NATIONAL BUREAU OF STANDARDS REPORT

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DYNAMIC THERMAL PERFORMANCE OF AN EXPERIMENTAL MASONRY BUILDING

Report to

Department of Housing and Urban Development
Washington, D. C.

NBS

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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DYNAMIC THERMAL PERFORMANCE OF AN EXPERIMENTAL MASONRY BUILDING

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Executive Summary

The main thrust of this effort was centered around the actual dynamic, rather than static, thermal behavior and response of the fabric of an experimental masonry building. Presently, most thermal design procedures for a building involve the assumptions that steady-state temperatures exist indoors and outdoors and that the mass of the building can be neglected. This report describes the dynamic (non-steady-state) thermal behavior of an experimental building as it is affected by changing outdoor air temperatures.

A full-scale building was erected in a high-bay environmental chamber and the exterior surfaces were exposed to a diurnal temperature cycle. Several features of the building were changed during the experiment to note the effect on the thermal performance of the building. These features were: fenestration, amount and location of insulation and indoor mass. In all cases measured values of temperature and heat transfer were compared with the corresponding values predicted by a computer program called National Bureau of Standards Load Determination (NBSLD).

The experimental structure was a one room house which was 20' long, 20' wide, and 10' high. The walls were made of solid concrete cinder aggregate blocks with fully bedded mortar joints. The floor consisted of two inch thick concrete placed over two inches of polystyrene board-type insulation. The roof was made from five reinforced pre-cast concrete slabs. When it was desired to simulate an indoor mass, 2600 pounds of concrete block were stacked on the floor. When insulation was used, 2 inch thick polystyrene board-type insulation was spot-glued to the inside or the outside surfaces of the building. This building was instrumented to obtain heat transfer data.

Two types of basic tests were performed. The first was a floating test in which no heat energy was added to or taken away from the interior of the building. For this test, the interior thermal environment of the building was allowed to respond to the outdoor air temperature cycle. For most of the tests the outdoor temperature was varied between 40 and 100 F each day. The second type of test was a thermostated test. For these tests the experimental building was exposed to the outdoor air temperature cycle, while the indoor air temperature was maintained within ± 1 °F by controlling four electric fan heaters located on the floor of the experimental structure.

It was found that the combination of mass in the walls and roof facing the interior with insulation placed on the outside surfaces of the building was very effective in reducing and controlling the variation of the indoor air temperature. This desired effect was predicted by the computer program. For example, when the inside air temperature was not controlled and the building was floating in response to the outside air temperature cycle (about 60 °F change) the indoor air temperature change over 24 hours was about ± 1 °F. In addition, comparing cases of no insulation, insulation inside, and insulation outside, the temperature differences from floor to ceiling on the walls and of the indoor air were lowest when the insulation was placed on the outside of the building.

The effect of an indoor mass on the thermal behavior of the experimental structure was small. For tests in which the variation of the inside temperature was small (such as the thermostated tests), the effect of an indoor mass was practically negligible.

The NBSLD computer program was experimentally validated for predicting the daily indoor air temperature profile as it is influenced by known outdoor temperature conditions and the effect of the mass and thermal resistance of this experimental building. Furthermore, when the inside air temperature was thermostated, this program predicted the peak and daily average heating loads and may therefore be used to size equipment needed to condition the interior of a building and to predict energy requirements. It was shown that steady-state methods of heating load calculation could result in oversizing heating equipment by 30% or more. The NBSLD dynamic method takes into account heat storage effects and therefore predicts the peak heating load more realistically. The maximum difference between the computer calculated peak heating load and measured values was six percent and the average difference was 3.5 percent for the five tests.

1. Introduction

To provide a functional and habitable indoor environment for a building requires careful consideration of the properties and performance of the materials that cover the building frame together with careful design, specification and installation of its mechanical and electrical systems. The building materials and systems taken together are a major part of the cost of a new building and the fuel consumption also constitutes a substantial long-term expense in the operation of a building.

The indoor thermal environment of a building is influenced by the weather, by the thermal behavior of the walls, roof and floors, by heat-producing occupant-related activities, and especially by the mechanical, electrical and service systems that must function to provide control of the heating and cooling devices that serve to make living spaces habitable.

This study explores the actual dynamic or time-variable flow of heat into and out of the fabric of a building and the resulting temperature patterns of the indoor air and the structure itself. Present practices are based largely on steady-state assumptions and techniques. The actual performance is dynamic because of the changing patterns of weather and climate. Therefore, analysis and predictions of hourly, daily and seasonal system performance should be based on dynamic considerations. The theory and basic mathematics for the dynamics of such a system were first explained by Fourier, about 1820, but the complexity of calculation and the time and expense involved has deterred architects and engineers from using such sophisticated procedures to design and evaluate buildings. Simplified steady-state approaches have been and are still used in combination with engineering judgment.

Design calculations for the heating and cooling loads for buildings have been performed virtually by a multiplicity of arithmetic and algebraic computations. It was not practical to make an extensive type of design analysis and the loads were generally determined by employing simple equations using selected fixed winter and summer design temperatures. Experience has shown that systems designed on this basis are sometimes oversized and may not operate at full load and optimum efficiency.

With the advent of high speed electronic digital computers with a large memory bank, it is now possible to make a comprehensive design analysis which includes the dynamic performance of buildings as affected by diurnal and seasonal patterns of the weather and the time dependent interactions within the building itself. This approach allows an engineer to rapidly and inexpensively calculate: (a) energy requirements with consideration of operating costs, (b) heating and cooling load profiles for equipment design or selection and operation, (c) the information that will permit the design engineer to rapidly evaluate a large number of options in the design process, and (d) optimum efficiency of energy utilization which is becoming increasingly important as a national concern.

Computer programs usually contain approximations that require experimental validation before being adopted for wide-scale use. In addition, the performance data on building materials and elements, design weather data and boundary conditions at surfaces need better definition to assure accuracy of predicted results.

It is the objective of this study to produce a computer program suited to the variable temperature and heat flow regimes in most real situations and to compare results as predicted by this program with measurements made in the laboratory on full scale structures that are subjected to changing simulated weather patterns. Further, it was hypothesized that building walls, roofs and floors can be better designed to take advantage of thermal lags that occur due to the mass of the building and thereby allow a reduction of the installed capacity of mechanical equipment for heating and cooling while still maintaining performance satisfactory for human comfort and health. For example, it was hypothesized that if the masonry of a building is located on the indoor side of walls and roofs with thermal insulation on the outside the stability of indoor temperature changes should be improved with less gross energy expended for maintaining a selected indoor temperature level. Also, locating masonry on the inside of the walls with insulation on the outside provides other potential advantages such as: a reduction of cracking and spalling because the masonry remains unexposed to weather and at essentially a constant temperature and moisture content; the use of strong durable indoor surfaces should allow a reduction in the costs of maintenance and redecorating; a possible improvement in acoustic performance; and a greater resistance of the building to an interior fire, or its rapid spread. When compared with the usual construction of walls with masonry outside and insulation inside, the proposed inverted system with insulation outside has elicited considerable interest.

A concerted effort towards the experimental verification of computer calculation methods and the technical merits of the inverted system is needed. At the National Bureau of Standards the initial experimental phases in this regard included laboratory testing in a high-bay environmental chamber employing a prototype building where the time varying external environment could be controlled, reproduced and variations in important parameters could be studied.

