Title

THERMAL MASS: A COMPARISON OF MEASUREMENTS AND BLAST PREDICTIONS FOR SIX TEST CELLS IN TWO CLIMATES

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THERMAL MASS: A COMPARISON OF MEASUREMENTS AND BLAST PREDICTIONS FOR SIX TEST CELLS IN TWO CLIMATES

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ABSTRACT

LBL has carried out a residential thermal-mass analysis project that had two major phases: (1) a validation phase in which predictions of the proposed simulation tool (BLAST*) were compared with measured data, and (2) a parametric simulation phase where the validated simulation program was used to systematically explore the dependence of energy use on varying amounts and types of thermal mass in the exterior walls of a typical residence.

This report contains the results of the comparison of BLAST predictions and measured data from three experimental test cells at each of two field sites operated by the New Mexico Research and Development Institute and the U.S. National Bureau of Standards, respectively. For each cell, comparisons were made for three simulation time periods representing different seasonal conditions; each of the comparison periods was about ten days in length. For each of these time periods, hourly comparisons were made for ten selected parameters: heating or cooling load, air temperature, and individual wall inside surface temperatures and heat fluxes. Statistical descriptions of the comparison results are summarized in tables. Time-series plots showing comparisons of selected measured and predicted parameters are also presented. During the simulation studies a number of issues have been identified and discussed in detail to explain the observed differences between the measured data and the BLAST predictions. These differences are generally within a range explainable by a combination of the measurement uncertantities, where they are quantifiable, and by unavoidable input assumption variances in the simulation compared to actual experimental conditions. Finally, the ability of BLAST to predict load changes among the cells due to climate or thermal mass is discussed.

* BLAST (Building Loads Analysis and System Thermodynamics) is trademarked by the Construction Engineering Research Laboratory, U.S. Department of the Army, Champaign, Illinois.

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1. INTRODUCTION

The Thermal Mass Analysis Project that LBL is carrying out for ORNL has two major phases: a validation phase in which simulation predictions are compared with measured data collected by other participants in the program, and a parametric simulation phase in which predictions of the effects of various thermal mass configurations in models which are intended to represent realistic buildings will be developed and analyzed. This report describes the results from the completed first phase of the effort. A companion report contains the results of the second phase of the effort [1].‡

All the energy performance simulations for both phases of the project use the building analysis computer program BLAST-3.0.* BLAST is a computerized, comprehensive energy analysis simulation tool that employs a detailed heat balance solution method with an hourly time increment that correctly accounts for the effects of structural thermal mass on the dynamics of building energy consumption. The general capabilities and characteristics of the BLAST program are described in references [2-5].

The first phase consisted of detailed hourly comparisons between measured data and BLAST predictions for three physical parameters including space loads, air and wall surface temperatures, and wall heat fluxes. Comparisons were made for several time periods for three test cells each at experimental field test sites operated by the New Mexico Energy Research and Development Institute (NMERDI), and the U.S. National Bureau of Standards (NBS). Subsequent sections of this report describe separately these comparison results for NMERDI and NBS test cells representing the first phase of the effort.

‡ Numbers in brackets indicate references cited at the end of this report.
* BLAST (Building Loads Analysis and System Thermodynamics) is trademarked by the Construction Engineering Research Laboratory, U.S. Department of the Army, Champaign, Illinois.

2. NMERDI TEST CELL COMPARISON

Three out of eight NMERDI test cells (Cells 1: 11-inch adobe, 6: 8-inch CMU block, and 7: insulated wood frame) were selected for comparison with BLAST simulations for the three time periods shown below.

NMERDI Test Cell Comparison Periods	
Winter:	Jan 12 - Jan 20
Spring:	Feb 28 - Mar 10
Summer:†	May 24 - Jun 5

Measured hourly data for the test cells consisted of the total electrical energy consumption used by both the circulating fans and the resistance heaters; the temperatures and fluxes measured at the wall surfaces, ceiling, and floor; the interior air temperature measured at the center of the cell in the destratification plenum and air temperatures measured near the wall interior surfaces at the center of each wall; and finally, site weather data and ground temperatures. The BLAST program has been used to predict corresponding hourly quantities for comparison with measured data for each of the cells. How the cell construction data are assembled and how the weather tapes are prepared for the BLAST simulations will be discussed in detail next, together with other assumptions. Additionally, complete BLAST inputs for each of the three test cells are included in Appendix 1.

2.1. NMERDI - Test Cell Simulation Input

Each of the three test cells are flat-roofed, windowless structures with insulated concrete floors. The construction details of the cells are given in reference [6], and BLAST inputs were developed from the information given there. When available from NMERDI sources [10], the material properties of the walls, ceiling and floor are taken from that source; otherwise NBS information was used [7], as recommended by NMERDI. Summaries of the construction and material properties are given in Tables 1 and 2. The

† The summer time period consisted of heating only; no cooling was used in the test cell.

TABLE 1: NMERDI Test Cell Simulation Model Construction Details†									
Construction	Cell 7 (Frame)			Cell 1 (Adobe)			Cell 6 (Masonry)		
	material	thk*	R‡	material	thk*	R‡	material	thk*	R‡
Wall-1	plywood	0.0521	0.781	adobe	0.9167	1.984	CMU	0.6667	2.564
(1.52 ft	stud	0.3021	4.529				furring	0.0625	0.937
x	gyp board	0.0417	0.451				gyp board	0.0417	0.451
7.50 ft)									
	Total		5.761	Total		1.984	Total		3.952
Wall-2	plywood	0.0521	0.781	adobe	0.9167	1.984	CMU	0.6667	2.564
(18.48 ft	wall ins.	0.3021	10.985				air space		0.940
x	gyp board	0.0417	0.451				gyp board	0.0417	0.451
7.50 ft)									
	Total		12.217	Total		1.984	Total		3.955
Floor	earth	1.0000	2.000	Same as Cell 7					
(20 ft	concrete	0.3333	0.417						
x	floor ins.	0.1667	11.993						
20 ft)									
	Total		14.410						
Roof-1	roofing	0.0313	0.331	Same as Cell 7					
(18.44 ft	plywood	0.0625	0.937						
x	roof ins.	1.0450	33.070						
20 ft)	gyp board	0.0417	0.451						
	Total		34.789						
Roof-2	roofing	0.0313	0.330	Same as Cell 7					
(1.56 ft	plywood	0.0625	0.937						
x	stud	1.0450	15.667						
20 ft)	gyp board	0.0417	0.451						
	Total		17.385						

† Solar absorptances of 0.78 and 0.82 have been assumed for the walls and ceilings, respectively. * Thickness: unit is *ft*. ‡ Resistance units are: $°F \cdot ft^2 \cdot hr / Btu$

TABLE 2: NMERDI Test Cell Material Thermophysical Properties			
Material	Thermal Conductivity ($Btu / hr \cdot ft \cdot °F$)	Density (lb / ft^3)	Specific Heat ($Btu / lb \cdot °F$)
adobe	0.462	75.0*	0.22
CMU	0.260	38.0	0.20
concrete	0.800	150.0	0.20
earth	0.500	120.0	0.20
fiberglass insulation	0.028	2.0	0.20
furring	0.067	32.0	0.33
gyp board	0.093	50.0	0.26
plywood	0.067	45.0	0.29
polyurethane floor insulation	0.014	2.0	0.22
roofing	0.095	70.0	0.35
stud	0.067	32.0	0.33

* See discussion in Section 2.3.1.

heating system for each cell consists of three 1500W electric resistance heaters arranged in a triangular pattern on the floor. The electric heaters are controlled by a thermostat located in a 2 ft^2 destratification plenum. A continuously-operating, 290-cfm fan located at the top of each cell circulates the air down through the plenum. The fan motor power, which is individually determined for each cell [8], is included in the BLAST inputs as an internal load, and given in Table 3. The energy used by the fan is also subtracted from the measured cell electricity consumption in order to directly compare space heating load.

TABLE 3:
Circulating Fan Motor Power

Cell	Power (W)
1	49
6	44
7	46

After repeated attempts to utilize the time-varying air temperatures measured near the cell walls as the interior control temperature in BLAST yielded no reasonable comparisons to measured data, we examined this issue in detail. A more detailed development contained in Appendix 3 shows from references to fundamental mixing principles based on a number of experimental and theoretical studies in the literature that under the conditions found in the test cells, it is reasonable to conclude that the interior air was well mixed and not stratified. This assertion is also directly supported by a study of the measured cell temperatures, which show that a simple weighted average of the plenum temperature (which was time-averaged for the period) and the respective surface temperature coincides almost exactly with the air-adjacent-to-wall temperatures. As a specific example, Figures 1 and 2 show the hourly plenum, surface, and adjacent-to-wall air temperatures, for the North and South walls respectively for Cell 1 during the winter comparison period. Additionally, the fourth trace on each plot shows an appropriate plenum-surface weighted average temperature. Although the figures only indicate the behavior for Cell 1, the same behavior (with slightly different weightings) was also exhibited by the air-adjacent-to-wall temperatures for the other cells. The weighting fraction was found to be approximately the same for all surfaces and time periods for a particular cell, with some variation from cell to cell. Consequently, the appropriate time-averaged constant plenum temperatures were used as the thermostat control temperature in all of the BLAST simulations. Since verification of this assumption is critical to the substantiability of the comparison, we believe that this issue needs further experimental and analytical study to conclusively determine the relationship between the plenum air temperature, the air temperature measured near the walls, the wall surface temperatures, and the true air temperatures in the cells.

Additionally, Figure 3 (Cell 1, winter time period) shows that the time-averaged plenum temperature, when used in a calculation of the surface film coefficient for all the walls combined, not only yields a meaningful result as a function of time, but also an average that is close to accepted values (approximately 0.65 $Btu/hr \cdot ft^2 \cdot {}^\circ F$, versus the ASHRAE-recommended 0.54 $Btu/hr \cdot ft^2 \cdot {}^\circ F$ [9]), which is the constant value used in the BLAST algorithm.† Therefore, the constant value in the BLAST algorithm is used throughout the simulations.

The air infiltration rate for each test cell was measured by using a sulfur hexafluoride tracer-gas technique, and the data were correlated as a function of the local wind velocity and the difference between the indoor and outdoor temperature. The correlation coefficients are reported in [8,10], and the resulting correlation is given by the following equation:

† The combined surface heat transfer coefficient, h, is calculated from measured heat flux and temperature data for the individual surfaces and the measured air temperature using the relation:

$$h = \frac{Q_s + Q_w + Q_n + Q_e}{4 \cdot \overline{T}_{air} - T_s - T_w - T_n - T_e}.$$

It can easily be shown that this expression corrects for the radiation components in the measured heat fluxes (radiation to the floor and ceiling are neglected). The air temperature we used in this calculation was the time-averaged measured plenum temperature.

$$L_{inf} = A \cdot W^2 + B \cdot \left| \frac{1}{T_{out}} - \frac{1}{T_{in}} \right| \qquad (1)$$

where

L_{inf} = infiltration rate (*air changes/hr*),
W = wind speed (m/s),
T_{out} = outdoor air temperature (K),
T_{in} = indoor air temperature (K).

For the BLAST simulations, Eq. (1) is slightly modified to be consistent with the correlation given in the infiltration algorithm of the BLAST program, which uses:

$$L_{inf} = A \cdot W^2 + B' \cdot \left| T_{out} - T_{in} \right| \qquad (2)$$

where

$$B' = \frac{B}{\overline{T}_{out} \cdot \overline{T}_{in}}.$$

The overbars in the definition of B' denote the average quantities. The coefficients used in the BLAST simulations with Eq. (2) for each time period are tabulated in Table 4, where the coefficients are expressed in units consistent with the infiltration unit L_{inf} used in BLAST of ft^3/min.

TABLE 4: NMERDI Infiltration Coefficients

	Period	A	B'
Cell 1:	Winter	0.00001516	0.08047
	Spring	0.00001516	0.07856
	Summer	0.00001516	0.07355
Cell 6:	Winter	0.00000228	0.04462
	Spring	0.00000228	0.04364
	Summer	0.00000228	0.04071
Cell 7:	Winter	0.00000287	0.04453
	Spring	0.00000287	0.04356
	Summer	0.00000287	0.04071

In the BLAST analyses, the ground temperature is assumed to be a constant value during each month. The monthly values of the ground temperatures used in the BLAST simulations were time averaged from hourly measured data and were taken from reference [8].

2.2. NMERDI - Weather File Construction

Onsite weather data collected by NMERDI and used to develop weather files for the BLAST simulations included the hourly outside dry bulb temperature, solar radiation (direct normal solar, total horizontal solar), and wind speed and direction. In addition to the directly measured data, BLAST requires hourly diffuse and ground-reflected components of solar radiation and sky temperature. The diffuse radiation can be calculated directly from the measured values for the total horizontal solar radiation and the direct normal solar radiation. The ground reflected radiation was assumed to be 20% of the measured total horizontal solar radiation.

Sky temperatures, which are used in the simulation to determine heat losses or gains from external surfaces due to infrared radiation, are normally calculated from atmospheric moisture (as measured by the dew point temperature) and cloud cover information. Because of the lack of measured cloud cover for the site the sky temperatures for clear skies are first determined, then modified based on a cloudiness estimate determined by comparing actual solar radiation measurements to corresponding clear-sky estimates. It has been shown that the sky temperature depression, which is the difference between outside dry bulb and sky temperature, remains almost constant for a day [11]. The sky temperature depression can be considered a weighted measure of the effects of atmospheric humidity and cloud cover. The hourly clear-sky emissivity, ϵ, is first determined from the relationship [12]:

$$\epsilon = \epsilon_o + \Delta\epsilon_h + \Delta\epsilon_e. \tag{3}$$

The first term in Eq. (3), ϵ_0, is the average daily clear-sky emissivity at sea level:

$$\epsilon_o = 0.711 + 0.56 \left(\frac{T_{dp}}{100}\right) + 0.73 \left(\frac{T_{dp}}{100}\right)^2 \tag{4}$$

where T_{dp} is the dew point temperature in $^\circ$C. Hourly dew point temperatures for the simulation periods were obtained from measurements made at the nearby Los Alamos National Laboratory. The second term in Eq. (3) is an approximate diurnal correction for predicting hourly emissivities:

$$\Delta\epsilon_h = 0.013 \cos(2\pi\frac{t}{24}), \tag{5}$$

where t is the hour of the day in solar time. The third term is a correction for the altitude of the site [14]:

$$\Delta\epsilon_e = 0.00012\,(P-1000), \tag{6}$$

where P is the station pressure in millibars, and is taken to be 800mb, the average barometric pressure at the altitude of the test site.

Once the clear-sky emissivity has been calculated, the sky temperature depression for clear days is readily obtained from the equation

$$\Delta T_s = T_{air} - T_{sky} = (1 - \epsilon^{1/4})T_{air}, \tag{7}$$

where T_{air} is the ambient dry bulb temperature and T_{sky} is the sky temperature and both are in degrees Kelvin.

Those days that can be considered clear days are determined by examining the measured solar data. For such clear days, Eq. (7) can be used directly to determine the sky temperature depression. For cloudy days, the sky temperature depression will be some value between totally-cloudy and totally-clear day sky temperature depressions. Sky temperature depression values for totally cloudy days have been independently calculated and are taken from monthly contour maps of Ref. [11]. The cloudy-day sky temperature depression is then determined by linear interpolation between the totally-cloudy and totally-clear day values using the ratio of the actual daily total solar radiation on a particular day to the total daily clear-day solar radiation. Finally, knowing the daily sky temperature depression and the hourly outside dry bulb temperature, hourly sky temperatures can be obtained from Eq. (7).

2.3. Comparison Results: NMERDI

For each of the nine test-cell/time-period combinations, comparisons were made between hourly measured data and BLAST predictions for ten physical parameters:

- Space load (either heating or cooling),
- Cell Air temperature,
- Inside wall surface temperatures (N, E, S, W),
- Inside wall surface conduction heat fluxes (N, E, S, W).

A summary of differences between the data and the BLAST predictions are shown separately for each combination in Tables 5 - 13, which are referenced in the individual discussions below. Additionally, we have plotted the hourly comparisons for a selected subset of the parameters† (typically all but the east and west surface temperatures and heat fluxes) in Figures 4 - 27. In all figures, the BLAST predictions are shown by a solid line; data is shown either by a dashed line or individual data points. The cell/time period for each figure is indicated by two digits,separated by a decimal point *e.g.*, "Cell 1.1" where the first digit is the cell number (see Table 1), and the second digit corresponding to the time period of the comparison (1, 2, and 3 corresponding to Winter, Spring, and Summer, respectively).

2.3.1. Cell 1: 11 inch Adobe

Preliminary comparisons for the winter time period using the nominal stated thermophysical properties for the adobe walls (from reference [10]) led to large differences between measurements and the BLAST predictions. The most notable difference was a time lag in the BLAST predictions three hours longer than the measured data. We found that a 36% decrease in the volumetric heat capacity, ρc_p, (which we then attributed entirely to the density) produced a correct time lag.§ This modified configuration led to a significant improvement between measured data and BLAST predictions for both the heating load and the wall heat fluxes, and an increase in the wall surface temperature differences. The modified adobe wall density was subsequently used for the spring and

† Generally, for each test cell the figures show comparisons for loads, north and south surface temperatures and heat fluxes for the winter comparison period and only loads and inside air temperatures (if temperature float occurs) for the other time periods.

§ A result similar to ours for the volumetric heat capacity was also deduced by Arumi, using an independent approach to check data consistency for the cells [15]. BLAST inputs require both density and specific heat, not the product; the 36% reduction was arbitrarily assigned to the density, and does not mean that we believe that the real physical density was 36% less than the nominal measured density.

Summary Tables 11-13 and figures 20-27 show the comparisons for this test cell for the three time periods. The figures show that the differences between all measured and predicted parameters are quite small, with the time variations in all parameters being predicted accurately. The agreement for heating loads is very good for all time periods. However, the tables and figures show that BLAST overpredicts the wall heat flux losses through the insulated cavity walls at night. This would tend to indicate that the actual wall insulation properties are different than those specified. If this were true, then there must also be some compensating and unidentified heat loss mechanism that makes the heating loads as large as they are. Candidates for this mechanism could be increased infiltration, conductive bridges at the wall and roof edges, or even a greater effective conductance through the stud sections of the walls. We believe that the BLAST overprediction of nighttime wall heat fluxes (losses) are within the limit of the unexplained discrepancy between measured heating load and total heat losses obtained by a heat balance based on the surface heat flux data (Figure 5 in reference [10]).

TABLE 5: NMERDI Test Cell - BLAST Comparison
Cell 1: 11 inch Adobe; Winter Period: Jan 12 - Jan 20

			Data	Prediction	Δ	Δ(%)
Load ($kBtu$)			1144.1	1299.7	155.7	13.6
T_{air} (^{o}F)			68.7	68.7	0.0	
T_{surf} (^{o}F)	South		60.4	59.7	-0.7	
	West		56.9	57.1	0.2	
	North		54.9	56.1	1.2	
	East		56.9	57.4	0.6	
	Avg.		57.3	57.6	0.3	
Q_{surf} (Btu/ft^2)	South	Gain	75.3	69.3	-5.9	-7.9
		Loss	-979.8	-1280.7	-300.8	30.7
		Net	-904.6	-1211.3	-306.8	33.9
	West	Gain	0.0	0.0	0.0	0.0
		Loss	-1870.4	-2080.1	-209.8	11.2
		Net	-1870.4	-2080.1	-209.8	11.2
	North	Gain	0.0	0.0	0.0	0.0
		Loss	-2077.1	-2411.3	-334.2	16.1
		Net	-2077.1	-2411.3	-334.2	16.1
	East	Gain	0.0	0.0	0.0	0.0
		Loss	-1606.1	-1973.5	-367.3	22.9
		Net	-1606.1	-1973.5	-367.3	22.9
	Avg.	Net	-1614.5	-1919.1	-304.5	18.9

TABLE 6: NMERDI Test Cell - BLAST Comparison
Cell 1: 11 inch Adobe; Spring Period: Feb 28 - Mar 10

			Data	Prediction	Δ	Δ(%)
Load ($kBtu$)			951.7	1103.6	151.9	16.0
T_{air} (^{o}F)			69.1	69.1	0.0	
T_{surf} (^{o}F)	South		63.2	62.8	-0.4	
	West		60.9	61.2	0.3	
	North		58.1	59.8	1.7	
	East		60.7	61.3	0.6	
	Avg.		60.8	61.3	0.5	
Q_{surf} (Btu/ft^2)	South	Gain	129.8	111.7	-18.1	-14.0
		Loss	-816.2	-1091.2	-275.0	33.7
		Net	-686.4	-979.5	-293.1	42.7
	West	Gain	0.0	5.5	5.5	
		Loss	-1467.4	-1635.7	-168.3	11.5
		Net	-1467.4	-1630.2	-162.8	11.1
	North	Gain	0.0	0.0	0.0	0.0
		Loss	-1974.2	-2210.3	-236.1	12.0
		Net	-1974.2	-2210.3	-236.1	12.0
	East	Gain	0.0	0.0	0.0	0.0
		Loss	-1281.1	-1596.0	-314.9	24.6
		Net	-1281.1	-1596.0	-314.9	24.6
	Avg.	Net	-1352.3	-1604.0	-251.7	18.6

TABLE 7: NMERDI Test Cell - BLAST Comparison
Cell 1: 11 inch Adobe; Summer Period: May 24 - Jun 5

			Data	Prediction	Δ	Δ(%)
Load (*kBtu*)			51.2	44.6	-6.6	-12.8
T_{air} (^oF)			72.2	74.5	2.2	
T_{surf} (^oF)	South		70.4	73.6	3.2	
	West		72.2	74.8	2.6	
	North		69.2	73.3	4.1	
	East		72.5	75.1	2.6	
	Avg.		71.1	74.2	3.1	
Q_{surf} (Btu/ft^2)	South	Gain	14.7	27.1	12.4	84.6
		Loss	-305.9	-261.5	44.3	-14.5
		Net	-291.2	-234.4	56.8	-19.5
	West	Gain	353.7	443.4	89.7	25.4
		Loss	-129.5	-162.3	-32.7	25.3
		Net	224.1	281.1	57.0	25.4
	North	Gain	0.0	3.2	3.2	
		Loss	-573.4	-400.5	172.8	-30.1
		Net	-573.4	-397.3	176.1	-30.7
	East	Gain	373.4	530.5	157.1	42.1
		Loss	-60.6	-72.9	-12.2	20.2
		Net	312.8	457.6	144.8	46.3
	Avg.	Net	-81.9	26.8	108.7	-132.7

TABLE 8: NMERDI Test Cell - BLAST Comparison
Cell 6: 8 inch CMU Block; Winter Period: Jan 12 - Jan 20

			Data	Prediction	Δ	Δ(%)
Load (*kBtu*)			825.7	862.5	36.8	4.5
T_{air} (^oF)			69.0	69.0	0.0	
T_{surf} (^oF)	South		63.1	62.8	-0.4	
	West		60.9	61.2	0.2	
	North		59.3	60.5	1.3	
	East		60.8	61.3	0.5	
	Avg.		61.0	61.4	0.4	
Q_{surf} (Btu/ft^2)	South	Gain	173.0	138.8	-34.2	-19.8
		Loss	-643.2	-954.0	-310.9	48.3
		Net	-470.2	-815.3	-345.1	73.4
	West	Gain	0.0	0.0	0.0	0.0
		Loss	-1108.3	-1344.5	-236.3	21.3
		Net	-1108.3	-1344.5	-236.3	21.3
	North	Gain	0.0	0.0	0.0	0.0
		Loss	-1420.1	-1561.9	-141.8	10.0
		Net	-1420.1	-1561.9	-141.8	10.0
	East	Gain	0.0	0.0	0.0	0.0
		Loss	-1125.8	-1295.1	-169.3	15.0
		Net	-1125.8	-1295.1	-169.3	15.0
	Avg.	Net	-1031.1	-1254.2	-223.1	21.6

TABLE 9: NMERDI Test Cell - BLAST Comparison
Cell 6: 8 inch CMU Block; Spring Period: Feb 28 - Mar 10

			Data	Prediction	Δ	Δ(%)
Load (*kBtu*)			717.3	751.3	34.0	4.7
T_{air} ($^{\circ}F$)			69.2	69.1	0.0	
T_{surf} ($^{\circ}F$)	South		65.1	64.7	-0.4	
	West		63.7	63.7	0.1	
	North		61.6	62.9	1.3	
	East		63.5	63.7	0.2	
	Avg.		63.5	63.8	0.3	
Q_{surf} (Btu/ft^2)	South	Gain	226.8	189.2	-37.6	-16.6
		Loss	-592.9	-871.0	-278.1	46.9
		Net	-366.2	-681.9	-315.7	86.2
	West	Gain	41.7	44.4	2.7	6.5
		Loss	-900.1	-1110.3	-210.2	23.3
		Net	-858.4	-1065.9	-207.5	24.2
	North	Gain	0.0	0.0	0.0	0.0
		Loss	-1360.0	-1419.9	-59.9	4.4
		Net	-1360.0	-1419.9	-59.9	4.4
	East	Gain	12.8	7.3	-5.5	-43.2
		Loss	-881.6	-1069.3	-187.7	21.3
		Net	-868.8	-1062.0	-19302	22.2
	Avg.	Net	-863.3	-1057.4	-194.1	22.5

TABLE 10: NMERDI Test Cell - BLAST Comparison
Cell 6: 8 inch CMU Block; Summer Period: May 24 - Jun 5

			Data	Prediction	Δ	Δ(%)
Load (*kBtu*)			56.2	86.8	30.6	54.5
T_{air} ($^{\circ}F$)			74.3	75.0	0.7	
T_{surf} ($^{\circ}F$)	South		72.6	74.1	1.5	
	West		73.8	74.8	0.9	
	North		72.4	73.9	1.5	
	East		74.1	75.0	0.9	
	Avg.		73.2	74.4	1.2	
Q_{surf} (Btu/ft^2)	South	Gain	31.0	108.1	77.1	248.3
		Loss	-272.0	-254.9	17.1	-6.3
		Net	-240.9	-146.8	94.1	-39.1
	West	Gain	308.1	323.2	15.0	4.9
		Loss	-174.9	-188.2	-13.3	7.6
		Net	133.2	135.0	1.7	1.3
	North	Gain	10.8	11.9	1.1	10.3
		Loss	-335.0	-277.2	57.8	-17.3
		Net	-324.3	-265.4	58.9	-18.2
	East	Gain	366.9	421.0	54.1	14.7
		Loss	-144.5	-173.3	-28.8	19.9
		Net	222.4	247.7	25.3	11.4
	Avg.	Net	-52.4	-7.4	45.0	-85.9

TABLE 11: NMERDI Test Cell - BLAST Comparison
Cell 7: Insulated Wood Frame; Winter Period: Jan 12 - Jan 20

			Data	Prediction	Δ	Δ(%)
Load (*kBtu*)			556.4	513.5	-42.9	-7.7
T_{air} (°*F*)			69.0	69.0	0.0	
T_{surf} (°*F*)	South		65.2	65.8	0.6	
	West		64.6	65.2	0.7	
	North		63.7	65.0	1.2	
	East		64.6	65.2	0.7	
	Avg.		64.5	65.3	0.8	
Q_{surf} (*Btu* / ft^2)	South	Gain	124.5	117.0	-7.5	-6.0
		Loss	-337.5	-461.4	-123.9	36.7
		Net	-213.0	-344.4	-131.4	61.7
	West	Gain	29.1	14.7	-14.3	-49.3
		Loss	-403.4	-555.3	-151.9	37.6
		Net	-374.4	-540.6	-166.2	44.4
	North	Gain	0.0	0.0	0.0	0.0
		Loss	-526.4	-628.5	-102.1	19.4
		Net	-526.4	-628.5	-102.1	19.4
	East	Gain	14.0	10.8	-3.2	-22.8
		Loss	-437.5	-541.3	-103.8	23.7
		Net	-423.5	-530.5	-107.0	25.3
	Avg.	Net	-384.3	-511.0	-126.7	33.0

TABLE 12: NMERDI Test Cell - BLAST Comparison
Cell 7: Insulated Wood Frame; Spring Period: Feb 28 - Mar 10

			Data	Prediction	Δ	Δ(%)
Load (*kBtu*)			465.8	460.9	-4.9	-1.0
T_{air} (°*F*)			69.3	69.2	-0.1	
T_{surf} (°*F*)	South		66.4	66.8	0.4	
	West		66.0	66.4	0.4	
	North		65.1	66.1	1.0	
	East		66.0	66.4	0.4	
	Avg.		65.9	66.4	0.5	
Q_{surf} (*Btu* / ft^2)	South	Gain	139.8	147.6	7.8	5.6
		Loss	-321.9	-441.6	-119.7	37.2
		Net	-182.1	-294.0	-111.9	61.5
	West	Gain	85.6	65.2	-20.4	-23.8
		Loss	-398.5	-499.3	-100.9	25.3
		Net	-312.9	-434.2	-121.2	-38.7
	North	Gain	0.0	0.9	0.9	
		Loss	-511.9	-571.4	-59.4	11.6
		Net	-511.9	-570.5	-58.5	11.4
	East	Gain	64.2	38.0	-26.2	-40.8
		Loss	-394.4	-480.0	-85.6	21.7
		Net	-330.2	-441.9	-111.8	33.9
	Avg.	Net	-334.3	-435.1	-100.9	30.2

TABLE 13: NMERDI Test Cell - BLAST Comparison
Cell 7: Insulated Wood Frame; Summer Period: May 24 - Jun 5

			Data	Prediction	Δ	Δ(%)
Load (*kBtu*)			48.4	54.3	5.9	12.2
T_{air} ($^\circ F$)			74.7	73.4	-1.3	
T_{surf} ($^\circ F$)	South		73.5	72.9	-0.6	
	West		73.8	73.1	-0.7	
	North		73.3	72.7	-0.6	
	East		74.0	73.2	-0.8	
	Avg.		73.6	73.0	-0.7	
Q_{surf} (Btu/ft^2)	South	Gain	45.4	133.4	87.9	193.5
		Loss	-150.9	-157.4	-6.5	4.3
		Net	-105.5	-24.0	81.5	-77.2
	West	Gain	178.6	206.8	28.2	15.8
		Loss	-140.9	-134.5	6.5	-4.6
		Net	37.6	72.3	34.7	92.2
	North	Gain	24.0	60.5	36.5	151.8
		Loss	-152.1	-138.5	13.6	-8.9
		Net	-128.1	-78.0	50.1	-39.1
	East	Gain	232.8	256.9	24.1	10.3
		Loss	-156.7	-144.9	11.7	-7.5
		Net	76.2	111.9	35.8	47.0
	Avg.	Net	-29.9	20.6	50.5	-168.6

3. NBS TEST CELL COMPARISON

Three NBS test cells (Cell 1: insulated wood frame, Cell 5: 7 inch log, and Cell 6: 8 inch CMU block) are used for the BLAST simulations. Like the NMERDI study three different time periods, indicated below, were used for comparisons with each of the test cells.

NBS Test Cell Comparison Periods	
Winter:	Feb 23 - Mar 5
Spring:	Apr 15 - Apr 25
Summer:	Jul 27 - Aug 5

3.1. NBS - Test Cell Simulation Input

The NBS test cells are about 20 *ft* wide by 20 *ft* long one-room buildings with a 7.5 *ft* high ceiling. They are identical except for the wall construction. The blueprints and the construction details of each test cell were sent to LBL from NBS. The building inputs for the BLAST simulations were prepared from the blueprints, with corrections and additions directly from NBS according to [16]. The material properties are taken from reference [7]. Tables 14 and 15 describe the construction details of the heat transfer surfaces and the thermophysical properties of the materials, respectively. Appendix 2 contains complete BLAST inputs for each of the three test cells.

Unlike the NMERDI test cells, these cells have windows on the south and north walls. The windows have a triple pane construction. Each window is modeled having two sections, one whose properties are modified to represent the presence of an insect screen on half of the window. The inner and outer gaps in the window units are filled with air and carbon dioxide, respectively.

TABLE 14: NBS Test Cell Simulation Model Construction Details

Construction	Cell 1 (Frame)			Cell 5 (Log)			Cell 6 (Masonry)*		
	material	*ft*	R§	material	*ft*	R§	material	*ft*	R§
Wall-1	plywood	0.0521	0.781	log	0.583	9.242	brick	0.2920	0.385
(4.24 ft	stud	0.3021	4.529				perlite	0.2920	9.211
x	gyp board	0.0417	0.451				CMU	0.6667	1.592
7.79 ft)							plaster	0.0417	0.321
	Total		5.761	Total		9.242	Total		11.509
Wall-2†	plywood	0.0521	0.781	log	0.583	9.242	brick	0.2920	0.385
(17.00 ft	wall ins.	0.3021	10.985				perlite	0.2920	9.211
x	gyp board	0.0417	0.451				CMU	0.6667	1.592
7.79 ft)							plaster	0.0417	0.321
	Total		12.217	Total		9.242	Total		11.509
Floor	earth	1.3333	2.667						
(21.24 ft	concrete	0.3333	0.417						
x	floor ins.	0.1667	11.113	Same as Cell 1					
21.24 ft)									
	Total		14.197						
Ceiling-1	insulation	0.9167	33.334						
(19.117 ft	gyp board	0.0417	0.451	Same as Cell 1					
x									
21.24 ft)			33.785						
Ceiling-2	insulation	0.6250	22.727						
(2.123 ft	stud	0.2920	4.378						
x	gyp board	0.0417	0.451	Same as Cell 1					
21.24 ft)									
	Total		27.556						
Roof	asphalt		0.440						
(21.24 ft	plywood	0.0417	0.625	Same as Cell 1					
x									
27.30 ft)	Total		1.065						
Door *(19.54 ft²)*	metal clad		4.44	Same as Cell 1					
Windows‡	glazing		0.013						
(16.87 ft²)	air space		0.967						
	glazing		0.013	Same as Cell 1					
	carbon dioxide		0.720						
	glazing		0.013						
	Total		1.727						

* Cell 6 has slightly different dimensions due to thicker walls: *22.5 ft x 22.5 ft x 8.25 ft.*

§ Resistance units are: $°F{-}ft^2{-}hr/Btu$.

† To obtain the net heat transfer area, the area of a window must be subtracted from the total areas of the north and south walls; the area of the door must be subtracted from the east wall total area.

‡ This is the total window area on a given wall; half of it is a screened window with a slightly different transmissivity than the other half (see Appendix 2).

