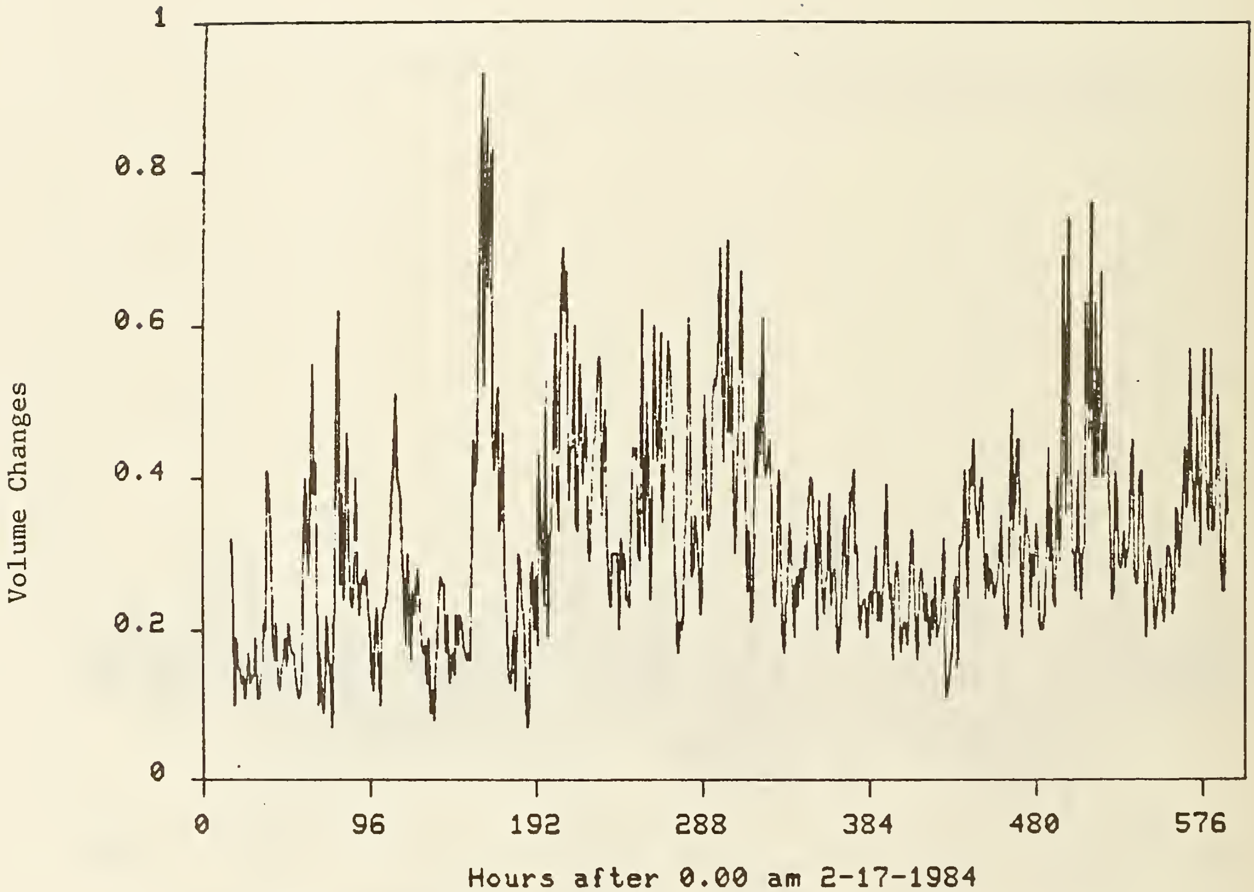


figure 8c. Air infiltration rates in cell #4 during 2/17 - 3/12/84

5.3 AIR TEMPERATURES

The outside air temperature is measured by four mechanically aspirated and shielded thermocouples. Two of these thermocouples are place about 22 mm from each other, about 1.2 m above ground and about 2.5 m south of the test building; the other two thermocouples are similarly situated on the north of the building. The room air temperature in cells #2, #3 and #4 is monitored by 22 shielded, 3 unshielded, and 22 shielded thermocouples, respectively. Figure 9 schematically shows the location of the sensors in cells #2 and #4; the locations of the 22 shielded thermocouples in cells #2 are identical to those of the 22 sensors in cell #4. The sensors are situated on the south to north centerline of the cell. Findings from a preliminary analysis of the air temperature data are given below.

Figures 10 and 11 show the variation of ambient air temperature and room air temperature in cells #2, #3, and #4, for the two periods respectively. The data shown in these figures represent the average of 4 sensors for the ambient air temperature; and the average of 22, 3, and 22 sensors for the air temperature in cells #2, #3, and #4, respectively. As expected, the air temperature during the solar hours was higher in cell #4 than the air temperatures in cell #2 and #3. Due to the thermal storage effects of the Trombe wall, the cell #2 temperature fluctuations lagged those of cells #3 and #4.

Figure 12 shows the variations of the average value of cell air temperature, TAVE, and the cell centroid temperature, TCEN (i.e. temperature recorded by sensor number 21 in Figure 9 which is located in the vicinity of the centroid of the cell), for cell #2 for the first period. Figure 13 shows data similar to that shown in Figure 12 for the second period. Figure 14 shows the variations of the average temperature, TAVE, the maximum temperature, TMAX, and the minimum temperature, TMIN, for cell #2 for the first period. Figure 15 shows data similar to that shown in Figure 14 for the second test period. Figures 16 through 19 show data similar to that described above, but for cell #4

The data presented in Figures 12 through 19 indicate the following. (1) Despite the use of fans (see section on test conditions for details), as expected, the room air in cells #2 and #4 was stratified, and the stratification (i.e. TMAX-TMIN) was higher during solar hours than it was during nonsolar hours. (2) Due to additional solar gain from the clerestory aperture during solar hours, the air stratification in cell #2 was higher (up to about 13°C) during the second test period than it was (up to about 7°C) during the first period. (3) Because of the two additional destratifying fans, the air stratification in cell #4 was about the same (up to 7°C) for both of the test periods. (4) Regardless of the magnitude of the air stratification TAVE and TCEN were almost identical to each other suggesting that TCEN adequately represented the average temperature of the cell air and may be sufficient for one-nodal energy analysis simulations. However, further investigation is needed to determine if the observation #4 stated above is valid for other experimental configurtions.