This report presents a computer program for prediction of dynamic thermal and energy loads of buildings, the experimental results obtained from laboratory measurements made on a prototype building and the comparison of experimental results with those calculated by the computer program. In conjunction with the experimental phases involving the dynamic thermal performance of a prototype building, two other significant experiments were performed on the building. The first experiment was concerned with the air infiltration rate of the building. The method, procedure and results are contained in Appendix A of this report. The second experiment involved a series of noise transmission measurements made on the building. The method, procedure and results are contained in Appendix B of this report. Other observations included monitoring of the moisture content of the prototype building and the movement of the walls of the building under the influence of the changes in simulated outdoor air temperatures. The moisture content reached low equilibrium values early in the program and remained stable thereafter. Wall movement was little and about what would be expected using predictive engineering calculations. No surface or through-the-wall cracks in masonry were observed at any time in the program.

2. Prediction and Evaluation Analyses

In order to evaluate the dynamic, rather than steady-state thermal behavior and response of the fabric of a building as affected by diurnal and seasonal variations of weather and the time dependent interactions within the building, it was necessary to make a comprehensive mathematical analysis of the various heat transfer problems and translate the derived expressions into computer programs. It was found that the heat conduction portion of the overall problem could not be satisfied by purely rigorous mathematical solutions to the applicable partial differential equations because some of the boundary conditions at solid surfaces cannot be represented in a rigorous form in a reasonable manner. For these reasons, the Response Factor method was employed for those portions of the problem involving heat conduction, because it allows a time variation of boundary conditions and can readily be related to similar and other modes of heat flow, such as radiation and time varying changes in the nature of convection heat flow.

Basically, the Response Factor method predicts one-dimensional heat flow by utilizing the superposition principle in such a manner that the overall thermal response of a solid at a selected time is the sum of the responses caused by many individual temperatures or heat flux pulses during preceding time steps. Thereby, transient boundary conditions are simulated by a train of pulses. By summing up the fluxes or temperatures caused by each pulse, the total heat flux or temperature at a given time can be determined. The differential equations of heat conduction for multi-layer systems of a building are solved in this method by employing matrix equations of the Laplace transforms. The matrix algebra, superposition principle, and inversion of the Laplace transforms are shown and discussed by Kusuda[*]. Experience has shown that when this method is compared with a rigorous analytical solution under simplified conditions, the agreement is very good, except for the case where sudden changes or amplitude peaks of a weather cycle are encountered. This is probably due to the time steps employed and is not considered to be a serious drawback.

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[*] Thermal Response Factors for Multi-layer Structures of Various Heat Conduction Systems, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Transactions, 1969, pp. 246-271.

Appendix C contains the complete computer program, NBSLD, Computer Programs to Obtain Heating and Cooling Loads and to Estimate Room Air Temperature Change Using Thermal Response Factors. For the purpose of predicting performance in the experiment certain subroutines of NBSLD were not needed. Appendix D is the computer program as adapted from NBSLD for use in this report for comparing predicted results with experimentally measured results. Appendix E gives a sample set of input and a print-out of corresponding computer results as used with the program of Appendix D.

For this thermal analysis, the following assumptions were made:

1. The conduction heat transfer through all the components of the experimental structure was assumed to be one-dimensional.
2. All building materials were assumed to be homogeneous having constant physical and thermal properties over the operating temperature range of the tests.
3. For the tests considered in this report the heat-transfer coefficients for the inside and outside surfaces of the experimental structure were assumed to be constant.
4. Heat and mass transfer of water in vapor or liquid form or the latent heats of condensation and evaporation were not considered in the analysis. For most tests, the dew point temperature of the outside air was maintained below that for any temperature occurring in daily cycle.

5. Infiltration of air from the outside to the inside and from the inside to the outside was considered to be a constant for a particular test. Two tests were performed for determining the air infiltration rates of the building, one with and the other without windows installed. The description and results for the air infiltration tests is in Appendix A.

3. Description of Building

The building was constructed in a high-bay environmental laboratory of approximately 70,000 cubic feet in volume. A photograph of the experimental structure located in the environmental chamber is shown in figure 1. In this laboratory the temperature and relative humidity can be controlled over the ranges -50 to 150 °F and 15 to 85 percent, respectively. Temperatures and relative humidities can be changed as a function of time using cam-operated controllers. The floor of the laboratory is undisturbed earth suitable for placing building foundations.

The outside plan dimensions of the building were 20' x 20' with 10 foot high walls. The flat roof consisted of five 20' long by 4' wide and 4 inch thick steel reinforced concrete roof slabs as shown in figure 2. The walls were made of nominal 8" high by 8" wide and 16" long solid cinder aggregate concrete blocks joined with fully bedded mortar joints. The blocks were of a nominal 100 pound per cubic foot density. Eight concrete lintels were installed at appropriate locations; one above each of the seven windows that were 40" high and 32" wide and one above the solid wood door measuring 79" high x 32" wide x 2" thick. Window openings were filled with blocks for the first two tests (see figure 2). The blocks were removed and the windows installed for the remaining tests. The exposed glass area was about 8 percent of the exposed wall area or about 18 percent of the floor area. Figure 3 shows the configuration.

A detailed illustration of the floor and the footing supporting the walls is given in figure 4. Below the ground level, four inch thick polystyrene insulation was placed on the outside and a one inch thickness on the inside of the concrete blocks to a depth of 16 inches. Below the 16 inch depth a one inch thickness was placed on the outside of the footing. The floor was made of two inches of polystyrene insulation placed on the earth with a two inch thick concrete slab on top of the insulation. Considerable insulation was purposedly placed below grade to reduce the known long-term influence of heat flow to the earth from the building and to minimize the time necessary for experimental test.

Cracks at the roof-wall interface and between the roof slabs were caulked with a polysulfide sealant. When the windows were installed, all cracks including those at the glass-wood frame interface were also caulked with the same sealant. Windows were as shown in figure 4.

Commercial expanded polystyrene board-type insulation 2 inches thick, when used, was spot glued to either the inside or outside surfaces and all cracks were tape sealed. The identical insulation was used inside and outside. An internal mass consisted of 2600 pounds of solid concrete blocks stacked on the floor as shown in figure 3 was used to simulate the heat capacity effect of interior partitions, furniture, etc.

4. Instrumentation and Transducers

Temperatures were measured using 24 gage copper-constantan thermocouples. The dots on figure 5 indicate thermocouple locations. The five vertical planes A, B, C, D and E, as shown on the plan view of figure 6, each contained the same thermocouple configuration given in figure 5, except for the indoor air thermocouples which were located only in the vertical plane B. Four thermocouples were placed in the air one foot from the outside surfaces. One of these was located at the center of the roof and the other three were located at the mid-height of the three walls denoted by vertical planes B, D and E of figure 6.

Six heat flow meters were placed on inside surfaces, five of them in vertical plane B of figure 6. One was placed at the center of the floor and a second meter was placed on the floor at a distance two feet in from the wall. Two meters were placed on the ceiling opposite those on the floor. The fifth meter was placed on wall at mid-height. The sixth meter was placed mid-height on the wall of vertical plane D. The heat flow meters were circular disks 2.0 in. in diameter and 0.13 in. thick, made of tan polyvinylchloride filler material, each having an embedded spiral of helically-wound wire comprising a large number of thermojunctions in series (with internal resistance range of 135 to 170 Ω) distributed over a circular area 1 5/8 inches in diameter located centrally in the disk. Two wires attached in each meter acted as leads for the series thermopile of the meter. The meters were calibrated in an 8 in. guarded hot plate apparatus conforming with the requirements of Standard Method of Test ASTM C177.