TABLE 15: NBS Test Cell Material Thermophysical Properties

Material	Thermal Conductivity ($Btu/hr \cdot ft \cdot {}^{\circ}F$)	Density (lb/ft^3)	Specific Heat ($Btu/lb \cdot {}^{\circ}F$)
brick	0.758	130.0	0.19
CMU	0.419	61.0	0.20
plaster	0.130	45.0	0.20
concrete	0.800	150.0	0.20
earth	0.500	120.0	0.20
fiberglass insulation	0.028	2.0	0.20
perlite	0.032	9.5	0.26
gyp board	0.093	50.0	0.26
polyurethane floor insulation	0.015	2.0	0.29
stud	0.067	32.0	0.33
plywood	0.067	45.0	0.29
log	0.063	26.5	0.36

In BLAST, each of the glazings and gaseous gaps are modeled explicitly. The resistance of the air and carbon dioxide gaps is calculated from the overall resistance of the window (0.36 $Btu/hr \cdot ft^2 \cdot {}^{\circ}F$). In the calculation of these resistances, the heat transfer coefficients used on the outside and inside surfaces including the radiative component are 1.332 and 2.813 $Btu/hr \cdot ft^2 \cdot {}^{\circ}F$. The same procedure is also used to calculate the resistance of the metal-clad door.

The measured air temperatures used in the comparisons with BLAST predictions and for determining the BLAST thermostat control were obtained by averaging six quantities: the two mid-height thermocouple string measurements and four measurements, made near the center of each of the walls. Infiltration coefficients used in BLAST are taken from reference [7]. The infiltration data obtained for each test cell were fitted to an equation similar to the one used in the BLAST algorithm.

Edge heat losses were dealt with in two ways. First, based on a recommendation from NBS [16], the geometric dimensions of the test cells were increased half the wall width. Secondly, a floor perimeter loss estimate provided by NBS [16] was accounted for as a "pseudo-conductance" that was included in the infiltration rate.

A constant internal load of about 290W was maintained using incandescent light bulbs within each of the test buildings. The exact values varied slightly from cell to cell and from one time period to another, and are shown explicitly in the BLAST inputs given in Appendix 2.

Original data logger records for the measured hourly heat transfer and the energy data for each test cell and time period were obtained from NBS and manually transcribed into a computerized data base. They were checked for typographical errors by plotting each measured data set as a time series and visually identifying and correcting anomalous data. Estimates of the hourly sensible space cooling loads supplied by the air conditioner were separately provided by NBS [16]. The BLAST cooling load predictions were directly compared with this quantity. No attempt was made to simulate an air conditioner in the BLAST model.

3.2. NBS - Weather File Construction

A digitized weather data file provided by NBS was used to obtain hourly outdoor temperature, wind speed, total horizontal and direct normal solar radiation. The ground reflected component is assumed to be 20% of the total horizontal solar gain.

Because radiation heat losses to the sky are an important component of the overall test cell heat losses, and because no experimental data from the site was available to allow us to determine the effective sky temperature, we had to devise another approach to estimate this quantity. For the calculation of sky temperatures, a different procedure from that used for the New Mexico weather data was used. Dulles Airport surface observation data were obtained, which contained cloud cover information and atmospheric moisture data used in the sky temperature calculations for the time periods corresponding to the comparison periods.

The calculation method can be briefly described as follows: The presence of cloud cover increases the total sky emissivity above the clear sky value. The sky emissivity for cloudy days is given by

$$\epsilon = \epsilon_0 + (1 - \epsilon_0) \cdot C \quad \text{and} \quad C = n \epsilon_c \Gamma \tag{8}$$

where ϵ_0 is the clear sky emissivity calculated from Eq. (4), n is the fractional area of the sky covered by clouds, ϵ_c is the hemispherical cloud emissivity, and Γ is a factor depending on the cloud height h. The parameter C is the "infrared cloud amount." The cloud factor Γ is expected to be small for high (cold) clouds, and to approach unity for low clouds. The functional form of $\Gamma(h)$ is given by [11]:

$$\Gamma(h) = \frac{\epsilon - \epsilon_0}{1 - \epsilon_0} \tag{9}$$

The expression for total clear sky emissivity, Eq. (6), can be generalized to include contributions from cloud layers at different heights, h_i:

$$\epsilon = \epsilon_0 + (1 - \epsilon_0) \sum_i n_i \epsilon_{c,i} \Gamma(h_i) \tag{10}$$

The cloud fractions n_i are those visible to an observer on the ground. Low- and mid-level clouds tend to be opaque ($\epsilon_{c,i} \approx 1.0$), while a great deal of variation is observed in the emissivity of cirrus clouds. After calculating the total sky emissivity, hourly values for the sky temperature are obtained from Eq. (7).

3.3. Comparison Results: NBS

Like the NMERDI results described above, there are BLAST-NBS data comparisons for nine test-cell/time-period combinations. For each time period, the same ten physical parameters are compared on an hourly basis. A summary of differences between the data and the BLAST predictions are shown in Tables 16-24, which are referenced in the individual discussions below. Additionally, we have plotted the hourly comparisons for a selected subset of the parameters (typically all but the east and west surface temperatures and heat fluxes) in Figures 28-50.

For all test cells, the winter time period has a large gap in the measured data, and it appeared that the measured data for the first 24 hours was anomalous. Therefore, although this data is shown in the figures, this first 24 hours of the simulation period was not included when the comparison statistics were calculated.

3.3.1. Cell 1: Insulated Wood Frame

For the wood frame wall test cell, the walls were modeled as two sections representing the insulated cavity section and the stud section, based on relative areas for each that matched the actual construction of the test cell. The presented values of heat fluxes and surface temperatures are for the insulated cavity wall sections, corresponding to the placement of the actual measurement transducers. However, the heating loads predicted by BLAST include the effect of heat flows through all the wall sections, including the studs. Actual values for all materials properties, as provided by the experimenters were used in the simulation model [7]. For this test cell only, the measured data for the inside air temperatures made it apparent that the thermostat setting was changed for a part of the day towards the end of the winter comparison period (approximately hours 210 through 224). The BLAST control schedule was adjusted to match this changed setting.

Summary Tables 16-18 and figures 28-36 show the comparisons for this test cell for the three time periods. For the winter and spring time periods, the heating loads are in good agreement (7% and 14%, respectively). In general, the wall surface temperatures and heat fluxes agree well, particularly their time variation. An exception consists of two short intervals during the winter time period when the interior temperature float occurs. The BLAST predictions of the float-up are less than the measurements indicate. For the spring comparison period, where temperature float occurs every day, the BLAST interior air temperature predictions are in very good agreement with measured data.

For the summer comparison period, BLAST overpredicts the sensible cooling load by 37%. However, figure 36 shows that the first 48 hours of the measured data is probably anomalous. For the remainder of the comparison period, the agreement is quite good, about 12%. For the other quantities compared, the agreement is good for the entire comparison period. The detailed hourly comparison plots show that the BLAST wall heat flux predictions appear to be time-smoothed representations of the measured data.

3.3.2. Cell 5: 7 inch Log

Cell 5 was simulated with the wall thermophysical properties obtained from NBS, without change. Summary Tables 19-21 and figures 37-42 show the comparisons for this test cell for the three time periods. The overall agreement for all time periods and all comparison parameters is quite good except for the wall heat fluxes for the summer. Plots of these heat fluxes (not shown) indicate measured data that for most hours agree well with the BLAST predictions, while for a few random hours the data exhibits a large and anomalous scatter which degrades and tends to decrease the meaningfulness of the comparison statistics. Like Cell 1, BLAST again overpredicts the sensible cooling load in the Summer time period — in this case by 19%.

3.3.3. Cell 6: 8 inch CMU Block - Insulated

Summary Tables 22-24 and figures 43-50 show the comparisons for this test cell for the three time periods. The results indicate a significant underprediction of the heating loads for the winter and spring time periods and overprediction of the cooling load for the summer time period. There is also an underprediction for the winter and spring comparison period of the wall heat losses, which is consistent with the load underprediction. All of these differences are consistent with the findings of Arumi [17]. Like Cell 1, there appears to be an anomalous day near the end of the winter time period where the thermostat was set higher than during the other times. However, this could be one of the contributing factors to the observed differences. Another factor contributing to the differences was the wall construction anomalies that have been noted previously by NBS [7]. For example, NBS reported that the part of the insulation under the windows was missing for one of the walls in this cell. We have made no attempt to model these anomalies in the BLAST inputs.

TABLE 16: NBS Test Cell - BLAST Comparison
Cell 1: Insulated Wood Frame; Winter Period: Feb 23 - Mar 5

			Data	Prediction	Δ	Δ(%)
Load (*kBtu*)			175.0	163.4	-11.6	-6.6
T_{air} (°*F*)			67.8	67.3	-0.5	
T_{surf} (°*F*)	South		66.6	65.3	-1.2	
	West		66.5	65.3	-1.1	
	North		65.7	65.3	-0.4	
	East		65.1	65.4	0.2	
	Avg.		66.0	65.3	-0.6	
Q_{surf} (*Btu* / *ft*^{2})	South	Gain	5.01	0.00	-5.01	
		Loss	-200.18	-194.29	5.89	-2.9
		Net	-195.17	-194.29	0.88	-0.4
	West	Gain	3.79	0.01	-3.78	
		Loss	-227.25	-197.47	29.78	-13.1
		Net	-223.45	-197.45	26.00	-11.6
	North	Gain	0.00	0.00	0.00	
		Loss	-226.07	-205.45	20.62	-9.1
		Net	-226.07	-205.45	20.62	-9.1
	East	Gain	0.00	0.00	0.00	
		Loss	-231.41	-190.96	40.45	-17.5
		Net	-231.41	-190.96	40.45	-17.5
	Avg.	Net	-219.03	-197.04	21.99	-10.0

TABLE 17: NBS Test Cell - BLAST Comparison
Cell 1: Insulated Wood Frame; Spring Period: Apr 15 - Apr 25

			Data	Prediction	Δ	Δ(%)
Load (*kBtu*)			129.7	111.5	-18.1	-14.0
T_{air} (°*F*)			72.7	72.7	0.0	
T_{surf} (°*F*)	South		72.0	72.1	0.1	
	West		72.5	72.2	-0.3	
	North		71.7	72.0	0.4	
	East		71.6	72.3	0.7	
	Avg.		72.0	72.2	0.2	
Q_{surf} (*Btu* / *ft*^{2})	South	Gain	0.0	0.9	0.9	
		Loss	-345.3	-270.3	75.0	-21.7
		Net	-345.3	-269.3	75.9	-22.0
	West	Gain	60.7	46.9	-13.8	-22.8
		Loss	-323.3	-244.5	78.8	-24.4
		Net	-262.6	-197.6	65.0	-24.7
	North	Gain	0.0	1.3	1.3	
		Loss	-351.6	-280.0	71.6	-20.4
		Net	-351.6	-278.7	72.9	-20.7
	East	Gain	38.9	48.1	9.2	23.6
		Loss	-291.6	-218.9	72.7	-24.9
		Net	-252.7	-170.8	81.8	-32.4
	Avg.	Net	-303.0	-229.1	73.9	-24.4

TABLE 18: NBS Test Cell - BLAST Comparison
Cell 1: Insulated Wood Frame; Summer Period: Jul 27 - Aug 5

			Data	Prediction	Δ	Δ(%)
Load (*kBtu*)			223.2	305.1	82.0	36.7
T_{air} ($^\circ F$)			75.1	74.6	-0.5	
T_{surf} ($^\circ F$)	South		75.7	75.9	0.2	
	West		76.4	76.1	-0.3	
	North		75.5	75.9	0.5	
	East		75.6	76.0	0.4	
	Avg.		75.8	76.0	0.2	
Q_{surf} (Btu/ft^2)	South	Gain	140.8	110.2	-30.6	-21.8
		Loss	-196.7	-68.7	128.1	-65.1
		Net	-55.9	41.5	97.4	-174.1
	West	Gain	176.8	189.9	13.1	7.4
		Loss	-171.7	-68.1	103.7	-60.4
		Net	5.0	121.8	116.8	2313.6
	North	Gain	152.2	107.5	-44.7	-29.4
		Loss	-181.7	-68.7	113.0	-62.2
		Net	-29.5	38.8	68.3	-231.8
	East	Gain	209.7	134.3	-75.5	-36.0
		Loss	-155.5	-65.1	90.4	-58.1
		Net	54.3	69.2	14.9	27.5
	Avg.	Net	-6.5	67.8	74.3	-1139.7

TABLE 19: NBS Test Cell - BLAST Comparison
Cell 5: 7 inch Log; Winter Period: Feb 23 - Mar 5

			Data	Prediction	Δ	Δ(%)
Load (*kBtu*)			175.7	168.1	-7.6	-4.3
T_{air} ($^\circ F$)			67.6	67.6	0.0	
T_{surf} ($^\circ F$)	South		65.1	65.4	0.3	
	West		65.4	65.4	-0.1	
	North		64.6	65.2	0.7	
	East		65.4	65.4	0.0	
	Avg.		65.1	65.4	0.2	
Q_{surf} (Btu/ft^2)	South	Gain	NA			
		Loss	NA			
		Net	NA			
	West	Gain	NA			
		Loss	NA			
		Net	NA			
	North	Gain	NA			
		Loss	NA			
		Net	NA			
	East	Gain	NA			
		Loss	NA			
		Net	NA			
	Avg.	Net	NA			

TABLE 20: NBS Test Cell - BLAST Comparison
Cell 5: 7 inch Log; Spring Period: Apr 15 - Apr 25

			Data	Prediction	Δ	Δ(%)
Load ($kBtu$)			67.1	62.5	-4.6	-6.9
T_{air} ($^\circ F$)			70.4	70.7	0.3	
T_{surf} ($^\circ F$)	South		69.1	70.2	1.1	
	West		70.4	70.5	0.1	
	North		68.9	70.2	1.2	
	East		69.2	70.5	1.3	
	Avg.		69.4	70.3	0.9	
Q_{surf} (Btu/ft^2)	South	Gain	1.6	2.4	0.8	50.9
		Loss	-347.1	-314.0	33.0	-9.5
		Net	-345.5	-311.7	33.8	-9.8
	West	Gain	16.7	43.9	27.2	163.3
		Loss	-290.2	-250.9	39.3	-13.5
		Net	-273.5	-207.0	66.5	-24.3
	North	Gain	2.2	2.8	0.6	27.1
		Loss	-366.4	-328.5	38.0	-10.4
		Net	-364.2	-325.6	38.6	-10.6
	East	Gain	7.4	17.7	10.3	138.8
		Loss	-212.3	-198.0	14.3	-6.7
		Net	-204.9	-180.3	24.6	-12.0
	Avg.	Net	-297.0	-256.2	40.9	-13.8

TABLE 21: NBS Test Cell - BLAST Comparison
Cell 5: 7 inch Log; Summer Period: Jul 27 - Aug 5

			Data	Prediction	Δ	Δ(%)
Load ($kBtu$)			224.0	267.4	43.5	19.4
T_{air} ($^\circ F$)			75.8	75.9	0.1	
T_{surf} ($^\circ F$)	South		75.9	77.1	1.2	
	West		76.9	77.4	0.5	
	North		75.8	77.1	1.4	
	East		76.2	77.2	1.0	
	Avg.		76.2	77.2	1.0	
Q_{surf} (Btu/ft^2)	South	Gain	172.3	87.7	-84.6	-49.1
		Loss	-113.7	-61.1	52.6	-46.3
		Net	58.6	26.6	-31.9	-54.5
	West	Gain	116.3	172.4	56.1	48.3
		Loss	-100.0	-44.1	55.9	-55.9
		Net	16.3	128.3	112.0	687.7
	North	Gain	144.5	85.5	-59.0	-40.9
		Loss	-101.3	-62.9	38.5	-38.0
		Net	43.2	22.6	-20.6	-47.6
	East	Gain	174.3	113.8	-60.5	-34.7
		Loss	-68.5	-49.6	18.8	-27.5
		Net	105.9	64.2	-41.7	-39.4
	Avg.	Net	56.0	60.4	4.5	8.0

TABLE 22: NBS Test Cell - BLAST Comparison
Cell 6: 8 inch CMU Block - Insulated; Winter Period: Feb 23 - Mar 5

			Data	Prediction	Δ	Δ(%)
Load (*kBtu*)			210.7	159.7	-50.9	-24.2
T_{air} ($^\circ F$)			68.2	68.2	0.0	
T_{surf} ($^\circ F$)	South		66.8	66.4	-0.5	
	West		67.5	66.3	-1.2	
	North		66.1	66.2	0.1	
	East		66.0	66.3	0.4	
	Avg.		66.6	66.3	-0.3	
Q_{surf} (Btu/ft^2)	South	Gain	0.0	0.0	0.0	0.0
		Loss	-282.6	-182.8	99.8	-35.3
		Net	-282.6	-182.8	99.8	-35.3
	West	Gain	0.0	0.0	0.0	0.0
		Loss	-265.1	-196.2	69.0	-26.0
		Net	-265.1	-196.2	69.0	-26.0
	North	Gain	0.0	0.0	0.0	0.0
		Loss	-259.6	-207.2	52.4	-20.2
		Net	-259.6	-207.2	52.4	-20.2
	East	Gain	0.0	0.0	0.0	0.0
		Loss	-264.8	-186.7	78.1	-29.5
		Net	-264.8	-186.7	78.1	-29.5
	Avg.	Net	-268.0	-193.2	74.8	-27.9

TABLE 23: NBS Test Cell - BLAST Comparison
Cell 6: 8 inch CMU Block - Insulated; Spring Period: Apr 15 - Apr 25

			Data	Prediction	Δ	Δ(%)
Load (*kBtu*)			47.9	15.8	-32.1	-67.0
T_{air} ($^\circ F$)			69.3	70.6	1.3	
T_{surf} ($^\circ F$)	South		69.2	70.4	1.2	
	West		68.7	70.6	1.9	
	North		68.1	70.3	2.2	
	East		68.7	70.6	1.9	
	Avg.		68.7	70.5	1.8	
Q_{surf} (Btu/ft^2)	South	Gain	0.0	18.8	18.8	
		Loss	-541.4	-245.4	296.0	-54.7
		Net	-541.4	-226.6	314.8	-58.2
	West	Gain	3.7	41.2	37.5	1011.2
		Loss	-360.3	-201.5	158.8	-44.1
		Net	-356.6	-160.3	196.3	-55.0
	North	Gain	1.5	14.0	12.5	837.0
		Loss	-357.8	-260.3	97.5	-27.2
		Net	-356.3	-246.3	110.0	-30.9
	East	Gain	2.9	47.7	44.7	1521.1
		Loss	-350.9	-171.0	179.9	-51.3
		Net	-348.0	-123.3	224.6	-64.6
	Avg.	Net	-400.6	-189.1	211.5	-52.8

TABLE 24: NBS Test Cell - BLAST Comparison
Cell 6: 8 inch CMU Block - Insulated; Summer Period: Jul 27 - Aug 5

			Data	Prediction	Δ	Δ(%)
Load (*kBtu*)			186.8	253.5	66.6	35.7
T_{air} (°*F*)			76.5	76.4	-0.1	
T_{surf} (°*F*)	South		76.7	77.5	0.8	
	West		76.6	77.7	1.2	
	North		77.2	77.5	0.3	
	East		76.9	77.6	0.7	
	Avg.		76.9	77.6	0.7	
Q_{surf} (*Btu*/ft^2)	South	Gain	70.5	65.1	-5.4	-7.6
		Loss	-292.3	-41.6	250.7	-85.8
		Net	-221.8	23.6	245.3	-110.6
	West	Gain	33.9	120.7	86.8	256.1
		Loss	-205.4	-20.6	184.8	-90.0
		Net	-171.5	100.2	271.7	-158.4
	North	Gain	60.5	62.3	1.8	3.1
		Loss	-222.0	-43.0	179.0	-80.6
		Net	-161.5	19.3	180.9	-112.0
	East	Gain	64.6	86.1	21.5	33.2
		Loss	-152.1	-31.7	120.4	-79.2
		Net	-87.5	54.4	141.9	-162.2
	Avg.	Net	-160.6	49.4	210.0	-130.7

4. TEST CELL ANNUAL PERFORMANCE

Two of the NBS test cell configurations, Cell 1 and Cell 6, have been used in BLAST simulations to determine their annual cumulative sensible heating and cooling requirements (AHR and ACR) in 12 U.S. climates. A zero-mass modification of Cell 6 was also modeled in order to explicitly separate annual requirement differences caused by mass from those caused by thermal resistance differences. The configurations were identical to the ones used in the previous comparisons, with two exceptions. First, both heating and cooling were assumed to occur, with setpoints of 69 °F and of 76 °F, respectively. Second, infiltration rates used were constant and based on the actual cell infiltration rate regressions for NBS Cell 6. The constant rate used was related to the annual mean values of wind speed and outside dry bulb temperature for each of the climates. Weather data used in the simulations were ASHRAE Typical Meteorological Years (TMY) [18]. The results of these simulations are given in Table 25 and figures 51 and 52.

TABLE 25: ANNUAL SPACE LOAD REQUIREMENTS (MBtu/yr)

Location	Heating			Cooling		
	Cell 1	Cell 6	Cell 6_{zm} †	Cell 1	Cell 6	Cell 6_{zm} †
Atlanta	2.75	1.46	2.87	5.51	5.91	5.72
Denver	6.32	5.46	6.52	3.38	2.35	3.86
Detroit	6.71	6.18	6.53	3.81	3.05	3.99
Fort Worth	2.10	1.02	2.27	7.39	7.64	7.53
Fresno	2.16	0.87	2.52	6.46	6.49	6.83
Houston	0.97	0.26	1.13	8.21	8.67	8.35
Los Angeles	0.51	0.00	0.87	4.17	4.18	4.76
Miami	0.10	0.00	0.15	11.04	12.24	10.95
Minneapolis	9.98	9.53	9.67	3.31	2.59	3.49
Phoenix	1.05	0.16	1.45	10.17	10.15	10.39
Seattle	4.44	3.67	4.42	1.91	1.04	2.25
Wash. D.C.	4.96	4.05	4.97	4.46	3.81	4.69

† Zero-mass variation for Cell 6.

A balance point temperature of 58 °F for Cell 6 (given in Ref. [19]) was used to calculate cooling and heating degree days (CDD and HDD) for each location. The annual cooling and heating loads were plotted as a function of CDD and HDD, respectively, in

Figures 51 and 52. Figure 51 shows the general trend that the mass reduces cooling loads by modest amounts for the more moderate climates, with decreasing benefits for the notter climates. However, for any specific climate the actual energy use of the high mass cell may in fact be either slightly higher or slightly lower than that of the low mass cell. Thus, there are other climate related determinants of energy use that are not explained by the CDD measure alone. We expect that one such determinant would be solar gains.

For heating, on the other hand, the thermal mass significantly reduces the AHR for most of the climates, as shown in figure 52. The least amount of reduction occurs for the mildest climates, *e.g.* Miami, where there are few heating hours at all, and for the coldest climates, *e.g.* Minneapolis and Detroit, where the climates are severe enough that there are few heating hours related to the moderate temperatures when thermal mass has an effect. It is interesting to note that Denver, although it has almost the same number of heating degree-days as Detroit, shows a significantly larger AHR reduction due to thermal mass than Detroit does. This is again attributable to other climate parameters not characterized by the degree-day measure — in this case probably the larger winter solar gains in Denver. Finally, the nonlinear appearance of the massive Cell 6 curve in figure 52, which is caused by the mass, could also be interpreted as a building with a lower balance temperature than the low mass cells, even though the thermal resistances of the envelopes of the cells are essentially the same. This points out an interesting potential measure for quantifying thermal mass effects, namely the change in the effective balance point temperature compared to a low-mass structure with the same envelope heat loss coefficient.

Finally, because of the differences between the test cells and typical houses in their design and operation, we caution that these annual comparative results should not be applied directly to estimate actual savings in residences. The reader is advised to consult the companion report to this one [1].

5. CONCLUSIONS

In this comparison study between measured data and BLAST predictions for six test cells with varying wall constructions in two climates, a number of results have been obtained and discussed. Overall, the quality of the agreement is within a reasonable range when all sources of uncertainties are accounted for. Such uncertainties include those directly associated with the measurement process; ambiguities and missing information about the material physical properties, construction details, and operation of the cells; and limitations in the simulation model algorithms, such as uniform one-dimensional heat transfer through walls that cannot account for non-homogeneous constructions and edge effects. All such factors contribute in unknown amounts to the observed differences. Some of the uncertainties that were identified follow.

- For both test cell locations, there was missing weather information in the form of the data necessary to determine the effective sky radiation temperature. We had to construct an estimate based on the best substitutable information that was available. Direct on-site measurements would have been much more accurate.
- For a number of the materials used in the construction of the test cells, directly-measured physical properties were not available. We were able to either calculate or approximate these properties by adjusting the properties in the simulation to best match the predictions with the measurements. Direct measurements of these values would have led to fewer uncertainties.
- For the NMERDI test cells, even though there was uncertainty over the interior air temperature and its consequent effect on the modeling results, there was still good agreement for a simple interpretation of the cell operation (constant interior temperatures).
- In some cases, there were either ambiguities or a lack of information about the experimental operation of the test cells that made it difficult for us to decide exactly how to arrive at certain assumptions necessary to develop a complete description

necessary for the simulation models. One example was an undocumented change in the thermostat control temperature for one of the NBS test cells during one of the comparison periods. The only way to deduce this effect was by statistically analyzing the measured interior air temperatures.

When all of these factors are considered, and the quantitative estimates of experimental uncertainty are also taken into account, we believe that the agreement between the BLAST predictions and the measurements are acceptably within the overall range of all uncertainties associated with the comparison.

It should also be noted that the comparisons in this study have focussed on the differences (or agreement) between absolute values of the ten physical parameters defined earlier in this report. Such a comparison is necessarily the most stringent, and the results of the comparisons between the measured data and the BLAST predictions show sufficient simultaneous agreement for all of these parameters to conclude that the algorithms are in fact correctly modeling the effects of thermal mass. However, another valuable question to address is how well such simulations predict the *changes* in energy use caused by the addition of thermal mass, compared to low-mass construction. The bar charts shown in Figures 53 and 54 consequently summarize the load comparisons for all periods for the NMERDI and NBS cells, respectively. It is clear that the patterns of change for each cell from one climate period to the next is accurately predicted.

There are two ways in which to examine such changes. The first focuses on load changes for the same cell as the climate changes from one comparison period to the next. In this case, since the cell is exactly the same, the load differences must come only from differences in climatic factors, and how the cell mass reacts to those factors during each time period. Table 26 summarizes these changes for both NMERDI and NBS cells by showing the differences in the absolute values of the loads between time periods for each of the cells separately. With the exception of the 15% difference between measurement and BLAST prediction for Cell 1 (Adobe) concerning the change from Spring to Summer periods, the agreement is quite close. If the lower adobe thermal conductance recommended by Arumi [15] had been used in the BLAST simulations, this single exception would also disappear.

TABLE 26: Comparison of Measured and Predicted Load Changes Due To Climate Changes (kBtu)

	NMERDI					
	Cell 1		Cell 6		Cell 7	
Periods	Data	BLAST	Data	BLAST	Data	BLAST
Win -> Spr	-192.4	-196.1	-108.4	-111.2	-90.6	-52.6
Spr -> Sum	-900.5	-1059.0	-661.1	-664.5	-411.5	-406.6

	NBS					
	Cell 1		Cell 5		Cell 6	
Periods	Data	BLAST	Data	BLAST	Data	BLAST
Win -> Spr	-45.3	-51.9	-108.6	-105.6	-162.8	-143.9
Spr -> Sum	-352.9	-416.6	-291.1	-329.9	-234.7	-269.3

The second approach is to focus on the changes between cells for the same weather comparison period as shown in Table 27, where the more thermally massive test cells are compared to the low-mass frame construction cell. In the case of the NBS test cells, the cells have the same wall thermal resistances, and consequently the difference in the seasonal load changes from one time period to the next is almost entirely due to thermal mass effects, and is accurately predicted by BLAST. In the Winter period, there is little thermal mass effect and the load difference from one cell to another is small. In the milder Spring period, the larger load differences seen in both measurements and BLAST predictions reflect the thermal mass effect. In Summer, the same is seen to hold, although the measured load difference between Cell 5 (log) and Cell 1(frame) is seen to be quite small compared to the predicted difference.

While the equivalent wall thermal resistance condition is approximately true for the NBS test cells, it is not true for the NMERDI cells, which have different wall thermal resistances. For the NMERDI cells, the load changes are caused by a number of factors, but the overall prediction of the change by BLAST is still in reasonable agreement. In these cases, however, it is not possible to isolate what part of the load difference between cells is due to thermal mass effects and what part is due to other factors. Finally, in addition to loads, the comparison figures presented and discussed earlier also show the correct changes to such quantities as inside surface temperature amplitudes and net heat fluxes as the mass level changes or as the seasonal weather changes.

TABLE 27: Comparison of Measured and Predicted Load Changes Due To Test Cell Wall Construction Differences For the Same Time Period (kBtu)

NMERDI

	Winter		Spring		Summer	
Cells	Data	BLAST	Data	BLAST	Data	BLAST
Cell 1 -> Cell 7	-587.7	-786.2	-485.9	-642.7	3.1	9.7
Cell 6 -> Cell 7	-269.3	-349.0	-251.5	-290.4	-1.9	-32.5

NBS

	Winter		Spring		Summer	
Cells	Data	BLAST	Data	BLAST	Data	BLAST
Cell 5 -> Cell 1	0.7	4.7	-62.6	-49.0	0.8	-37.7
Cell 6 -> Cell 1	35.7	-3.7	-81.8	-95.7	-36.4	-51.6

6. REFERENCES

1. W. L. Carroll, R. Sullivan, A. Mertol, "Thermal Mass: BLAST Residential Parametric Simulations," Lawrence Berkeley Laboratory Report LBL-19681, January, 1987.

2. D. C. Hittle, "The Building Loads Analysis and System Thermodynamics (BLAST) Program, Version 1.0," CERL-TR-E-153, U.S. Army Construction Engineering Research Laboratory, Champaign, Ill., June, 1979.

3. D. C. Hittle, "The BLAST Program, Version 2.0: User's Manual, Vol. 2," CERL-TR-E-153, U.S. Army Construction Engineering Research Laboratory, Champaign, Ill., June, 1979.

4. D. Herron, G. Walton, L. Lawrie, "BLAST Program User's Manual - Volume 1 Supplement (Version 3.0)," CERL-TR-E-171, U.S. Army Construction Engineering Research Laboratory, Champaign, Ill., March, 1981.

5. G. Walton, "Passive Solar Extension of the BLAST Program," Draft Report, U.S. Army Construction Engineering Research Laboratory, Champaign, Ill., December, 1980.

6. J. Gustinis and D. K. Robertson, "Southwest Thermal Mass Study — Tesuque Pueblo, New Mexico: Construction and Instrumentation Phase," New Mexico Energy Research and Development Institute Report, University of New Mexico, 1981.

7. D. M. Burch, W. E. Remmert, D. F. Krintz, C. S. Barnes, "A Field Study of the Effect of Wall Mass On Heating and Cooling Loads of Residential Buildings," in *Proceedings of the Building Thermal Mass Seminar - 1982*, G. Courville and E. L. Bales, Eds., pp. 265-312, Oak Ridge National Laboratory, CONF-8206130, August, 1983.

8. H. A. McLain, J. E. Christian, S. Y. Ohr, and J. L. Bledsoe, "Simulation of the SWTMS Test Cells Using the DOE 2.1A Model," ORNL/CON-221, 1986.

9. **Handbook of Fundamentals**, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, New York, 1977.

10. J. Gustinis and D. K. Robertson, "The Effect of Envelope Thermal Mass on the Heating Energy Use of Eight Test Buildings in a High Desert Climate," New Mexico Energy Research and Development Institute Information Center, University of New Mexico, Albuquerque, 1983 (Draft).

11. M. Martin and P. Berdahl, "Characteristics of Infrared Sky Radiation in the United States," *Solar Energy,* **33**, pp. 321-336, 1984 (also Lawrence Berkeley Laboratory Report LBL-16344).

12. P. Berdahl and M. Martin, "Emissivity of Clear Skies," *Solar Energy,* **32**, pp. 663-664, 1984 (also Lawrence Berkeley Laboratory Report LBL-15367).

13. P. Berdahl and R. Fromberg, "The Thermal Radiance of Clear Skies," *Solar Energy*, **29**, pp. 299-314, 1982. (also Lawrence Berkeley Laboratory Report LBL-12720).

14. D. Staley and G. Jurica, "Effective Atmospheric Emissivity Under Clear Skies," *J. Appl. Meteor.*, **2**, p. 349, 1972.

15. F. Arumi-Noe, "Data Consistency Study of the New Mexico Test Cells (S.W.T.M.S): DEROB Simulation of the Air Temperature and Heating Load Analysis," Unpublished report prepared for ORNL under Subcontract 000S11-X39027V, September 26, 1984.

16. D. M. Burch, private communications to W. L. Carroll.

17. F. Arumi-Noe, "National Bureau of Standards Thermal Mass Project: Data Consistency Tests - DEROB Simulations," Draft Report, December, 1983.

18. "Typical Meteorological Year User's Manual: Hourly Solar Radiation - Surface Meteorological Observations", TD-9734, National Climatic Center, April, 1981.

19. D. M. Burch, D. F. Krintz and R. S. Spain, "The Effect of Wall Mass on Winter Heating Loads and Indoor Comfort-An Experimental Study," *ASHRAE Transactions*, **90**, Part 1b, 94-121, 1984.