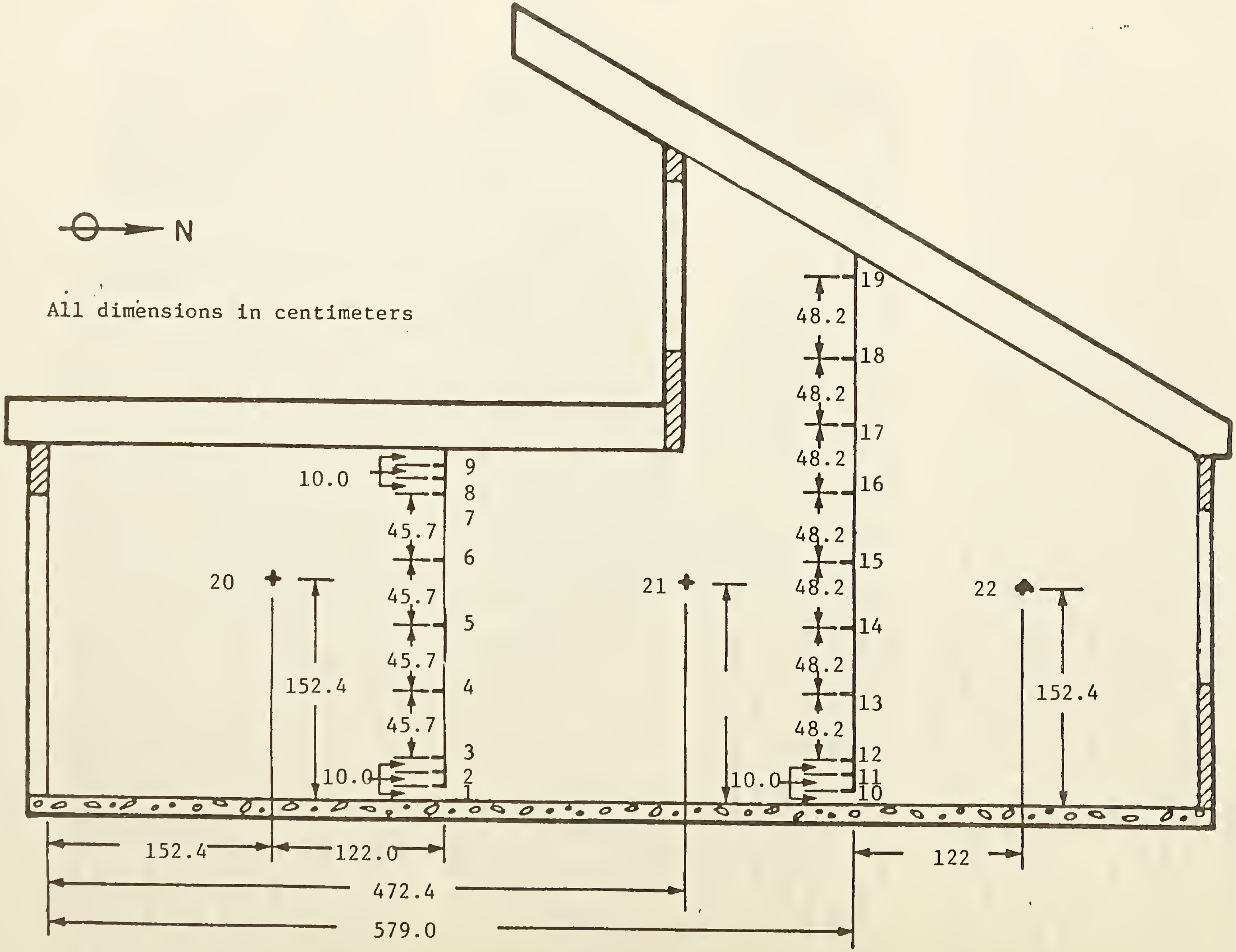


Figure 9. Schematic locations of air temperature sensors in cells #2 and #4

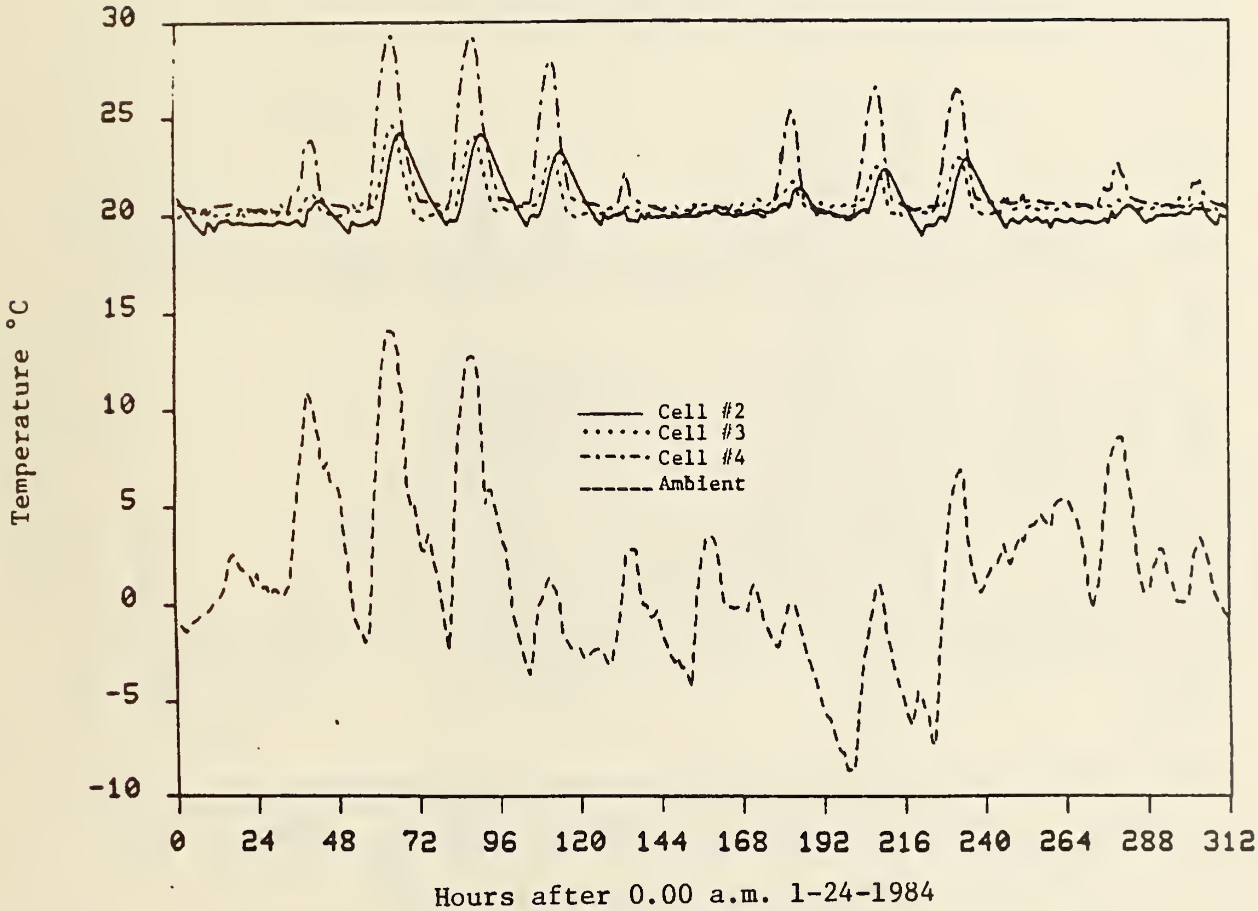
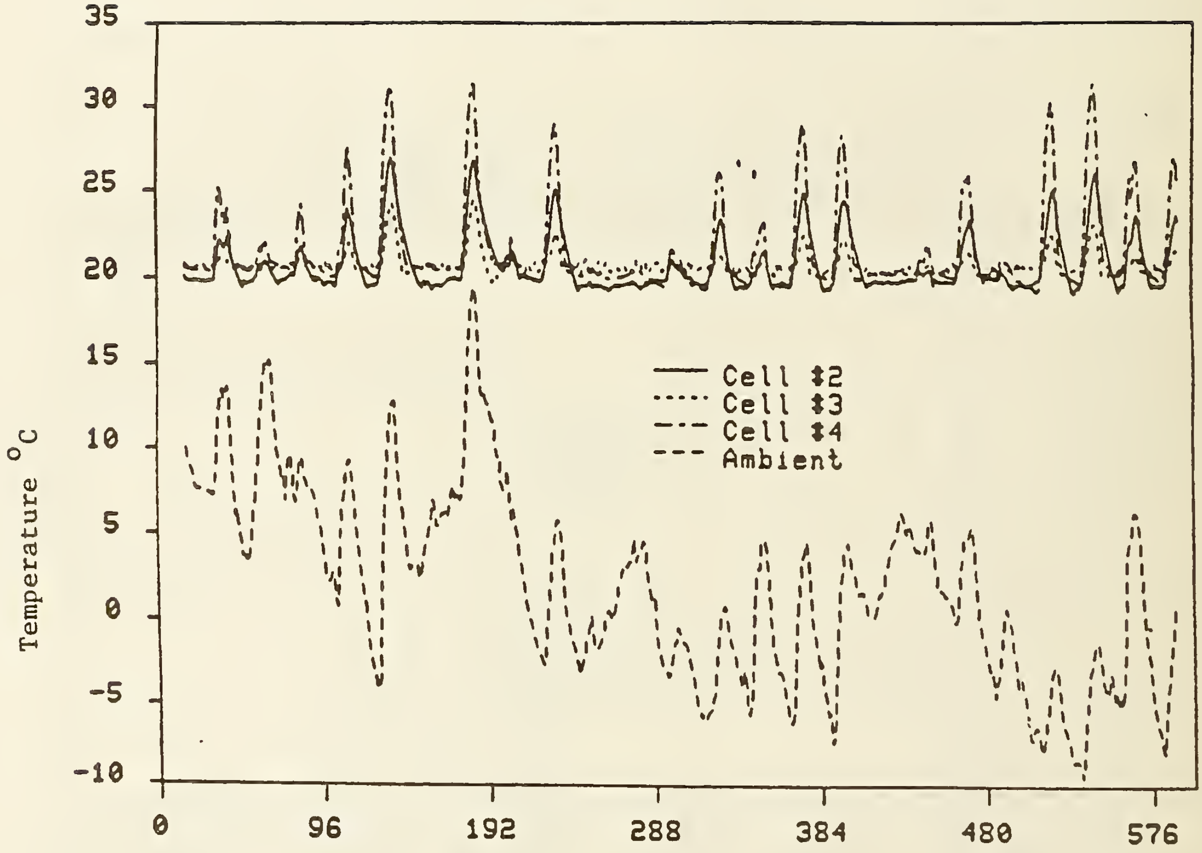


Figure 11. Ambient and room air temperature variations during 2/17 - 3/12/84.



Hours after 0.00 a.m. 2-17-1984

Figure 11. Ambient and room air temperature variations during 2/17 - 3/12/84.

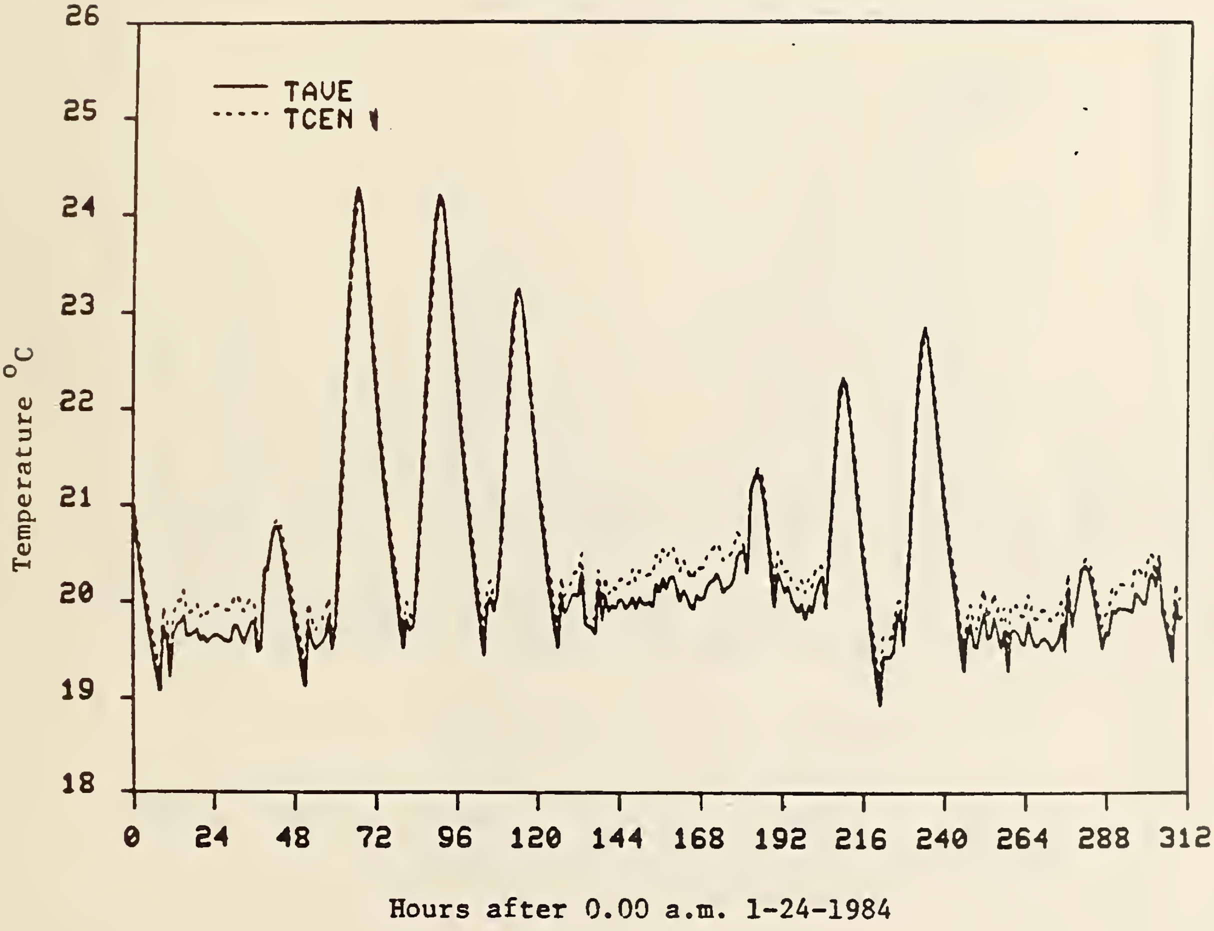


Figure 12. Variations of average and centroidal air temperature in cell #2 during 1/24-2/5/1984

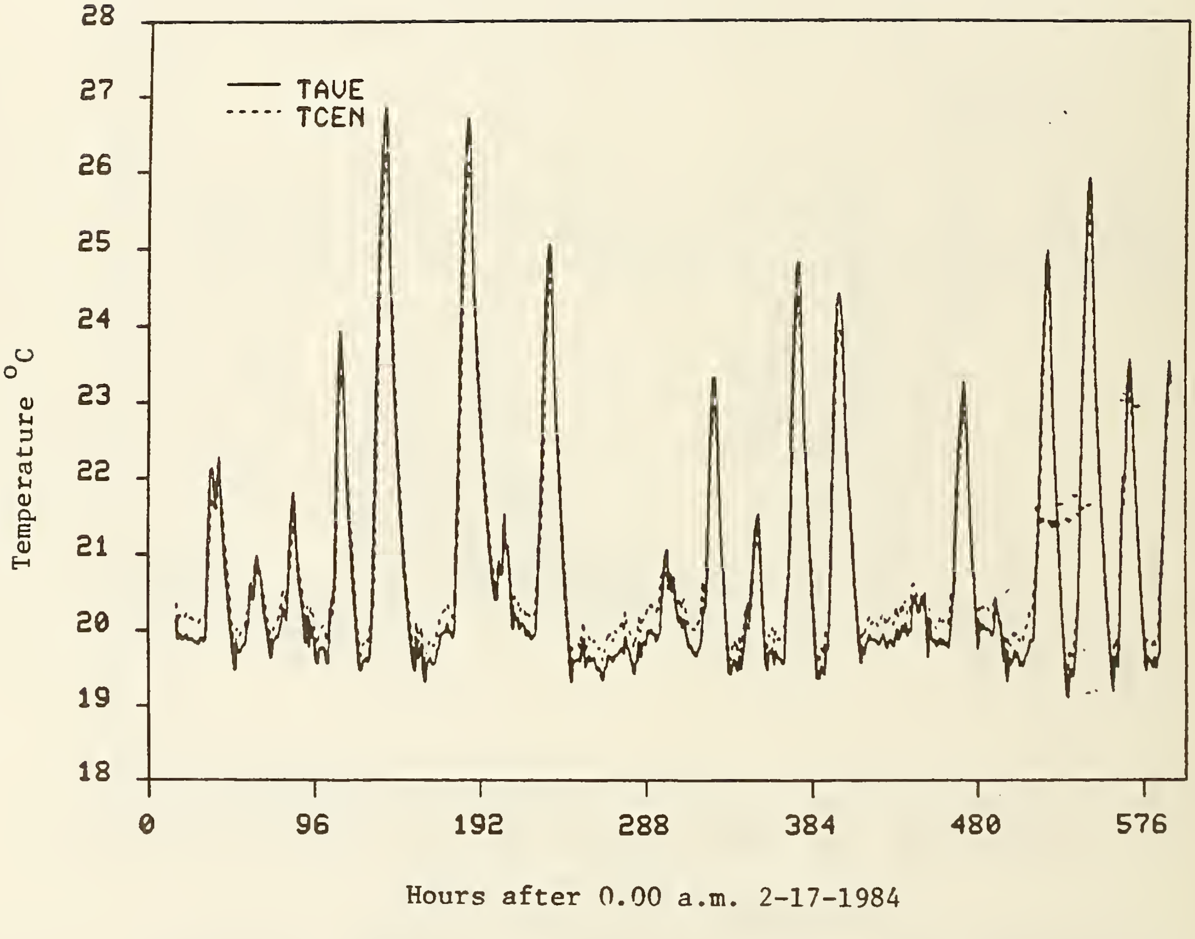


Figure 13. Variations of average and centroidal air temperature in cell #2 during 2/17-3/12/1984

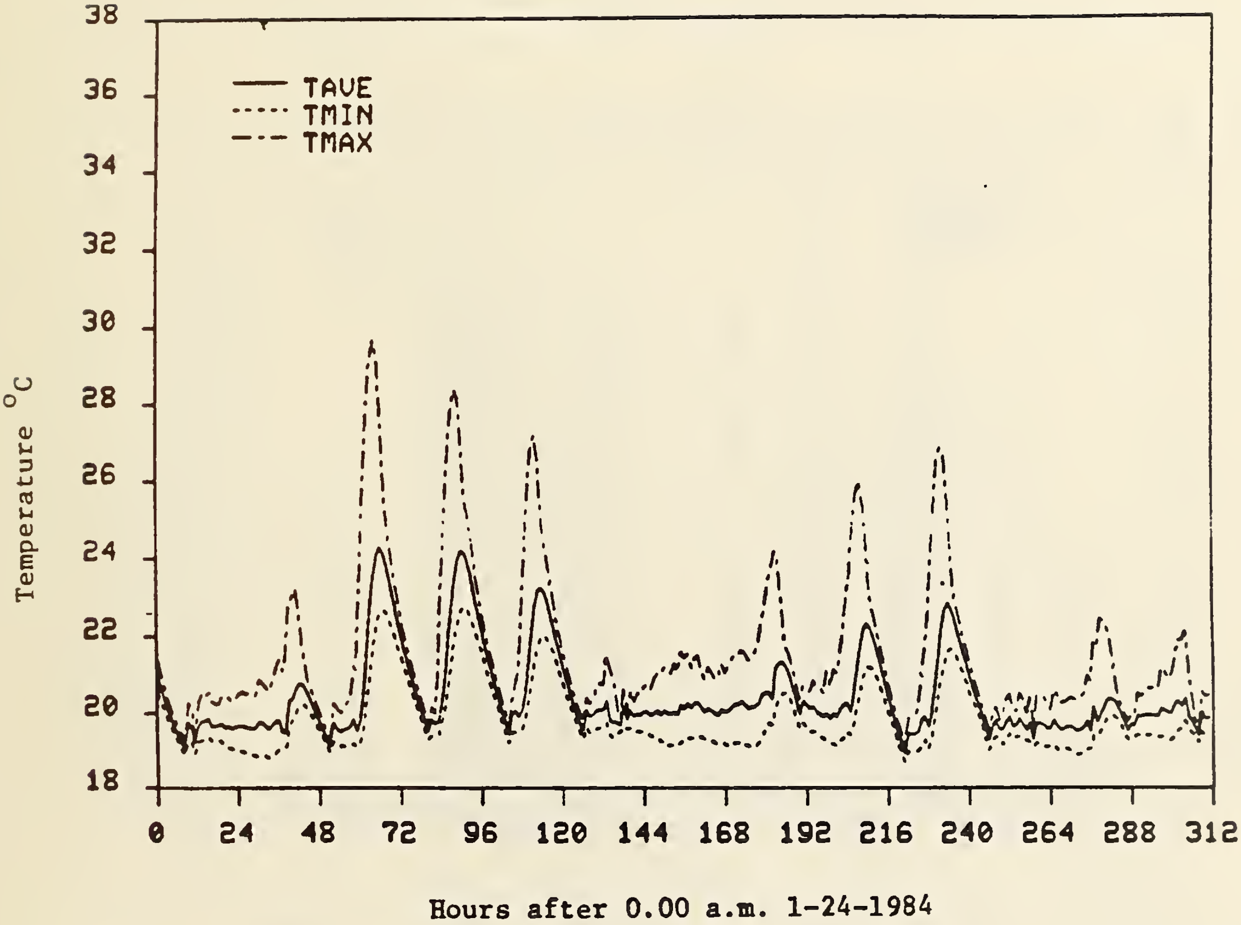


Figure 14. Variations of average, maximum and minimum air temperatures in cell #2 during 1/24-2/5/1984