All thermocouple and heat flow meter leads were connected to thermally isolated terminal strips at the center of the room from which copper leads went to a data acquisition system. The terminal strips were mounted on a one-quarter inch thick aluminum plate which in turn was surrounded by three inches of polyurethane insulation. All lead wires were surrounded by three inches of the same insulation for a distance of seven inches. This assembly is termed a zone box. Four additional thermocouple leads were connected to the terminal strips at ends of the zone box and their junctions were placed in an ice point reference external to the building. The readings from these four thermocouples gave the temperature of the zone box as a reference temperature for the other thermocouple leads.

Copper leads from the zone box were connected to terminals of the data acquisition system which converted the analog signals to digital information which in turn was recorded on punched cards.

Electric power, when supplied, to the building was measured using a calibrated single-phase watthour meter equipped with an impulse generator. The impulse generator is a photo-electric device which counts the revolutions of the disk inside the watthour meter. A digital signal (number of revolutions of the disk) was fed into the data acquisition system which in turn recorded the digital signal on punched cards at selected time intervals.

5. Experimental Procedure

Figure 7 is a representative sample of the outside air temperature wave-form imposed on the structure for each 24-hour time period. The limits 40 °F to 100 °F were selected for experimental convenience and because their average would be approximately a normal room temperature. The curve is the average of the four individual temperatures indicated by thermocouples in the air one foot from the exterior surface of the structure. The maximum difference in temperature between any of these four locations was always less than 4 °F. The outside dew point temperature was maintained constant at approximately 5 °F below the lowest temperature of a cycle. The temperature cycle of figure 7 was selected as a simulated sol-air temperature pattern as given in Table 25, page 490 of the "Handbook of Fundamentals", published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1967. Sol-air temperatures were area averaged for orientations north, east, south, west and horizontal. The temperature variation as indicated on figure 7 was maintained for a period of from three to four days before a final set of data was taken. This conditioning period was deemed to be necessary and sufficient to eliminate transient heat flows thereby giving only those heat flows that would occur in a steady-periodic condition.

A complete set of data for each test consisted of recording the digital output from analog signals of 171 sensing elements (thermocouples, etc.) every 30 minutes for a 24 hour period. The recorded data on punched cards was fed into the computer programmed to process the data into temperatures, heat flows, etc. The converted data were then transferred to magnetic tape for use in analyses, and plotting as temperature and heat flow patterns.

The results from ten tests given in this report are derived from the five floating tests and five thermostated tests summarized in Tables 1 and 2.

a. Floating Tests

Floating tests are defined as those tests where no heat energy was added or taken away from the interior air of the experimental structure by mechanical equipment. The temperature of the interior air was allowed to "float" or respond to changes in the outside air temperature. Five floating tests were conducted with variations in test conditions as shown in Table 1.

Table 1

Floating Tests

Test No.	Insulation	Windows	Internal Mass
1	None	None	None
2	None	None	Mass*
3	None	Single Pane	None
4	Inside	Single Pane	Mass*
5	Outside	Single Pane	Mass*

* 2600 lbs of concrete blocks

b. Thermostated Tests

Thermostating tests are defined as those tests where heat energy was added to the interior air of the experimental structure by four electric heaters under thermostatic control. The variations in test conditions are shown in Table 2 along with the average inside air temperature maintained and its root mean square deviation.

Table 2

Thermostated Tests

Test No.	Insulation	Windows	Internal Mass	Inside Air Temp.
6	None	Single Pane	None	78.9 ± 1.2
7	Inside	Single Pane	Mass*	76.9 ± 0.8
8	Outside	Single Pane	Mass*	77.6 ± 0.6
9	Outside	Double Pane	Mass*	77.6 ± 0.6
10	Outside	Double Pane	Mass*	74.2 ± 0.8

* 2600 lbs of concrete blocks

The sensing element for thermostating was a thermocouple placed in the middle of the room at mid-height. It controlled the operation of four fan heaters placed as shown in figure 3 in an on-off type of control with a differential of approximately ± 2 °F. Each drum-type fan heater, as shown in figure 8, consisted of a 600 watt cone heater and a blower which takes air from the floor level passes it through the heater chamber and into the room through peripheral holes near the top of the drum. For test 10, the daily temperature cycle for the outside air ranged from 10 to 70 °F, but the cycle was identical in shape to that given in figure 7.

6. Results and Discussion

The thermal and physical properties of the materials comprising the building which are necessary for use in the computer program are given in Table 3.

Table 3

Thermal and Physical Properties

	Thickness in.	Thermal Conductivity Btu hr^{-1} ft^{-1} F^{-1}	Density lbs ft^{-3}	Specific Heat Btu lb^{-1} F^{-1}
Concrete Block	7.5	.29	100	.18
Roof Slab	4.	.80	150	.2
Polystyrene Insulation	2.	.018	2.5	.27
Concrete Floor	2.	.80	150	.2
Earth		.5	120	.2

Measurements of thermal conductivity, thickness and density were made on oven-dried samples of the concrete block and polystyrene insulation in accordance with the hot plate method given in ASTM C177. All other properties were obtained from available literature.

The coefficients of heat transfer at the inside and outside surfaces were the most difficult of the numerous parameters to define for this experimental work. Values given in literature are usually determined from steady-state conditions whereas the test conditions were dynamic and the coefficients vary with orientation of surfaces, direction of heat flow, temperature of surface and the air motion over the surface.

During one of the tests, an attempt was made to measure air velocities at inside and outside surfaces of the building with a vane anemometer. The air velocities were not sufficient to rotate the vanes indicating that the velocities were somewhat less than 50 fpm and that conditions at the surfaces could be considered as natural convection. Under natural convection conditions the convection component of the heat transfer coefficients is defined in literature as being proportional to the one-third power of the absolute temperature difference between a surface and the adjacent air if in the turbulent range. This relationship may apply to vertical surfaces, heated horizontal surfaces facing upward and cooled horizontal surfaces facing downward. For horizontal surfaces either heated facing downward or cooled facing upward, the adjacent air is considered to be in the laminar range and the convection component becomes very small and the radiation component of the heat transfer coefficient becomes dominant.

From the above considerations, values for the coefficients of heat transfer at the various surfaces were selected and used in the computer program as constants for the time period of a test. The coefficients used for the inside surfaces at the ceiling, walls, and floor were 1.08, 1.1, and 1.08 Btu hr^{-1} ft^{-2} F^{-1}, respectively. The heat transfer coefficient for the outside surfaces was selected to be 1.47 Btu hr^{-1} ft^{-2} F^{-1}. In general these values are based on a value of 0.9 for the radiation component of heat transfer and time averaged temperature differences between surfaces and adjacent air of 1 F and 14 F for the inside and the outside, respectively. For test 10, where the outside temperature was considerably lower, the coefficient selected was 3 Btu hr^{-1} ft^{-2} F^{-1}. Reasonable variations in these coefficients show a negligible effect on results from the computer program.