APPENDIX 1: BLAST Inputs for NMERDI Test Cells

```
BEGIN INPUT;
**        NEW MEXICO TEST STRUCTURE NO. 1
**        11 INCH ADOBE
**        SANTA FE EXP. WEATHER
RUN CONTROL:
    NEW ZONES,
    REPORTS (26,27),
    UNITS (IN=ENGLISH,OUT=ENGLISH);
TEMPORARY LOCATION:
    SANTA FE=(LAT=35.81,LONG=106.97,TZ=7);
END;
TEMPORARY SCHEDULE (INT-LDS-SCHD):
    MONDAY THRU SUNDAY=(00 TO 24 -1.0),
    HOLIDAY=SUNDAY;
END;
TEMPORARY SCHEDULE (RESIDENTIAL-INF):
    MONDAY THRU SUNDAY=(00 TO 24 -1.0),
    HOLIDAY=SUNDAY;
END;
TEMPORARY CONTROLS (THERMOSTAT):
  PROFILES:
**    WINTER
     STANDARD=(1. AT 67.69, 0 AT 67.73);
**    SPRING
**      STANDARD=(1. AT 69.05, 0 AT 69.09);
**    SUMMER
**      STANDARD=(1. AT 69.88, 0 AT 69.92);
  SCHEDULES:
    MONDAY THRU SUNDAY=(00 TO 24 - STANDARD),
    HOLIDAY=SUNDAY;
END;
TEMPORARY MATERIALS:
    EARTH=(L=1.0,K=0.5,D=120,CP=0.2);
    CONCRETE=(L=0.3333,K=0.8,D=150,CP=0.2);
    POLYINSUL=(L=0.1667,K=0.0139,D=2,CP=0.22);
    ROOFING=(L=0.0313,K=0.0947,D=70,CP=0.35,ABS=0.82);
    PLYWOOD=(L=0.0625,K=0.0667,D=45,CP=0.29);
    EXTPLYWD=(L=0.0521,K=0.0667,D=45,CP=0.29);
    FIBGLINSUL=(L=1.045,K=0.0316,D=2,CP=0.2);
    WALINSUL=(L=0.3021,K=0.0316,D=2,CP=0.2);
    STUD2X4=(L=0.3021,K=0.0667,D=32,CP=0.33);
    STUD2X12=(L=1.045,K=0.0667,D=32,CP=0.33);
    GYPBOARD=(L=0.0417,K=0.0925,D=50,CP=0.26);
**      A D J U S T E D
    ADOBE=(L=0.91667,K=0.462,D=75.0,CP=0.22,ABS=0.78);
**      N O M I N A L
**   ADOBE=(L=0.91667,K=0.462,D=116.2,CP=0.22,ABS=0.78);
END;
TEMPORARY FLOORS:
    BLDG-FLOOR=(EARTH,CONCRETE,POLYINSUL);
END;
TEMPORARY ROOFS:
```

```
    INS-ROOF=(ROOFING,PLYWOOD,FIBGLINSUL,GYPBOARD);
    STUD-ROOF=(ROOFING,PLYWOOD,STUD2X12,GYPBOARD);
END;
TEMPORARY WALLS:
    ADOBE-WALL=(ADOBE);
END;
PROJECT= " NEW MEXICO TEST CELL NO. 1 ";
    LOCATION=SANTA FE;
**  WINTER
    WEATHER TAPE FROM 12 JAN THRU 20 JAN;
** SPRING
**   WEATHER TAPE FROM 28 FEB THRU 10 MAR;
** SUMMER
**   WEATHER TAPE FROM 25 MAY THRU 05 JUN;
GROUND TEMPERATURES=(59,56.4,56.2,57.2,59,60.2,73,73,73,67,67,67);
MAKE UP WATER TEMPERATURES=(50,50,50,50,50,50,50,50,50,50,50,50);
BEGIN BUILDING DESCRIPTION;
OUTSIDE CONVECTION=2;
BUILDING= " NEW MEXICO TEST CELL NO. 1 "
    NORTH AXIS=0;
DIMENSION:
    N=0,
    E=90,
    S=180,
    W=270,
    L1=4.0,
    L2=16.0,
    L=20,
    H=7.5;
ZONE 1 " MAIN ZONE ":
  ORIGIN: (0,0,0);
  NORTH AXIS=N;
    INFILTRATION=1,
** WINTER COEFFICIENTS
    RESIDENTIAL-INF,WITH COEFFICIENTS(0.,0.08047,0.,0.00001516);
** SPRING COEFFICIENTS
**  RESIDENTIAL-INF,WITH COEFFICIENTS(0.,0.07856,0.,0.00001516);
** SUMMER COEFFICIENTS
**  RESIDENTIAL-INF,WITH COEFFICIENTS(0.,0.07355,0.,0.00001516);
   ELECTRIC EQUIPMENT=0.1669,RESIDENTIAL-INF,0 PERCENT RADIANT,
             0 PERCENT LATENT,0 PERCENT LOST;
    CONTROLS=THERMOSTAT, 15.358 HEATING;
EXTERIOR WALLS:
    STARTING AT (0,0,0) FACING (S)
    ADOBE-WALL   (L BY H),
    STARTING AT (L,0,0) FACING (E)
    ADOBE-WALL   (L BY H),
    STARTING AT (L,L,0) FACING (N)
    ADOBE-WALL   (L BY H),
    STARTING AT (0,L,0) FACING (W)
    ADOBE-WALL   (L BY H);
ROOF:
    STARTING AT (0,0,H) FACING (S) TILTED (0)
    STUD-ROOF (1.56 BY L),
```

```
    STARTING AT (1.56,0,H) FACING (S) TILTED (0)
    INS-ROOF (18.44 BY L);
SLAB ON GRADE FLOOR:
    STARTING AT (0,L,0) FACING (S)
    BLDG-FLOOR (L BY L);
END;
END BUILDING DESCRIPTION;
```

```
BEGIN INPUT;
**        NEW MEXICO TEST STRUCTURE NO. 6
**        8 INCH CMU BLOCK
**        SANTA FE EXP. WEATHER
RUN CONTROL:
    NEW ZONES,
    REPORTS (26,27),
    UNITS (IN=ENGLISH,OUT=ENGLISH);
TEMPORARY LOCATION:
    SANTA FE=(LAT=35.81,LONG=106.97,TZ=7);
END;
TEMPORARY SCHEDULE (INT-LDS-SCHD):
    MONDAY THRU SUNDAY=(00 TO 24 -1.0),
    HOLIDAY=SUNDAY;
END;
TEMPORARY SCHEDULE (RESIDENTIAL-INF):
    MONDAY THRU SUNDAY=(00 TO 24 -1.0),
    HOLIDAY=SUNDAY;
END;
TEMPORARY CONTROLS (THERMOSTAT):
 PROFILES:
**   WINTER
**     STANDARD=(1. AT 68.95, 0 AT 68.99);
**   SPRING
**     STANDARD=(1. AT 69.08, 0 AT 69.12);
**   SUMMER
      STANDARD=(1. AT 69.64, 0 AT 69.68);
 SCHEDULES:
    MONDAY THRU SUNDAY=(00 TO 24 - STANDARD),
    HOLIDAY=SUNDAY;
END;
TEMPORARY MATERIALS:
    EARTH=(L=1.0,K=0.5,D=120,CP=0.2);
    CONCRETE=(L=0.3333,K=0.8,D=150,CP=0.2);
    POLYINSUL=(L=0.1667,K=0.0139,D=2,CP=0.22);
    ROOFING=(L=0.0313,K=0.0947,D=70,CP=0.35,ABS=0.82);
    PLYWOOD=(L=0.0625,K=0.0667,D=45,CP=0.29);
    EXTPLYWD=(L=0.0521,K=0.0667,D=45,CP=0.29);
    FIBGLINSUL=(L=1.045,K=0.0316,D=2,CP=0.2);
    WALINSUL=(L=0.3021,K=0.0316,D=2,CP=0.2);
    STUD2X4=(L=0.3021,K=0.0667,D=32,CP=0.33);
    STUD2X12=(L=1.045,K=0.0667,D=32,CP=0.33);
    GYPBOARD=(L=0.0417,K=0.0925,D=50,CP=0.26);
    ADOBE=(L=0.91667,K=0.474,D=117,CP=0.22);
    FURRING=(L=0.0625,K=0.0667,D=32,CP=0.33);
    AIRSPACE=(R=0.94,AIR);
    CMU=(L=0.6667,K=0.26,D=38,CP=0.2,ABS=0.78);
END;
TEMPORARY FLOORS:
    BLDG-FLOOR=(EARTH,CONCRETE,POLYINSUL);
END;
TEMPORARY ROOFS:
    INS-ROOF=(ROOFING,PLYWOOD,FIBGLINSUL,GYPBOARD);
    STUD-ROOF=(ROOFING,PLYWOOD,STUD2X12,GYPBOARD);
```

```
END;
TEMPORARY WALLS:
     FURR-WALL=(CMU,FURRING,GYPBOARD);
     AIR-WALL=(CMU,AIRSPACE,GYPBOARD);
END;
PROJECT= " NEW MEXICO TEST CELL NO. 6 ";
     LOCATION=SANTA FE;
** WINTER
**    WEATHER TAPE FROM 12 JAN THRU 20 JAN;
** SPRING
**    WEATHER TAPE FROM 28 FEB THRU 10 MAR;
** SUMMER
     WEATHER TAPE FROM 25 MAY THRU 05 JUN;
GROUND TEMPERATURES=(59,56.4,56.2,57.2,59,60.2,73,73,73,67,67,67);
MAKE UP WATER TEMPERATURES=(50,50,50,50,50,50,50,50,50,50,50,50);
BEGIN BUILDING DESCRIPTION;
OUTSIDE CONVECTION=2;
BUILDING= " NEW MEXICO TEST CELL NO. 6 "
     NORTH AXIS=0;
DIMENSION:
     N=0,
     E=90,
     S=180,
     W=270,
     L1=1.52,
     L2=18.48,
     L=20,
     H=7.5;
ZONE 1 " MAIN ZONE ":
  ORIGIN: (0,0,0);
  NORTH AXIS=N;
     INFILTRATION=1,
** WINTER COEFFICIENTS
**   RESIDENTIAL-INF,WITH COEFFICIENTS(0.,0.04462,0.,0.00000228);
** SPRING COEFFICIENTS
**   RESIDENTIAL-INF,WITH COEFFICIENTS(0.,0.04364,0.,0.00000228);
** SUMMER COEFFICIENTS
    RESIDENTIAL-INF,WITH COEFFICIENTS(0.,0.04071,0.,0.00000228);
   ELECTRIC EQUIPMENT=0.1488,RESIDENTIAL-INF,0 PERCENT RADIANT,
               0 PERCENT LATENT,0 PERCENT LOST;
     CONTROLS=THERMOSTAT, 15.358 HEATING;
EXTERIOR WALLS:
     STARTING AT (0,0,0) FACING (S)
     FURR-WALL   (L1 BY H),
     STARTING AT (L1,0,0) FACING (S)
     AIR-WALL   (L2 BY H),
     STARTING AT (L,0,0) FACING (E)
     FURR-WALL   (L1 BY H),
     STARTING AT (L,L1,0) FACING (E)
     AIR-WALL   (L2 BY H),
     STARTING AT (L,L,0) FACING (N)
     FURR-WALL   (L1 BY H),
     STARTING AT (L2,L,0) FACING (N)
     AIR-WALL   (L2 BY H);
```

```
    STARTING AT (0,L,0) FACING (W)
    FURR-WALL   (L1 BY H),
    STARTING AT (0,L2,0) FACING (W)
    AIR-WALL   (L2 BY H);
ROOF:
    STARTING AT (0,0,H) FACING (S) TILTED (0)
    STUD-ROOF (1.56 BY L),
    STARTING AT (1.56,0,H) FACING (S) TILTED (0)
    INS-ROOF (18.44 BY L);
SLAB ON GRADE FLOOR:
    STARTING AT (0,L,0) FACING (S)
    BLDG-FLOOR (L BY L);
END;
END BUILDING DESCRIPTION;
```

```
BEGIN INPUT;
**         NEW MEXICO TEST STRUCTURE NO. 7
**         INSULATED WOOD FRAME
**         SANTA FE EXP. WEATHER
RUN CONTROL:
     NEW ZONES,
     REPORTS (26,27),
     UNITS (IN=ENGLISH,OUT=ENGLISH);
TEMPORARY LOCATION:
     SANTA FE=(LAT=35.81,LONG=106.97,TZ=7);
END;
TEMPORARY SCHEDULE (INT-LDS-SCHD):
     MONDAY THRU SUNDAY=(00 TO 24 -1.0),
     HOLIDAY=SUNDAY;
END;
TEMPORARY SCHEDULE (RESIDENTIAL-INF):
     MONDAY THRU SUNDAY=(00 TO 24 -1.0),
     HOLIDAY=SUNDAY;
END;
TEMPORARY CONTROLS (THERMOSTAT):
  PROFILES:
**   WINTER
**      STANDARD=(1. AT 68.98, 0 AT 69.02);
**   SPRING
**      STANDARD=(1. AT 69.12, 0 AT 69.16);
**   SUMMER
       STANDARD=(1. AT 69.23, 0 AT 69.27);
  SCHEDULES:
     MONDAY THRU SUNDAY=(00 TO 24 - STANDARD),
     HOLIDAY=SUNDAY;
END;
TEMPORARY MATERIALS:
     EARTH=(L=1.0,K=0.5,D=120,CP=0.2);
     CONCRETE=(L=0.3333,K=0.8,D=150,CP=0.2);
     POLYINSUL=(L=0.1667,K=0.0139,D=2,CP=0.22);
     ROOFING=(L=0.0313,K=0.0947,D=70,CP=0.35,ABS=0.82);
     PLYWOOD=(L=0.0625,K=0.0667,D=45,CP=0.29);
     EXTPLYWD=(L=0.0521,K=0.0667,D=45,CP=0.29,ABS=0.78);
     WALINSUL=(L=0.3021,K=0.0275,D=2,CP=0.2);
     FIBGLINSUL=(L=1.045,K=0.0275,D=2,CP=0.2);
     STUD2X4=(L=0.3021,K=0.0667,D=32,CP=0.33);
     STUD2X12=(L=1.045,K=0.0667,D=32,CP=0.33);
     GYPBOARD=(L=0.0417,K=0.0925,D=50,CP=0.26);
END;
TEMPORARY FLOORS:
     BLDG-FLOOR=(EARTH,CONCRETE,POLYINSUL);
END;
TEMPORARY ROOFS:
     INS-ROOF=(ROOFING,PLYWOOD,FIBGLINSUL,GYPBOARD);
     STUD-ROOF=(ROOFING,PLYWOOD,STUD2X12,GYPBOARD);
END;
TEMPORARY WALLS:
     STUD-WALL=(EXTPLYWD,STUD2X4,GYPBOARD);
     INS-WALL=(EXTPLYWD,WALINSUL,GYPBOARD);
```

```
END;
PROJECT= " NEW MEXICO TEST CELL NO. 7 ";
    LOCATION=SANTA FE;
** WINTER
**    WEATHER TAPE FROM 12 JAN THRU 20 JAN;
** SPRING
**    WEATHER TAPE FROM 28 FEB THRU 10 MAR;
** SUMMER
    WEATHER TAPE FROM 25 MAY THRU 05 JUN;
GROUND TEMPERATURES=(59,56.4,56.2,57.2,59,60.2,73,73,73,67,67,67);
MAKE UP WATER TEMPERATURES=(50,50,50,50,50,50,50,50,50,50,50,50);
BEGIN BUILDING DESCRIPTION;
OUTSIDE CONVECTION=2;
BUILDING= " NEW MEXICO TEST CELL NO. 7 "
    NORTH AXIS=0;
DIMENSION:
    N=0,
    E=90,
    S=180,
    W=270,
    L1=4.0,
    L2=16.0,
    L=20.7,
    H=8.0;
ZONE 1 " MAIN ZONE ":
  ORIGIN: (0,0,0);
  NORTH AXIS=N;
**    INFILTRATION=12.0,
**    RESIDENTIAL-INF,WITH COEFFICIENTS(1.,0.,0.,0.);
    INFILTRATION=1,
** WINTER COEFFICIENTS
**   RESIDENTIAL-INF,WITH COEFFICIENTS(0.,0.04453,0.,0.00000287);
** SPRING COEFFICIENTS
**   RESIDENTIAL-INF,WITH COEFFICIENTS(0.,0.043561,0.,0.00000287);
** SUMMER COEFFICIENTS
    RESIDENTIAL-INF,WITH COEFFICIENTS(0.,0.04071,0.,0.00000287);
  ELECTRIC EQUIPMENT=0.1544,RESIDENTIAL-INF,0 PERCENT RADIANT,
          0 PERCENT LATENT,0 PERCENT LOST;
    CONTROLS=THERMOSTAT,15.358 HEATING;
EXTERIOR WALLS:
    STARTING AT (0,0,0) FACING (S)
    STUD-WALL   (L1 BY H),
    STARTING AT (L1,0,0) FACING (S)
    INS-WALL    (L2 BY H),
    STARTING AT (L,0,0) FACING (E)
    STUD-WALL   (L1 BY H),
    STARTING AT (L,L1,0) FACING (E)
    INS-WALL    (L2 BY H),
    STARTING AT (L,L,0) FACING (N)
    STUD-WALL   (L1 BY H),
    STARTING AT (L2,L,0) FACING (N)
    INS-WALL    (L2 BY H),
    STARTING AT (0,L,0) FACING (W)
    STUD-WALL   (L1 BY H),
```

```
    STARTING AT (0,L2,0) FACING (W)
    INS-WALL    (L2 BY H);
ROOF:
    STARTING AT (0,0,H) FACING (S) TILTED (0)
    STUD-ROOF (1.56 BY L),
    STARTING AT (1.56,0,H) FACING (S) TILTED (0)
    INS-ROOF (18.44 BY L);
SLAB ON GRADE FLOOR:
    STARTING AT (0,L,0) FACING (S)
    BLDG-FLOOR (L BY L);
END;
END BUILDING DESCRIPTION;
```

APPENDIX 2: BLAST Inputs for NBS Test Cells

```
BEGIN INPUT;
**        N B S  TEST CELL NO. 1
**        INSULATED WOOD FRAME
**        DULLES  EXP. WEATHER
RUN CONTROL:
    NEW ZONES,
    REPORTS (26,27),
    UNITS (IN=ENGLISH,OUT=ENGLISH);
TEMPORARY LOCATION:
    WASHINGTON=(LAT=39.0,LONG=77.4,TZ=5);
END;
TEMPORARY SCHEDULE (INT-LDS-SCHD):
    MONDAY THRU SUNDAY=(00 TO 24 -1.0),
    HOLIDAY=SUNDAY;
END;
TEMPORARY SCHEDULE (INF-SCH):
    MONDAY THRU SUNDAY=(00 TO 24 -1.0),
    HOLIDAY=SUNDAY;
END;
TEMPORARY CONTROLS (THERMOSTAT):
 PROFILES:
 ** WINTER
     STANDARD=(1. AT 66.78, 0 AT 66.82);
 ** SPRING
 **   STANDARD=(1 AT 69.48, 0 AT 69.52);
 ** SUMMER
 **   STANDARD=(-0 AT 74.78, -1 AT 74.82);
 SCHEDULES:
    MONDAY THRU SUNDAY=(00 TO 24 - STANDARD),
    HOLIDAY=SUNDAY;
END;
TEMPORARY CONTROLS (THER1):
 PROFILES:
 ** WINTER
    STAND1=(1. AT 68.92, 0 AT 68.96);
    STAND2=(1. AT 66.78, 0 AT 66.82);
 SCHEDULES:
    MONDAY THRU SUNDAY=(00 TO 16 - STAND2,16 TO 24-STAND1),
    HOLIDAY=SUNDAY;
END;
TEMPORARY CONTROLS (THER2):
 PROFILES:
 ** WINTER
    STAND3=(1. AT 68.92, 0 AT 68.96);
    STAND4=(1. AT 66.78, 0 AT 66.82);
 SCHEDULES:
    MONDAY THRU SUNDAY=(00 TO 10 - STAND3,10 TO 24-STAND4),
    HOLIDAY=SUNDAY;
END;
TEMPORARY MATERIALS:
    EARTH=(L=1.3333,K=0.5,D=120,CP=0.2);
    CONCRETE=(L=0.3333,K=0.8,D=150,CP=0.2);
```

```
    POLYINSUL=(L=0.1667,K=0.015,D=2.7,CP=0.29);
    ASPHALT=(R=0.44,ABS=0.78,ROUGH);
    ROOFPLYWD=(L=0.0417,K=0.0667,D=45,CP=0.29);
    EXTPLYWD=(L=0.0521,K=0.0667,D=45,CP=0.29,ABS=0.62);
    FIBGINSUL=(L=0.9167,K=0.0275,D=2.0,CP=0.2);
    FIBG-STUD=(L=0.625,K=0.0275,D=2.0,CP=0.2);
    WALINSUL=(L=0.3021,K=0.0275,D=2.0,CP=0.2);
    STUD2X4=(L=0.3021,K=0.0667,D=32.0,CP=0.33);
    CSTUD=(L=0.292,K=0.0667,D=32.0,CP=0.33);
    GYPBOARD=(L=0.0417,K=0.0925,D=50,CP=0.26,ABS=0.7);
    GLAZING=(R=0.0132,TABS=0.9,TRANS=0.8,GLASS,VERY SMOOTH);
    GLAZ-SCR=(R=0.0132,TABS=0.9,TRANS=0.72,GLASS,VERY SMOOTH);
    AIRSPACE=(R=0.967,AIR);
    CARBONDIOXIDE=(R=0.7201,AIR);
    METAL-DOOR=(R=4.44);
    WMASS=(L=0.16,K=0.067,D=32,CP=0.33);
    EQMASS=(L=0.02,K=0.067,D=32,CP=0.33);
    SASH=(L=0.083,K=0.067,D=32,CP=0.33,ABS=0.62);
END;
TEMPORARY FLOORS:
    BLDG-FLOOR=(EARTH,CONCRETE,POLYINSUL);
    ATTIC-FLOOR-STUD=(GYPBOARD,CSTUD,FIBG-STUD);
    ATTIC-FLOOR-INS=(GYPBOARD,FIBGINSUL);
END;
TEMPORARY ROOFS:
    BLDG-ROOF=(ASPHALT,ROOFPLYWD);
    STUD-CEIL=(FIBG-STUD,CSTUD,GYPBOARD);
    INS-CEIL=(FIBGINSUL,GYPBOARD);
END;
TEMPORARY WALLS:
    STUD-WALL=(EXTPLYWD,STUD2X4,GYPBOARD);
    INS-WALL=(EXTPLYWD,WALINSUL,GYPBOARD);
    ATTIC-WALL=(EXTPLYWD);
    Z1MASS=(WMASS);
    Z2MASS=(EQMASS);
END;
TEMPORARY WINDOWS:
    WIND1=(GLAZING,AIRSPACE,GLAZING,CARBONDIOXIDE,
            GLAZING);
    WIND2=(GLAZING,AIRSPACE,GLAZ-SCR,CARBONDIOXIDE,
            GLAZING);
END;
TEMPORARY DOORS:
    BLDG-DOOR=(METAL-DOOR);
    WFRAME=(SASH);
END;
PROJECT= " N B S TEST CELL NO. 1 ";
    LOCATION=WASHINGTON;
** WINTER
   WEATHER TAPE FROM 23 FEB THRU 05 MAR;
** SPRING
**  WEATHER TAPE FROM 15 APR THRU 25 APR;
** SUMMER
**  WEATHER TAPE FROM 27 JUL THRU 05 AUG;
```

```
GROUND TEMPERATURES=(55.7,55.7,55.7,55.9,55.9,63.6,63.6,63.6,63.6,60,60,60);
MAKE UP WATER TEMPERATURES=(50,50,50,50,50,50,50,50,50,50,50,50);
BEGIN BUILDING DESCRIPTION;
OUTSIDE CONVECTION=2;
BUILDING= " N B S  TEST CELL NO. 1 "
    NORTH AXIS=0;
DIMENSION:
    N=0,
    E=90,
    S=180,
    W=270,
    WL=8.24,
    WWIDTH=5.34,
    WHEIGHT=1.58,
    L=21.24,
    H=7.79;
**** USE ONLY FOR WINTER AND SUMMER ****
   DETACHED SHADING "SHADE1":
    (200 BY 13) STARTING AT (100,-22,0) FACING (N) TILTED (30);
*** USE FOR ALL TIME PERIODS ***
DETACHED SHADING "SHADE4":
  (20 BY 11) STARTING AT (0,60,0) FACING (S) TILTED (90);
DETACHED SHADING "SHADE5":
  (20 BY 11) STARTING AT (-40,0,0) FACING (E) TILTED (90);
DETACHED SHADING "SHADE6":
  (1000 BY 40) STARTING AT (-200,-500,0) FACING (E) TILTED (90);
ZONE 1 " MAIN ZONE ":
  ORIGIN: (0,0,0);
  NORTH AXIS=N;
** WINTER AND SPRING
    INFILTRATION=1, INF-SCH,WITH COEFFICIENTS(4.58,0.134,0.,0.00000215);
** SUMMER
**   INFILTRATION=1, INF-SCH,WITH COEFFICIENTS(3.14,0,0,0);
**  WINTER
     LIGHTS=0.9898,
** SPRING AND SUMMER
**    LIGHTS=0.927,
INT-LDS-SCHD,80 PERCENT RADIANT, 10 PERCENT VISIBLE;
**  WINTER AND SPRING
    CONTROLS=THERMOSTAT,14 HEATING,FROM 23 FEB THRU 2 MAR;
    CONTROLS=THER1,14 HEATING,FROM 3 MAR THRU 3 MAR;
    CONTROLS=THER2,14 HEATING,FROM 4 MAR THRU 4 MAR;
    CONTROLS=THERMOSTAT,14 HEATING,FROM 5 MAR THRU 5 MAR;
EXTERIOR WALLS:
    STARTING AT (0,0,0) FACING (S)
    INS-WALL (17.56 BY H)
    WITH WINDOWS OF TYPE
     WIND1 (WWIDTH BY WHEIGHT) AT (1.38,4.5) REVEAL (0.13)
    WITH WINDOWS OF TYPE
     WIND2 (WWIDTH BY WHEIGHT) AT (1.38,2.8) REVEAL (0.13)
    WITH DOORS OF TYPE
     WFRAME (3.9 BY 1) AT (10,0) REVEAL (0.13)
     WITH OVERHANGS (17.56 BY 2.5) AT (0,H),
    STARTING AT (17.56,0,0) FACING (S)
```

```
    STUD-WALL (3.68 BY H)
     WITH OVERHANGS (3.68 BY 2.5) AT (0,H),
    STARTING AT (L,0,0) FACING (E)
    STUD-WALL (3.74 BY H),
    STARTING AT (L,3.74,0) FACING (E)
    INS-WALL (17.5 BY H)
      WITH DOORS OF TYPE
      BLDG-DOOR (2.96,6.6) AT (12.26,0) REVEAL (0.13),
    STARTING AT (L,L,0) FACING (N)
    INS-WALL (17.56 BY H)
      WITH WINDOWS OF TYPE
      WIND1 (WWIDTH BY WHEIGHT) AT (1.38,4.5) REVEAL (0.13)
    WITH WINDOWS OF TYPE
     WIND2 (WWIDTH BY WHEIGHT) AT (1.38,2.8) REVEAL (0.13)
    WITH DOORS OF TYPE
     WFRAME (3.9 BY 1) AT (10,0) REVEAL (0.13)
     WITH OVERHANGS (17.56 BY 2.5) AT (0,H),
    STARTING AT (3.68,L,0) FACING (N)
    STUD-WALL (3.68 BY H)
     WITH OVERHANGS (3.68 BY 2.5) AT (0,H),
    STARTING AT (0,L,0) FACING (W)
    STUD-WALL (4.24 BY H),
    STARTING AT (0,17,0) FACING (W)
    INS-WALL (17 BY H);
INTERZONE CEILING:
    STARTING AT (0,0,H) FACING (S) TILTED (0)
    INS-CEIL (L BY 19.117) ADJACENT TO ZONE (2),
    STARTING AT (0,19.117,H) FACING (S) TILTED (0)
    STUD-CEIL (L BY 2.123) ADJACENT TO ZONE (2);
SLAB ON GRADE FLOOR:
    STARTING AT (0,L,0) FACING (S)
    BLDG-FLOOR (L BY L);
INTERNAL MASS:
    Z1MASS (10 BY 25),
    Z2MASS (10 BY 19.4);
END;
ZONE 2 " ATTIC ":
  ORIGIN: (0,-2.5,H);
  NORTH AXIS= N;
  INFILTRATION = 35.0,
   INF-SCH, WITH COEFFICIENTS(1.0,0.,0.,0.);
EXTERIOR WALLS:
    STARTING AT (L,0,0) FACING (E)
    ATTIC-WALL ((24.74,0),(12.37,5.917)),
    STARTING AT (0,24.74,0) FACING (W)
    ATTIC-WALL ((24.74,0),(12.37,5.917)),
    STARTING AT (0,0,0) FACING (S) TILTED (-90)
    ATTIC-WALL (L BY 2.37),
    STARTING AT (L,24.74,0) FACING (N) TILTED (-90)
    ATTIC-WALL (L BY 2.37);
ROOF:
    STARTING AT (0,0,0) FACING (S) TILTED (25)
    BLDG-ROOF (L BY 13.65),
    STARTING AT (L,24.74,0) FACING (N) TILTED (25)
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    BLDG-ROOF (L BY 13.65);
INTERZONE FLOOR:
    STARTING AT (0,21.617,0) FACING (S)
    ATTIC-FLOOR-INS (L BY 19.117) ADJACENT TO ZONE (1),
    STARTING AT (0,23.74,0) FACING (S)
    ATTIC-FLOOR-STUD (L BY 2.123) ADJACENT TO ZONE (1);
END;
END BUILDING DESCRIPTION;
```

```
BEGIN INPUT;
**        N B S  TEST CELL NO. 5
**        7 INCH LOG
**        DULLES  EXP. WEATHER
RUN CONTROL:
    NEW ZONES,
    REPORTS (26,27),
    UNITS (IN=ENGLISH,OUT=ENGLISH);
TEMPORARY LOCATION:
    WASHINGTON=(LAT=39.0,LONG=77.4,TZ=5);
END;
TEMPORARY SCHEDULE (INT-LDS-SCHD):
    MONDAY THRU SUNDAY=(00 TO 24 -1.0),
    HOLIDAY=SUNDAY;
END;
TEMPORARY SCHEDULE (INF-SCH):
    MONDAY THRU SUNDAY=(00 TO 24 -1.0),
    HOLIDAY=SUNDAY;
END;
TEMPORARY CONTROLS (THERMOSTAT):
  PROFILES:
** WINTER
**   STANDARD=(1. AT 67.58, 0 AT 67.62);
** SPRING
    STANDARD=(1 AT 68.58, 0 AT 68.62);
** SUMMER
**   STANDARD=(-0 AT 75.88, -1 AT 75.92);
  SCHEDULES:
    MONDAY THRU SUNDAY=(00 TO 24 - STANDARD),
    HOLIDAY=SUNDAY;
END;
TEMPORARY MATERIALS:
    EARTH=(L=1.3333,K=0.5,D=120,CP=0.2);
    CONCRETE=(L=0.3333,K=0.8,D=150,CP=0.2);
    POLYINSUL=(L=0.1667,K=0.015,D=2.7,CP=0.29);
    ASPHALT=(R=0.44,ABS=0.78,ROUGH);
    ROOFPLYWD=(L=0.0417,K=0.0667,D=45,CP=0.29);
    EXTPLYWD=(L=0.0521,K=0.0667,D=45,CP=0.29,ABS=0.62);
    FIBGINSUL=(L=0.9167,K=0.0275,D=2.0,CP=0.2);
    FIBG-STUD=(L=0.625,K=0.0275,D=2.0,CP=0.2);
    WALINSUL=(L=0.3021,K=0.0275,D=2.0,CP=0.2);
    STUD2X4=(L=0.3021,K=0.0667,D=32.0,CP=0.33);
    CSTUD=(L=0.292,K=0.0667,D=32.0,CP=0.33);
    GYPBOARD=(L=0.0417,K=0.0925,D=50,CP=0.26,ABS=0.7);
    GLAZING=(R=0.0132,TABS=0.9,TRANS=0.8,GLASS,VERY SMOOTH);
    GLAZ-SCR=(R=0.0132,TABS=0.9,TRANS=0.72,GLASS,VERY SMOOTH);
    AIRSPACE=(R=0.967,AIR);
    CARBONDIOXIDE=(R=0.7201,AIR);
    METAL-DOOR=(R=4.44);
    WMASS=(L=0.16,K=0.067,D=32,CP=0.33);
    EQMASS=(L=0.02,K=0.067,D=32,CP=0.33);
    SASH=(L=0.083,K=0.067,D=32,CP=0.33,ABS=0.62);
    LOG=(L=0.583,K=0.06308,D=26.5,CP=0.36,ABS=0.62);
END;
```

```
TEMPORARY FLOORS:
    BLDG-FLOOR=(EARTH,CONCRETE,POLYINSUL);
    ATTIC-FLOOR-STUD=(GYPBOARD,CSTUD,FIBG-STUD);
    ATTIC-FLOOR-INS=(GYPBOARD,FIBGINSUL);
END;
TEMPORARY ROOFS:
    BLDG-ROOF=(ASPHALT,ROOFPLYWD);
    STUD-CEIL=(FIBG-STUD,CSTUD,GYPBOARD);
    INS-CEIL=(FIBGINSUL,GYPBOARD);
END;
TEMPORARY WALLS:
    EXT-WALL=(LOG);
    ATTIC-WALL=(EXTPLYWD);
    Z1MASS=(WMASS);
    Z2MASS=(EQMASS);
END;
TEMPORARY WINDOWS:
    WIND1=(GLAZING,AIRSPACE,GLAZING,CARBONDIOXIDE,
             GLAZING);
    WIND2=(GLAZING,AIRSPACE,GLAZ-SCR,CARBONDIOXIDE,
             GLAZING);
END;
TEMPORARY DOORS:
    BLDG-DOOR=(METAL-DOOR);
    WFRAME=(SASH);
END;
PROJECT= " N B S TEST CELL NO. 5 ";
    LOCATION=WASHINGTON;
** WINTER
**  WEATHER TAPE FROM 23 FEB THRU 05 MAR;
** SPRING
   WEATHER TAPE FROM 15 APR THRU 25 APR;
** SUMMER
**  WEATHER TAPE FROM 27 JUL THRU 05 AUG;
GROUND TEMPERATURES=(55.7,55.7,55.7,55.9,55.9,63.6,63.6,63.6,63.6,60,60,60);
MAKE UP WATER TEMPERATURES=(50,50,50,50,50,50,50,50,50,50,50,50);
BEGIN BUILDING DESCRIPTION;
OUTSIDE CONVECTION=2;
BUILDING= "  N B S  TEST CELL NO. 5 "
    NORTH AXIS=0;
DIMENSION:
    N=0,
    E=90,
    S=180,
    W=270,
    WL=8.24,
    WWIDTH=5.34,
    WHEIGHT=1.58,
    L=21.24,
    H=7.79;
****  USE FOR WINTER AND SPRING ONLY  ****
   DETACHED SHADING "SHADE1":
    (200 BY 13) STARTING AT (100,-22,0) FACING (N) TILTED (30);
*** USE FOR ALL TIME PERIODS ***
```

```
DETACHED SHADING "SHADE4":
 (20 BY 11) STARTING AT (0,60,0) FACING (S) TILTED (90);
DETACHED SHADING "SHADE5":
 (20 BY 11) STARTING AT (60,20,0) FACING (W) TILTED (90);
DETACHED SHADING "SHADE6":
 (20 BY 11) STARTING AT (-40,0,0) FACING (E) TILTED (90);
DETACHED SHADING "SHADE7":
 (1000 BY 40) STARTING AT (-200,-500,0) FACING (E) TILTED (90);
ZONE 1 " MAIN ZONE ":
 ORIGIN: (0,0,0);
 NORTH AXIS=N;
** WINTER AND SPRING
    INFILTRATION=1, INF-SCH,WITH COEFFICIENTS(5.21,0.171,0.,0.00000145);
** SUMMER
**   INFILTRATION=1, INF-SCH,WITH COEFFICIENTS(1.52,0,0,0);
**  WINTER
**    LIGHTS=0.9898,
** SPRING AND SUMMER
     LIGHTS=0.908,
INT-LDS-SCHD,80 PERCENT RADIANT, 10 PERCENT VISIBLE;
**  WINTER AND SPRING
    CONTROLS=THERMOSTAT,14 HEATING;
**  SUMMER
**   CONTROLS=THERMOSTAT,10 COOLING;
EXTERIOR WALLS:
    STARTING AT (0,0,0) FACING (S)
    EXT-WALL (L BY H)
    WITH WINDOWS OF TYPE
     WIND1 (WWIDTH BY WHEIGHT) AT (1.38,4.5) REVEAL (0.13)
    WITH WINDOWS OF TYPE
     WIND2 (WWIDTH BY WHEIGHT) AT (1.38,2.8) REVEAL (0.13)
    WITH DOORS OF TYPE
     WFRAME (3.9 BY 1) AT (10,0) REVEAL (0.13)
     WITH OVERHANGS (L BY 2.5) AT (0,H),
    STARTING AT (L,0,0) FACING (E)
    EXT-WALL (L BY H)
      WITH DOORS OF TYPE
      BLDG-DOOR (2.96,6.6) AT (16.0,0) REVEAL (0.13),
    STARTING AT (L,L,0) FACING (N)
    EXT-WALL (L BY H)
      WITH WINDOWS OF TYPE
      WIND1 (WWIDTH BY WHEIGHT) AT (1.38,4.5) REVEAL (0.13)
    WITH WINDOWS OF TYPE
     WIND2 (WWIDTH BY WHEIGHT) AT (1.38,2.8) REVEAL (0.13)
    WITH DOORS OF TYPE
     WFRAME (3.9 BY 1) AT (10,0) REVEAL (0.13)
     WITH OVERHANGS (L BY 2.5) AT (0,H),
    STARTING AT (0,L,0) FACING (W)
    EXT-WALL (L BY H);
INTERZONE CEILING:
    STARTING AT (0,0,H) FACING (S) TILTED (0)
    INS-CEIL (L BY 19.117) ADJACENT TO ZONE (2),
    STARTING AT (0,19.117,H) FACING (S) TILTED (0)
    STUD-CEIL (L BY 2.123) ADJACENT TO ZONE (2);
```

```
SLAB ON GRADE FLOOR:
     STARTING AT (0,L,0) FACING (S)
     BLDG-FLOOR (L BY L);
INTERNAL MASS:
     Z1MASS (10 BY 22.7),
     Z2MASS (10 BY 5.9);
END;
ZONE 2 " ATTIC ":
  ORIGIN: (0,-2.5,H);
  NORTH AXIS= N;
  INFILTRATION = 35.0,
    INF-SCH, WITH COEFFICIENTS(1.0,0.,0.,0.);
EXTERIOR WALLS:
     STARTING AT (L,0,0) FACING (E)
     ATTIC-WALL ((24.74,0),(12.37,5.917)),
     STARTING AT (0,24.74,0) FACING (W)
     ATTIC-WALL ((24.74,0),(12.37,5.917)),
     STARTING AT (0,0,0) FACING (S) TILTED (-90)
     ATTIC-WALL (L BY 2.37),
     STARTING AT (L,24.74,0) FACING (N) TILTED (-90)
     ATTIC-WALL (L BY 2.37);
ROOF:
     STARTING AT (0,0,0) FACING (S) TILTED (25)
     BLDG-ROOF (L BY 13.65),
     STARTING AT (L,24.74,0) FACING (N) TILTED (25)
     BLDG-ROOF (L BY 13.65);
INTERZONE FLOOR:
     STARTING AT (0,21.617,0) FACING (S)
     ATTIC-FLOOR-INS (L BY 19.117) ADJACENT TO ZONE (1),
     STARTING AT (0,23.74,0) FACING (S)
     ATTIC-FLOOR-STUD (L BY 2.123) ADJACENT TO ZONE (1);
END;
END BUILDING DESCRIPTION;
```

```
BEGIN INPUT;
**        N B S  TEST CELL NO. 6
**        8 INCH CMU BLOCK - INSULATED
**        DULLES  EXP. WEATHER
RUN CONTROL:
    NEW ZONES,
    REPORTS (26,27),
    UNITS (IN=ENGLISH,OUT=ENGLISH);
TEMPORARY LOCATION:
    WASHINGTON=(LAT=39.0,LONG=77.4,TZ=5);
END;
TEMPORARY SCHEDULE (INT-LDS-SCHD):
    MONDAY THRU SUNDAY=(00 TO 24 -1.0),
    HOLIDAY=SUNDAY;
END;
TEMPORARY SCHEDULE (INF-SCH):
    MONDAY THRU SUNDAY=(00 TO 24 -1.0),
    HOLIDAY=SUNDAY;
END;
TEMPORARY CONTROLS (THERMOSTAT):
 PROFILES:
** WINTER
**  STANDARD=(1. AT 68.18, 0 AT 68.22);
** SPRING
    STANDARD=(1 AT 67.88, 0 AT 67.92);
** SUMMER
**  STANDARD=(-0 AT 76.38, -1 AT 76.42);
 SCHEDULES:
    MONDAY THRU SUNDAY=(00 TO 24 - STANDARD),
    HOLIDAY=SUNDAY;
END;
TEMPORARY MATERIALS:
    EARTH=(L=1.3333,K=0.5,D=120,CP=0.2);
    CONCRETE=(L=0.3333,K=0.8,D=150,CP=0.2);
    POLYINSUL=(L=0.1667,K=0.015,D=2.7,CP=0.29);
    ASPHALT=(R=0.44,ABS=0.78,ROUGH);
    ROOFPLYWD=(L=0.0417,K=0.0667,D=45,CP=0.29);
    EXTPLYWD=(L=0.0521,K=0.0667,D=45,CP=0.29,ABS=0.62);
    FIBGINSUL=(L=0.9167,K=0.0275,D=2.0,CP=0.2);
    FIBG-STUD=(L=0.625,K=0.0275,D=2.0,CP=0.2);
    WALINSUL=(L=0.3021,K=0.0275,D=2.0,CP=0.2);
    STUD2X4=(L=0.3021,K=0.0667,D=32.0,CP=0.33);
    CSTUD=(L=0.292,K=0.0667,D=32.0,CP=0.33);
    GYPBOARD=(L=0.0417,K=0.0925,D=50,CP=0.26,ABS=0.7);
    GLAZING=(R=0.0132,TABS=0.9,TRANS=0.8,GLASS,VERY SMOOTH);
    GLAZ-SCR=(R=0.0132,TABS=0.9,TRANS=0.72,GLASS,VERY SMOOTH);
    AIRSPACE=(R=0.967,AIR);
    CARBONDIOXIDE=(R=0.7201,AIR);
    METAL-DOOR=(R=4.44);
    WMASS=(L=0.16,K=0.067,D=32,CP=0.33);
    EQMASS=(L=0.02,K=0.067,D=32,CP=0.33);
    SASH=(L=0.083,K=0.067,D=32,CP=0.33,ABS=0.62);
    LOG=(L=0.583,K=0.06308,D=26.5,CP=0.36,ABS=0.62);
    FACE-BRICK=(L=0.292,K=0.7575,D=130,CP=0.19,ABS=0.62);
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```
     PERLITE=(L=0.292,K=0.0317,D=9.5,CP=0.26);
     WALL-CONCRETE=(L=0.667,K=0.419,D=61,CP=0.2);
     PLASTER=(L=0.0417,K=0.13,D=45,CP=0.2);
END;
TEMPORARY FLOORS:
     BLDG-FLOOR=(EARTH,CONCRETE,POLYINSUL);
     ATTIC-FLOOR-STUD=(GYPBOARD,CSTUD,FIBG-STUD);
     ATTIC-FLOOR-INS=(GYPBOARD,FIBGINSUL);
END;
TEMPORARY ROOFS:
     BLDG-ROOF=(ASPHALT,ROOFPLYWD);
     STUD-CEIL=(FIBG-STUD,CSTUD,GYPBOARD);
     INS-CEIL=(FIBGINSUL,GYPBOARD);
END;
TEMPORARY WALLS:
     EXT-WALL=(FACE-BRICK,PERLITE,WALL-CONCRETE,PLASTER);
     ATTIC-WALL=(EXTPLYWD);
     Z1MASS=(WMASS);
     Z2MASS=(EQMASS);
END;
TEMPORARY WINDOWS:
     WIND1=(GLAZING,AIRSPACE,GLAZING,CARBONDIOXIDE,
            GLAZING);
     WIND2=(GLAZING,AIRSPACE,GLAZ-SCR,CARBONDIOXIDE,
            GLAZING);
END;
TEMPORARY DOORS:
     BLDG-DOOR=(METAL-DOOR);
     WFRAME=(SASH);
END;
PROJECT= " N B S TEST CELL NO. 6 ";
     LOCATION=WASHINGTON;
** WINTER
**  WEATHER TAPE FROM 23 FEB THRU 05 MAR;
** SPRING
   WEATHER TAPE FROM 15 APR THRU 25 APR;
** SUMMER
**  WEATHER TAPE FROM 27 JUL THRU 05 AUG;
GROUND TEMPERATURES=(55.7,55.7,55.7,55.9,55.9,63.6,63.6,63.6,63.6,60,60,60);
MAKE UP WATER TEMPERATURES=(50,50,50,50,50,50,50,50,50,50,50,50);
BEGIN BUILDING DESCRIPTION;
OUTSIDE CONVECTION=2;
BUILDING= "  N B S  TEST CELL NO. 6 "
     NORTH AXIS=0;
DIMENSION:
     N=0,
     E=90,
     S=180,
     W=270,
     WL=8.24,
     WWIDTH=5.34,
     WHEIGHT=1.58,
     L=22.5,
     H=8.25;
```

```
*** USE FOR SUMMER AND WINTER ONLY ***
** DETACHED SHADING "SHADE1":
** (200 BY 13) STARTING AT (100,-80,0) FACING (N) TILTED (30);
*** USE FOR ALL TIME PERIODS ***
DETACHED SHADING "SHADE4":
 (20 BY 11) STARTING AT (20,-40,0) FACING (N) TILTED (90);
DETACHED SHADING "SHADE5":
 (20 BY 11) STARTING AT (60,20,0) FACING (W) TILTED (90);
DETACHED SHADING "SHADE6":
 (1000 BY 40) STARTING AT (-100,-500,0) FACING (E) TILTED (90);
ZONE 1 " MAIN ZONE ":
 ORIGIN: (0,0,0);
 NORTH AXIS=N;
** WINTER AND SPRING
    INFILTRATION=1, INF-SCH,WITH COEFFICIENTS(5.35,0.0821,0.,0.000000694);
** SUMMER
**   INFILTRATION=1, INF-SCH,WITH COEFFICIENTS(1.54,0,0,0);
** WINTER
**   LIGHTS=0.9898,
** SPRING AND SUMMER
    LIGHTS=0.944,
INT-LDS-SCHD,80 PERCENT RADIANT, 10 PERCENT VISIBLE;
** WINTER AND SPRING
    CONTROLS=THERMOSTAT,14 HEATING;
** SUMMER
**   CONTROLS=THERMOSTAT,10 COOLING;
EXTERIOR WALLS:
    STARTING AT (0,0,0) FACING (S)
    EXT-WALL (L BY H)
    WITH WINDOWS OF TYPE
     WIND1 (WWIDTH BY WHEIGHT) AT (1.38,4.5) REVEAL (0.13)
    WITH WINDOWS OF TYPE
     WIND2 (WWIDTH BY WHEIGHT) AT (1.38,2.8) REVEAL (0.13)
    WITH DOORS OF TYPE
     WFRAME (3.9 BY 1) AT (10,0) REVEAL (0.13)
     WITH OVERHANGS (L BY 2.5) AT (0,H),
    STARTING AT (L,0,0) FACING (E)
    EXT-WALL (L BY H)
      WITH DOORS OF TYPE
      BLDG-DOOR (2.96,6.6) AT (16.0,0) REVEAL (0.13),
    STARTING AT (L,L,0) FACING (N)
    EXT-WALL (L BY H)
      WITH WINDOWS OF TYPE
      WIND1 (WWIDTH BY WHEIGHT) AT (1.38,4.5) REVEAL (0.13)
    WITH WINDOWS OF TYPE
     WIND2 (WWIDTH BY WHEIGHT) AT (1.38,2.8) REVEAL (0.13)
    WITH DOORS OF TYPE
     WFRAME (3.9 BY 1) AT (10,0) REVEAL (0.13)
     WITH OVERHANGS (L BY 2.5) AT (0,H),
    STARTING AT (0,L,0) FACING (W)
    EXT-WALL (L BY H);
INTERZONE CEILING:
    STARTING AT (0,0,H) FACING (S) TILTED (0)
    INS-CEIL (L BY 20.25) ADJACENT TO ZONE (2),
```

```
    STARTING AT (0,20.25,H) FACING (S) TILTED (0)
    STUD-CEIL (L BY 2.25) ADJACENT TO ZONE (2);
SLAB ON GRADE FLOOR:
    STARTING AT (0,L,0) FACING (S)
    BLDG-FLOOR (L BY L);
INTERNAL MASS:
    Z1MASS (10 BY 11.8),
    Z2MASS (10 BY 13.7);
END;
ZONE 2 " ATTIC ":
  ORIGIN: (0,-2.5,H);
  NORTH AXIS= N;
  INFILTRATION = 35.0,
   INF-SCH, WITH COEFFICIENTS(1.0,0.,0.,0.);
EXTERIOR WALLS:
    STARTING AT (L,0,0) FACING (E)
    ATTIC-WALL ((24.74,0),(12.37,5.917)),
    STARTING AT (0,24.74,0) FACING (W)
    ATTIC-WALL ((24.74,0),(12.37,5.917)),
    STARTING AT (0,0,0) FACING (S) TILTED (-90)
    ATTIC-WALL (L BY 2.37),
    STARTING AT (L,24.74,0) FACING (N) TILTED (-90)
    ATTIC-WALL (L BY 2.37);
ROOF:
    STARTING AT (0,0,0) FACING (S) TILTED (25)
    BLDG-ROOF (L BY 13.65),
    STARTING AT (L,24.74,0) FACING (N) TILTED (25)
    BLDG-ROOF (L BY 13.65);
INTERZONE FLOOR:
    STARTING AT (0,22.62,0) FACING (S)
    ATTIC-FLOOR-INS (L BY 20.25) ADJACENT TO ZONE (1),
    STARTING AT (0,24.87,0) FACING (S)
    ATTIC-FLOOR-STUD (L BY 2.25) ADJACENT TO ZONE (1);
END;
END BUILDING DESCRIPTION;
```