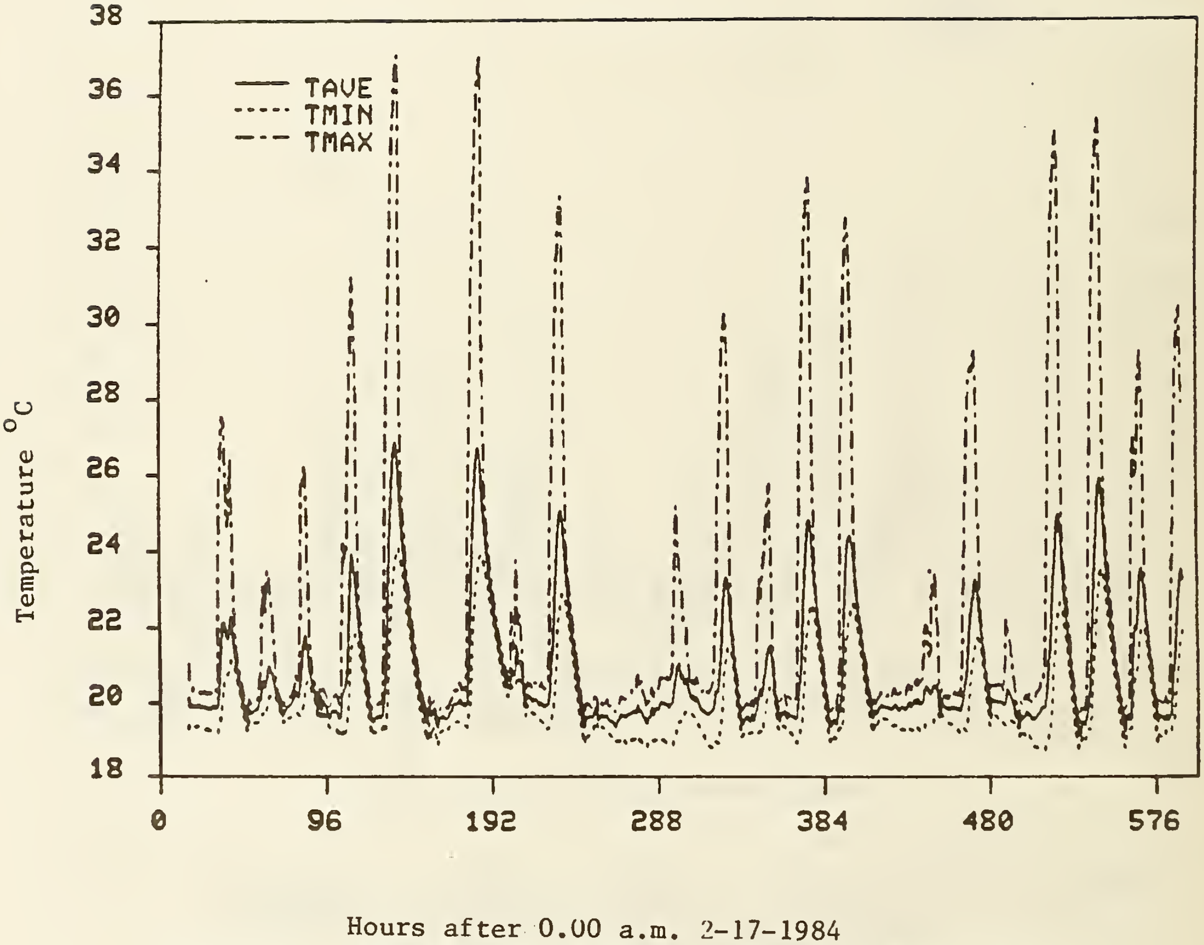


Figure 15. Variations of average, maximum, and minimum air temperature in cell #2 during 2/17 - 3/12/84.

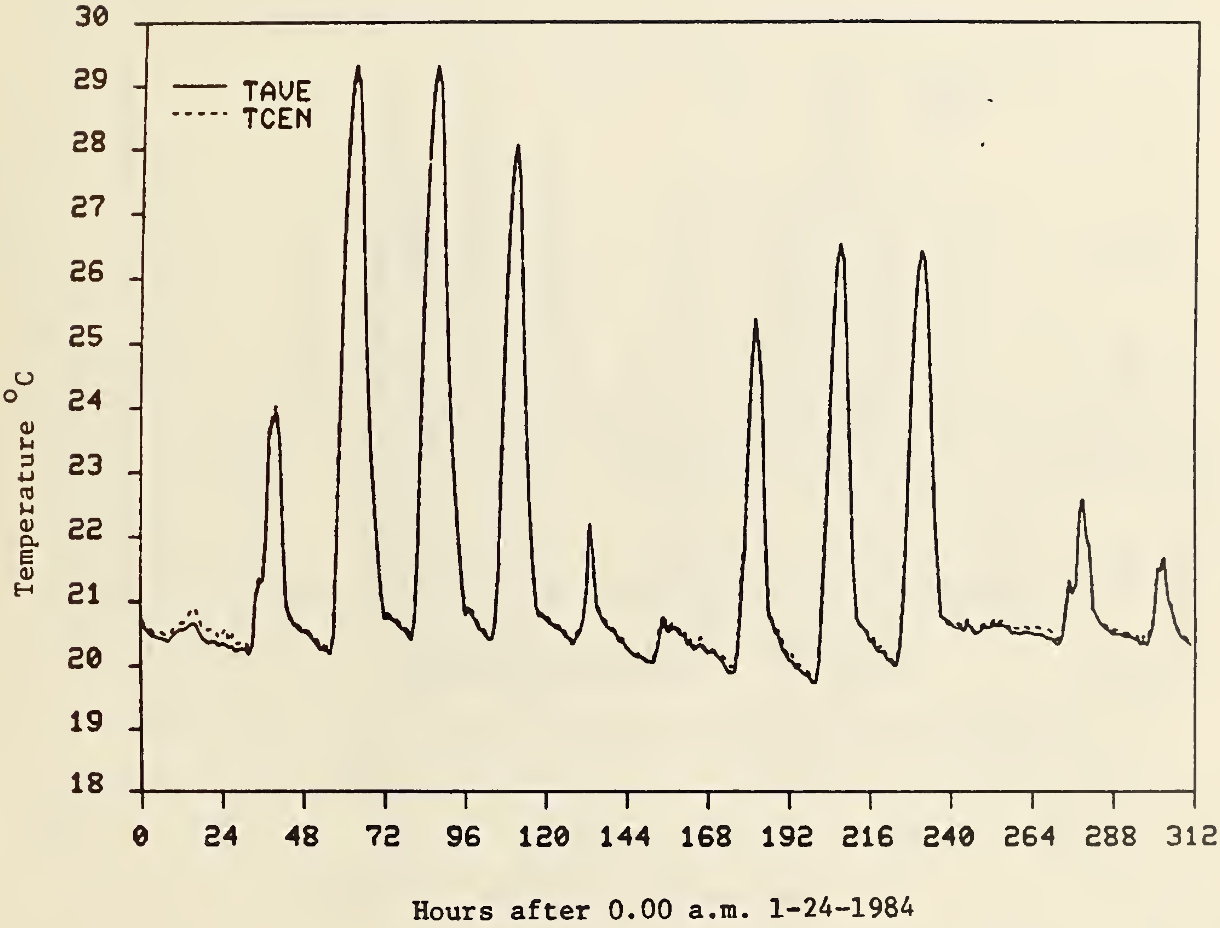


Figure 16. Variations of average and centroidal air temperature in cell #4 during 1/24-2/5/1984

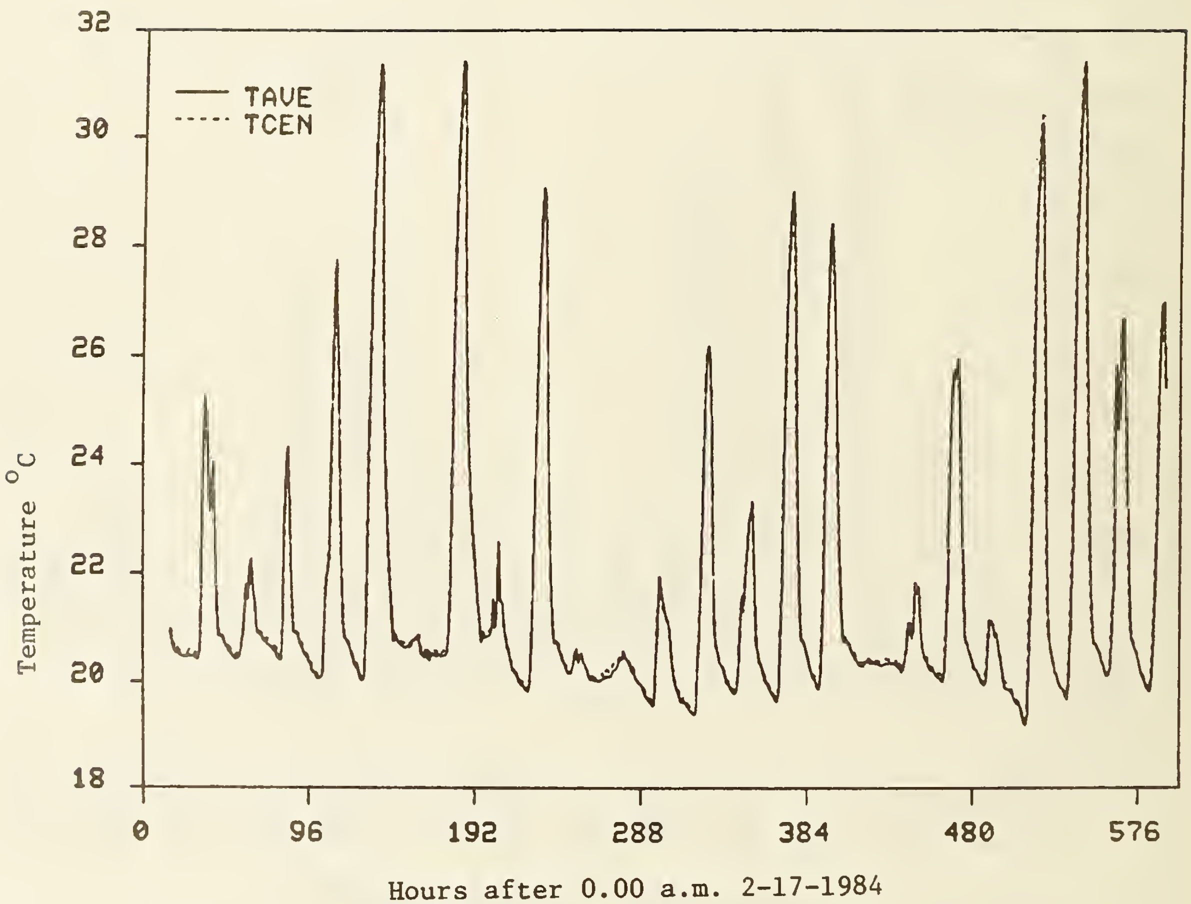


Figure 17. Variations of average and centroidal air temperatures in cell #4 during 2/17 - 3/12/1984