For the computer program, the heat capacity effects of the door and windows were assumed to be negligibly small and only the thermal resistance of these components was used. For the door and single and double pane windows the overall coefficients of heat transfer were calculated to be 0.25, 0.45, and 0.39 Btu hr^{-1} ft^{-2} F^{-1}, respectively, for the conditions of tests 1 through 9. For the double pane windows of test 10 the selected coefficient was 0.46.

For heat flow to or from the floor, the underlying earth was considered to be a one-dimensional semi-infinite medium for the Response Factor program, and the average of temperatures measured at the one-foot depth in the earth was used as the earth temperature at a depth considerably removed from the floor. For the duration of the tests this was deemed an adequate assumption because the root mean square deviation of the earth temperatures at the one-foot level was less than 0.2 °F for all tests where the diurnal outside air temperature varied from 40 to 100 °F and less than 0.3 °F for the 10 to 70 °F cycle. For the 40 to 100 °F tests, the average temperature at the top of the footing (figure 5) was about .5 F lower than the earth temperature at the one-foot level, and for the 10 to 70 °F test was about 2 F lower. This indicates that some of the heat is flowing from the earth underlying the floor toward the footing and was not accounted for in the one-dimensional heat transfer approach of the Response Factor program. The error due to this heat flow is believed to be very small in relation to other heat flows. A mathematical analysis was performed for the heat flow at the ground level in the wall section below ground level to the top of the footing (figure 4) using the temperature variations with time from thermostated test 6. The computed heat flows showed that heat was flowing into and out of this section with time, but the magnitude of these heat flows was small in relation to other heat flows.

Air infiltration rates were determined by a tracer gas method using helium as the tracer gas. (See Appendix A.) For the building without and with windows, measured values were 0.06 and 0.38 air changes per hour, respectively. Since there was little air movement at the inside and outside surfaces, the thermal head (the difference in temperature between the inside and outside air) is the predominant driving force for air infiltration. The above values are considered maximum rates for air infiltration, because the tests were performed when the thermal head was the greatest. It would be expected that the air infiltration rate would be proportional to the thermal head. For this reason, average air infiltration rates were selected as being 2 cfm for tests with no windows and 10 cfm for test with windows. The tests of Appendix A were performed on the building without thermal insulation. Placing insulation on either the inside or outside surfaces would increase the resistance to air infiltration. For this reason, a rate of 5 cfm was used for tests with insulation.

Noise reduction measurements were made on the prototype building as given in Appendix B. The results for conditions of no windows, single pane windows only, single-pane windows with insulation inside and single-pane windows with insulation outside are shown in figure 2 of Appendix B. As indicated and expected the noise reduction was greatest without windows and some improvement is shown when insulation was applied. Comparison of noise reduction measurements for the tests with insulation on the inside and on the outside indicate that insulation on the inside had better characteristics because of the higher noise reduction values in the range from 500 to 2500 Hz. This range is considered to contain the most objectionable portion of the audible frequency spectrum.

As mentioned in the introduction an equilibrium moisture content of the block was rapidly achieved and the influence of moisture in these tests is considered to be negligible. The moisture content of the block was monitored by observing the change of weight of a single oven dried concrete block placed in the environmental chamber and the test room throughout the tests. The equilibrium moisture content of the single block was 4% by weight. Similarly, vertical and horizontal thermal expansion of the concrete block wall attained an equilibrium range and was considered to be desirably low especially since no surface or through the wall cracks were visible.

a. Floating Tests

For the floating tests numbered 1 through 5, Table 1, the measured and computer calculated inside air temperatures are plotted in figures 9 through 13, respectively, each with its measured outdoor air temperatures. The curve of measured indoor air temperature is the arithmetic average of the six indoor air thermocouples as shown in figure 5. The vertical distribution of temperature within the room will be treated later in this discussion. There was generally good agreement between the measured and predicted average inside air temperatures in all cases, although there is a trend for the predicted values to have slightly higher maximum values and lower minimum values during the 24-hour cycle. This indicates that the mass of the building dampens temperature changes more than is accounted for in the predictive computer program. This may be due to several factors such as the theoretical model that was used in the computer programs neglects the additional thermal inertia introduced at the corners of the building and neglects slight changes in material physical properties during exposure as compared with measured dry values.

Comparing the indoor air temperature curves of figures 9 through 13, it can be seen that placing insulation on inside and outside building surfaces had a marked influence on the inside air temperature profiles. Compare figure 12 with figure 11, and figure 13 with figure 11. The temperature deviations from the daily average inside air temperature for the building with windows are plotted in figure 14 for the cases of no insulation, insulation on the inside building surface, and insulation on the outside building surface (corresponding to figures 11, 12 and 13). Adding insulation on the inside surface of the building reduced the peak to peak variations of the inside air temperature from about 10.5 to 5.5 °F. The effect of the insulation then was to damp out the cyclic fluctuations of inside air temperature with windows installed. Furthermore, when insulation was placed on the outside surfaces, the peak to peak variation was reduced to about 2 °F. This experimental finding is considered to be significant because no heat energy was purposedly added to or taken away from the indoor air during the tests and the performance results illustrate that considerable control of the indoor air temperature can be exercised by simply placing the mass of the walls and roof facing indoors with insulation facing the outdoors.

To investigate the effect of an interior mass on the inside air temperature for a floating test, a comparison was made between tests 1 and 2, (figures 9 and 10). Temperature deviations from the measured mean inside air temperature for these two tests are plotted in figure 15. It can be seen that for these cases with no insulation, the presence of an internal mass slightly damps the inside air temperature cycle. This effect was also predicted by the Response Factor program. For floating tests with either insulation on the inside or outside surfaces (figures 10 and 11), the effect of an internal mass is reduced to negligible proportions. This is because the heat absorption and rejection by the internal mass is very small when the cyclic fluctuations of the inside air temperature are small.

To examine the effect of windows on the inside air temperature, a comparison was made between tests numbered 1 and 3. The measured temperature deviations from the mean inside air temperature for these two tests are plotted in figure 16. From figure 16 it may be seen that for the two cases without insulation the effect of adding windows had little effect on the cyclic fluctuations of the inside air temperature. The percent glass to wall area was 8.4. For cases with insulation, one would expect the addition of windows would have a more pronounced effect on the cyclic fluctuations of the inside air temperature, since the heat flow through windows would be a larger percentage of the total heat flow. Direct experimental comparison is not possible because measurements were not made on the structure with insulation either inside or outside without windows. For practical purposes an improvement in the indoor temperature profile as shown in figure 13 by elimination of windows is considered to be negligible.

Figures 17 and 18 show the inside and outside wall surface temperature variations for test 1; no insulation, no windows and no internal mass. Each curve represents the average temperature of five thermocouples located at the same height above the floor and at the wall positions as shown in figure 6. From these graphs it can be seen that the inside and outside wall surface temperatures for this floating test differ from each other within a 2 °F band except for the average temperatures at the 0 and 10 foot levels. This suggests that the assumption of one-dimensional heat transfer is valid over a major area of the wall surface, multi-dimensional effects being confined in a region near the junctures of the floor to wall and the roof to wall. Figures 17 and 18 also show by comparison the effect of thermal resistance and mass of the building, i.e., at the 10 foot level the outside surface changed in temperature by about 30 °F while the inside surface at the same level changed by about 16 °F. Also, the highest and lowest temperatures on the outside surface occurred about 2 hours sooner than the inside surface. The use of thermal insulation resulted in a much more uniform inside wall temperature distribution. For instance, when insulation was placed on the outside surface of the building (floating test numbered 5) a maximum inside wall surface temperature fluctuation of 2.3 °F occurred over the 24-hour cycle at the juncture of the wall and the ceiling. In addition, at any instant the maximum floor to ceiling temperature difference along the inside wall surface was 1.8 °F.