APPENDIX 3: DISCUSSION ON THE AIR TEMPERATURE MEASUREMENTS OF NEW MEXICO TEST CELLS

The purpose of this note is to support the assumptions used in the BLAST simulations for the New Mexico experimental test cells. In the BLAST simulations, the single zone representation of the cells has been used rather than the two-zone model which includes the plenum at the center of each test cell as a separate zone.

In general, air temperature in actual buildings or rooms is stratified such that there is a stagnant air layer at the core which is at a uniform (constant) temperature and a region close to the boundaries in which the sudden changes in temperature occur [1].‡ This region is called thermal boundary layer.

As mentioned in the New Mexico reports [2,3], the zone air temperatures were measured approximately one foot away from the walls which lies in the well mixed region (uniform temperature region) which is outside the thermal boundary layer. The Refs. [4-6] discuss the development of the thermal boundary layer for simple systems under the turbulent natural convection flow conditions. Because of the fan inside the cells, the air movement induced by the operation of the fan becomes turbulent. Therefore, the information obtained from Refs. [4-6] can be used here to support our decision. The experimental and the theoretical studies mentioned in Refs. [4-6] indicate that the thickness of the thermal boundary layer is about two orders of magnitude smaller than the distance between the top and bottom surfaces [4]. The thickness of the boundary layer is inversely proportional to the Rayleigh number in convective flows but independent of the surface separation distance [6]. In the most recent work by Kaviany and Seban [5], the Prandtl number dependence is also included in the calculation of the thermal boundary layer thickness. The following expression predicts the boundary layer thickness to within 11 percent of the detailed calculations [5].

‡ Numbers in brackets indicate references cited at the end of this Appendix.

$$\frac{\delta}{L} = \left(\frac{17}{Ra_L}\right)^{\frac{1}{3}} Pr^{0.22} \tag{A1}$$

where δ is the thermal boundary layer thickness, L is the distance between the hot and cold surfaces, Ra_L is the Rayleigh number based on the separation distance, L and Pr is the Prandtl number. For Pr $=$ 0.71 and $Ra_L = 10^7$, the detailed calculation yields $\delta = 0.0127L$ [5]. The corresponding values recommended by Chang [7] and Kraichnan [8] are 0.0186L and 0.0345L, respectively.

In general, the heat transfer in buildings has a three dimensional nature. The studies on the three-dimensional analyses have shown that the two-dimensional studies predict reasonably well the boundary layer development [9,10]. Therefore, Eq. (A1), which is developed from the two-dimensional study, predicts the thickness of the thermal layer reasonably well under the turbulent conditions.

For the New Mexico test cell measurements we will show that the thermocouples are placed outside the thermal boundary layer. For this demonstration, the air properties are taken at 27 ° C.

$$\nu = 15.89 \times 10^{-6}\ m^2/s\,,\ \alpha = 22.5 \times 10^{-6}\ m^2/s \quad \text{and} \quad Pr = 0.707,$$

where ν is the kinematic viscosity, α the thermal diffusivity, and Pr is the Prandtl number for air under conditions in the test cells. The temperature difference between the hot and cold surfaces are assumed to be 5 ° C. Therefore, the Rayleigh number for the test cells is:

$$Ra_L = \frac{g\beta\Delta TL^3}{\nu\alpha} = \frac{9.8m/s^2 \cdot \frac{1}{300K} \cdot 5K \cdot L^3}{15.89 \times 10^{-6}\ m^2/s \cdot 22.5 \times 10^{-6} m^2/s}$$

$$Ra_L = 4.677 \times 10^8\, L^3 \tag{A2}$$

where g is the acceleration due to gravity, β is the inverse absolute temperature, and L is in meters. From Eq. (A1), it is found that the boundary layer thickness is independent of

L which is equal to:

$$\delta = 0.00307\ m\ = 0.01\ ft\ = 0.12\ in \tag{A3}$$

If we use the recommended values of Ref. [8], which yields thicker boundary layer than the recommendation of Ref. [7], by assuming the maximum separation distance as the height of the test cell, i.e.,7½ ft;

$$\delta = 0.0345L\ = 0.0345 \cdot 7½\ ft\ = 0.259\ ft\ = 3.1\ in \tag{A4}$$

Note that Eq. (A4) is valid for $Ra\ = 10^7$, for our case, the boundary layer thickness will be less than the value predicted by Eq. (A4), because the Rayleigh number for the test cells is greater than 10^7.

From the above calculations, it is seen that the thermal boundary layer thickness is much less than one foot. Therefore, we can conclude that the measurements in the New Mexico test cells were taken outside the boundary layer, i.e., within the well mixed region. Hence we should expect that all thermocouple readings should give the same result within the precision of the instrument. In the experimental data, the measurements vary quite a lot. We conclude on the basis of the arguments above that this measured variation must be caused by something other than variations in the actual air temperature.

REFERENCES

1. K. Ruberg, "Heat Distribution by Natural Convection: A Modelling Procedure for Enclosed Spaces," Master of Architecture Thesis, Massachusetts Institute of Technology, Sept. 1978.

2. J. Gustinis and D. K. Robertson, "Southwest Thermal Mass Study Tesuque Pueblo, New Mexico, Construction and Instrumentation Phase," New Mexico Energy Research and Development Institute Report, Oct. 1981.

3. J. Gustinis and D. K. Robertson, "Southwest Thermal Mass Study Tesuque Pueblo, New Mexico, The Effect of Envelope Thermal Mass on the Heating Energy Use of Eight Test Buildings in a High Desert Climate," New Mexico Energy Research and Development Institute Report, Apr. 1984.

4. H. Tanaka and H. Miyata, "Turbulent Natural Convection in a Horizontal Water Layer Heated From Below," Int. J. Heat Mass Transfer, **23**, pp. 1273-1281, 1980.

5. M. Kaviany and R. Seban, "Analysis of Turbulent Thermal Convection Between Horizontal Plates," J. Heat Transfer, **105**, pp. 789-794, 1983.

6. E. F. C. Somerscales and I. W. Gazda, "Thermal Convection in High Prandtl Number Liquids at High Rayleigh Numbers, Int. J. Heat Mass Transfer, **12**, pp. 1491-1511, 1969.

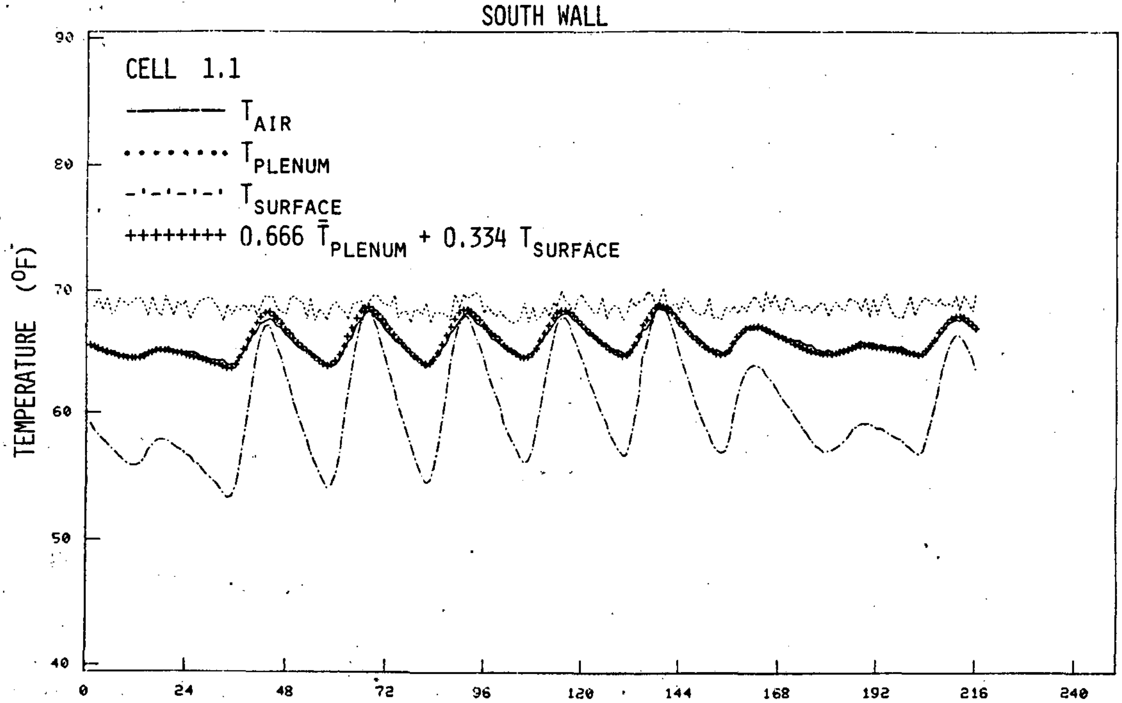
7. Y. P. Chang, "A Theoretical Analysis of Heat Transfer in Natural Convection and in Boiling, ASME Transactions, pp. 1501-1513, 1957.

8. R. A. Kraichnan, "Turbulent Thermal Convection at Arbitrary Prandtl Number," The Physics of Fluids, **5**, pp. 1374-1389, 1962.

9. H. Ozoe, M. Ohmura, A. Mouri, S. Mishima, H. Sayama and S. W. Churchill, "Laser-Doppler Measurements of the Velocity Along a Heated Wall of a Rectangular Enclosure," J. Heat Transfer, **105**, pp. 782-788, 1983.

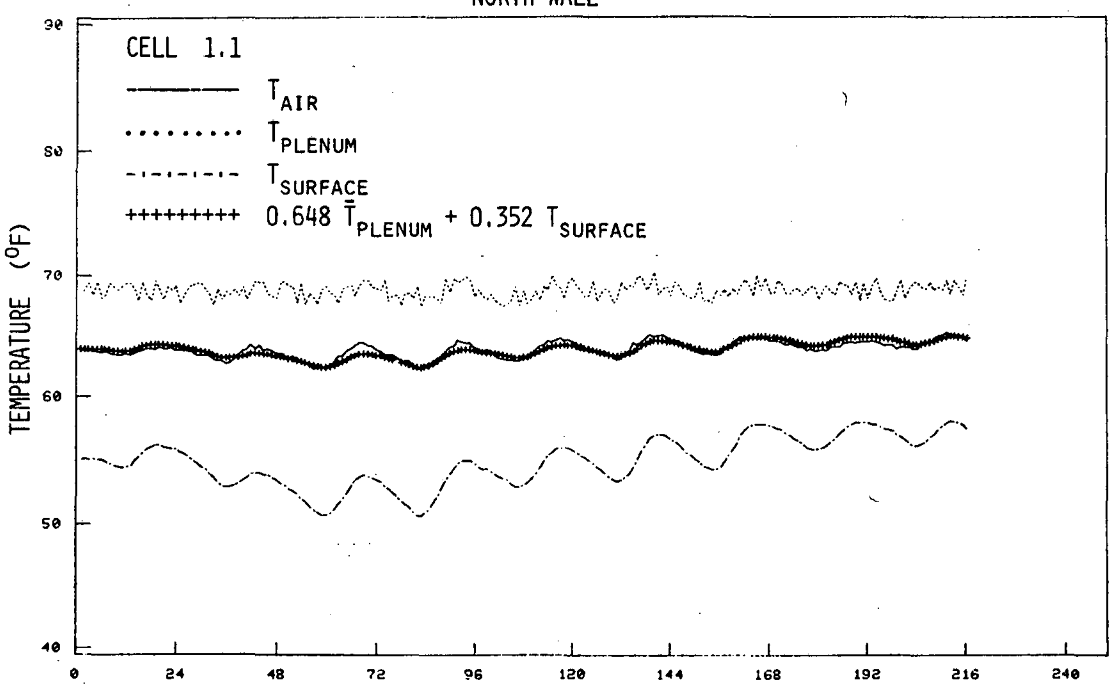
10. M. S. Bohn, A. T. Kirkpatrick, and D. A. Olson, "Experimental Study of Three-Dimensional Natural Convection High-Rayleigh Number," J. Heat Transfer, **106**, pp. 339-345, 1984.

FIGURE 1. N.M.E.R.D.I. SOUTH WALL



ELAPSED HOURS: 01/12/1:00 TO 01/20/24:00

FIGURE 2. N.M.E.R.D.I. NORTH WALL



ELAPSED HOURS: 01/12/1:00 TO 01/20/24:00

FIGURE 3.

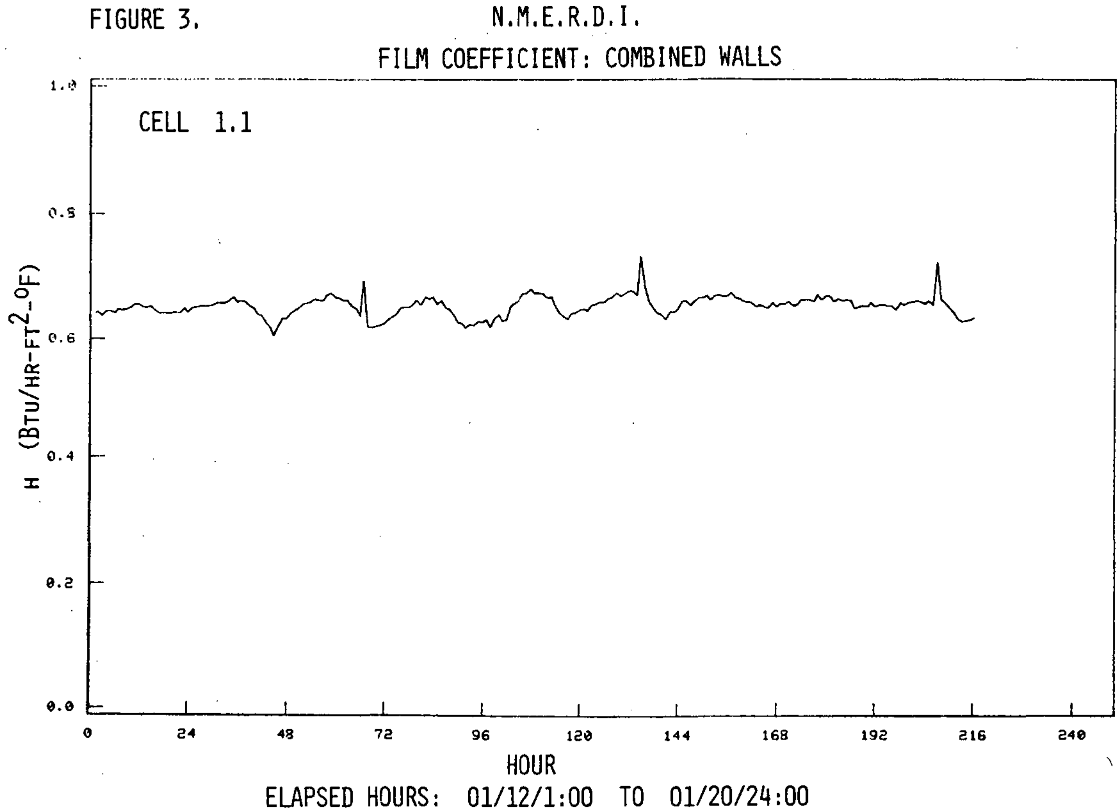


FIGURE 4.

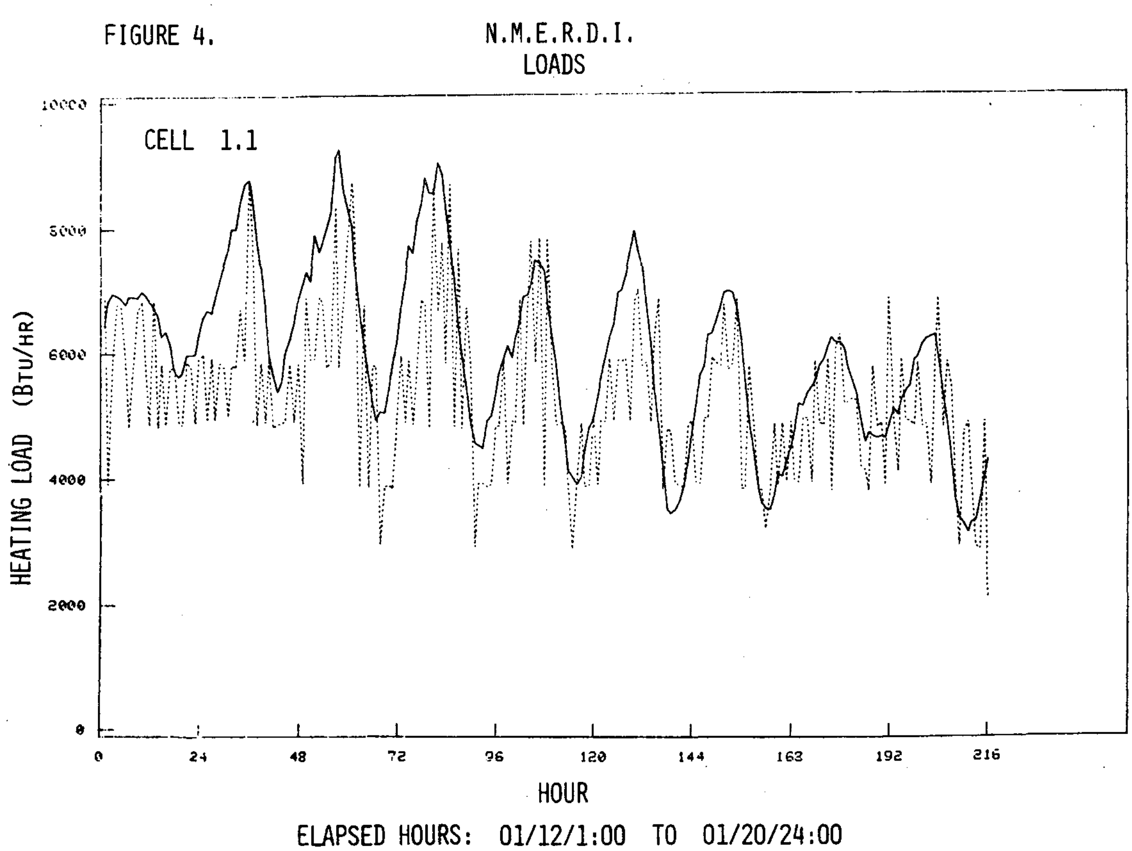
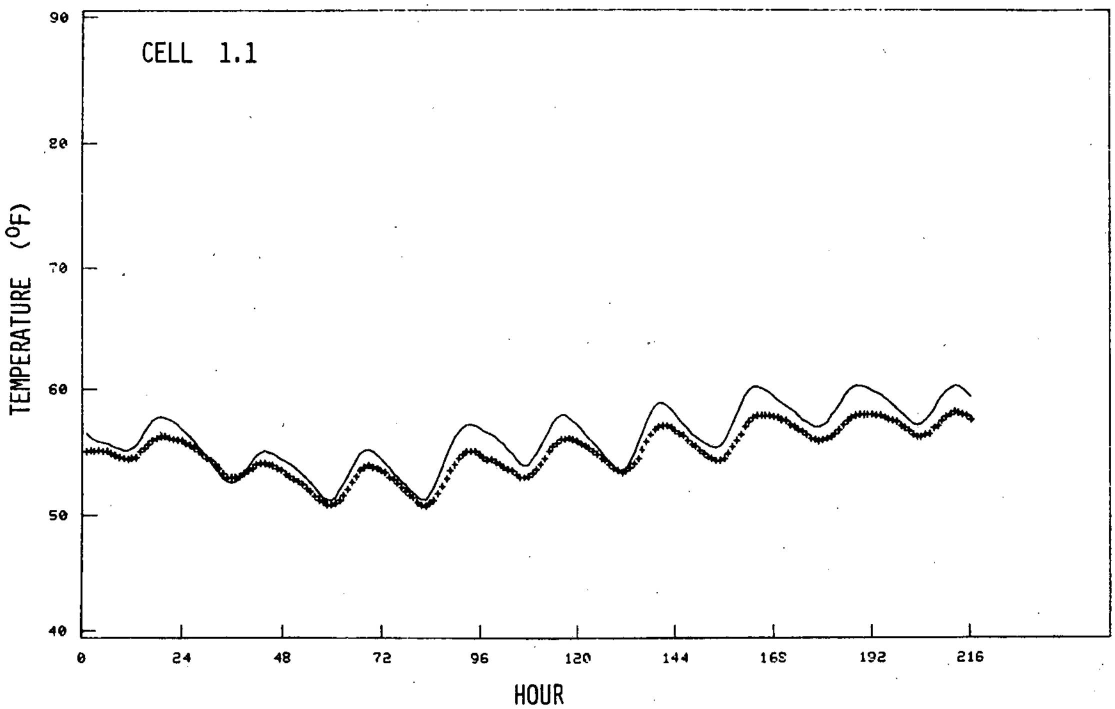


FIGURE 5. N.M.E.R.D.I.