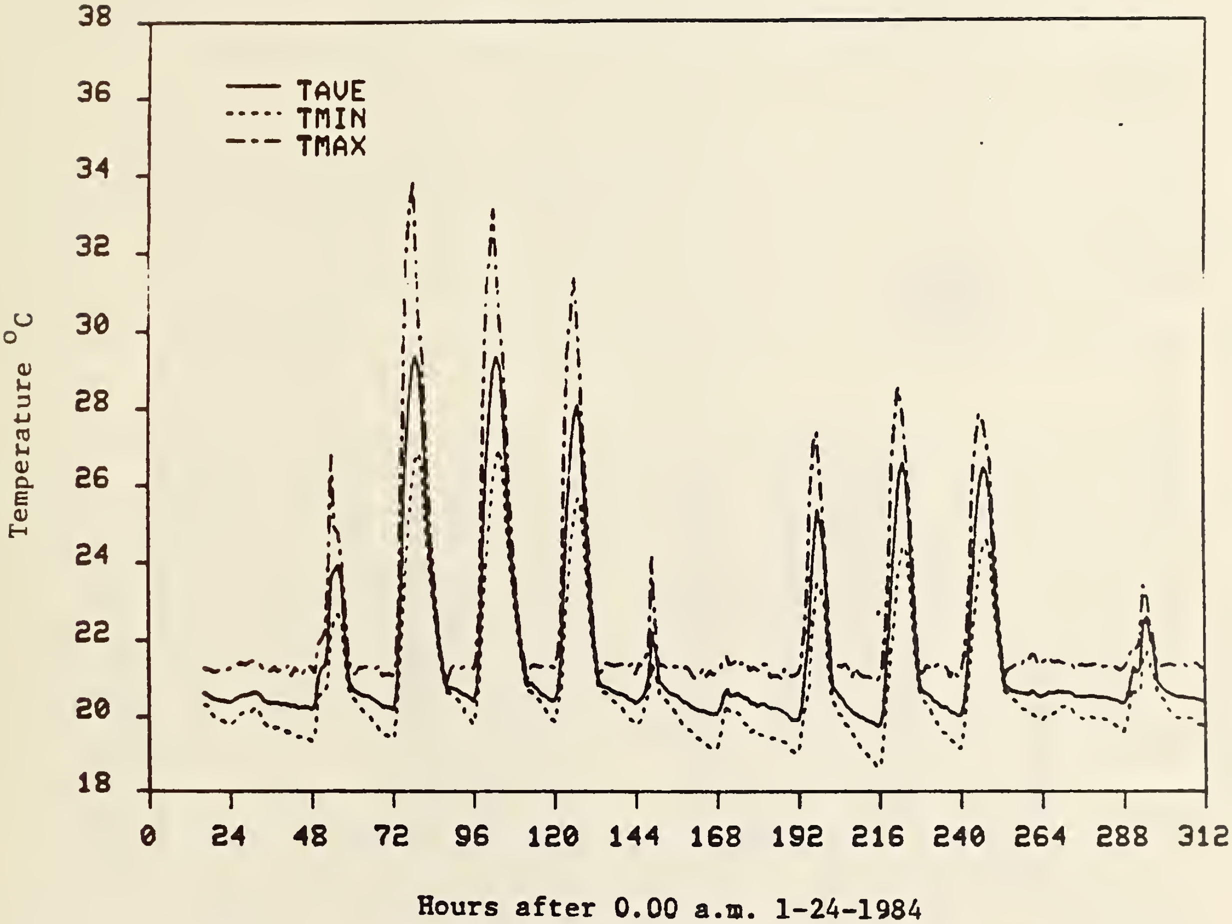


Figure 18. Variations of average, maximum, and minimum air temperatures in cell #4 during 2/17 - 3/12/84.

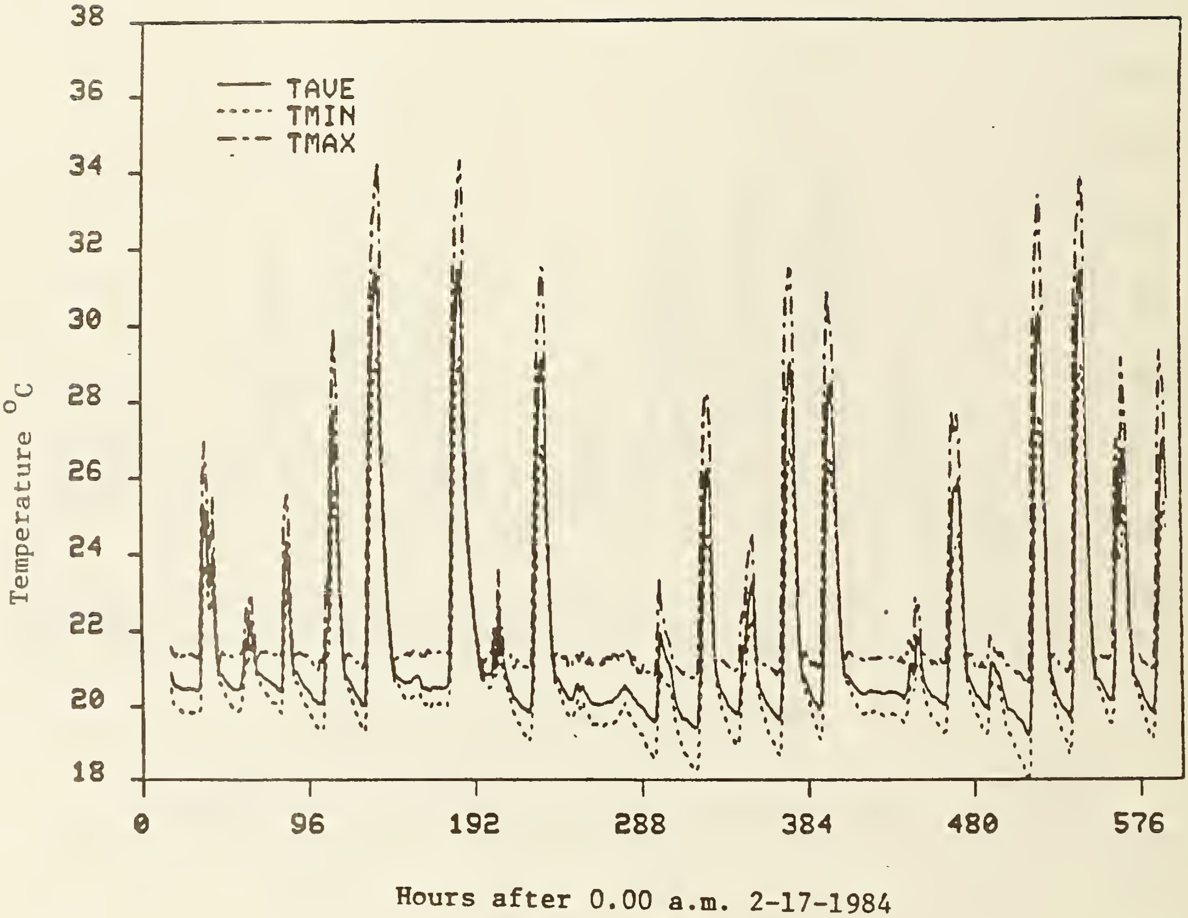


Figure 19. Variations of average, maximum, and minimum air temperatures in cell #4 during 2/17 - 3/12/84.

5.4 FLOOR SURFACE TEMPERATURE

Surface temperatures of the concrete floor at four identical locations along the south to north centerline of the three cells are presented in Figures 21 through 26; and these four locations are shown schematically in Figure 20. Figures 21 and 22 show the data for cell #2 for the two test periods respectively. Figures 23, 24, 25, and 26 show the data for cell #4 and cell #3 respectively. The data presented in these figures indicates that the floor surface temperature in the three cells was not uniform. Due to the solar irradiation received by the floor through the south glazing during the first test period, location D1 in cell #4 (Figure 23) and location D2 in cell #3 (Figure 25) experienced higher temperatures than the other floor locations. During the second test period location D1 in cell #4 and #3 (Figures 24 and 26) experienced the higher temperatures for the same reason. These observations suggest that the assumption of a uniform floor temperature is not justified for passive solar systems, particularly if a portion of the floor receives direct sunlight.

A close examination of Figures 21 through 24 also indicates that during the solar hours the floor surface temperatures in cells #2 and #4, in general and at location D4 in particular, were somewhat higher during the second test period than they were during the first test period. This occurred because during the second test period a fraction of the solar irradiation which was reflected from the sloped ceiling reached the floor. An examination of Figures 25 and 26 reveals that due to the location of the south window in cell #3 and the changing solar declination, different parts of the floor surface received direct sunlight during different days of the year. This effect of the solar declination on the floor surface receiving direct sunlight is depicted schematically in Figure 27.

5.5 AUXILIARY ENERGY SUPPLIED

The auxiliary energy supplied to the test cells is shown in figures 28 and 29 for the two test periods respectively. Figures 28a and 29a, 28b and 29b, and 28c and 29c are respectively for cells #2, #3 and #4. These values of auxiliary energy include the energy used by the heaters, fans, and other energy consuming devices such as signal conditioning equipment in the cells. These devices establish the lower bounds to the auxiliary energy supplied that are apparent in Figures 28 and 29. As expected, cell #4 consumed the most auxiliary energy of the three during nonsolar hours because it had the largest heat loss through the direct gain aperture.

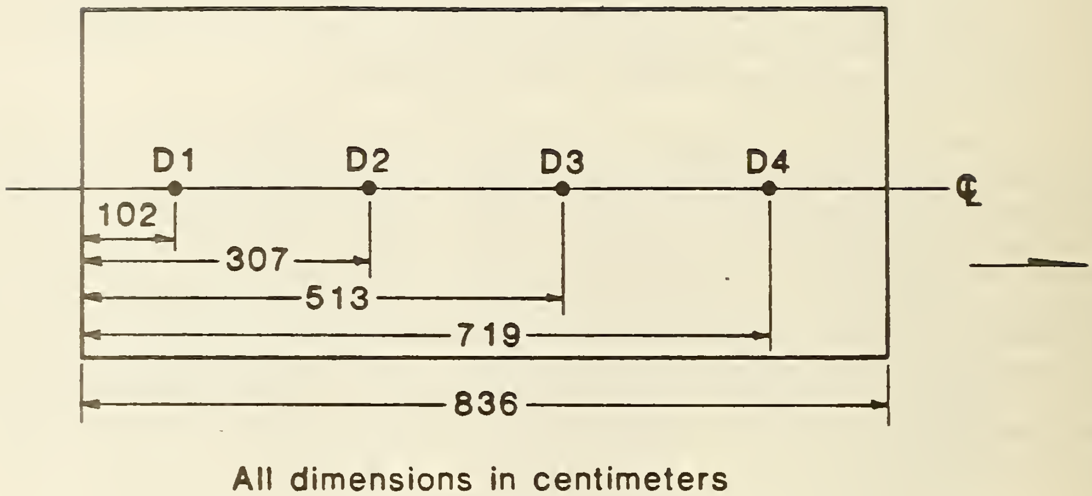


Figure 20. Schematic location of floor surface sensors in cells #2, #3, and #4.

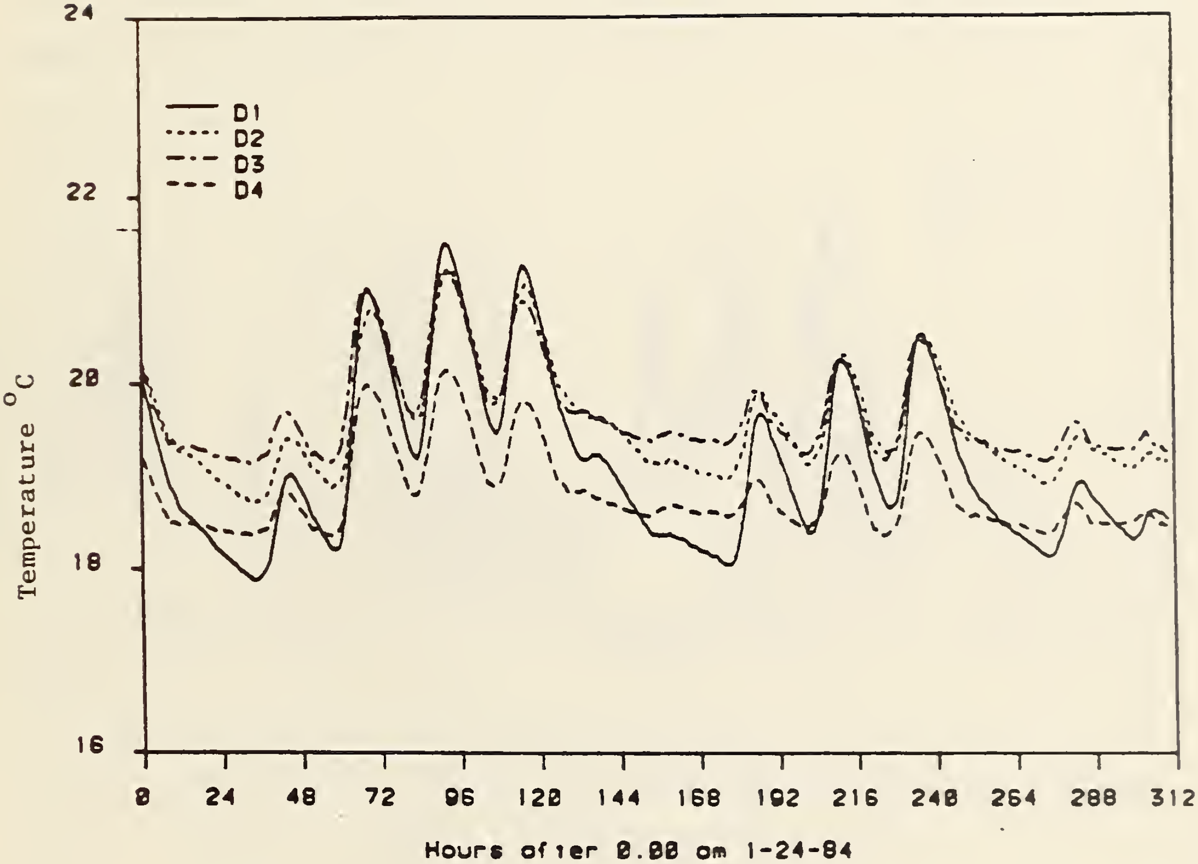


Figure 21. Variations of floor surface temperatures in cell #2 during 1/24-2/5/1984