Comparisons between the measured and calculated heat fluxes at the inside surfaces of major building components for floating test 1 are shown in figures (19) through (21) where negative values denote heat flow into the room. Measured heat fluxes shown for the floor, roof, and the wall were obtained using heat flow meters located at the center of the floor, the center of the roof, and at the midpoint of wall in plane B, respectively, (see figure 6). Since both the measured and calculated data contain many small fluctuations due to local variations of the inside air temperature, it was necessary to apply a harmonic analysis to each set of heat flux data, maintaining only the first eight terms to give the smoothed curves shown in the graphs. From figures 19 and 20 it can be seen that the agreement between the measured and calculated heat fluxes at the inside surface for floor and the roof was very good.

Figure 21 shows fairly large deviations for the smoothed measured wall heat flux from the calculated values. The same type of performance characteristic was obtained in other tests where the floor and ceiling also showed good agreement. The calculated heat flux values were completed assuming a constant film resistance for all heat flow conditions. From previous discussion concerning the film resistance, it will not be a constant, but will be a function of the heat flow conditions that promote air flow adjacent to the surfaces. Heat flow meters are very sensitive instruments and the signals from them can vary considerably when subjected to the turbulent air motion along a wall. Readings that were taken at one instant and at half-hour intervals would not be expected to give a true representation of average signal from the meters for the time period under consideration. For measuring heat flow at wall surfaces the signal from the meters should have been recorded for finite time periods to give more representative values.

To study the processes which combine together to produce the thermal performance of the air inside a building, the profiles of the heat flux at the separate inside surfaces during the outside air temperature cycle were plotted. Figure 22 shows the variations of the heat flux at the inside surfaces of the roof, walls, floor and window for the case of no insulation (floating test 3). The heat flux profiles appearing in these graphs were calculated by the Response Factor computer program. Positive values signify heat flow in a direction from the inside to the outside. The net heat transfer to or from the indoor air at any instant of time is equal to the algebraic sum of the products of the heat fluxes at the surfaces and their respective areas plus the heat exchange resulting from air infiltration. For the floating tests this sum should be equal to zero. The heat flux at the inside surface is affected by the resistance to heat flow and the thermal heat capacity of the materials across which heat must flow to the surface as well as the dynamic conditions of the temperature of the outside and inside air. For this reason, heat is simultaneously flowing out of and into different surfaces of the room. The heat flow at the windows is in phase with the temperature potential created by the difference in the outside and inside air temperature because heat storage (mass) of the windows was negligible. The roof and walls are not in phase with this potential due to their appreciable heat storage capacity and their minimum values (maximum heat flows into the room) lag behind that for the windows by about 3 and 9 hours, respectively. The roof was approximately one-half the thickness of the walls, and a smaller delay time to reach a maximum or minimum was expected. Heat flow into and out of the floor was approximately in phase with the inside air temperature cycle shown in figure 11. This was as expected because the ground temperature beneath the floor was relatively constant with time.

A similar analysis of heat flow was performed for the case of insulation placed on the outside surfaces (floating test 5). Figure 23 shows the profiles of the heat flow at the inside surfaces for this test condition. With the peak outside air temperature at the fourteenth hour, the delay times for maximum heat flows into the room were 12 and 5 hours for the walls and roof, respectively. The effect of placing insulation on the outside surface was to increase the delay time (9 and 3 versus 12 and 5) and considerably reduce the amplitude of the heat flux profiles.

Figure 24 is a plot of deviations of the inside air temperature from the instantaneous average of the six air thermocouple locations shown in figure 5 over a twenty-four hour period for the case of no insulation (floating test 3). As in all previous plots, the peak outside air temperature occurred at the fourteenth hour. Positive deviations signify that the air temperature at that location was higher than the average inside air temperature. On a daily average the air adjacent to the ceiling was about 2 °F warmer than the air layer next to the floor with the floor being as much as 3 °F warmer and 8.5 °F colder than the ceiling during portions of the cycle. The portion of the cycle with the largest floor to ceiling temperature difference (about hour 18) shows a good example for a heated surface facing downward (ceiling) and a cooled surface facing upward (floor) where the air flows adjacent to the two surfaces were in the laminar range thus producing little mixing of air and large vertical temperature gradients. Conversely, the portion of the cycle with the smaller temperature differences (about hour 5) shows an example for a cooled surface facing downward (ceiling) and a heated surface facing upward (floor) where the air flows adjacent to the surfaces were in the turbulent region producing mixing of air by natural convection and smaller vertical temperature gradients. One must conclude from figures 22 to 24 that the indoor convection pattern is continually changing, as well as surface coefficients of heat transfer. The same observations can be made from the plots of deviations from the average inside air temperatures given in figures 25 and 26 for insulation placed on the inside (test 4) and the outside (test 5) surfaces, respectively. In these two cases the vertical temperature gradients are considerably dampened due to the addition of insulation, and subsequent reductions in variations of the surface temperatures.

b. Thermostated Tests

For the thermostated tests the inside room air temperature was maintained within an approximate 2 °F band by controlling the heat input to the experimental structure. The room air temperature was obtained by averaging the six air temperatures (figure 5) at each time interval.

Figures (27) through (31) are graphs for tests numbered 6 to 10 which compare the measured power supplied to the electric heaters and the heating load calculated by the Response Factor program over the 24-hour outdoor air temperature cycle as shown in each figure. The calculated load was computed by summing the net heat flows through each building component and heat flow due to air infiltration at each time interval. Areas used for computing heat flows were the arithmetic averages of the inside and outside areas of each building component. Since both the measured and calculated heating load data contained many small fluctuations due to variations of the inside air temperature, it was necessary to apply a harmonic analysis to each set of heat load data. Only the first eight terms were maintained to give the smoothed curves shown in the graphs.

As shown on figures 27 through 31 the minimum measured and calculated heating load usually occurred later in the day than the peak outside air temperature (hour 14) because of the effect of the mass of the building and insulation retarding heat flow through building components. Comparing the cases without and with insulation, figure 27 with figures 28, 29, 30 and 31, it can be seen that the effect of placing insulation on either the inside or outside surfaces of the building was to substantially reduce the amount of heating needed to maintain a constant inside air temperature. Generally the correlation between computer prediction and the measured heating load profiles is reasonably good. There was less than a six percent difference between the maximum computed and measured heating loads for all cases. The average difference was 3.5 percent for the five tests.

For test 10 (figure 31) and test 9 (figure 30) the building was identical but for test 10 the outdoor temperature cycle was changed from 40 - 100 F to 10 - 70 F and the indoor air temperature was changed from 77.6 F to 73.8 F. The shape of the heating load profiles are similar but for test 9 the maximum and minimum loads were about 2600 and 500 Btu/hr, respectively, and for test 10 about 6300 and 3600 Btu/hr, respectively. The maximum loads for both tests are lower than the values that would be estimated on the basis of steady-state procedures as is discussed later in this paper in detail.