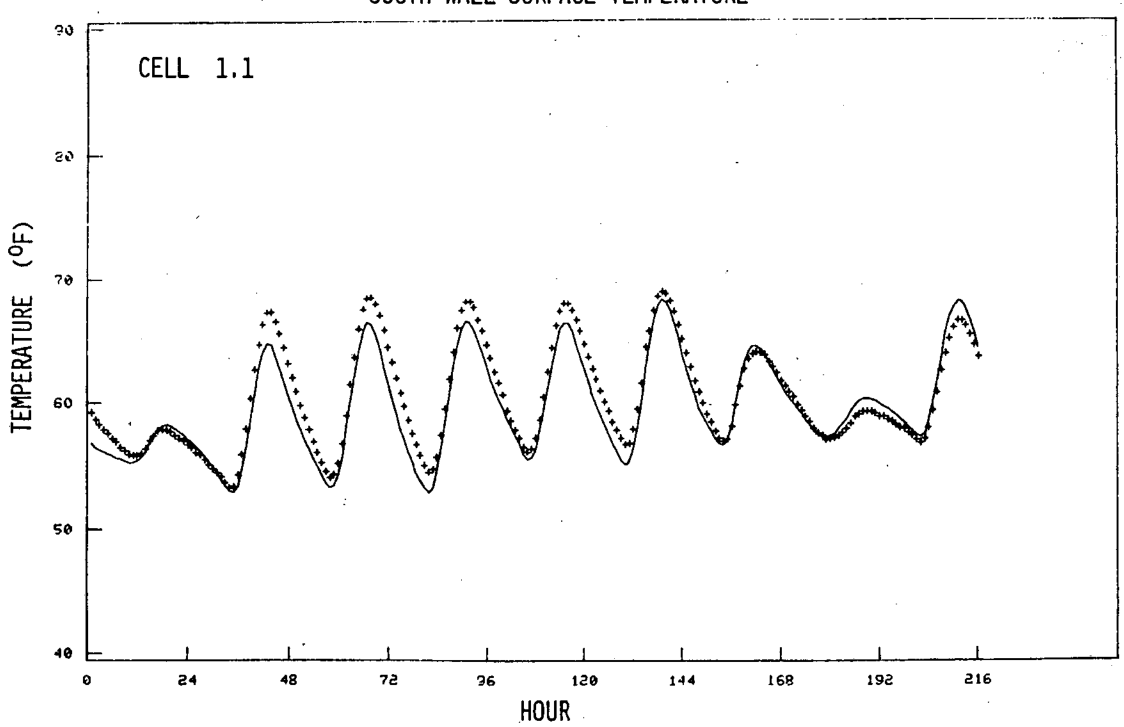
NORTH WALL SURFACE TEMPERATURE



ELAPSED HOURS: 01/12/1:00 TO 01/20/24:00

FIGURE 6. N.M.E.R.D.I.

SOUTH WALL SURFACE TEMPERATURE

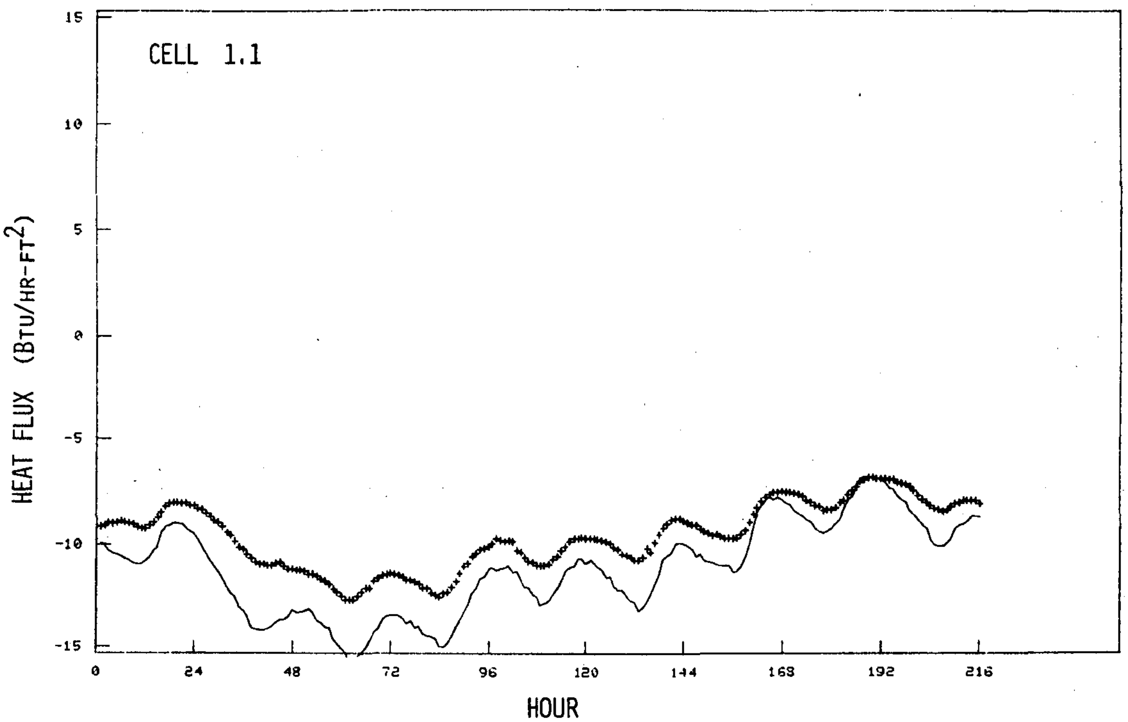


ELAPSED HOURS: 01/12/1:00 TO 01/20/24:00

FIGURE 7.

N.M.E.R.D.I.

NORTH WALL HEAT FLUX

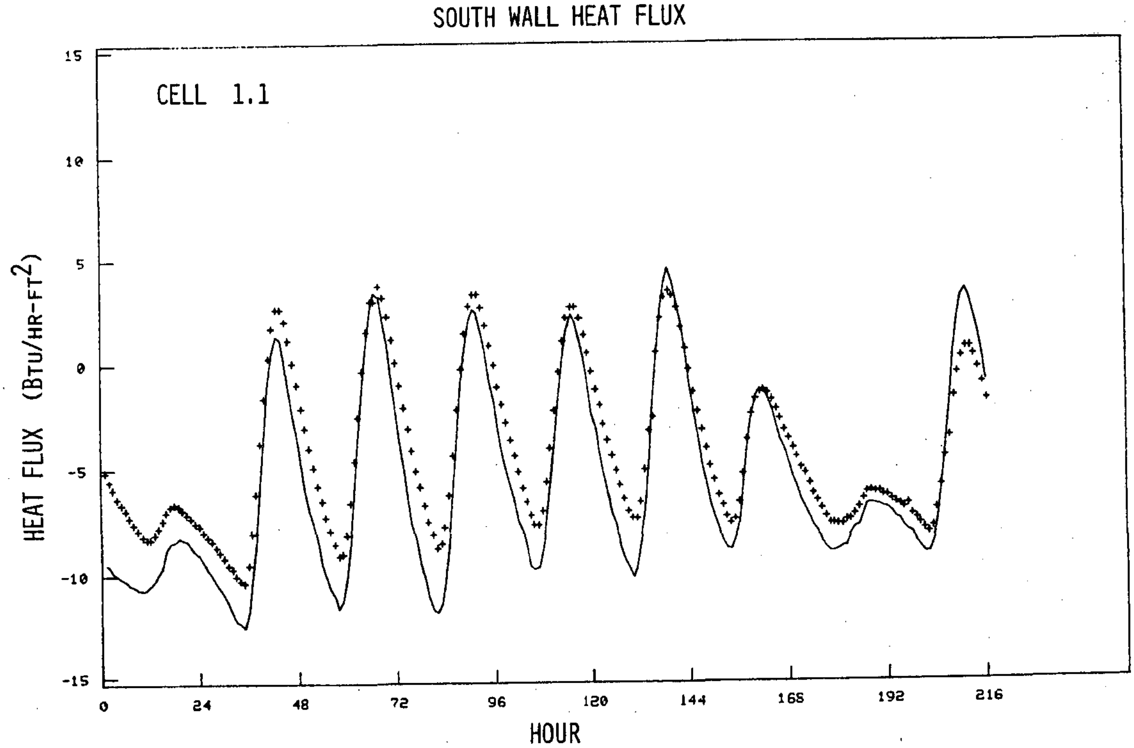


ELAPSED HOURS: 01/12/1:00 TO 01/20/24:00

FIGURE 8.

N.M.E.R.D.I.

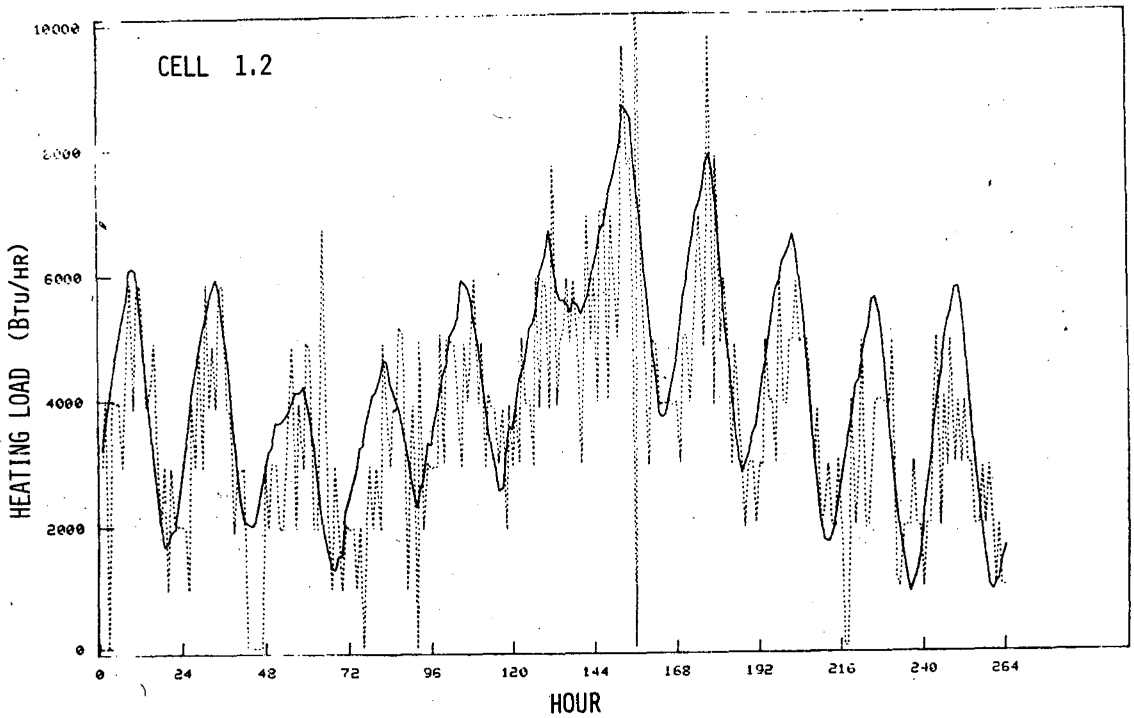
SOUTH WALL HEAT FLUX



ELAPSED HOURS: 01/12/1:00 TO 01/20/24:00

FIGURE 9.

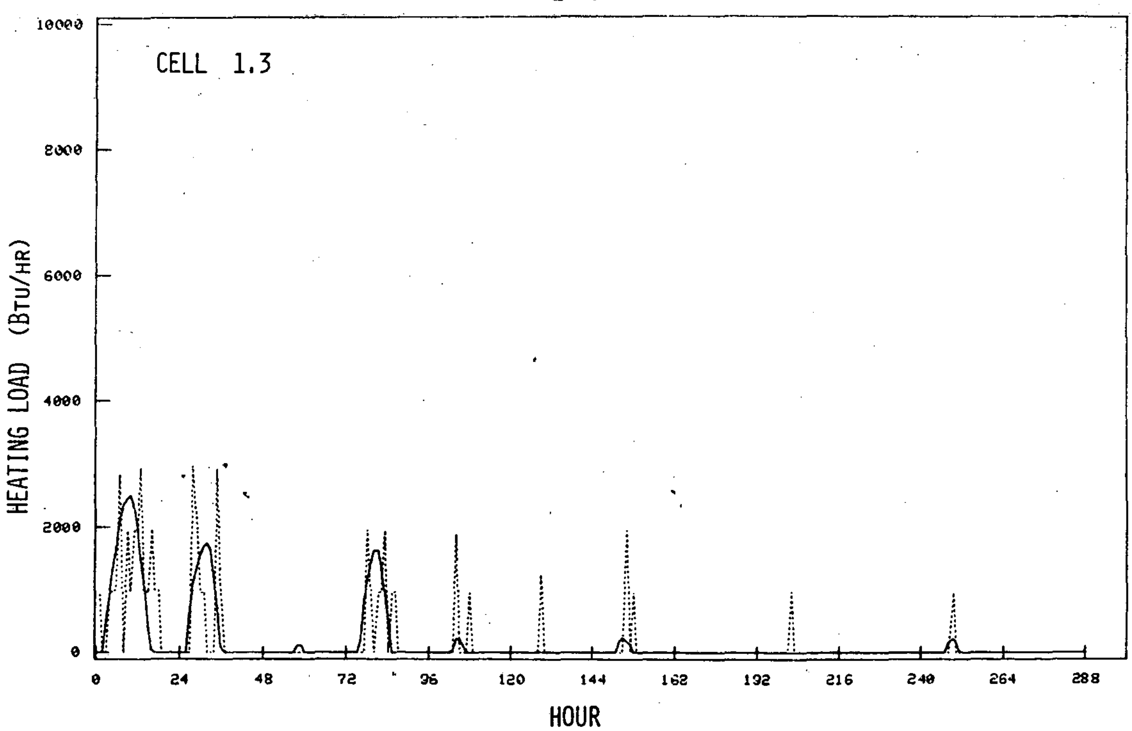
N.M.E.R.D.I.
LOADS



ELAPSED HOURS: 02/28/1:00 TO 03/10/24:00

FIGURE 10.

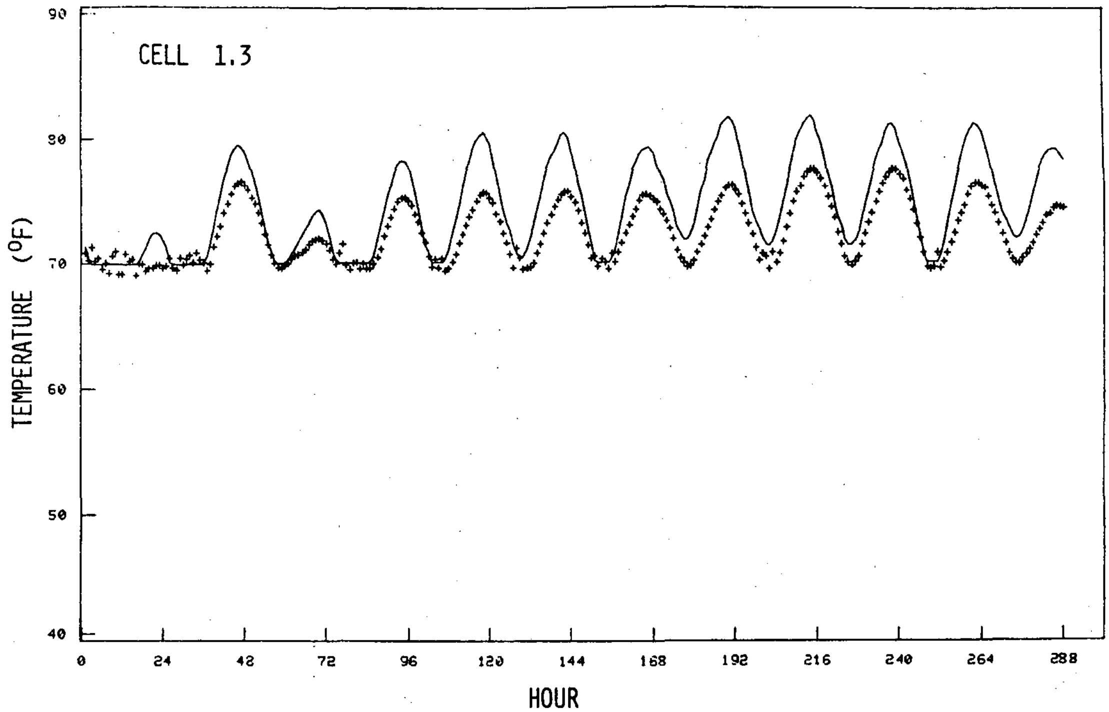
N.M.E.R.D.I.
LOADS



ELAPSED HOURS: 05/25/1:00 TO 06/05/24:00

FIGURE 11.

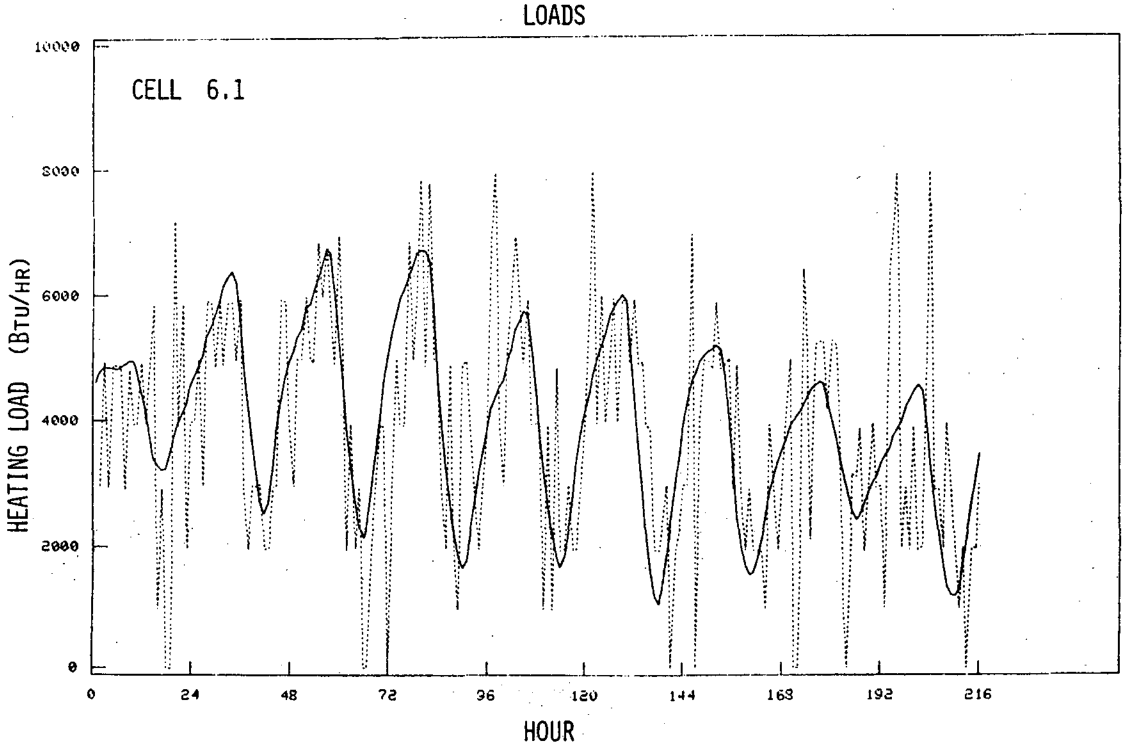
N.M.E.R.D.I.
AIR TEMPERATURE



ELAPSED HOURS: 05/25/1:00 TO 06/05/24:00

FIGURE 12.

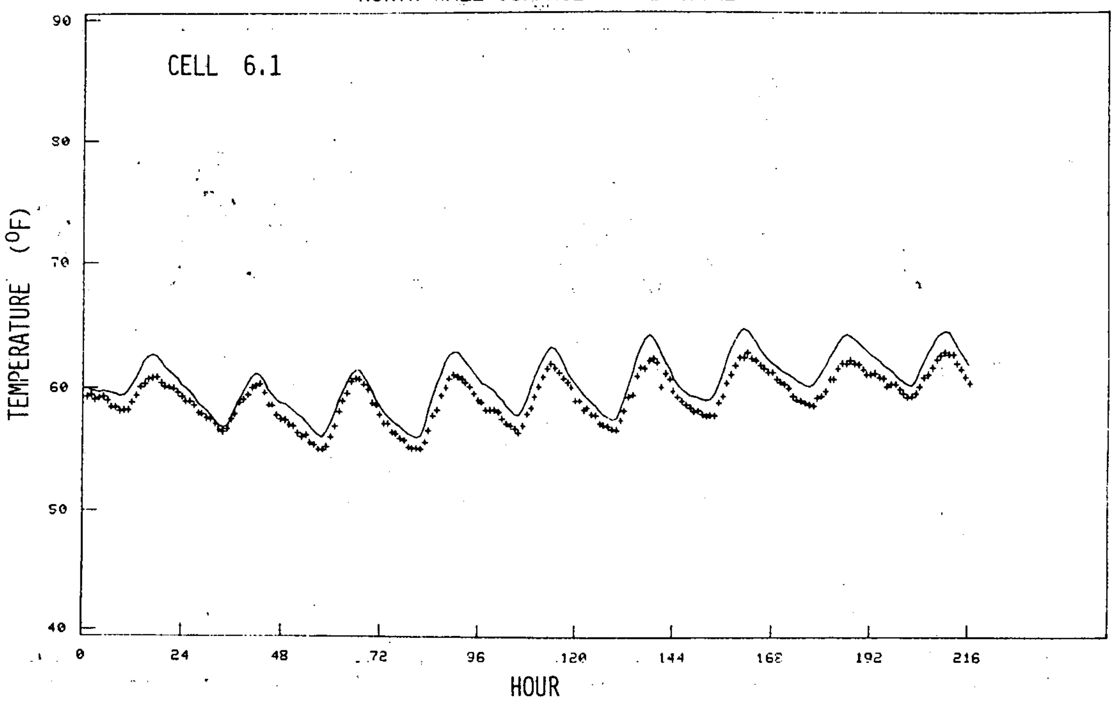
N.M.E.R.D.I.
LOADS



ELAPSED HOURS: 01/12/1:00 TO 01/20/24:00

FIGURE 13. N.M.E.R.D.I.

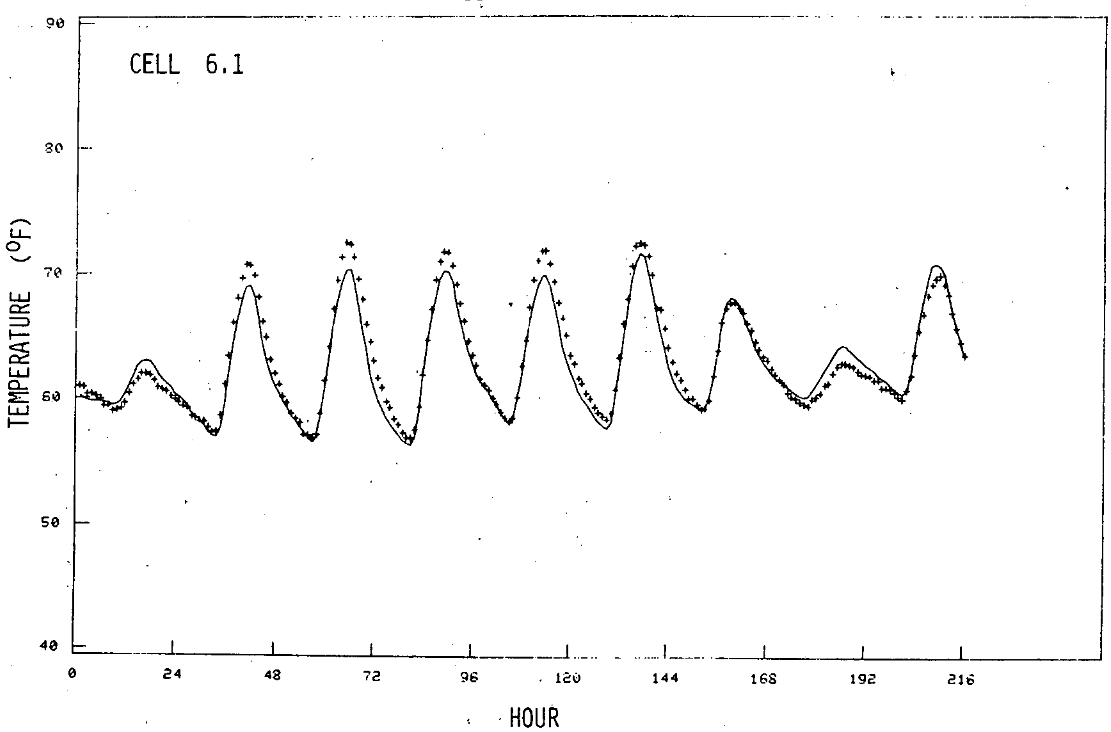
NORTH WALL SURFACE TEMPERATURE



ELAPSED HOURS: 01/12/1:00 TO 01/20/24:00

FIGURE 14. N.M.E.R.D.I.

SOUTH WALL SURFACE TEMPERATURE



ELAPSED HOURS: 01/12/1:00 TO 01/20/24:00

FIGURE 15. N.M.E.R.D.I.

NORTH WALL HEAT FLUX

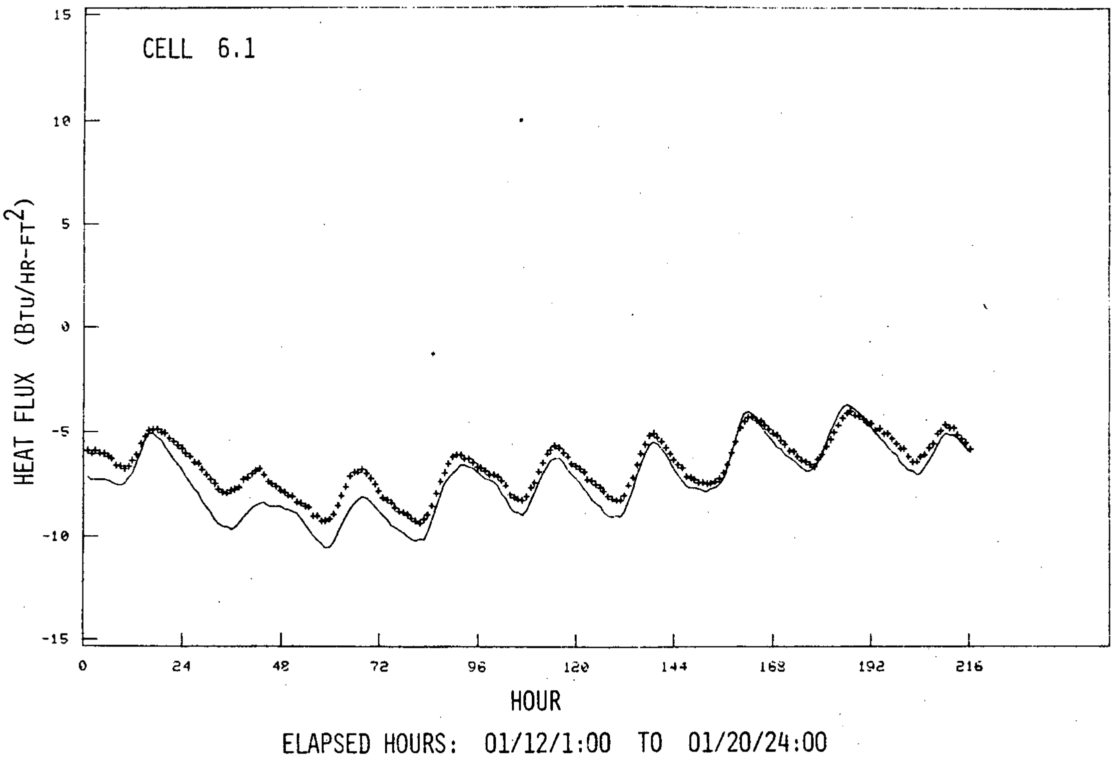


FIGURE 16. N.M.E.R.D.I.

SOUTH WALL HEAT FLUX

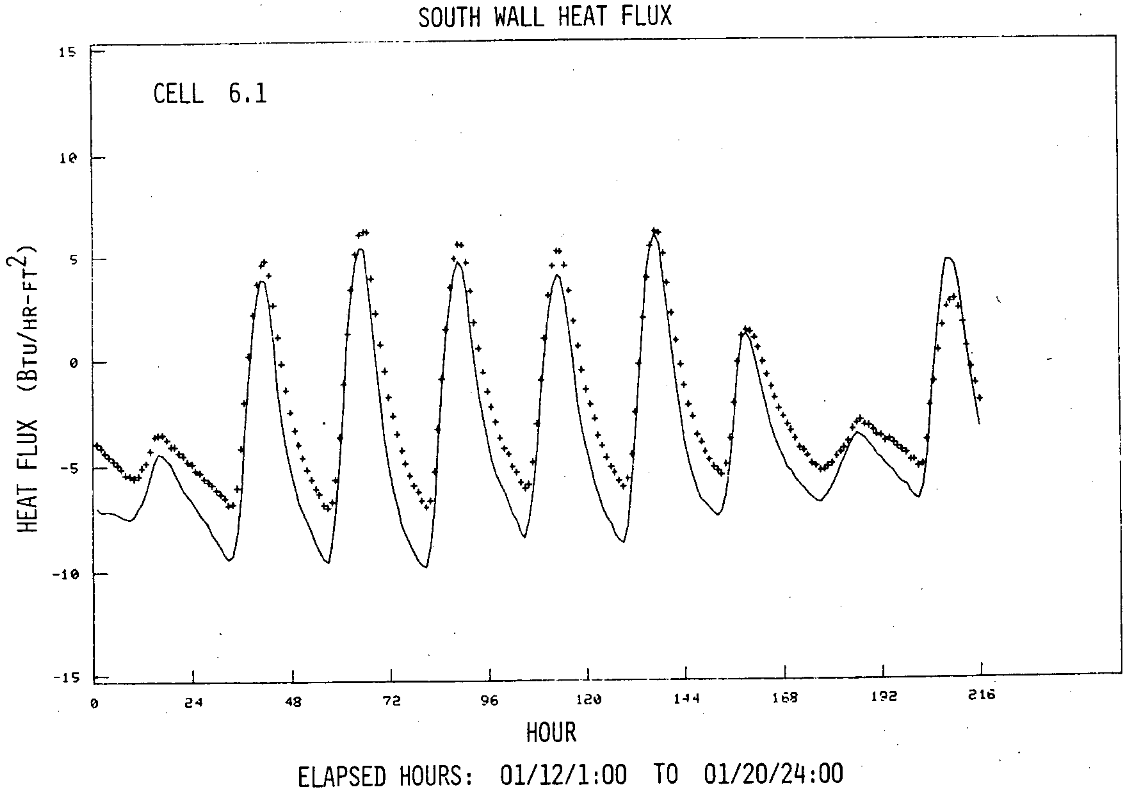


FIGURE 17.

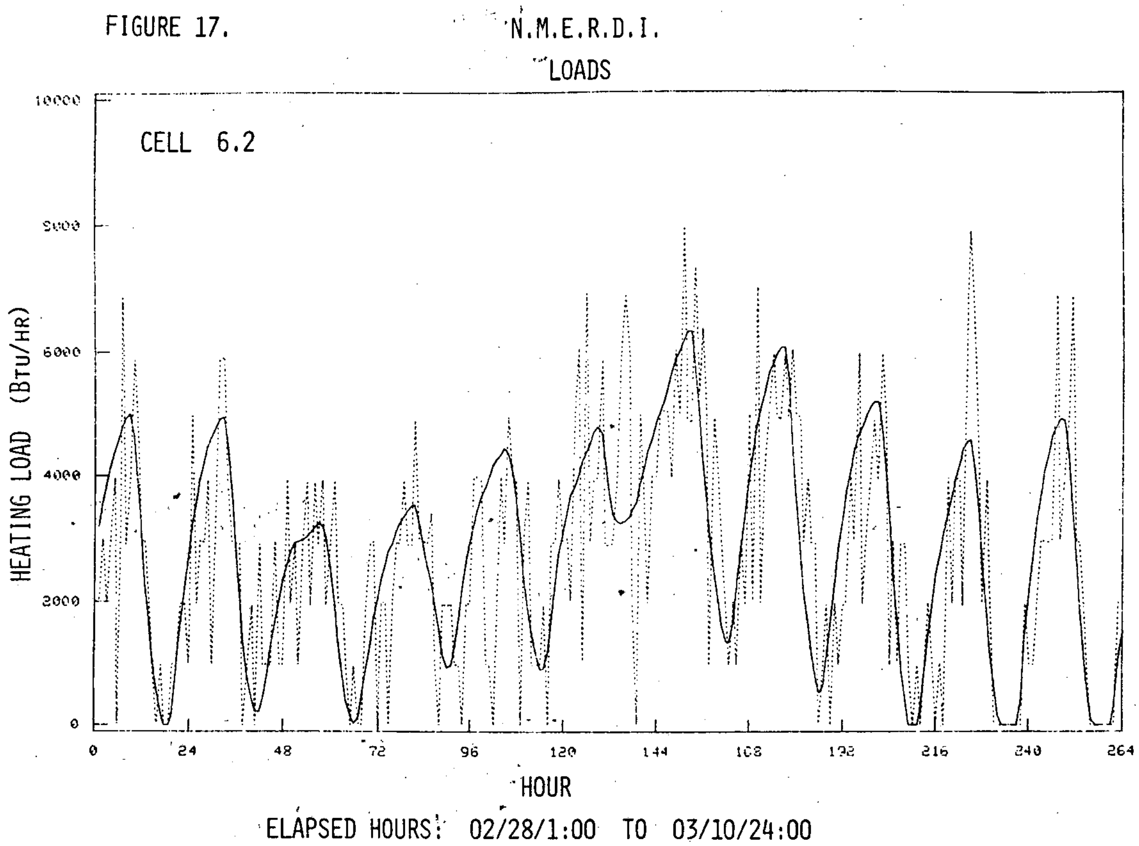


FIGURE 18.