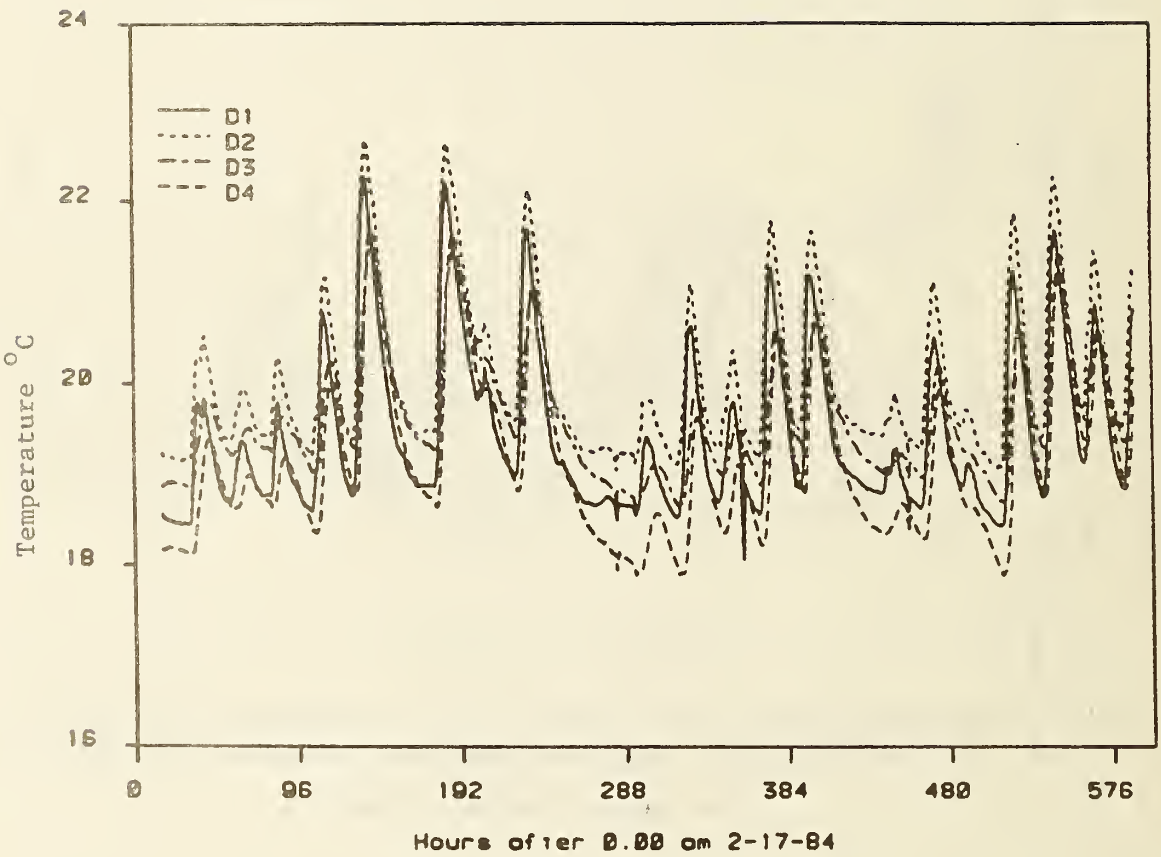


Figure 22. Variations of floor surface temperature in cell #2 during 2/17-3/12/1984

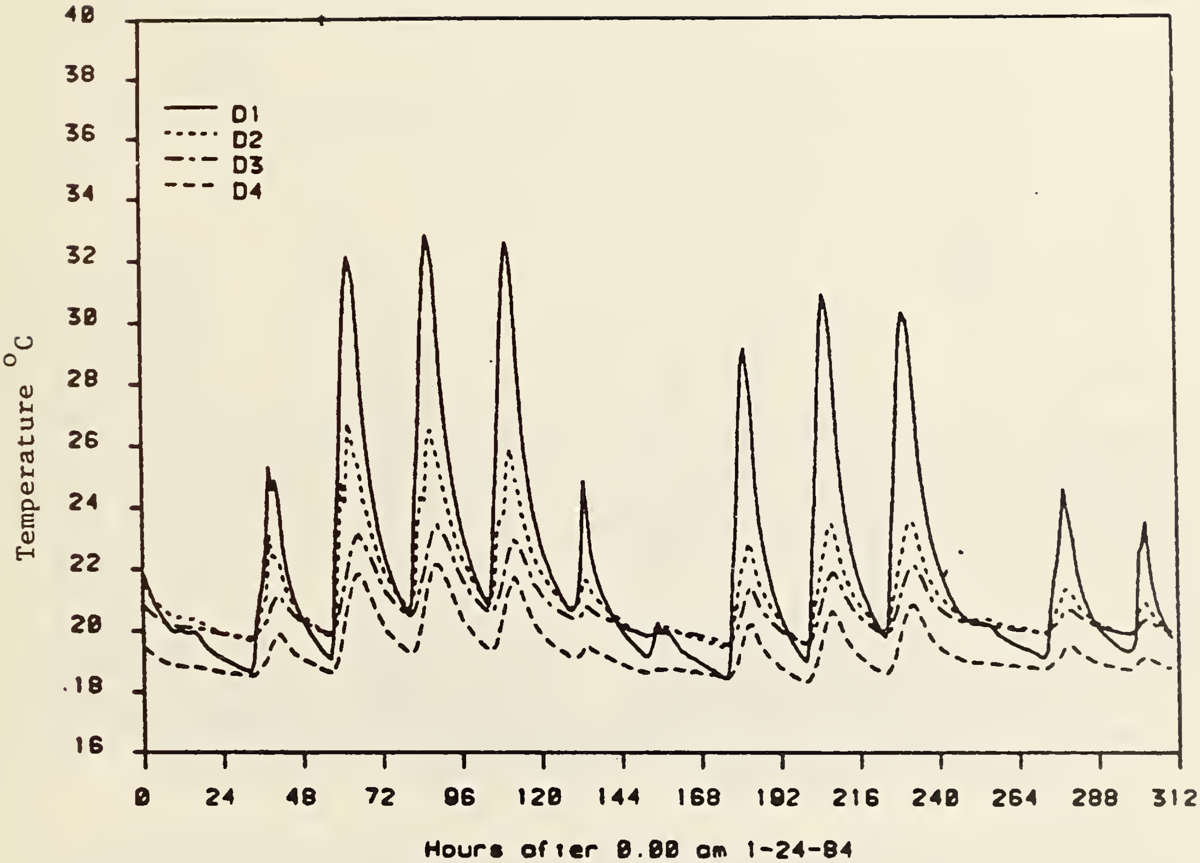


Figure 23. Variations of floor surface temperature in cell #4 during 1/24-2/5/1984

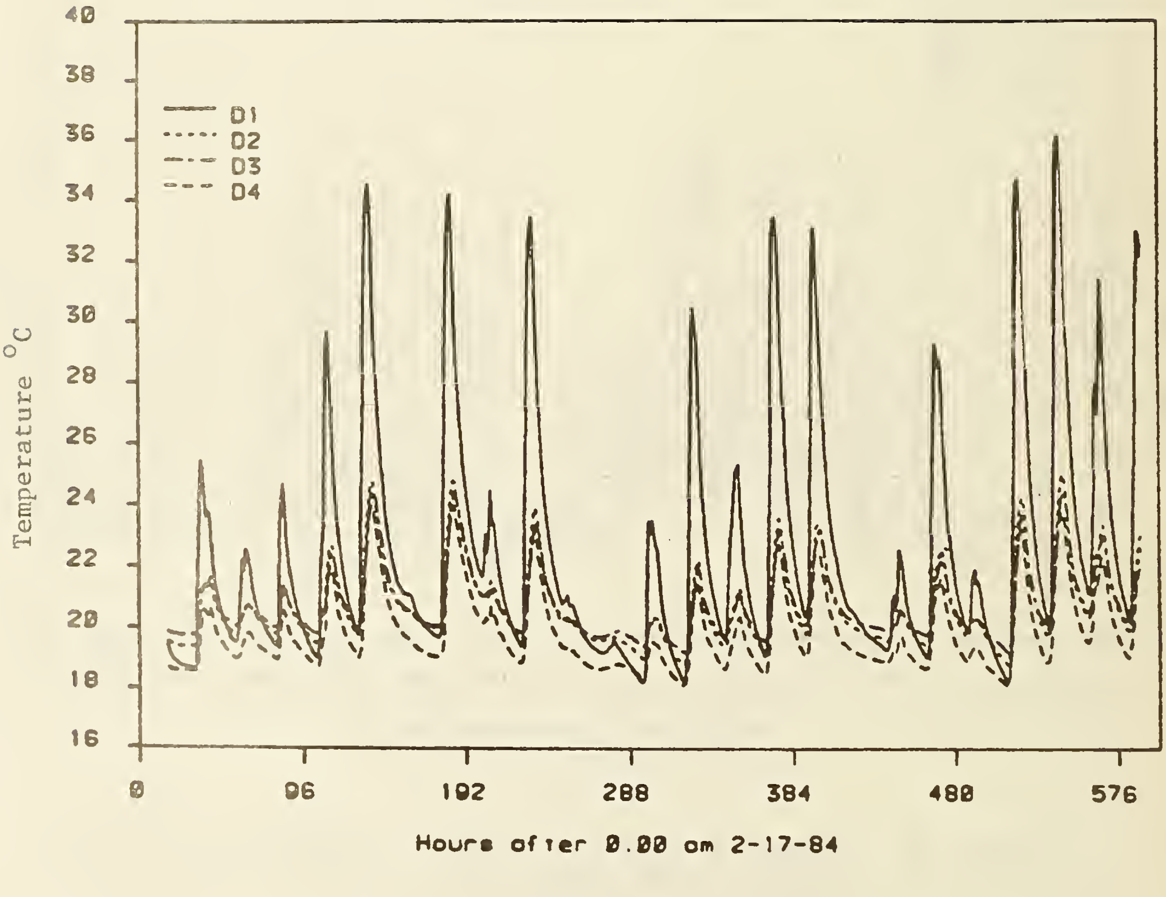


Figure 24. Variations of floor surface temperature in cell #4 during 2/17-3/12/1984

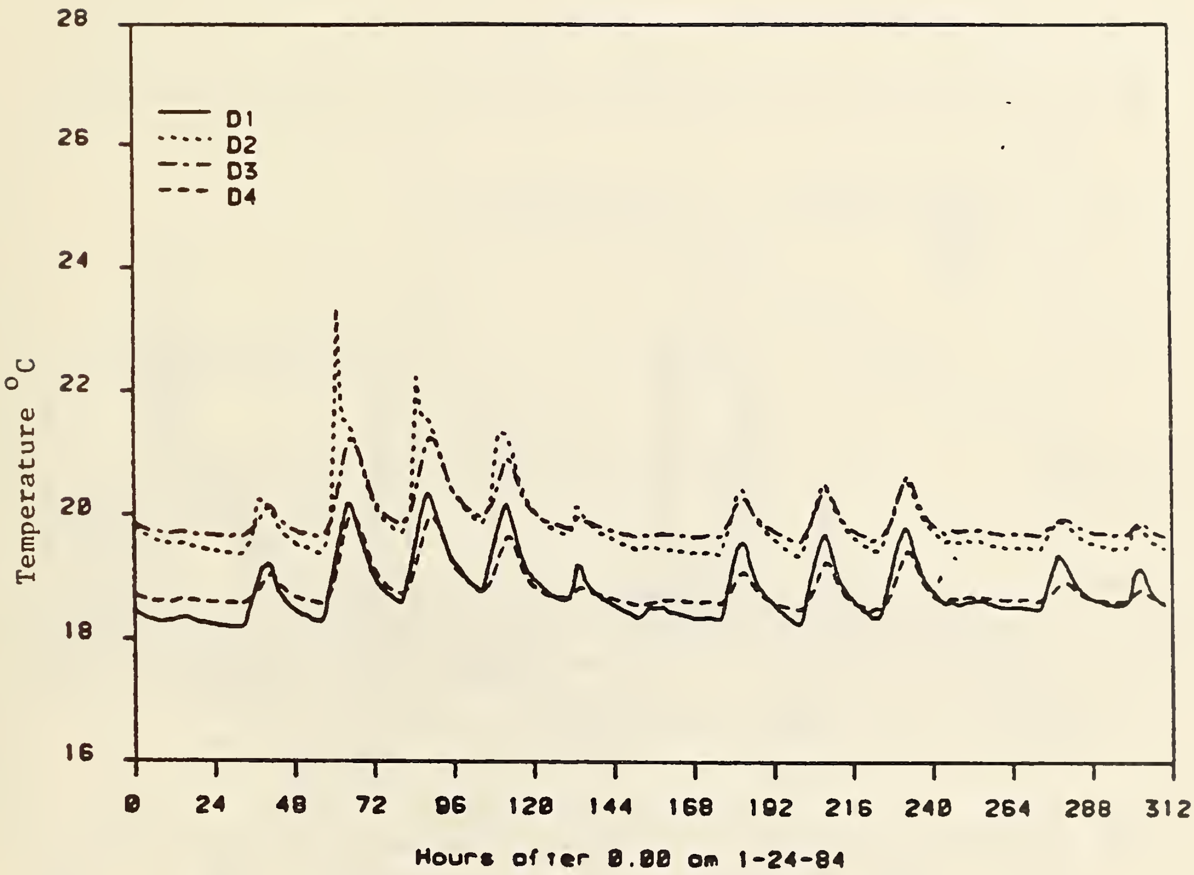


Figure 25. Variations of floor surface temperature in cell #3 during 1/24-2/5/1984