For the thermostated tests with insulation (tests 7 through 10), the measured heating loads lag the calculated heating loads over part of the 24-hour cycle. Consistently, the phase lag occurred on the profiles in the time period between the maximum and minimum loads. Also, some phase lags occurred following the minimum loads. The reasons for these phase lags are not obvious because the phase lags varied from one test to the other and the lag is especially evident in test 9, figure 30. It was found during analysis that the calculated heating load was influenced by whether the inside, outside or average area was used, lack of heat flow allowance for corners and the building foundation, variations of inside air temperature, and heat transfer coefficients at the inside and outside surfaces.

To illustrate the effect of windows on the thermal behavior of the experimental house, calculations were made using the Response Factor method for the cases of 7 single pane windows, 7 double pane windows, and no windows with insulation on the outside surfaces. The outside air temperature cycle used was 40 - 100 F and the inside air temperature was 77.6 °F. Figure 32 shows the computed heating load profiles for the above cases. The peak heating loads for single pane windows was 50% higher and occurred approximately two hours earlier than the case without windows. The peak heating load for double pane windows was 7% lower than single pane windows. Some validation by measurement of the latter can be seen by comparing the peak heating loads as shown in figures 29 and 30, about 4% difference.

c. Heating Load Predictions

Steady-state methods are usually used for predicting maximum heating loads from which the size of heating equipment is selected. Sometimes this process results in oversizing of heating equipment. To illustrate and compare the steady-state procedure and the dynamic procedure as given by the computer programs in Appendices C and D, Table 4 was prepared.

The values listed in the column under Steady-State Method in Table 4 were calculated for the experimental structure as used in tests 6 through 10, and for the outside air temperature cycles used during the tests. The steady-state maximum heat flow rate was calculated using the following formula:

$$q = U_F A_F (T_i - T_g) + (T_i - T_o) \Sigma U_n A_n + 1.08 V (T_i - T_o)$$

where q = heating load, Btu hr^{-1}

U_F = coefficient of transmission for the floor, Btu hr^{-1} ft^{-2} F^{-1}

A_F = area of the floor, ft^2

T_i = average inside air temperature,

T_g = average ground temperature, F

T_o = outdoor temperature, F

U_n = coefficient of transmission for the nth surface, Btu hr^{-1}, ft^{-2} F^{-1}

A_n = area of the nth surface, ft^2

V = air infiltration rate, cfm

The first term corresponds to the heat transferred through the floor. The second term is for heat transferred through the walls, windows and roof. The third term is heat transfer due to air infiltration. When the above equation was used to predict the maximum heating load the minimum outdoor temperature was used for T_o. When the above equation was used to calculate the daily average heating load, the daily mean outdoor temperature was used for T_o.

The peak and daily average heating loads as calculated using the steady-state and Response Factor methods are presented for comparison with measured values in Table 4.

The maximum heat flow rates as calculated by the steady-state method for the conditions during tests 6, 7, 8, 9, and 10 were 31, 59, 65, 68 and 30 percent, respectively, higher than the measured rates. The maximum heat flow rates as predicted by the Response Factor method were 6 percent or less of the rates measured during the tests. The above high percentages indicate that when steady-state maximum rates are used to size heating equipment without taking into account the heat capacity effects of the building considerable oversizing could result.

When comparing daily average heat flow rates between the steady-state method, the response factor method and measured values, Table 4 shows that all values are reasonably close to each other for a given test number (about 10% or less). This was expected because a minimum quantity of heat energy is necessary to maintain the indoor air temperature over a period of 24 hours.

Table 4

Comparison of Maximum and Average Heating Loads

Test	Maximum Heat Flow Rate, (Btu/hr)			Daily Average Heat Flow Rate, (Btu/hr)		
	Steady-State Method	Response Factor Method	Measured	Steady-State Method	Response Factor Method	Measured
6	14925	11184	11372	4785	4997	5346
7	4368	2905	2748	1337	1490	1475
8	4642	2939	2811	1523	1578	1664
9	4537	2558	2700	1465	1524	1639
10	8207	6332	6321	4988	5097	5062

7. Conclusions

The NBSLD computer program was experimentally validated for predicting the daily indoor air temperature as it is influenced by known outdoor temperature conditions and the mass and thermal resistance of the building. Furthermore, when the inside air temperature was thermostated, this program predicted the peak and daily average heating loads and may therefore be used to size equipment needed to condition the interior of a building and to predict energy requirements. It was shown that steady-state methods of heating load calculations could result in oversizing heating equipment by 30% or more. The NBSLD dynamic method takes into account heat storage effects and therefore predicts the peak heating load more realistically. The maximum percent difference between the computer calculated peak heating load and measured values was six percent, and the average difference was 3.5 percent for the five tests.

The combination of mass in the walls and roof facing the interior with insulation placed on the outer surfaces of the building was very effective in reducing and controlling the variation of the indoor air temperature. This desired effect was also predicted by the computer program. When the inside air temperature was not thermostated and the building floated in response the outside air temperature condition, placing insulation on the inside building surface reduced the variation of the inside air temperature from 10 1/2 F to 5 1/2 F. Furthermore, when this insulation was placed on the outside surface of the building, the peak to peak variation in the inside air temperature was reduced to 2 °F. In addition, comparing cases of no insulation, insulation inside, and insulation outside, the temperature distribution from floor to ceiling on walls and in the indoor air was a minimum when insulation was placed on the outside of the building.

The effect of an internal mass on the thermal behavior of the experimental structure was generally small. An internal mass may have a greater effect in a less massive building. On the other hand, windows had a significant effect on the computed thermal behavior of the experimental structure. For instance, the peak heating load for the experimental structure with windows and insulation was 50% higher than the same building without windows. Use of storm windows reduced the peak heating load by 7 percent.

8. Acknowledgments

The authors wish to thank H. E. Robinson for his many ideas, conceptual approach and technical suggestions prior to and during the experimental phases of this investigation. Also appreciation is expressed to D. R. Showalter, J. D. Allen, J. M. Dungan and J. W. Grimes for their technical assistance in the installation of the instrumentation and day to day operation of the experiments. The very helpful suggestions and comments made during review of this paper by P. R. Achenbach are gratefully acknowledged.