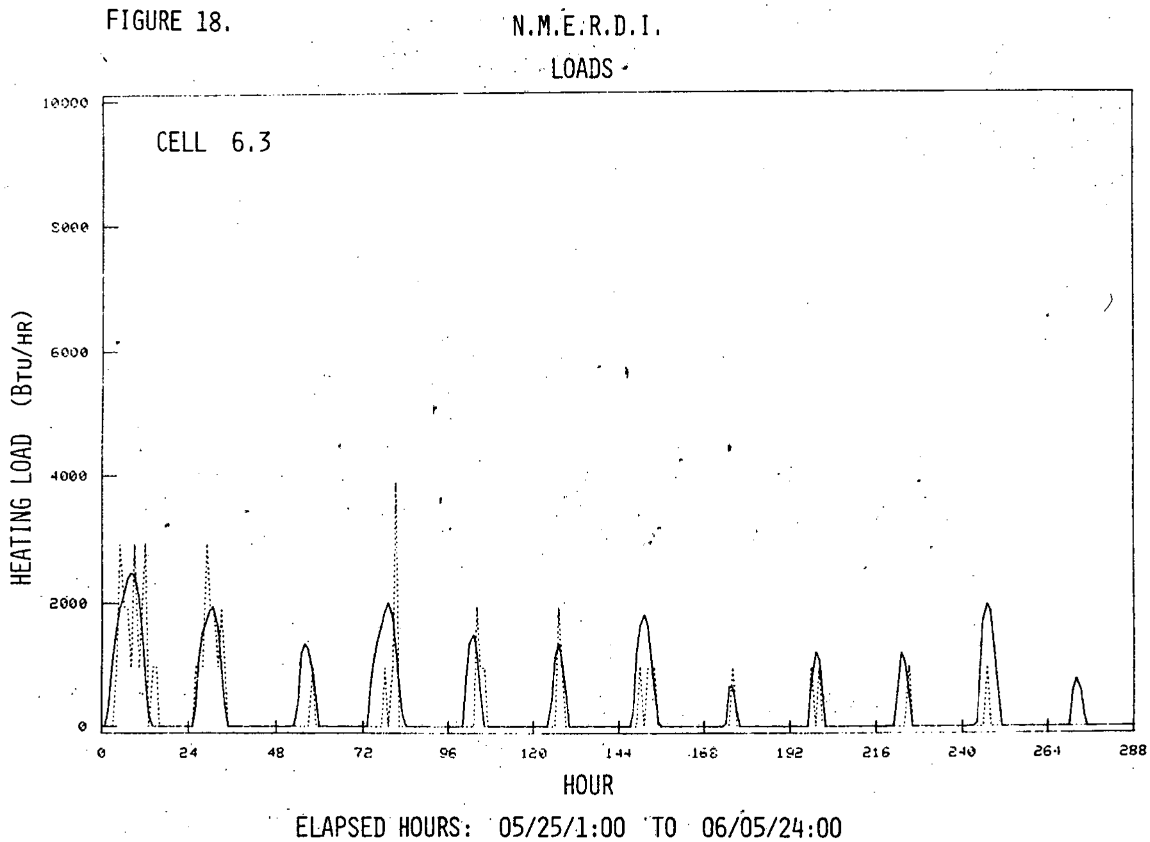
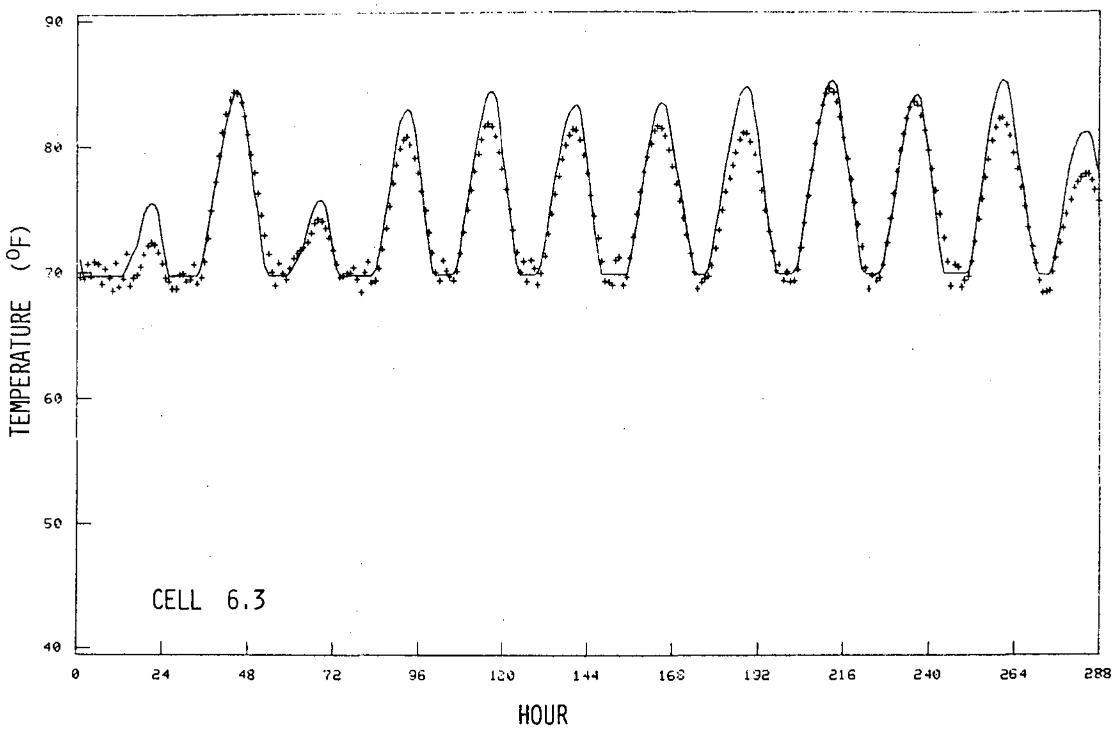


FIGURE 19. N.M.E.R.D.I.

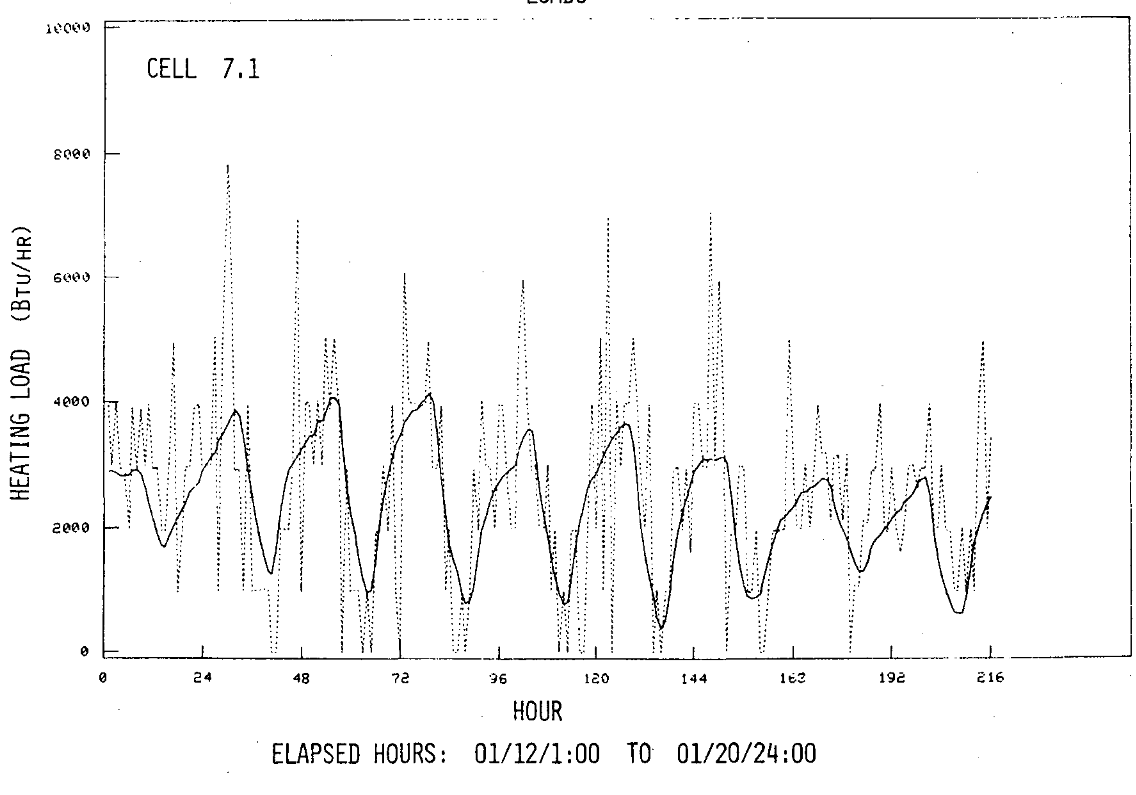
AIR TEMPERATURE



ELAPSED HOURS: 05/25/1:00 TO 06/05/24:00

FIGURE 20. N.M.E.R.D.I.

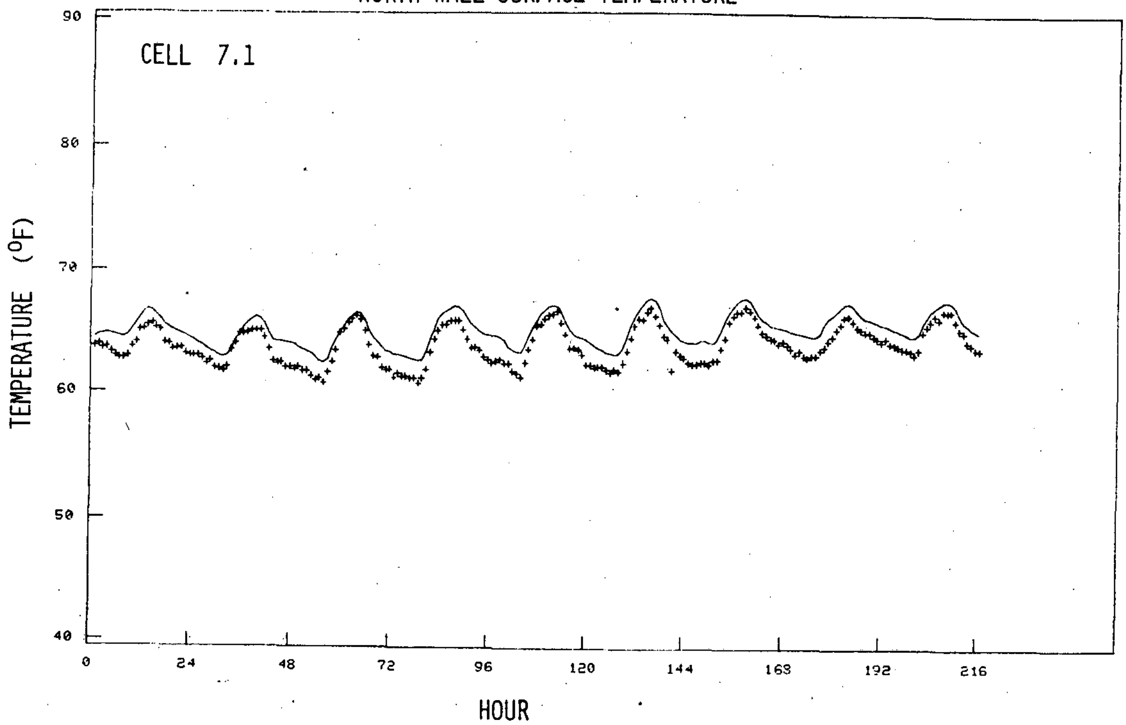
LOADS



ELAPSED HOURS: 01/12/1:00 TO 01/20/24:00

FIGURE 21. N.M.E.R.D.I.

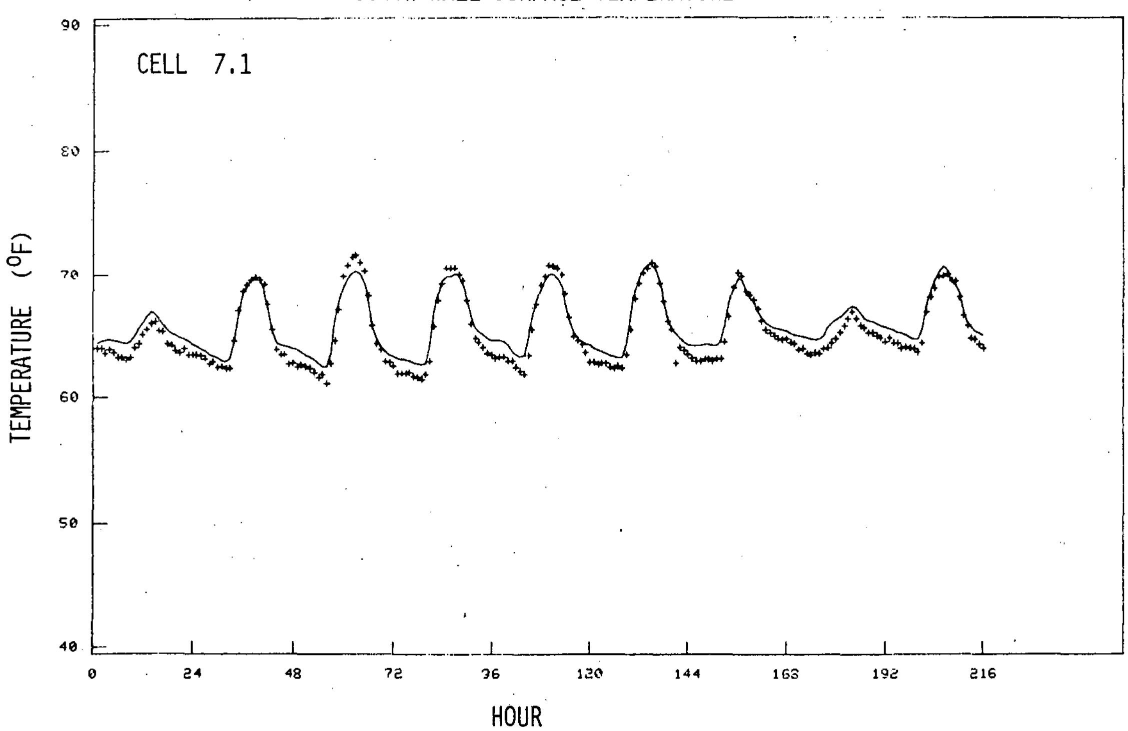
NORTH WALL SURFACE TEMPERATURE



ELAPSED HOUR: 01/12/1:00 TO 01/20/24:00

FIGURE 22. N.M.E.R.D.I.

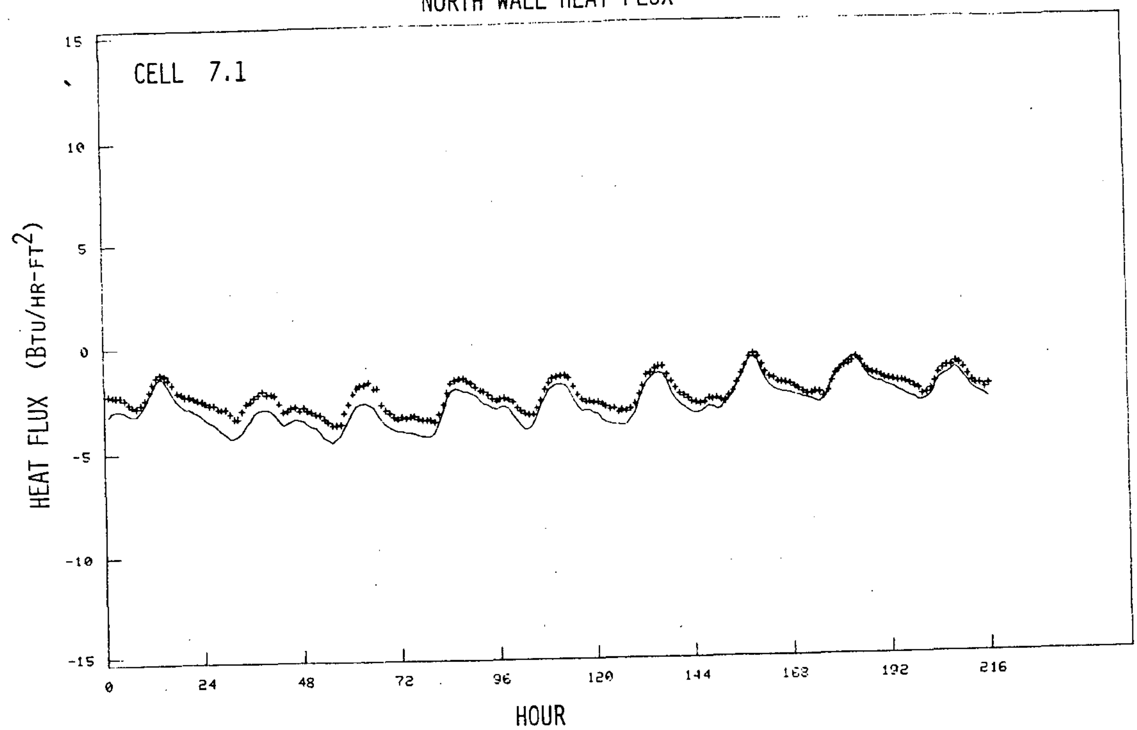
SOUTH WALL SURFACE TEMPERATURE



ELAPSED HOURS: 01/12/1:00 TO 01/20/24:00

FIGURE 23. N.M.E.R.D.I.

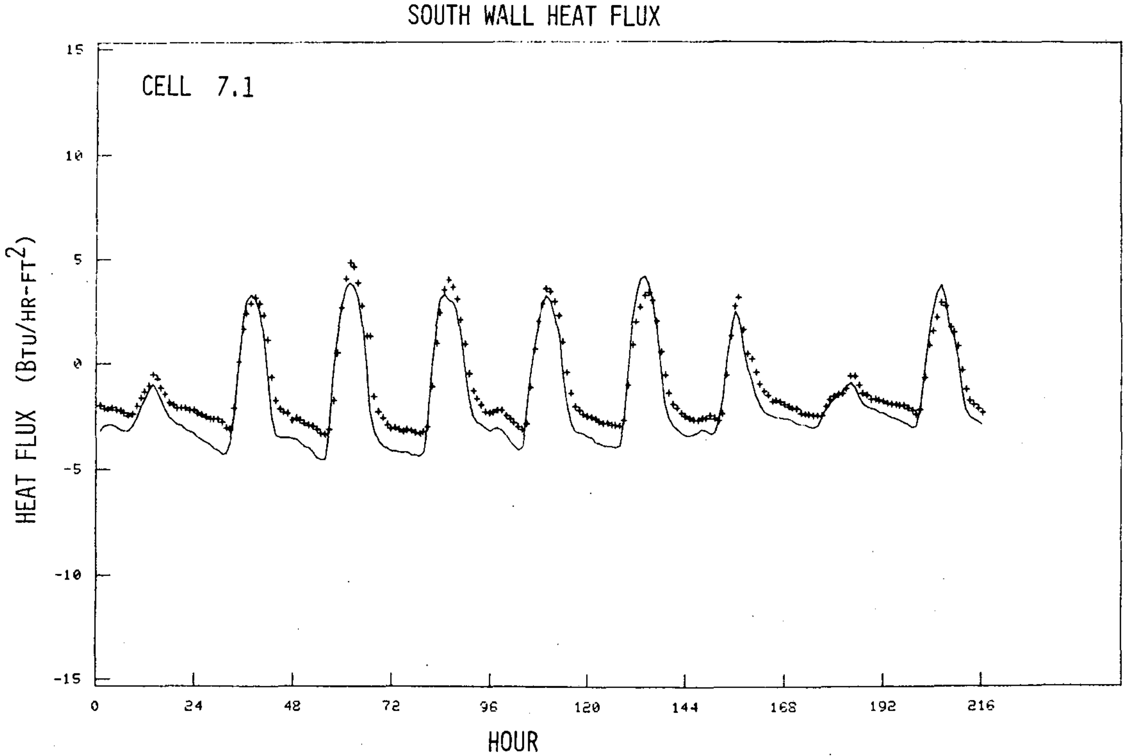
NORTH WALL HEAT FLUX



ELAPSED HOUR: 01/12/1:00 TO 01/20/24:00

FIGURE 24. N.M.E.R.D.I.

SOUTH WALL HEAT FLUX

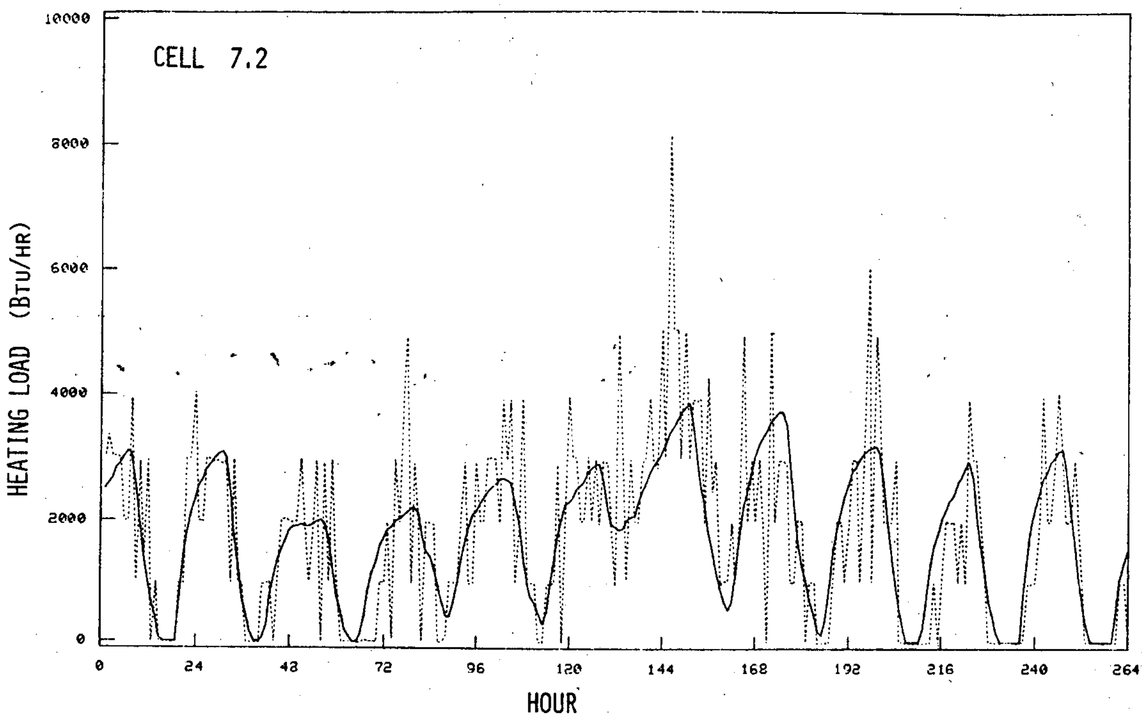


ELAPSED HOUR: 01/12/1:00 TO 01/20/24:00

FIGURE 25.

N.M.E.R.D.I.

LOADS

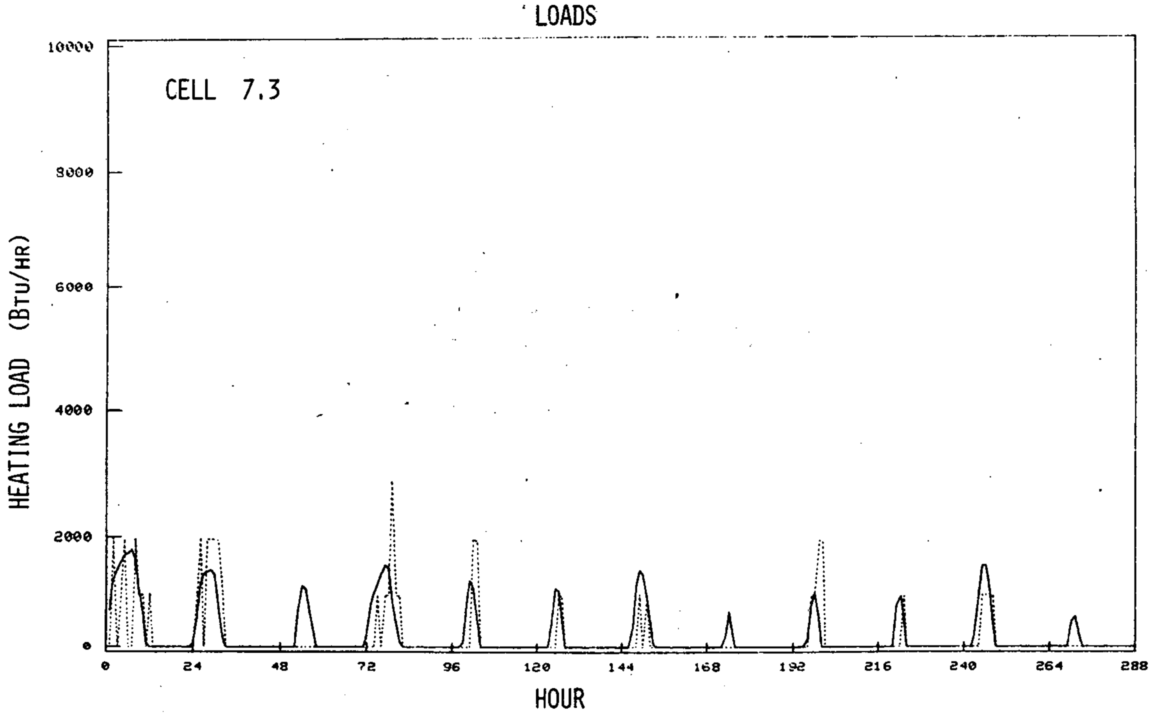


ELAPSED HOURS: 02/28/1:00 TO 03/10/24:00

FIGURE 26.

N.M.E.R.D.I.

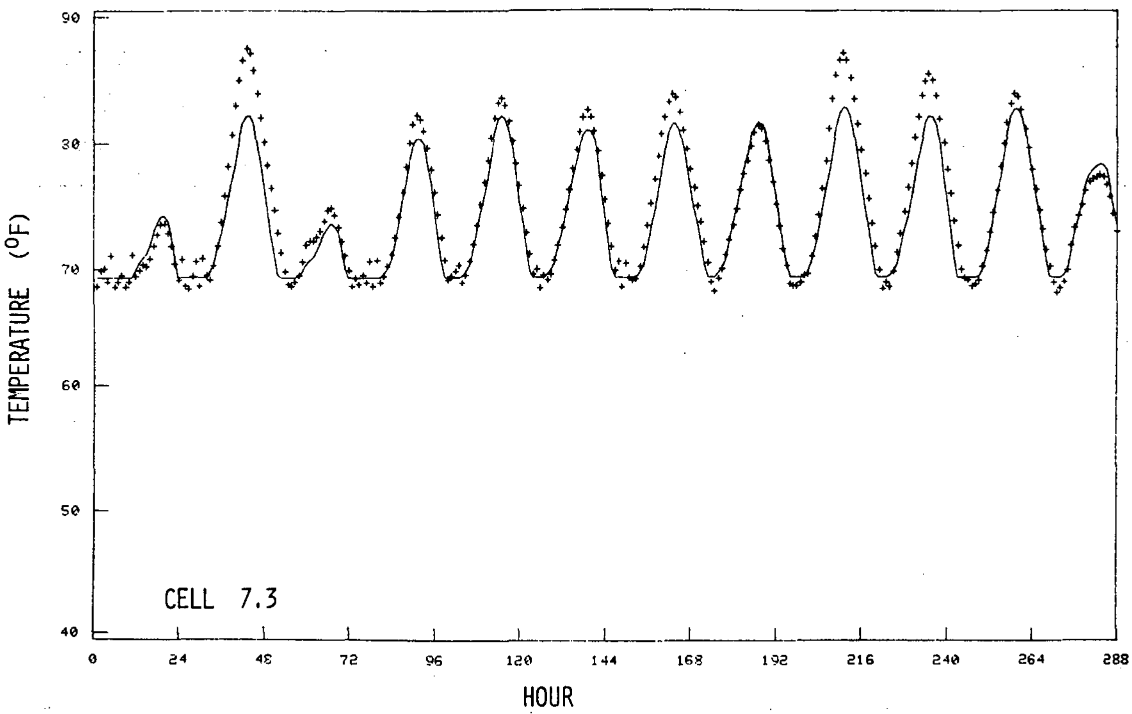
LOADS



ELAPSED HOURS: 05/25/1:00 TO 06/05/24:00

FIGURE 27. N.M.E.R.D.I.

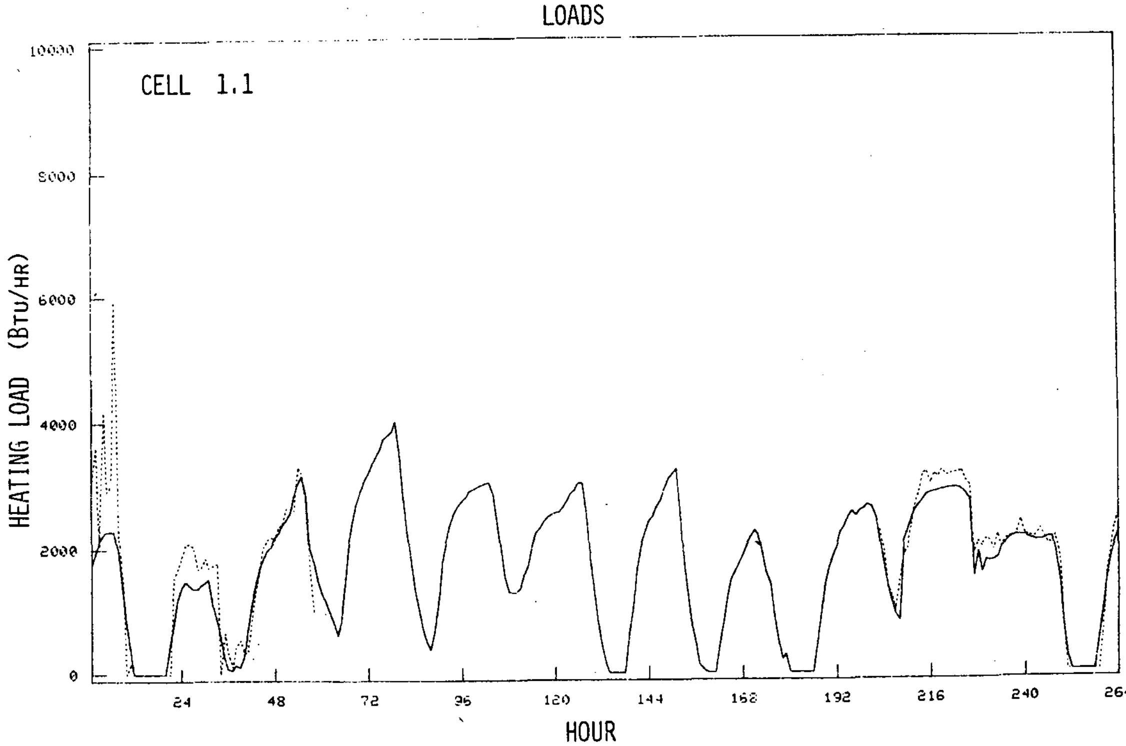
AIR TEMPERATURE



ELAPSED HOURS: 05/25/1:00 TO 06/05/24:00

FIGURE 28. N.B.S.

LOADS



ELAPSED HOURS: 02/23/1:00 TO 03/05/24:00

FIGURE 29.

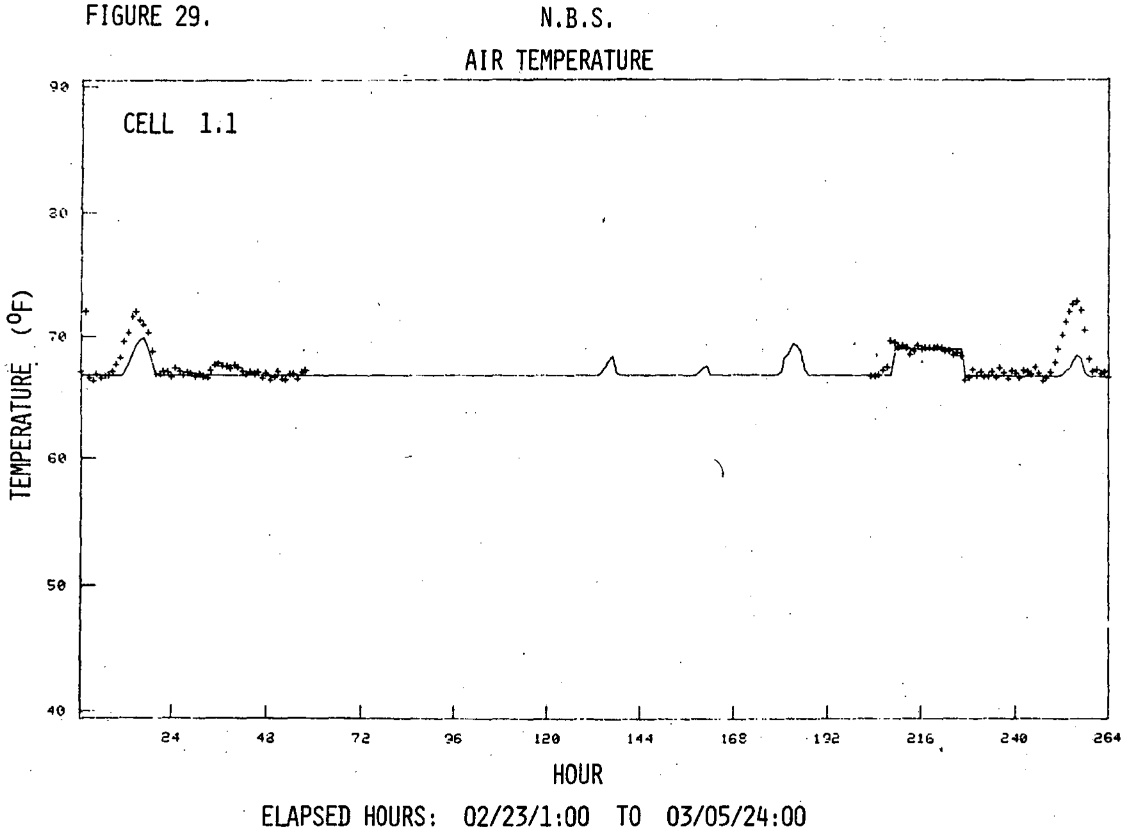


FIGURE 30.