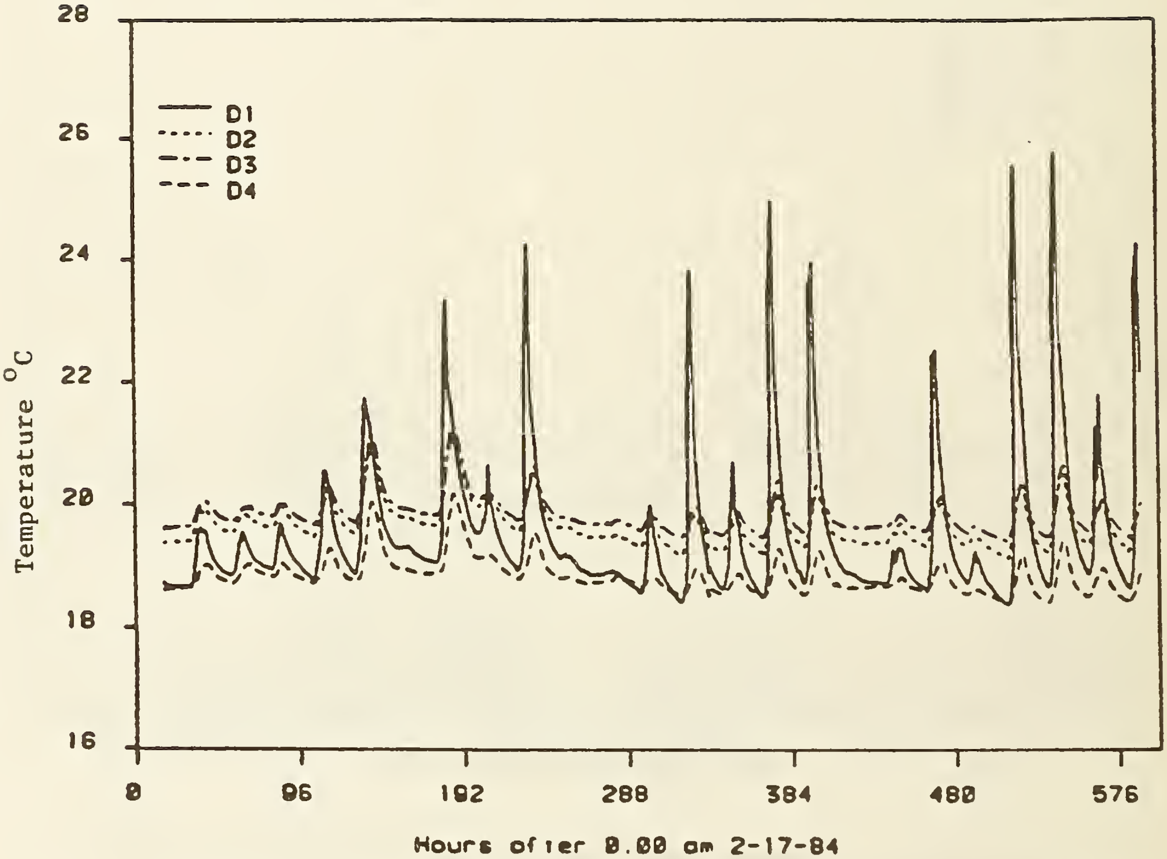


Figure 26. Variations of floor surface temperature in cell #3 during 2/17-3/12/1984