Figure 1 Experimental structure in environmental chamber

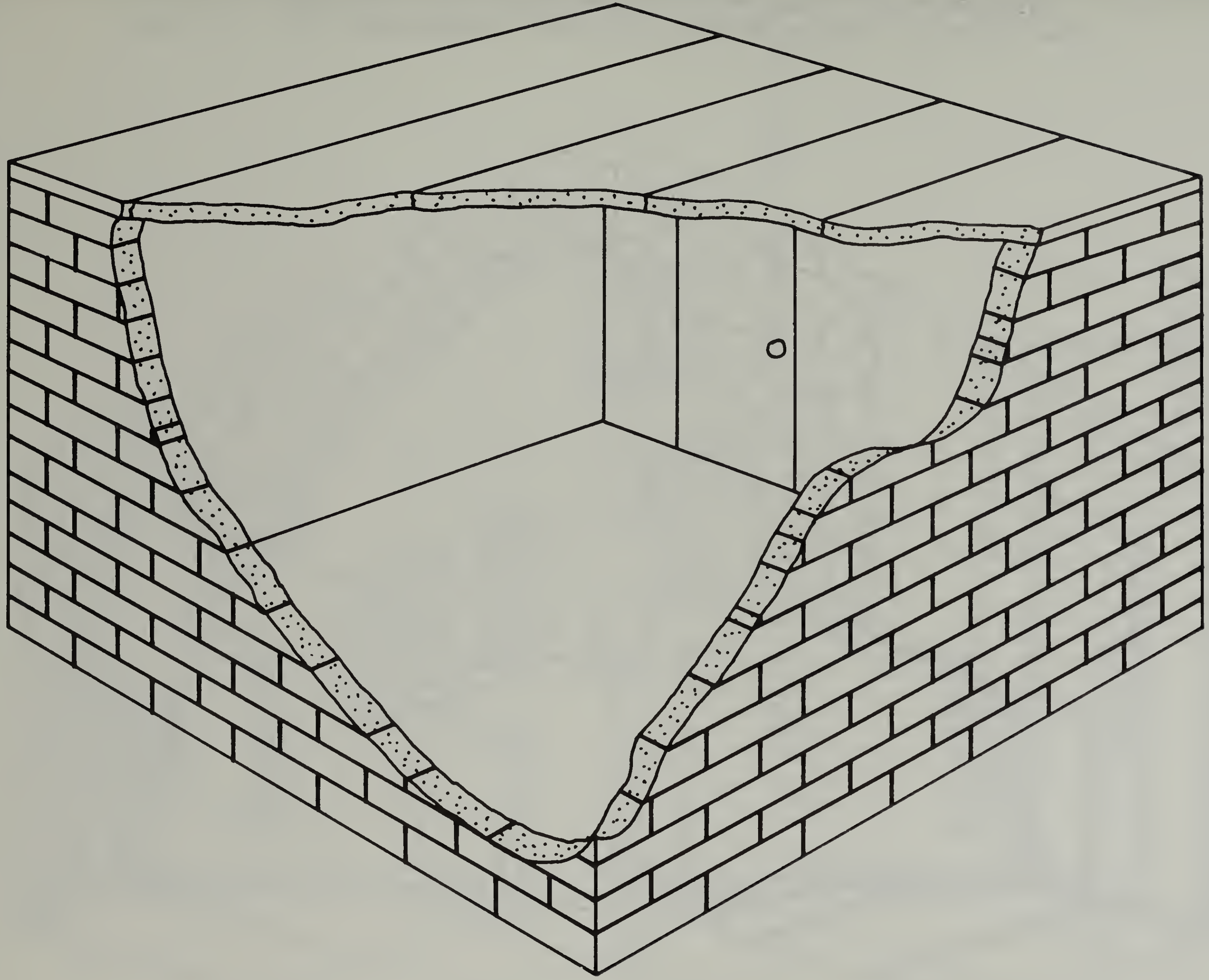


Figure 2 The basic experimental structure

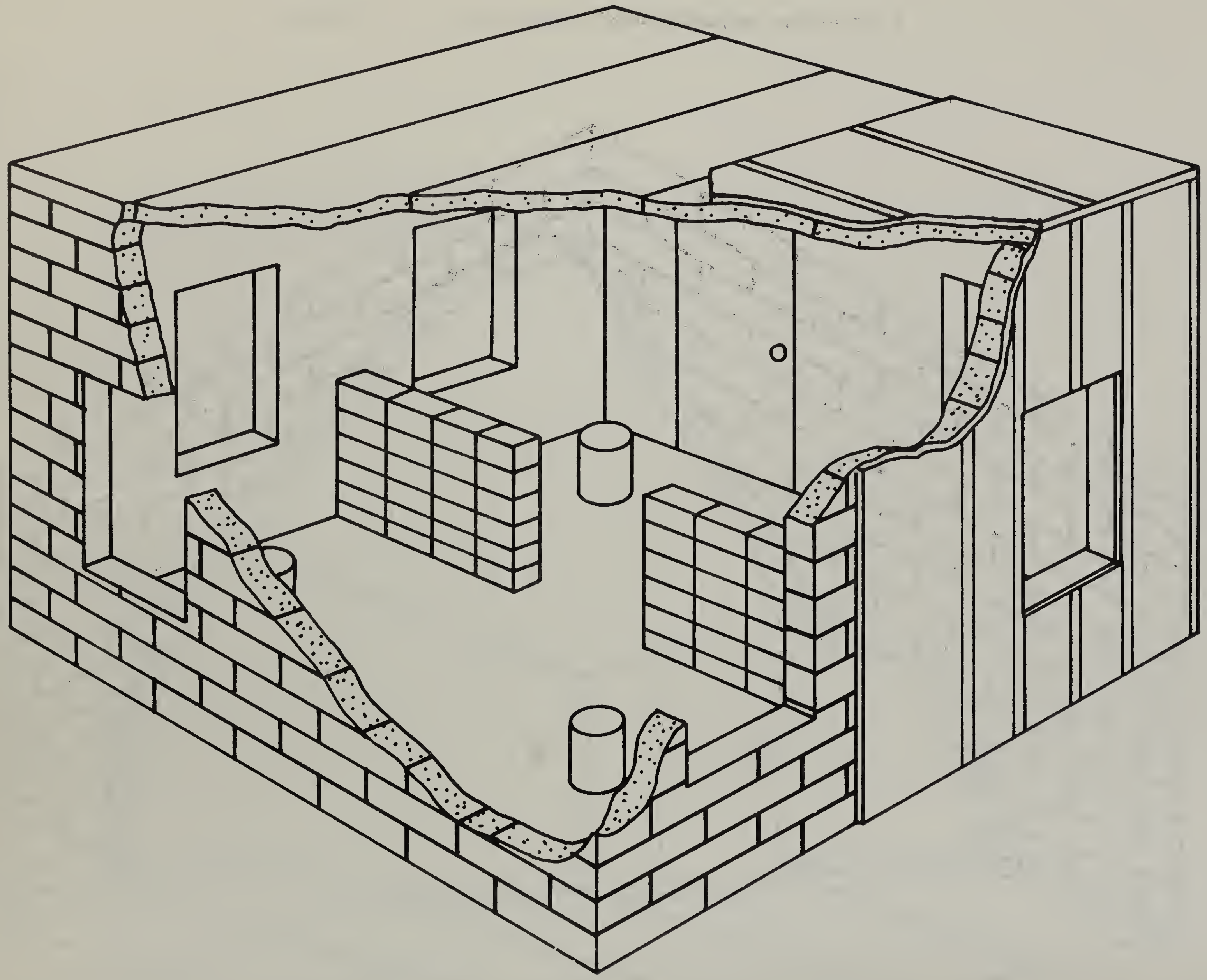


Figure 3 The experimental structure showing windows, internal mass, heaters, and insulation on the outside of the building