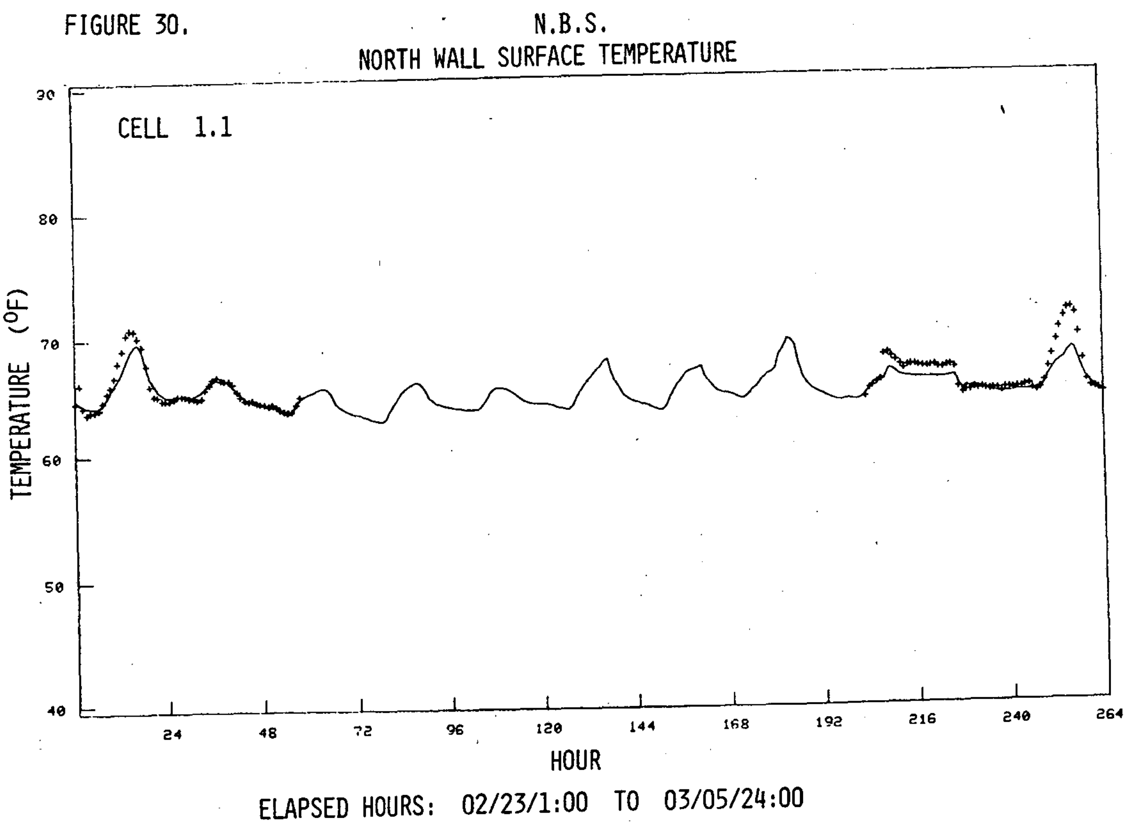


FIGURE 31. N.B.S.
SOUTH WALL SURFACE TEMPERATURE

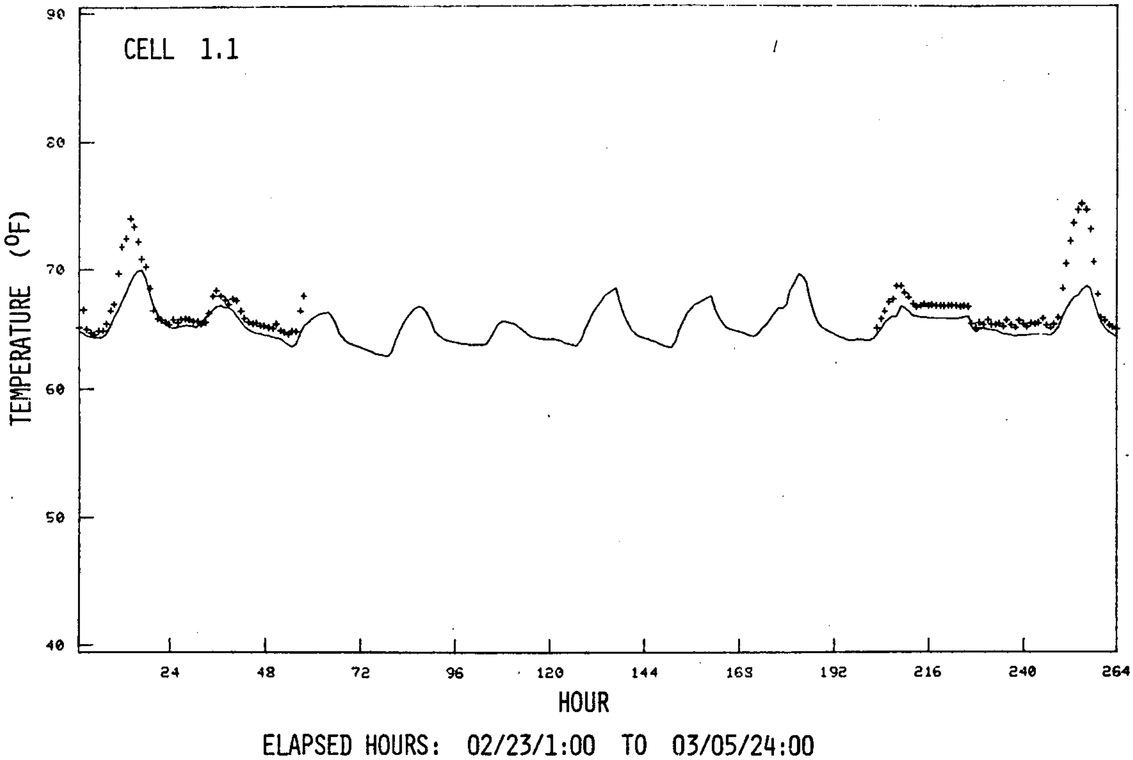


FIGURE 32. N.B.S.
NORTH WALL HEAT FLUX

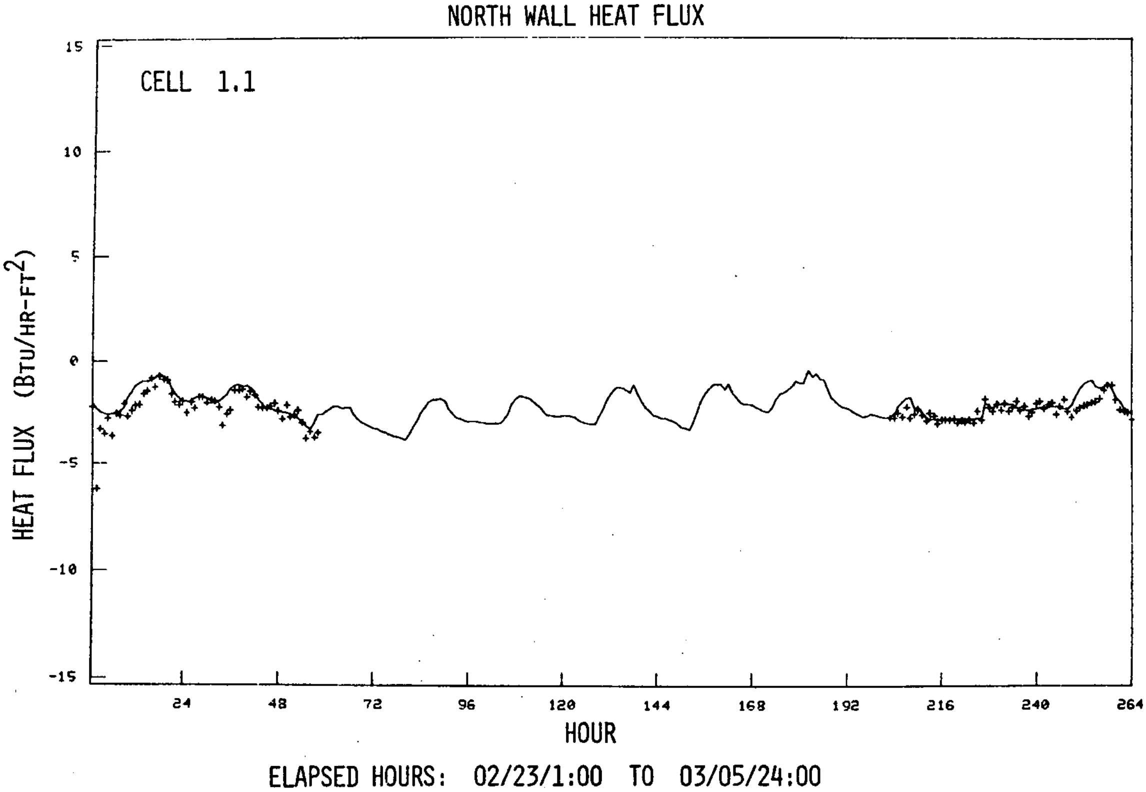


FIGURE 33.

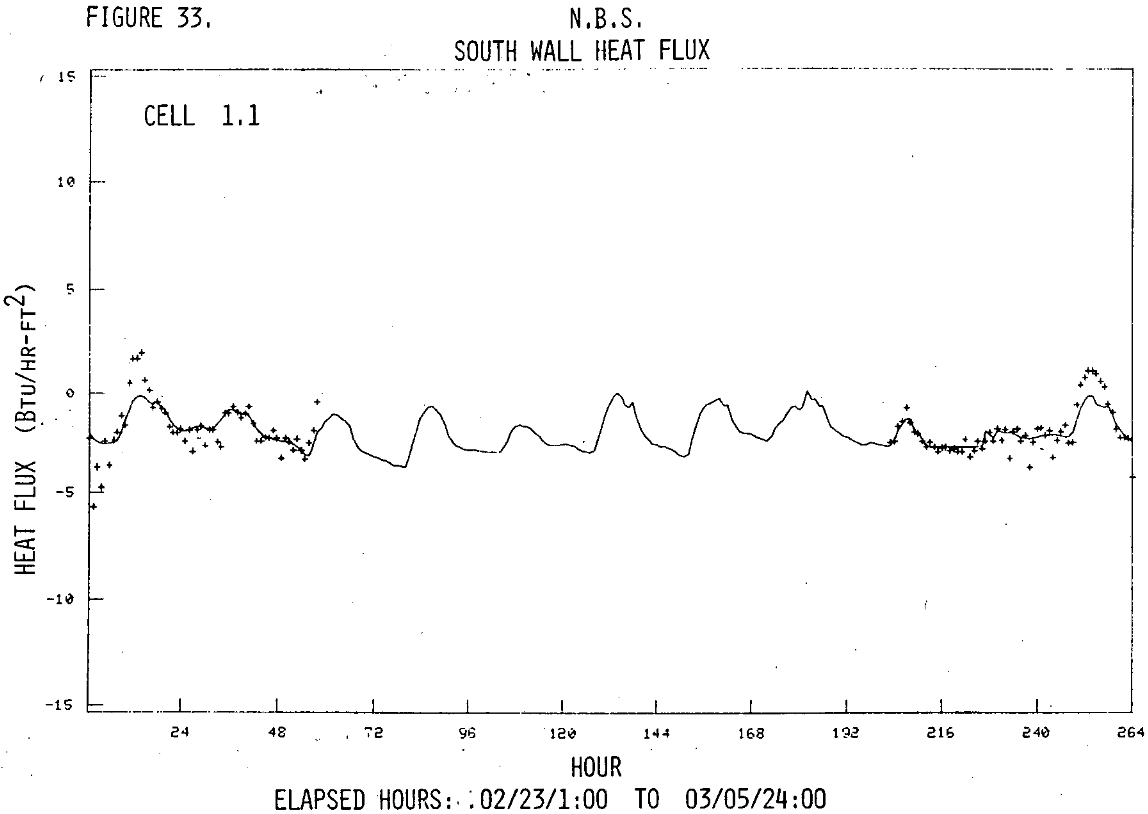


FIGURE 34.

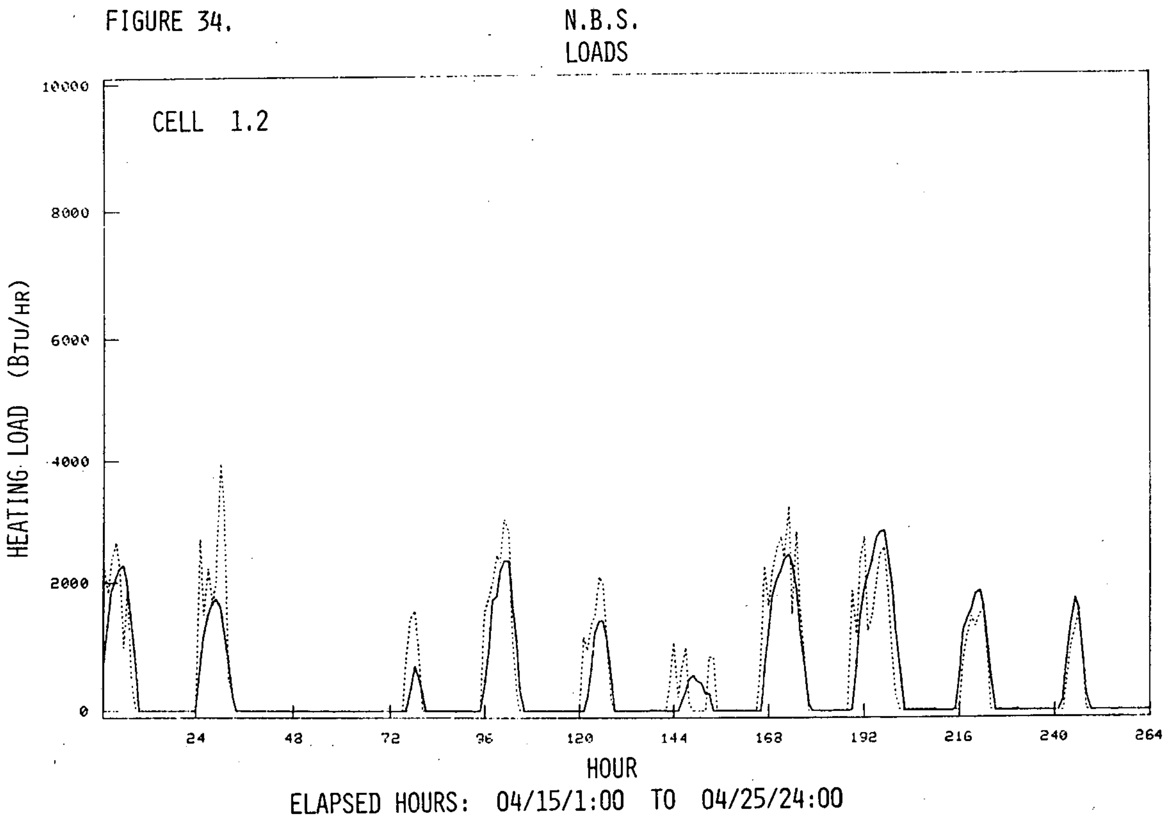


FIGURE 35.

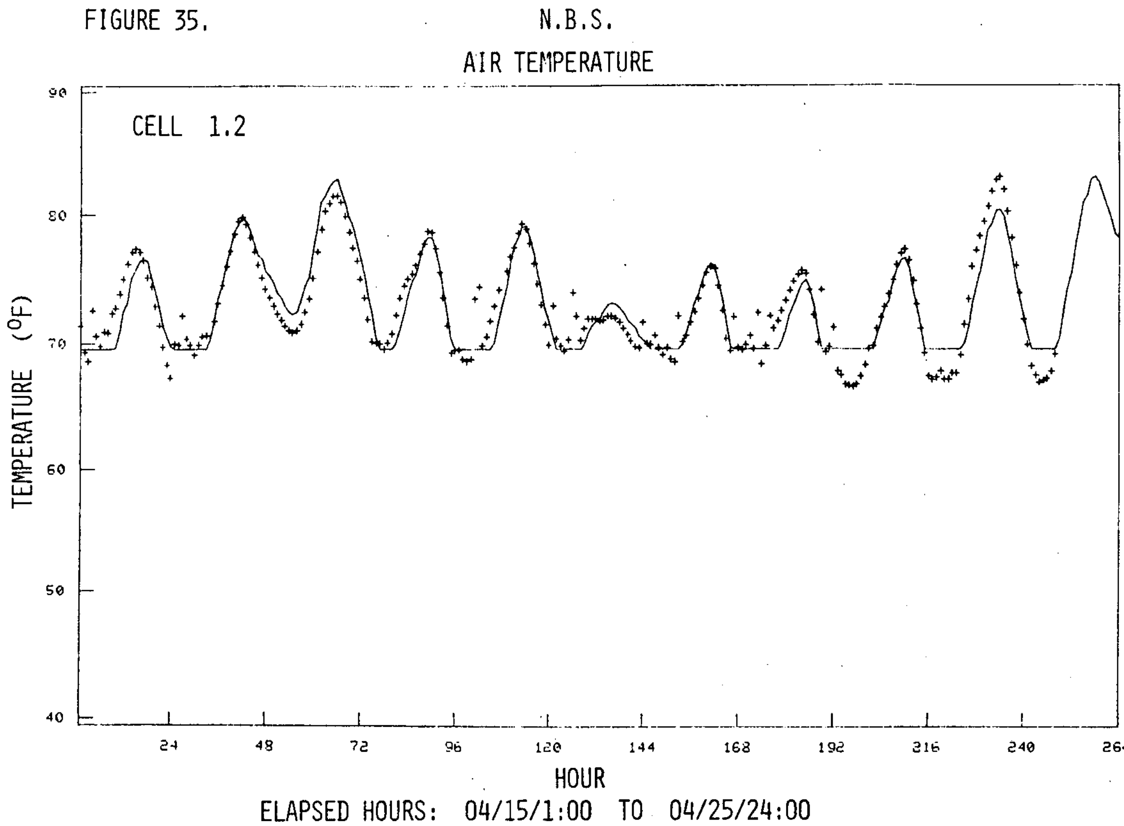


FIGURE 36.

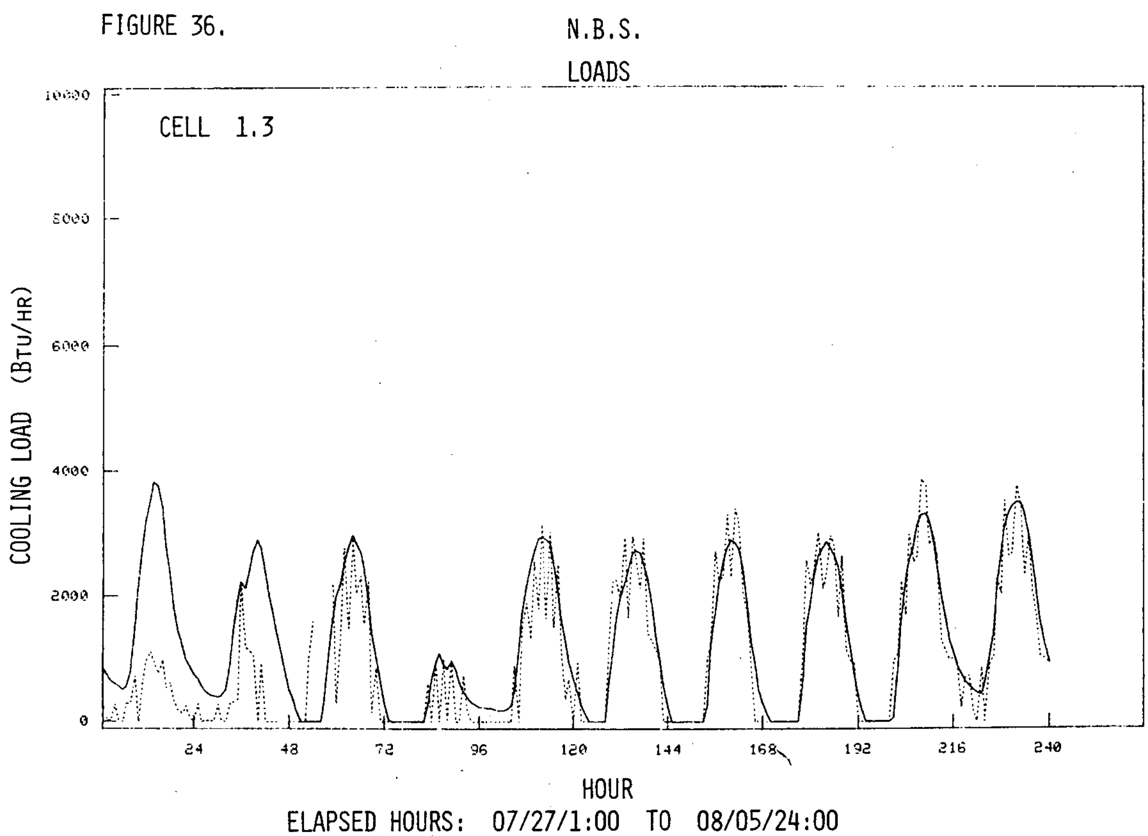


FIGURE 37.

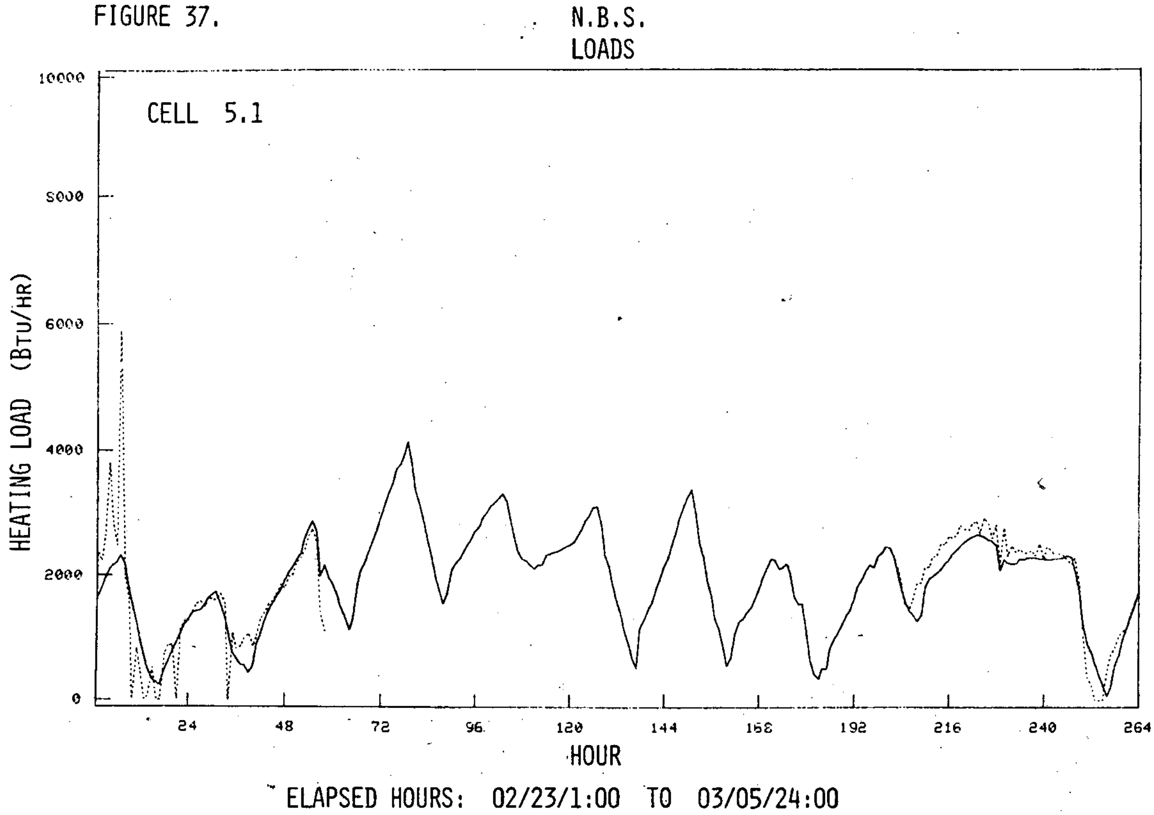


FIGURE 38.

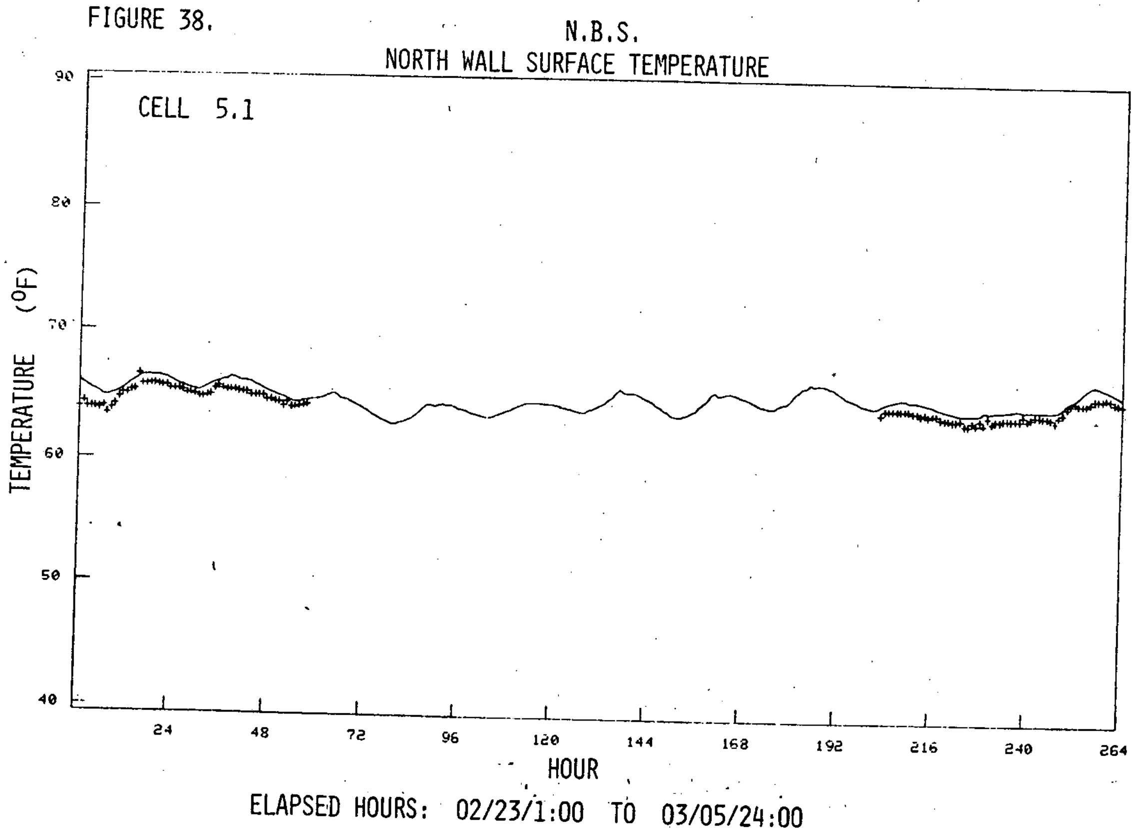


FIGURE 39.

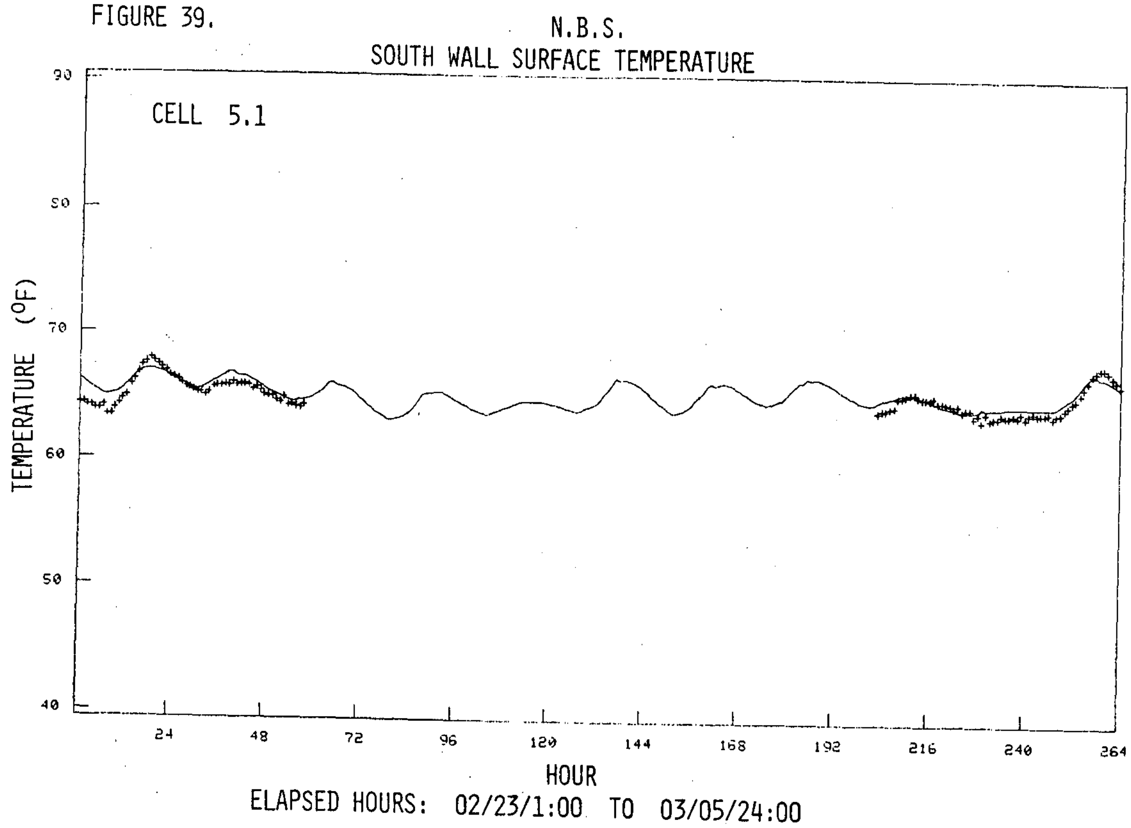


FIGURE 40.

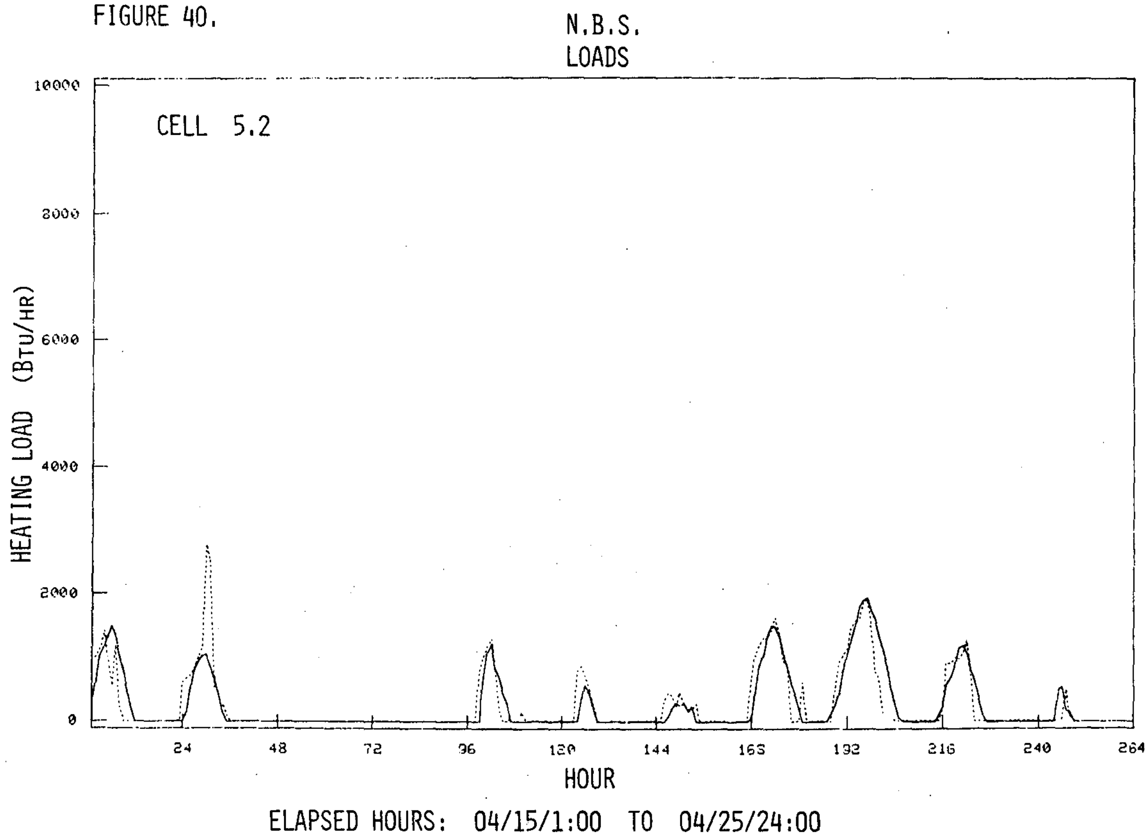


FIGURE 41.

N.B.S.

AIR TEMPERATURE

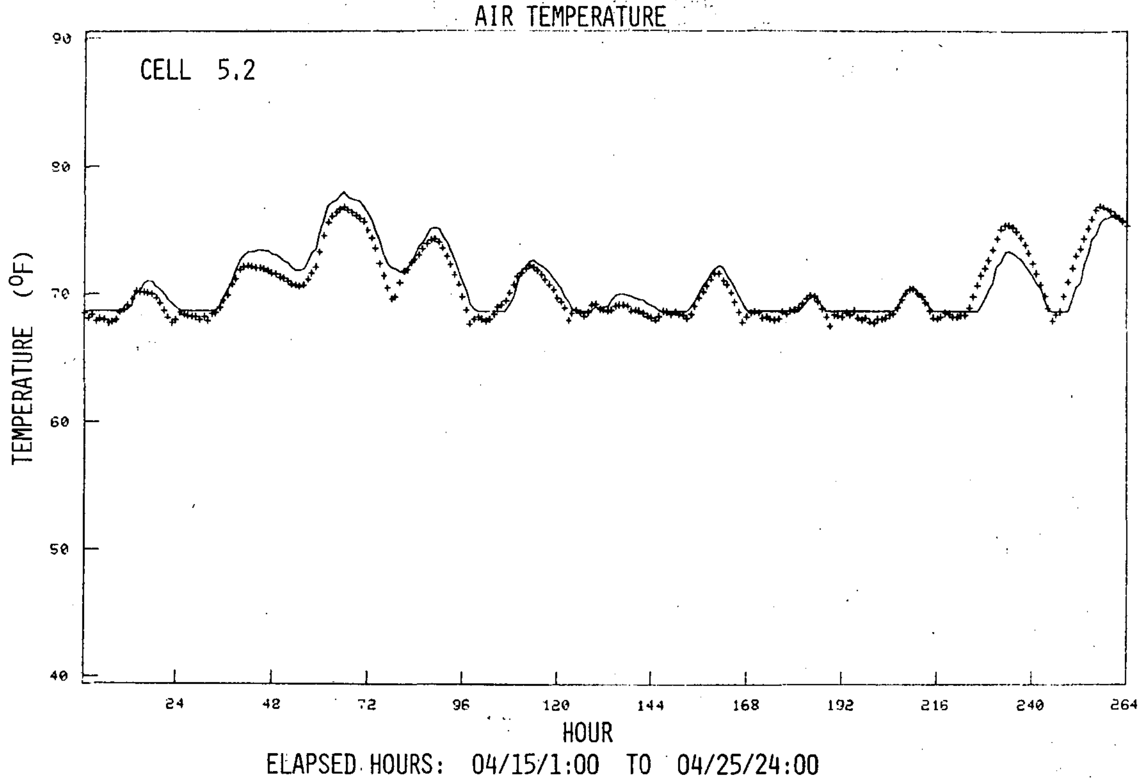


FIGURE 42.

N.B.S.