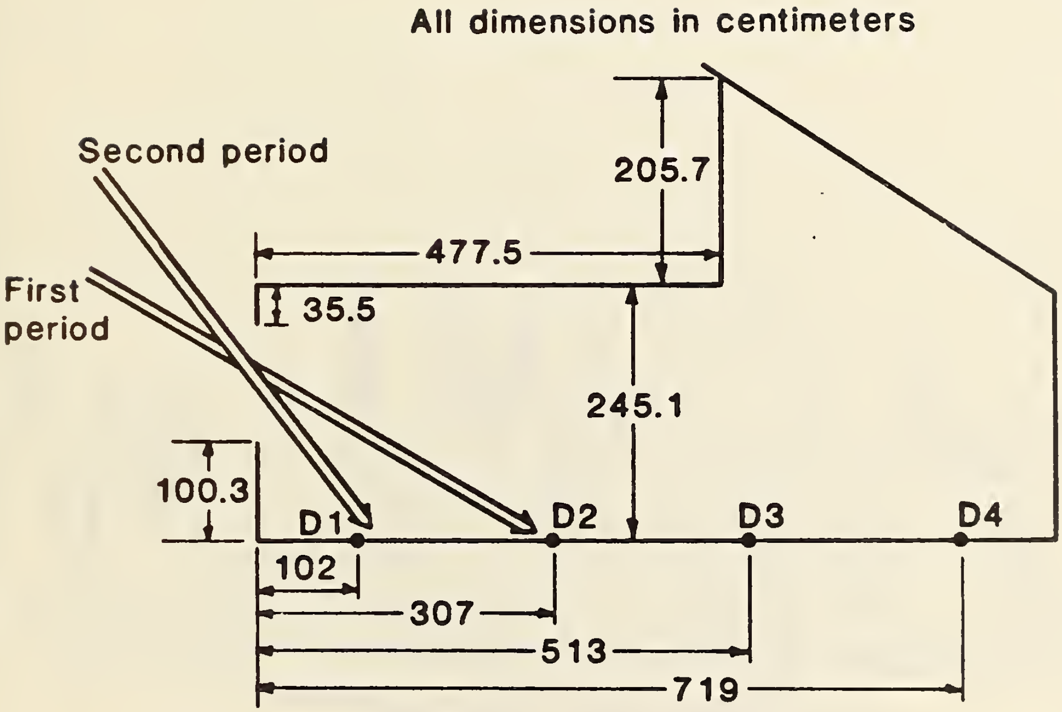


Figure 27. Effects of the solar declination on the floor surface in cell #3

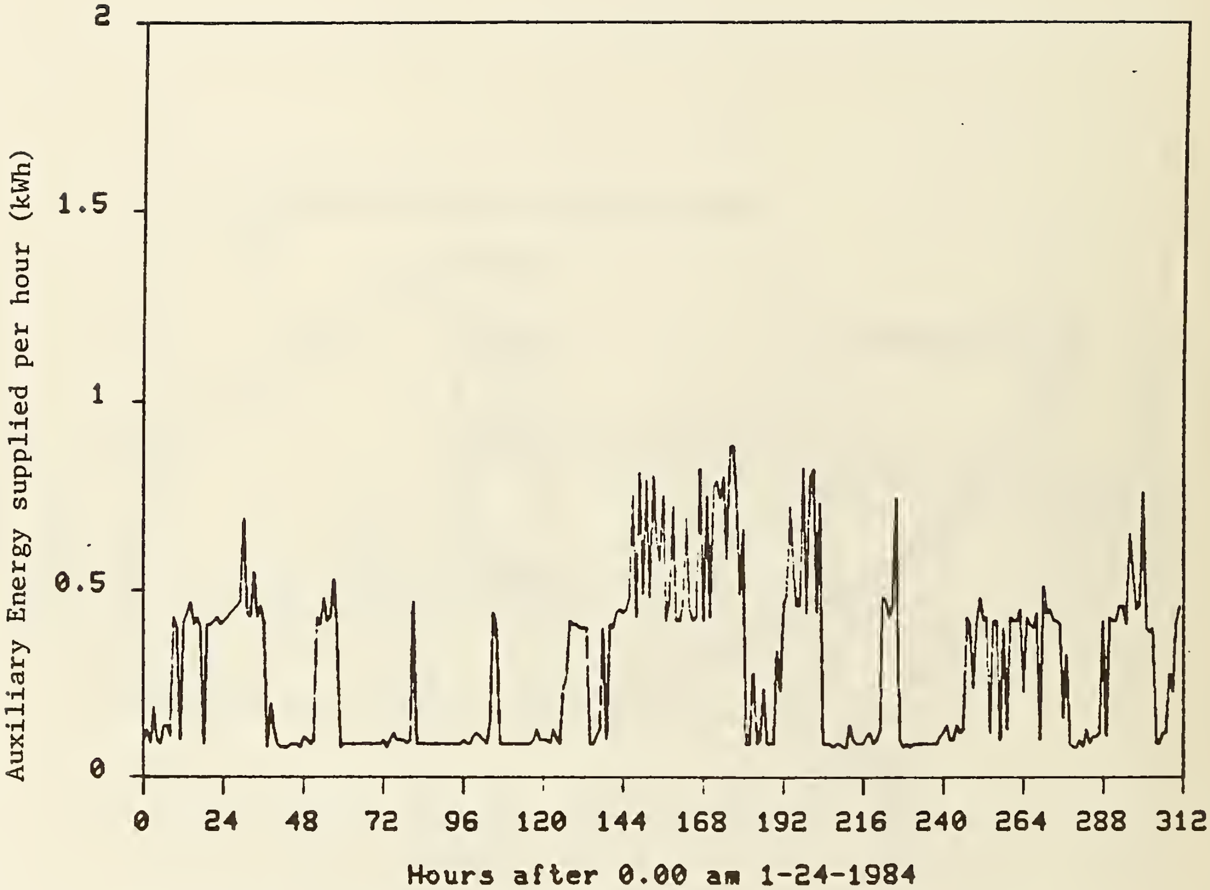


Figure 28a. Auxiliary energy supplied to cell #2 during 1/24 - 2/5/84

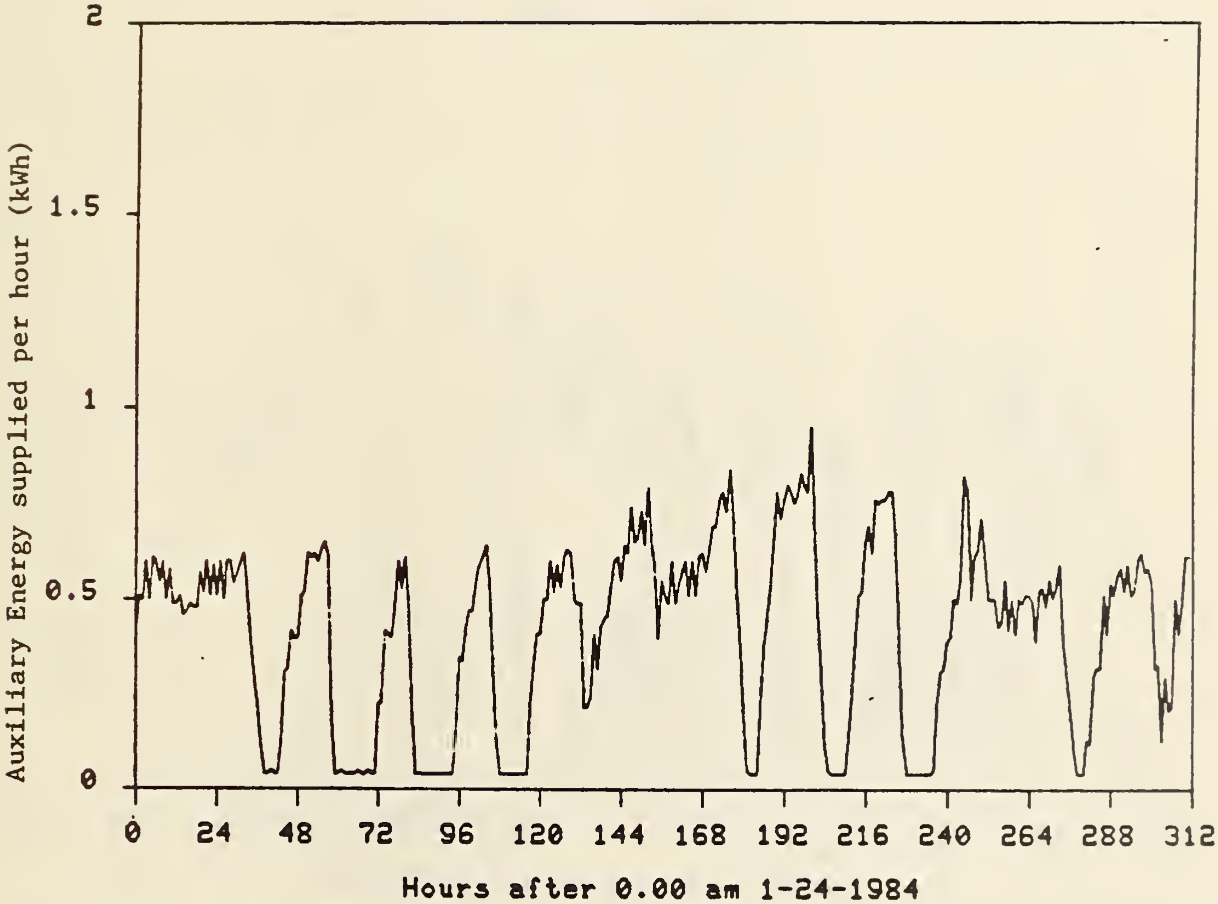


Figure 28b. Auxiliary energy supplied to cell #3 during 1/24 - 2/5/84

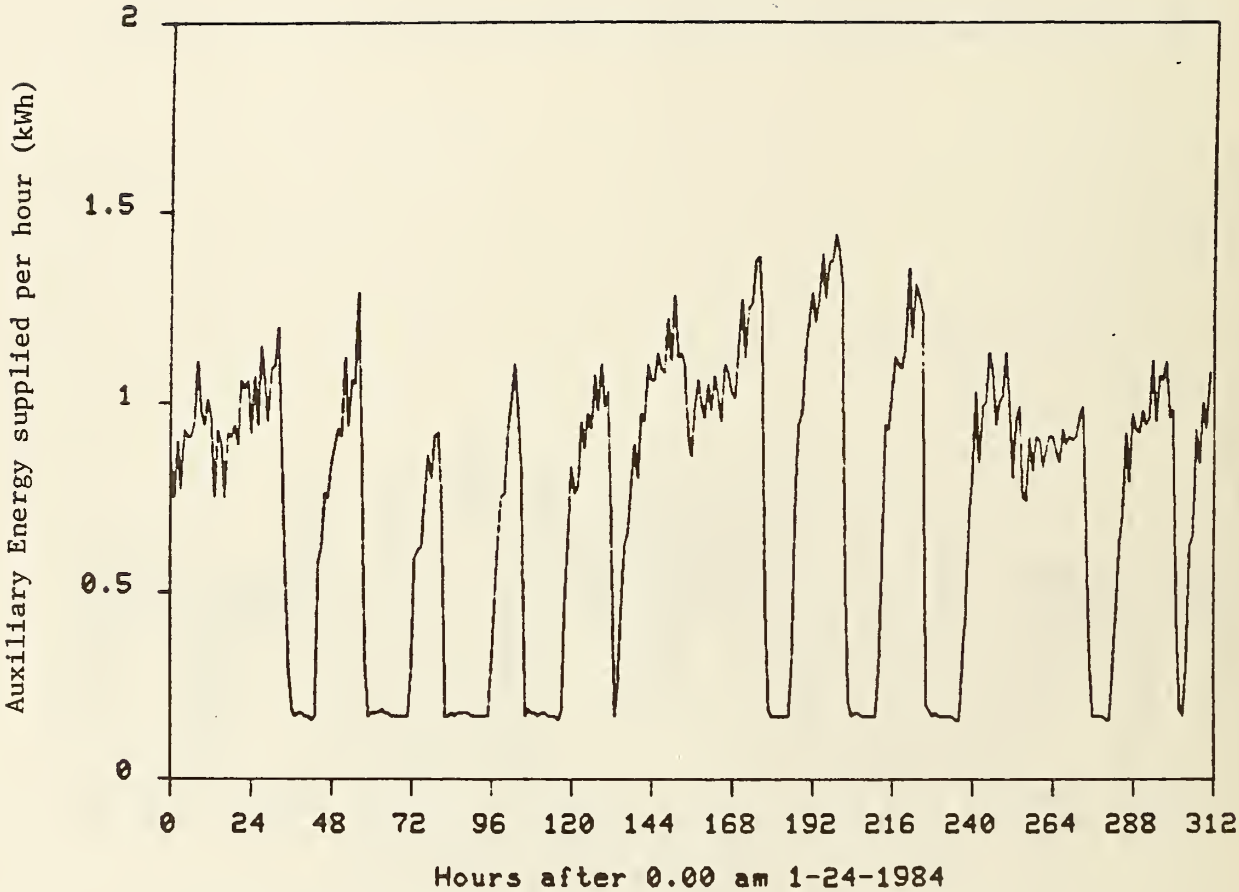


Figure 28c. Auxiliary energy supplied to cell #4 during 1/24 - 2/5/84

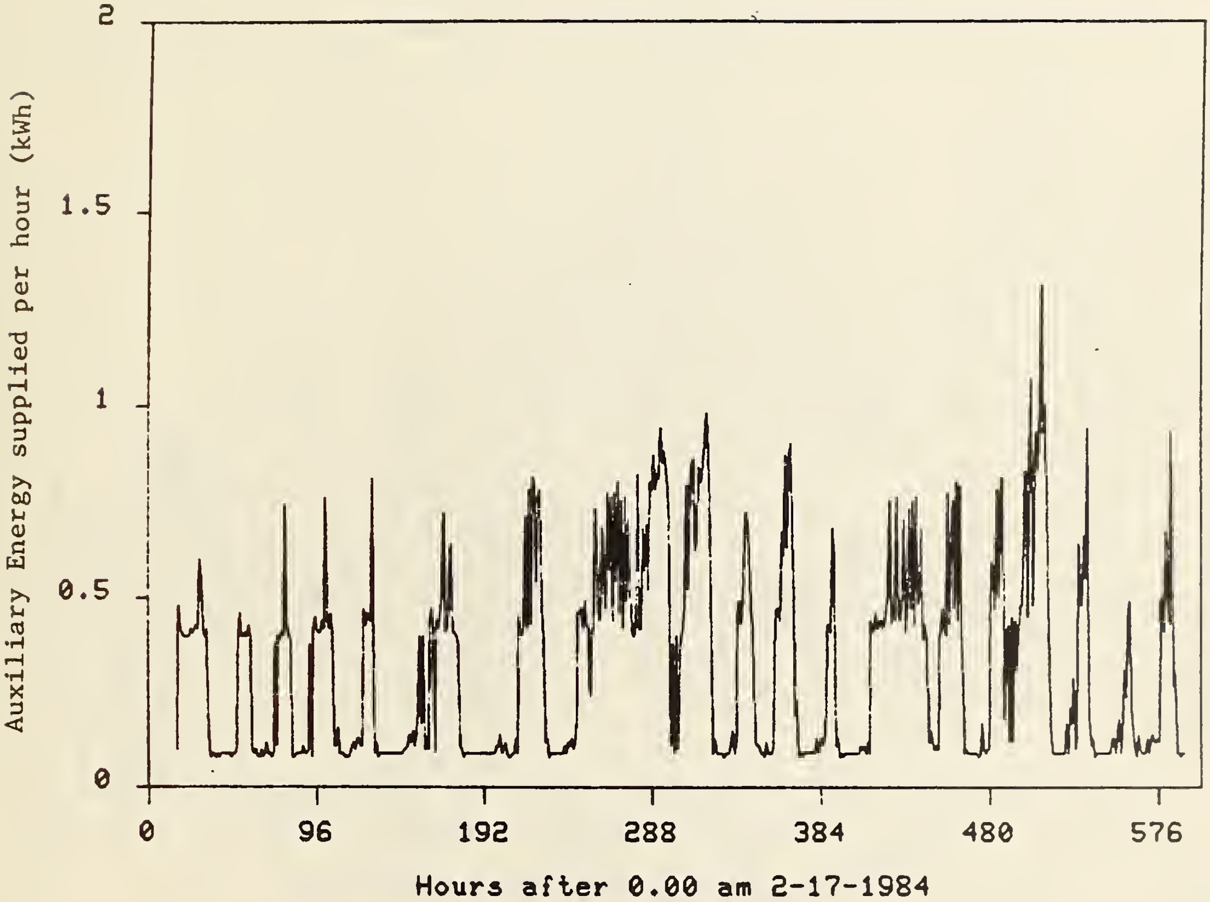


Figure 29a. Auxiliary energy supplied to cell #2 during 2/17 - 3/12/84

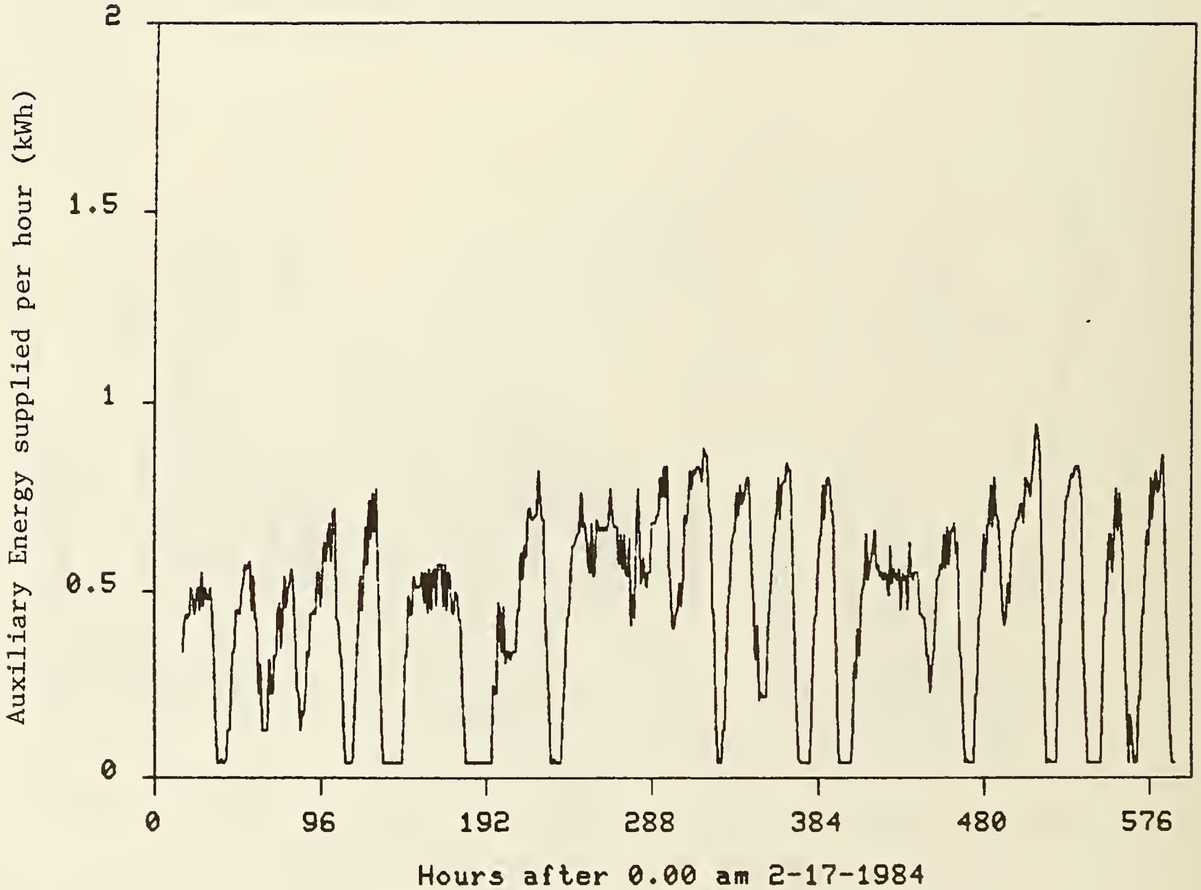


Figure 29b. Auxiliary energy supplied to cell #3 during 2/17 - 3/12/84

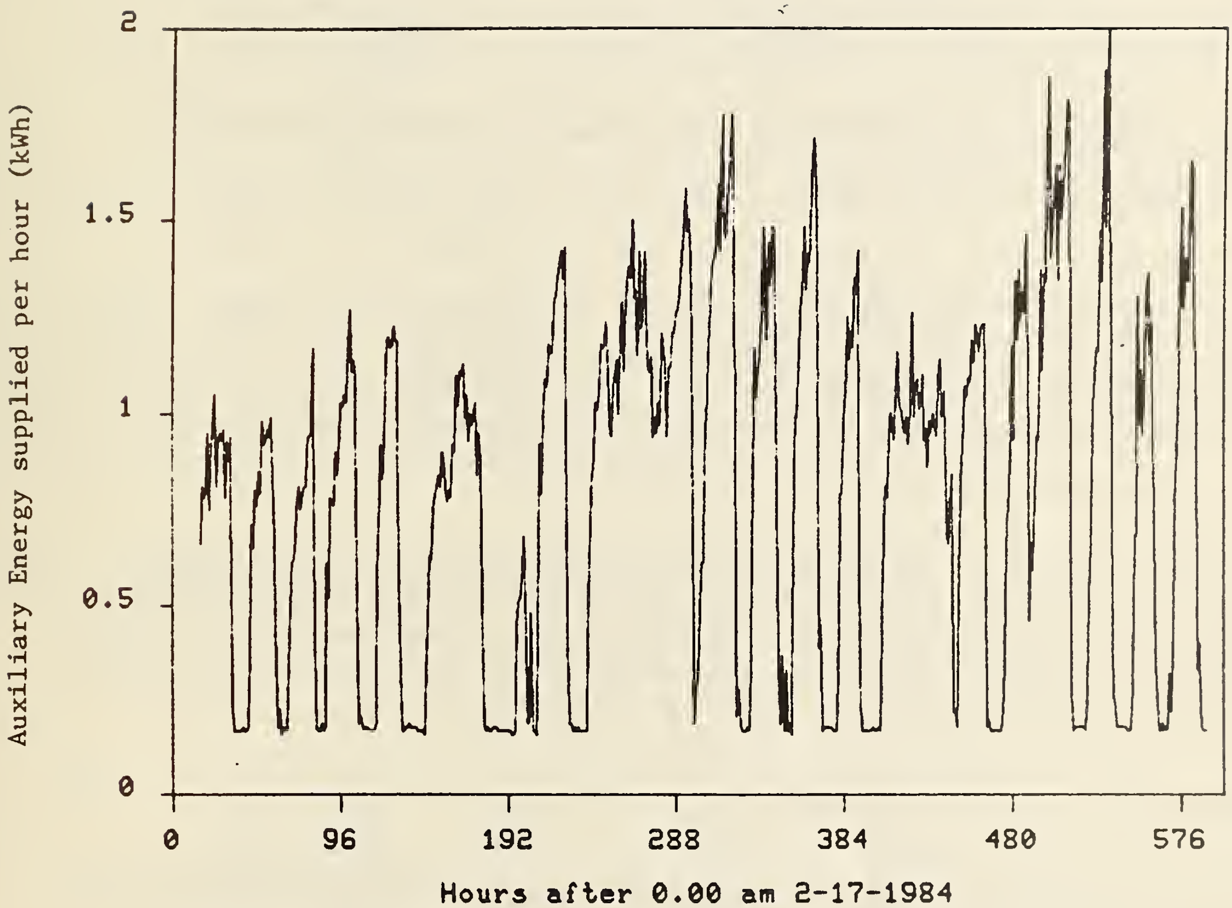


Figure 29c. Auxiliary energy supplied to cell #4 during 2/17 - 3/12/84

5.6 COMPARISON OF SOME OF THE DATA WITH PREDICTED VALUES

5.6.1 Solar Radiation

For the purpose of comparison, the ratios of various solar irradiation quantities were calculated from the measured data given in Table 2 and predicted by following the procedure outlined in the Passive Solar Design Handbook Volume Three [8]. The results are presented in Table 3 and show very good agreement between the measured and predicted ratios of various solar irradiation quantities.