LOADS

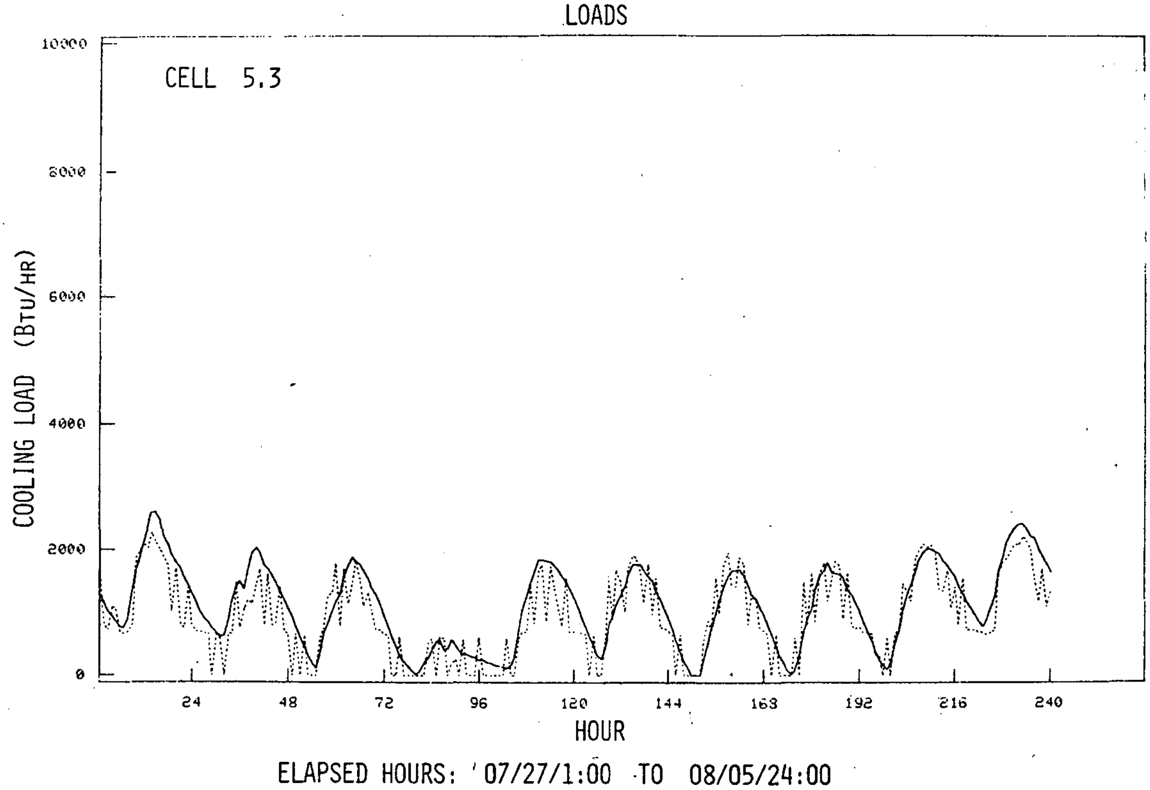
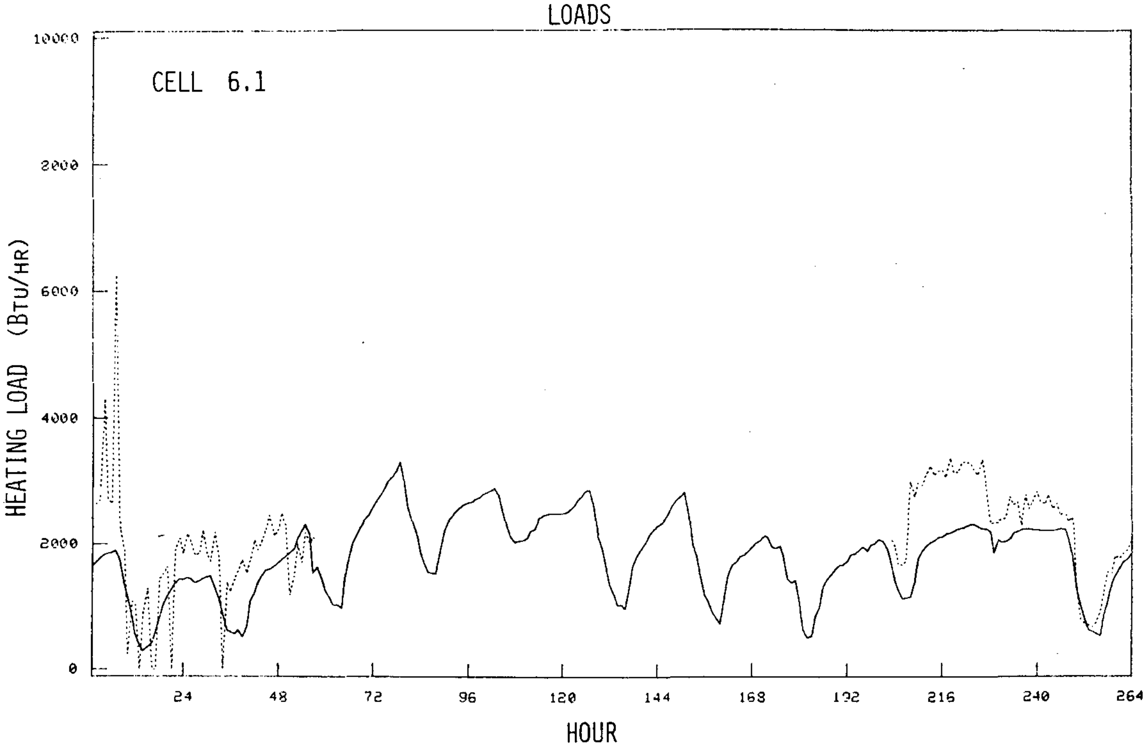


FIGURE 43. N.B.S.

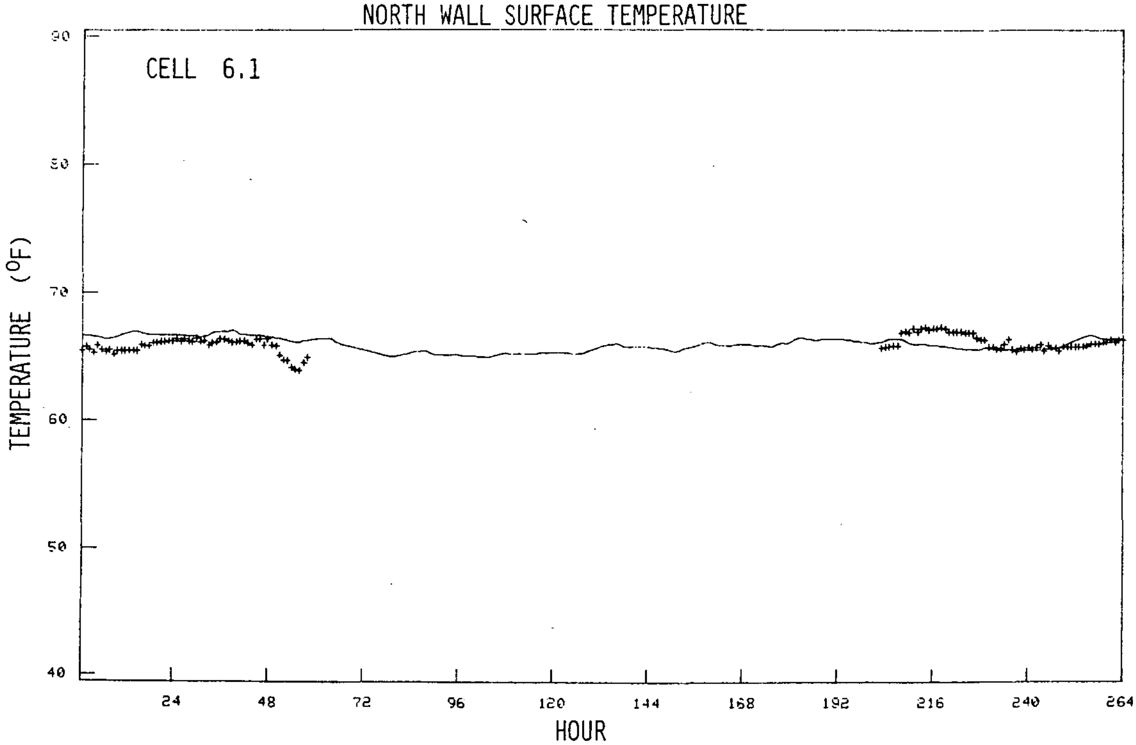
LOADS



ELAPSED HOURS: 02/23/1:00 TO 03/05/24:00

FIGURE 44. N.B.S.

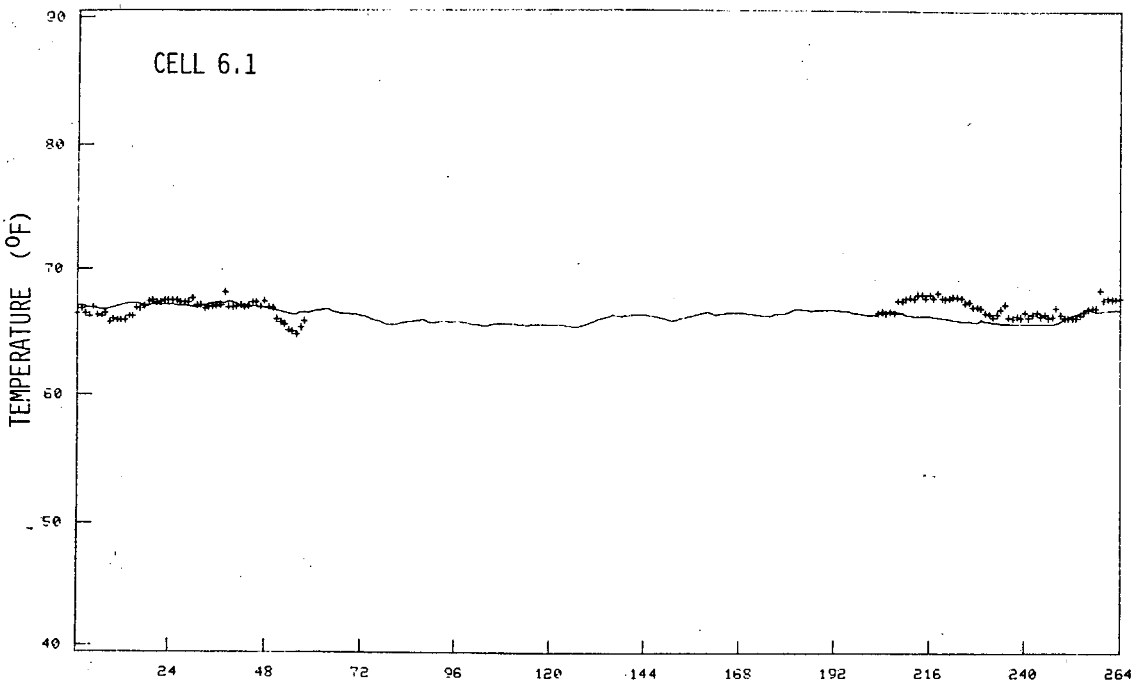
NORTH WALL SURFACE TEMPERATURE



ELAPSED HOURS: 02/23/1:00 TO 03/05/24:00

FIGURE 45. N.B.S.

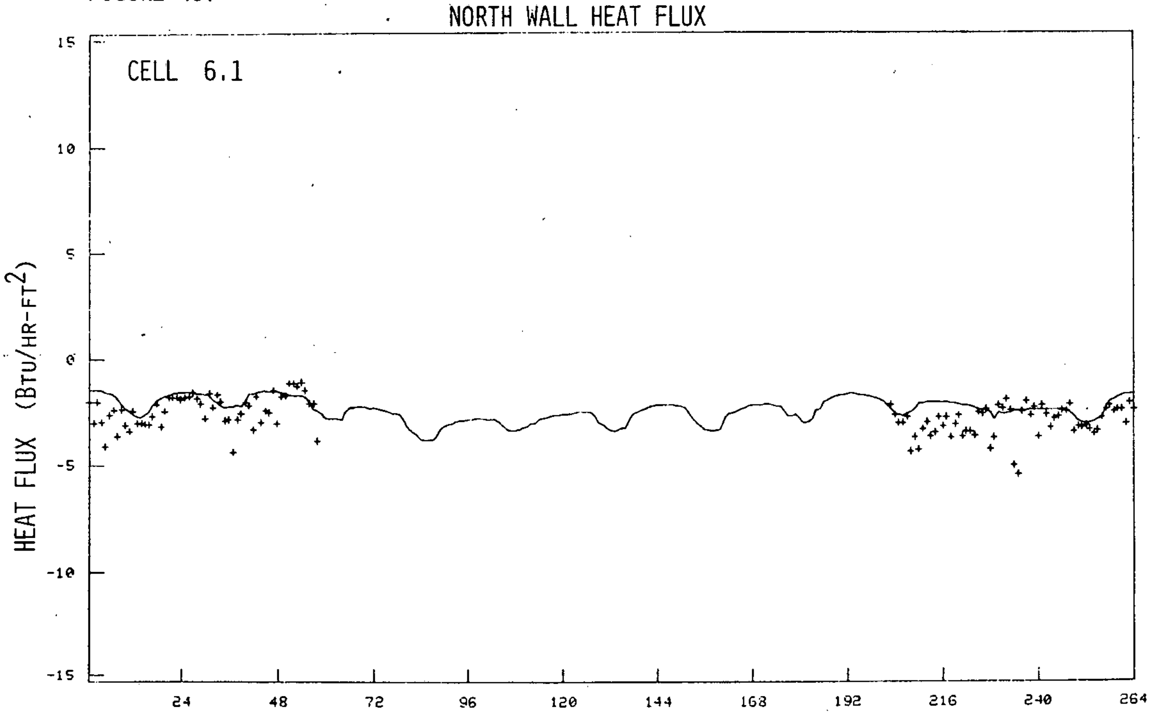
SOUTH WALL SURFACE TEMPERATURE



ELAPSED HOURS: 02/23/1:00 TO 03/05/24:00

FIGURE 46. N.B.S.

NORTH WALL HEAT FLUX



ELAPSED HOURS: 02/23/1:00 TO 03/05/24:00

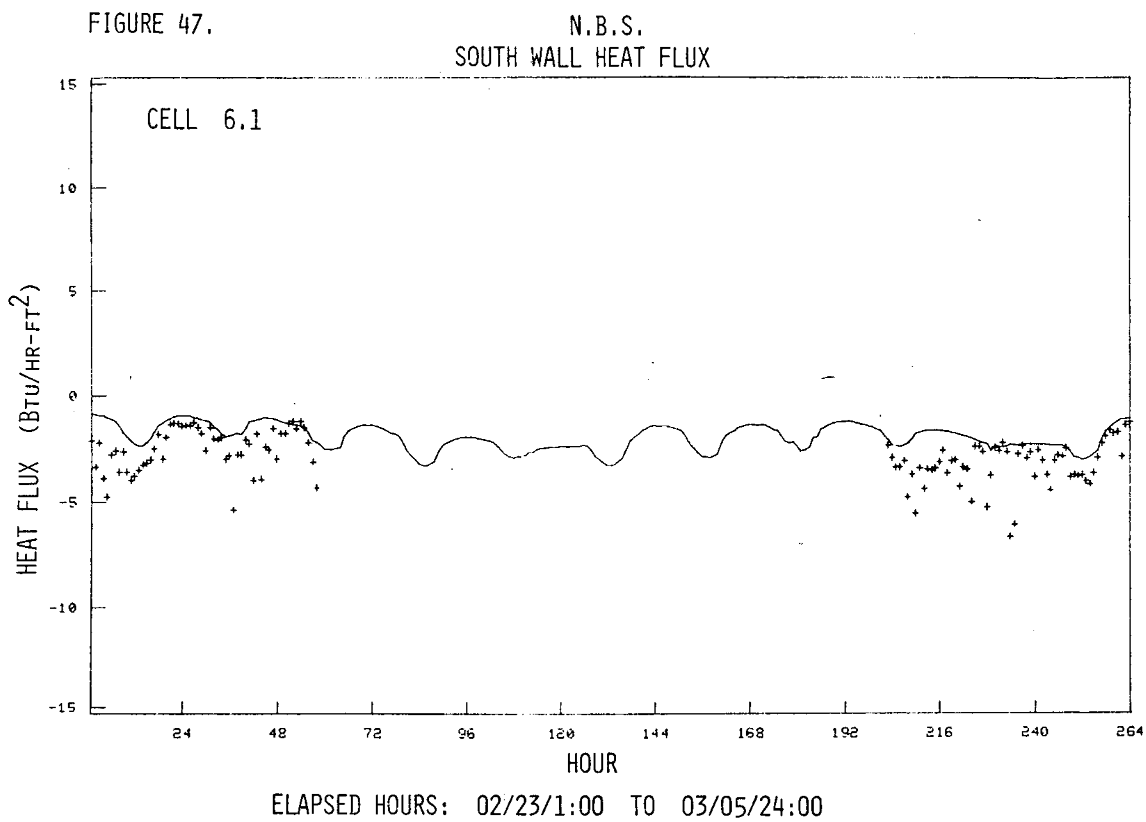


FIGURE 47.
N.B.S.
SOUTH WALL HEAT FLUX
CELL 6.1
HEAT FLUX (BTU/HR-FT2)
15
10
5
0
-5
-10
-15
24
48
72
96
120
144
168
192
216
240
264
HOUR
ELAPSED HOURS: 02/23/1:00 TO 03/05/24:00

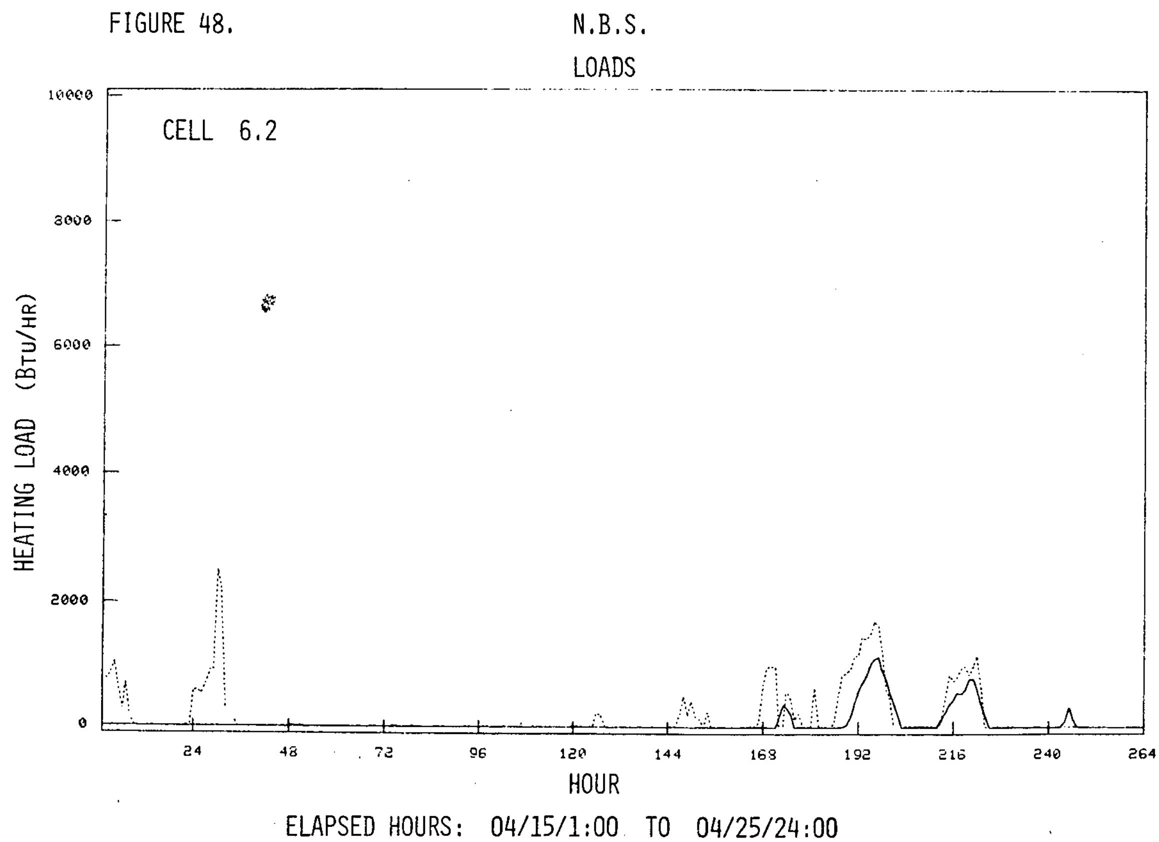


FIGURE 48.
N.B.S.
LOADS
CELL 6.2
HEATING LOAD (BTU/HR)
10000
8000
6000
4000
2000
0
24
48
72
96
120
144
168
192
216
240
264
HOUR
ELAPSED HOURS: 04/15/1:00 TO 04/25/24:00

FIGURE 49. N.B.S.

AIR TEMPERATURE

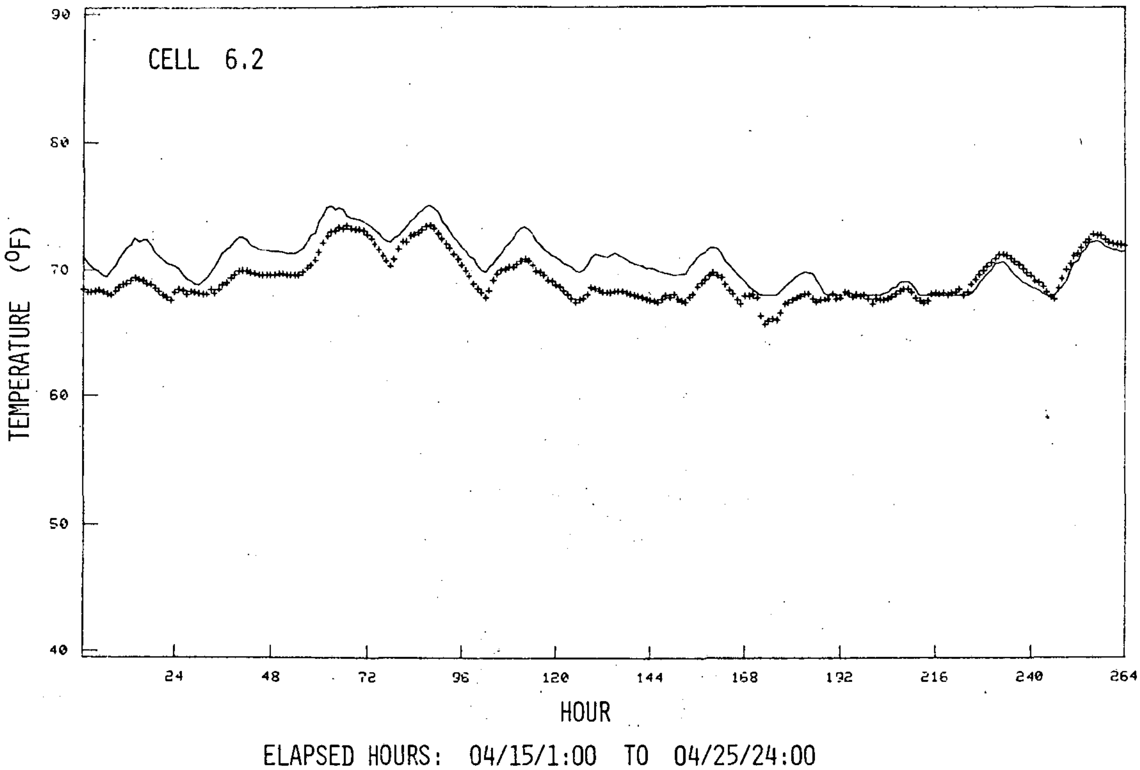


FIGURE 50. N.B.S.

LOADS

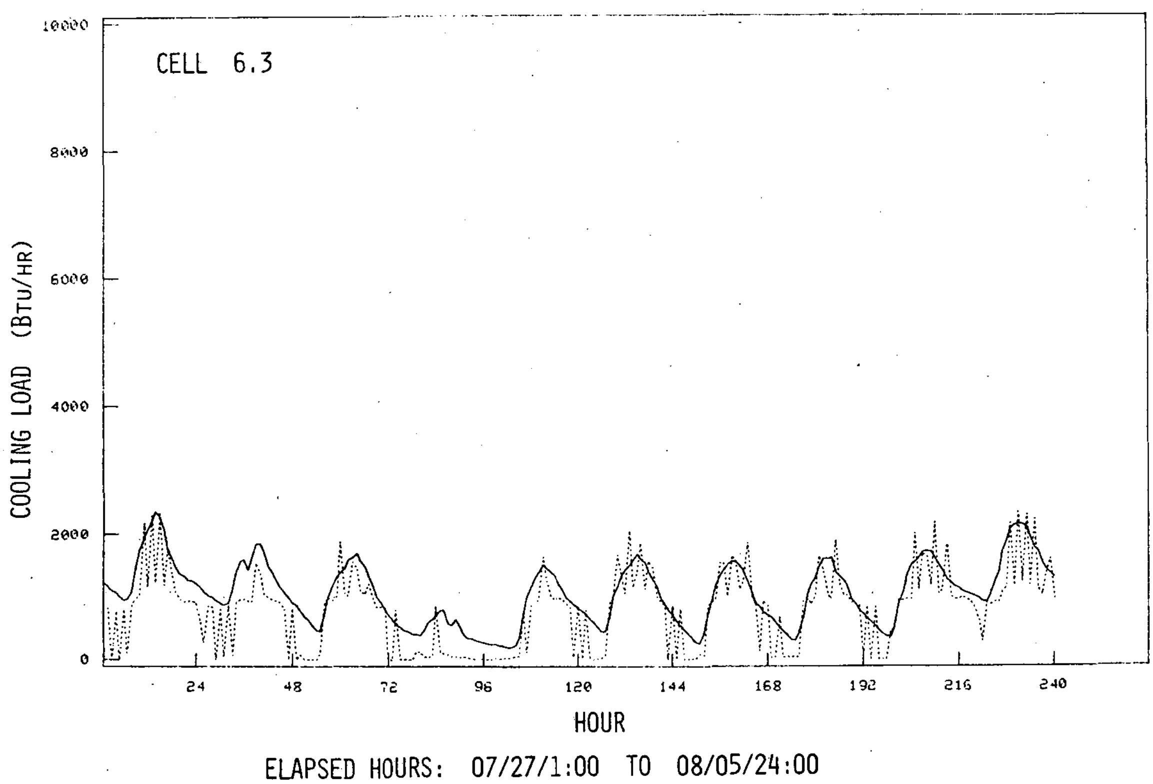


FIGURE 51. N.B.S.

ANNUAL COOLING REQUIREMENT

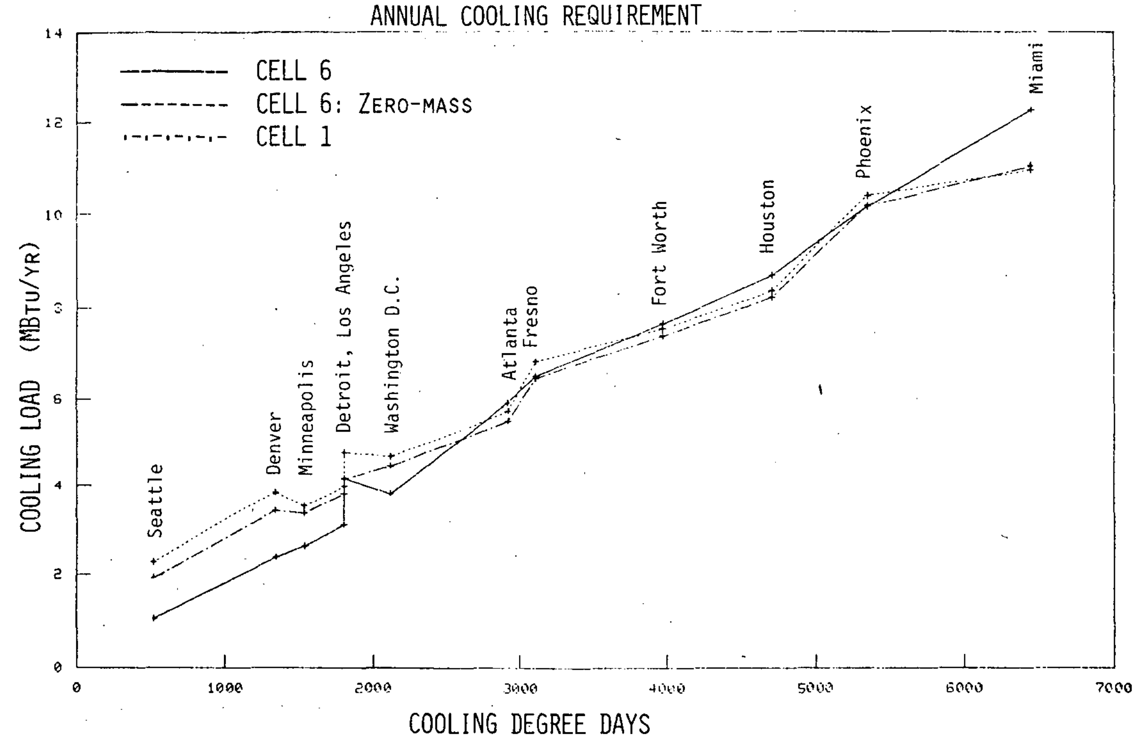


FIGURE 52. N.B.S.

ANNUAL HEATING REQUIREMENT

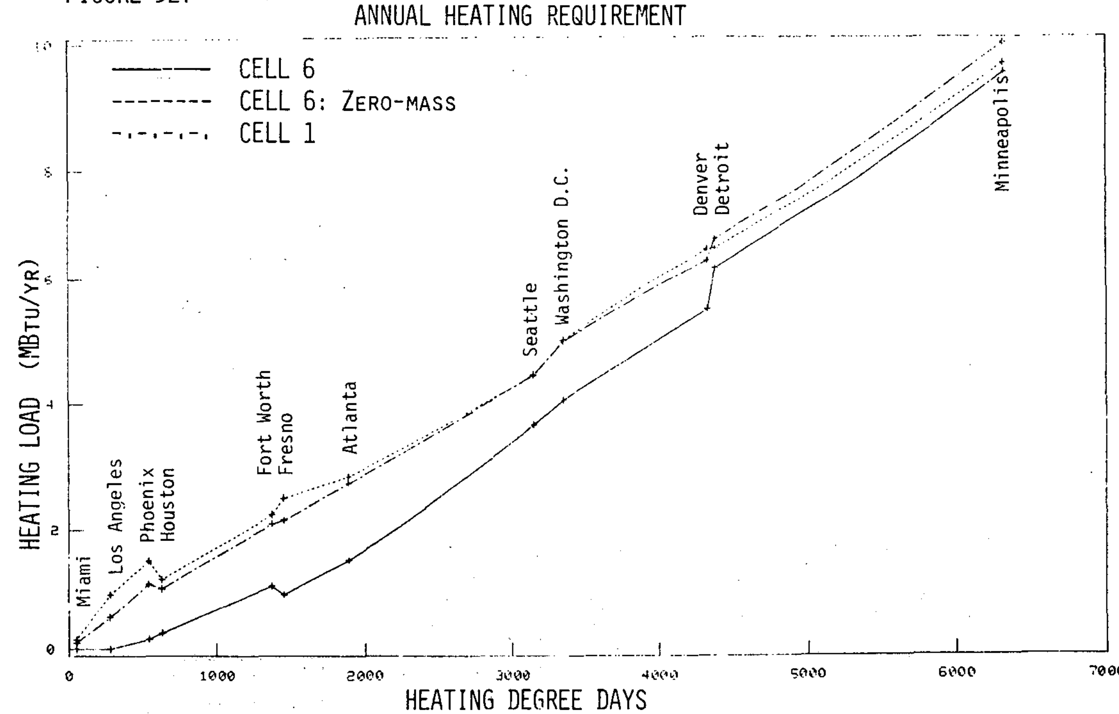


Figure 53: BLAST-NMERDI Loads Comparison

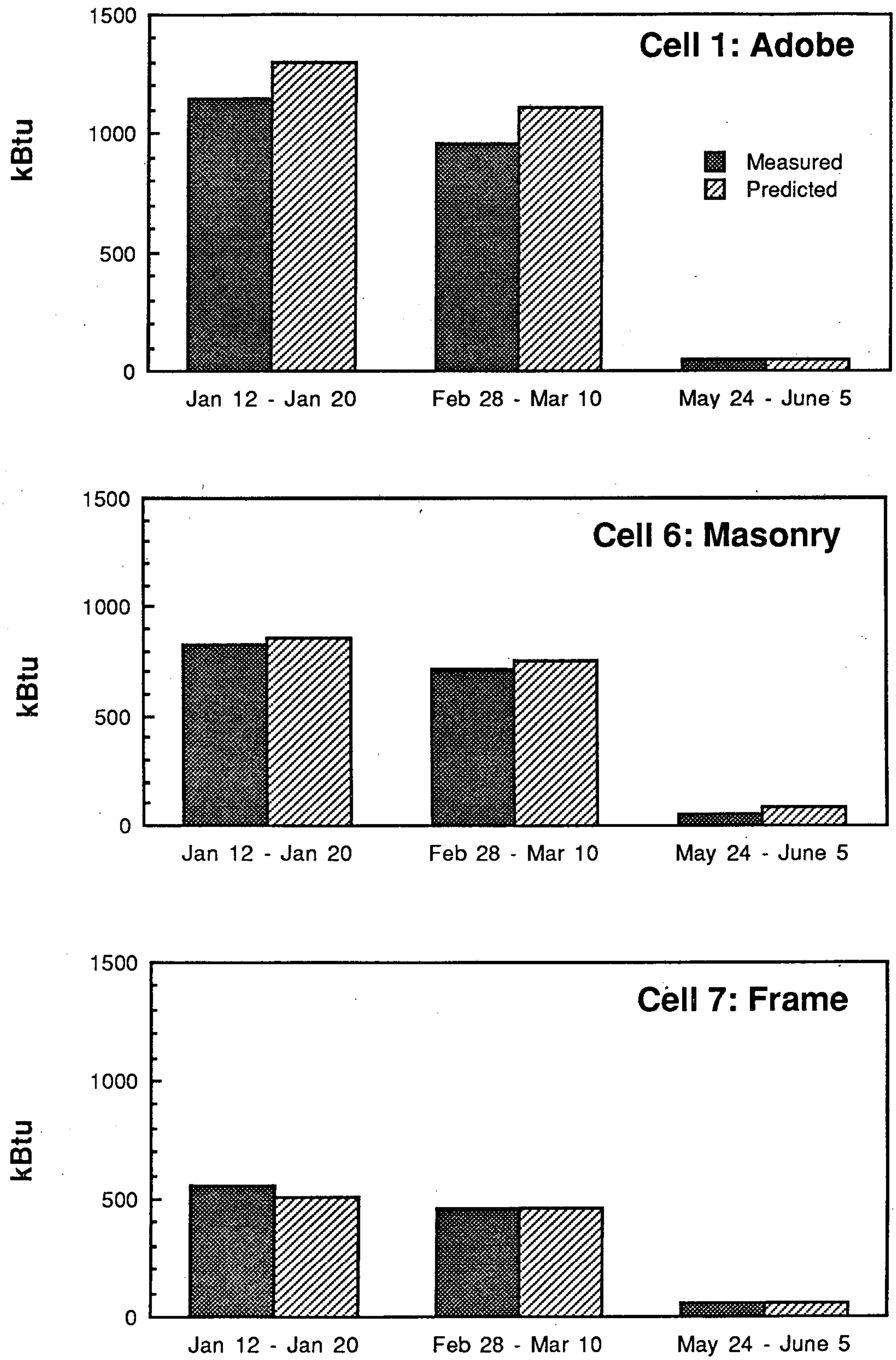


Figure 54: BLAST-NBS Loads Comparison