Table 3. Ratio of Various Solar Irradiation Quantities

Ratio	January 24 to February 5, 1984		February 17 to March 12, 1984	
	Measured	Predicted	Measured	Predicted
H_v/H_h	1.447	1.410	1.010	1.041
H_t/H_o	0.625	0.649	0.594	0.610
H_t/H_h	0.904	0.915	0.600	0.634
H_g/H_h	0.282	*	0.239	*

* Assumed in reference 8 to be 0.3.

5.6.2 Energy

For the purpose of comparison, the auxiliary energy required to maintain cell temperature during the test periods was computed in two different ways. First, the energy required to maintain the test cells at the 20°C lower bound temperature in the absence of the solar radiation was calculated as:

$$QREQ = \sum_{i}^{n} [(UA + \dot{m}\, C_p)(20-Ta)]_i \qquad (1)$$

where n = the duration of the test period in hours, and where other quantities are defined in the nomenclature.

Second, the predicted auxiliary energy required, to maintain the test cells at the 20°C lower bound temperature, was calculated as:

$$AUXP = QNET\ (1 - SSF) \qquad (2)$$

where, QNET, the net reference load or the energy required to maintain the nonsolar portion of the test cells at the 20°C lower bound temperature is calculated as:

$$QNET = \sum_{i}^{n} [(LC + \dot{M} C_p)(20-Ta)]_i \qquad (3)$$

Note that the difference between QNET and QREQ is the energy loss through the solar aperture. Both the QREQ and QNET are calculated by using the hourly averages of the measured values of air infiltration ($\dot{m}$) and ambient temperature (Ta).

The solar saving fraction, SSF, was estimated by following the procedures outlined in Appendix C of reference 8. For this calculation the Trombe wall in cell #2 of the NBS test facility was taken as reference design type G2 as defined in reference 8 for both test periods. Cell #3 was taken to be of reference design type A1 for both test periods and Cell #4 was taken to be of reference design type C1 for the first test period (when the clerestory window shutters were closed) and type A1 for the second test period when the clerestory window shutters were open). Measured solar irradiation data, and degree days computed from the measured values of ambient temperature (Ta) and the 20°C fixed base temperature were used in the calculation of SSF.

The auxiliary energy supplied (shown in Figures 28 and 29) has been summed over the test periods and the resulting values of total auxiliary energy supplied, AUXM, are shown in Tables 4 and 5 and Figures 30 and 31 along with the values of AUXP, QNET, and QREQ. The values of SSF, LC, and UA are also shown in Tables 4 and 5. The data presented in Tables 3 and 4 and Figures 30 and 31 show a good agreement between AUXM and AUXP.

Table 4. Energy Values and SSF for the Three Test Cells for a Period of 312 Hours During the January-February, 1984 Experiment

Quality	Cell #2	Cell #3	Cell #4
AUXM (kWh)	89.3	129.9	225.3
AUXP (kWh)	95.9	130.0	229.3
QNET (kWh)	141.0	139.0	259.3
QREQ (kWh)	244.9	195.0	422.6
LA (W/K)	18.2	18.2	37.9
UA (W/K)	32.6	27.8	66.0
SSF	0.32	0.03	0.116

Table 5. Energy Values and SSF for the Three Cells for a Period of 576 Hours During the February-March, 1984 Experiment

Quality	Cell #2	Cell #3	Cell #4
AUXM (kWh)	186.8	260.0	454.5
AUXP (kWh)	188.8	247.7	459.0
QNET (kWh)	250.7	260.0	494.2
QREQ (kWh)	553.4	493.0	869.8
LA (W/K)	17.2	18.2	37.9
UA (W/K)	46.4	41.6	74.0
SSF	0.247	0.025	0.071

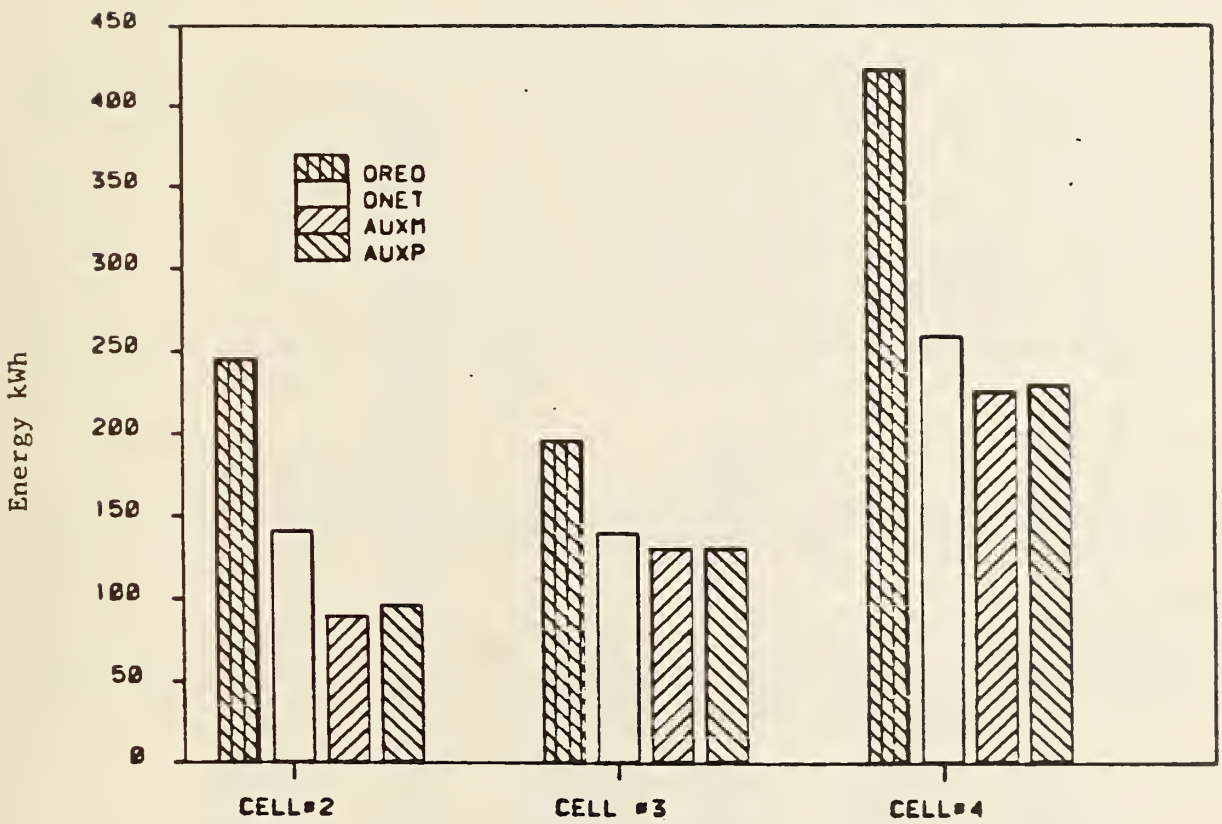


Figure 30. Total values of various energies for the 13-day period during 1/24-2/5/84

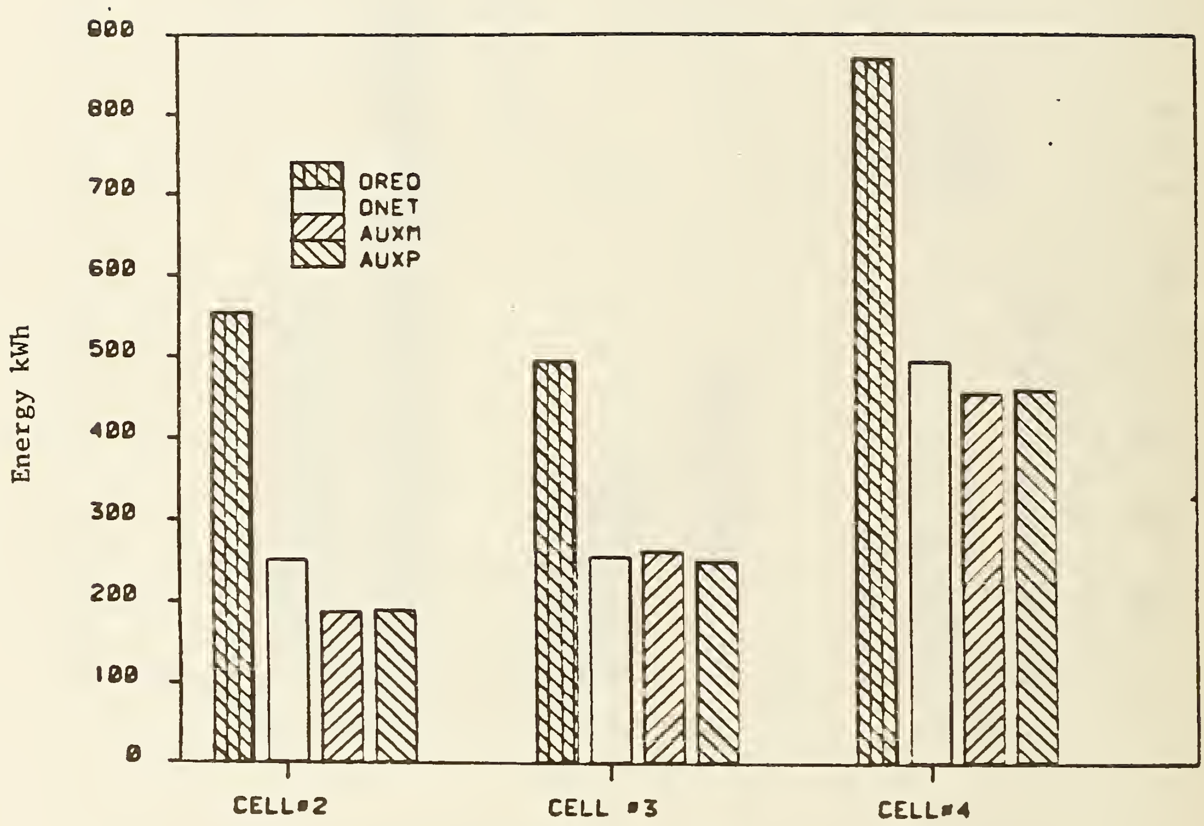


Figure 31. Total values of various energies for a 24-day period during 2/17-3/12/84

6. CONCLUSIONS

Although the primary purpose of these experiments was to acquire detailed performance data for model validation, some characterization of the passive subsystems is also possible. Based on the data of these short-duration winter-time performance monitoring experiments the following conclusions may be drawn. 1) The Trombe wall cell (i.e. cell #2) performed best of the three test cells in terms of its solar saving fraction and energy consumption. 2) Regardless of the magnitude of the air stratification, the temperature recorded by the sensor located in the vicinity of the centroid of the cell represents the average temperature of the cell air in the direct gain and Trombe wall cells. 3) The floor surface temperature in the test cells was not uniform. The assumption of a uniform floor temperture is not justified for passive solar systems, particularly if a portion of the floor receives direct sunlight. 4) The direct gain cell (i.e. cell #4) consumed the largest amount of auxiliary energy of the three cells, and had the largest upward temperature (average values) fluctuations. 5) The good agreement between the data and predicted ratios of various solar irradiation quantities and between measured and predicted values of auxiliary energies suggests that the procedures for predicting these quantities outlined in reference 8 are valid.

7. ACKNOWLEDGEMENTS

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here*)

The performances of three full-sized adjoining rooms, each with a different south-facing passive feature, were monitored for two short periods during January-February and February-March, 1984. These rooms are a Trombe wall cell, a control cell, and a direct gain cell in the NBS Passive Solar Test facility. During the experiment data from 436 sensors were collected. The data include: auxiliary energy supplied, continuous air infiltration, temperatures, solar radiation, and wind speed and direction. This report briefly describes the test facility, instrumentation, data acquisition system and procedures and test conditions for the experiments. The report presents representative data and results of a preliminary analysis of the data. It compares the performances of three test cells, and the values of average, centroidal, maximum and minimum air temperatures in the direct gain and Trombe wall cells. Results indicate that regardless of the magnitude of the stratification the temperature recorded by the sensor placed in the vicinity of the centroid of the cell was equal to the average value of the cell air temperature.
The report also compares data with the predicted values of (1) the ratios of various solar radiation quantities; and (2) the auxiliary energy required to maintain the fixed value of the lower bound temperature in the test cells. The data and predicted values show good agreement suggesting that the procedures outlined in the "Passive Solar Design Handbook Volume Three" for predicting these quantities are valid.

12. KEY WORDS (*Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons*)

auxiliary; average; centroidal; comparison; data; energy; passive solar; performance; predicted value; surface; systems; temperatures

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