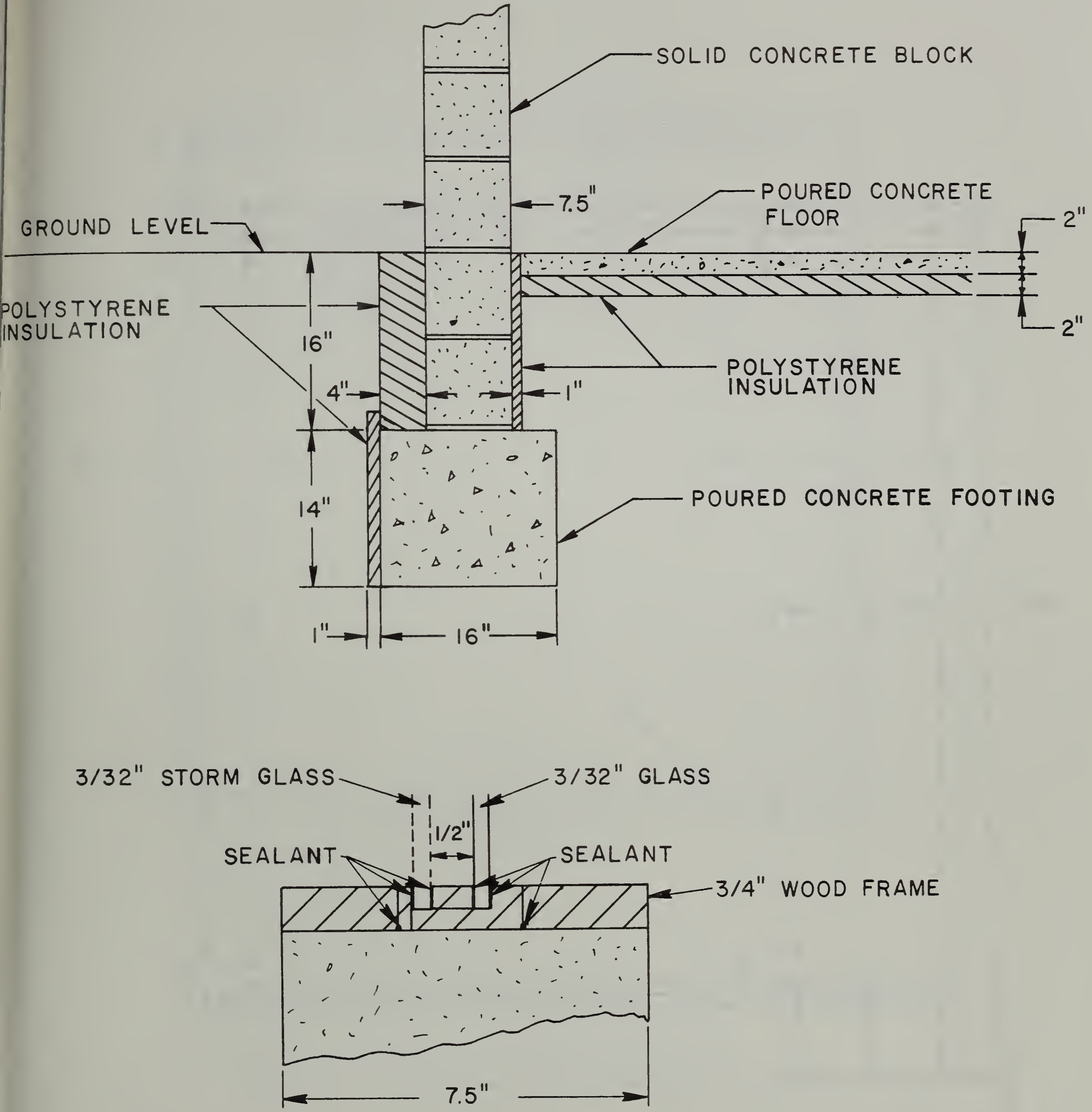


Figure 4 Floor, footing and window details

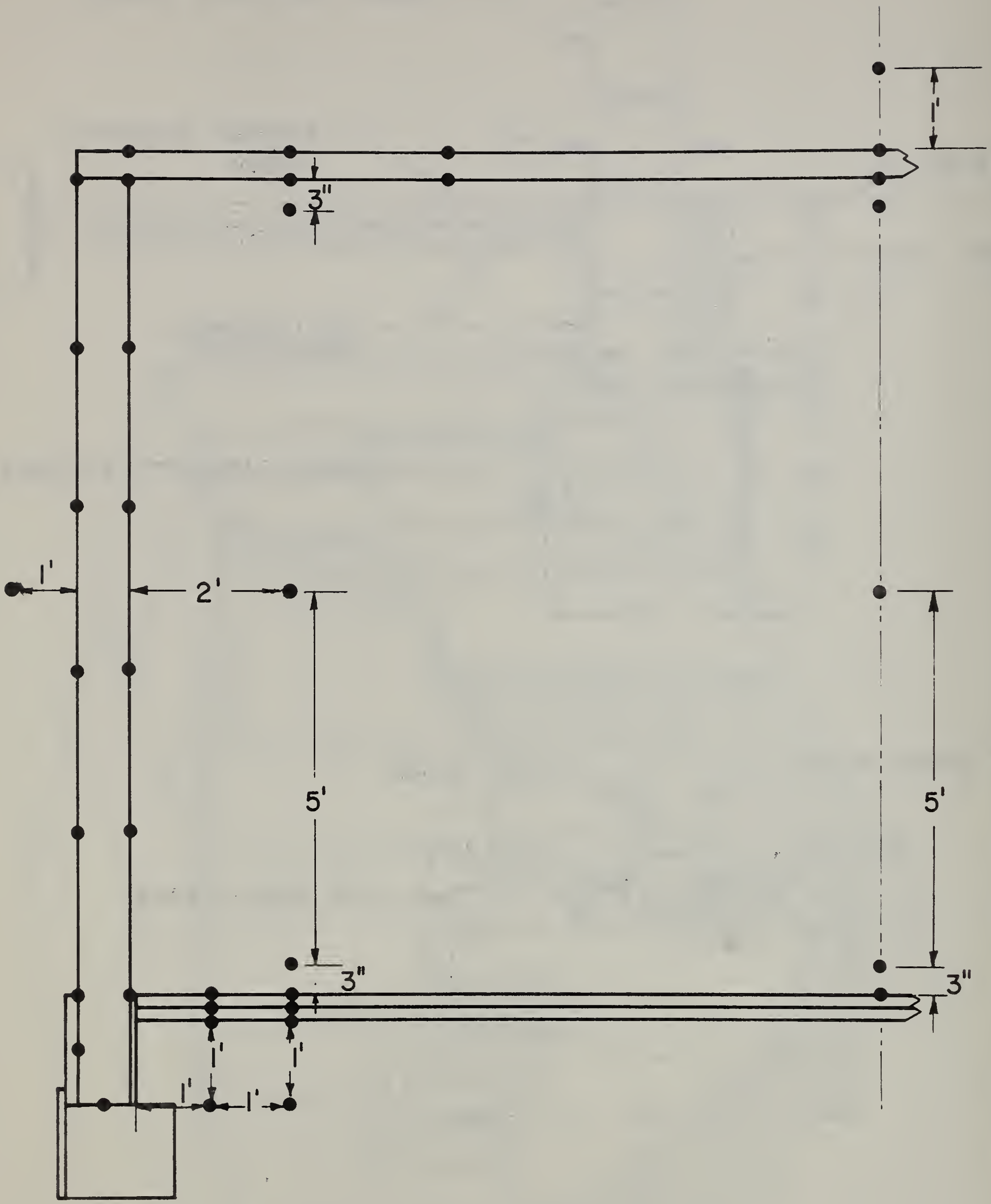


Figure 5 The experimental structure showing thermocouple locations

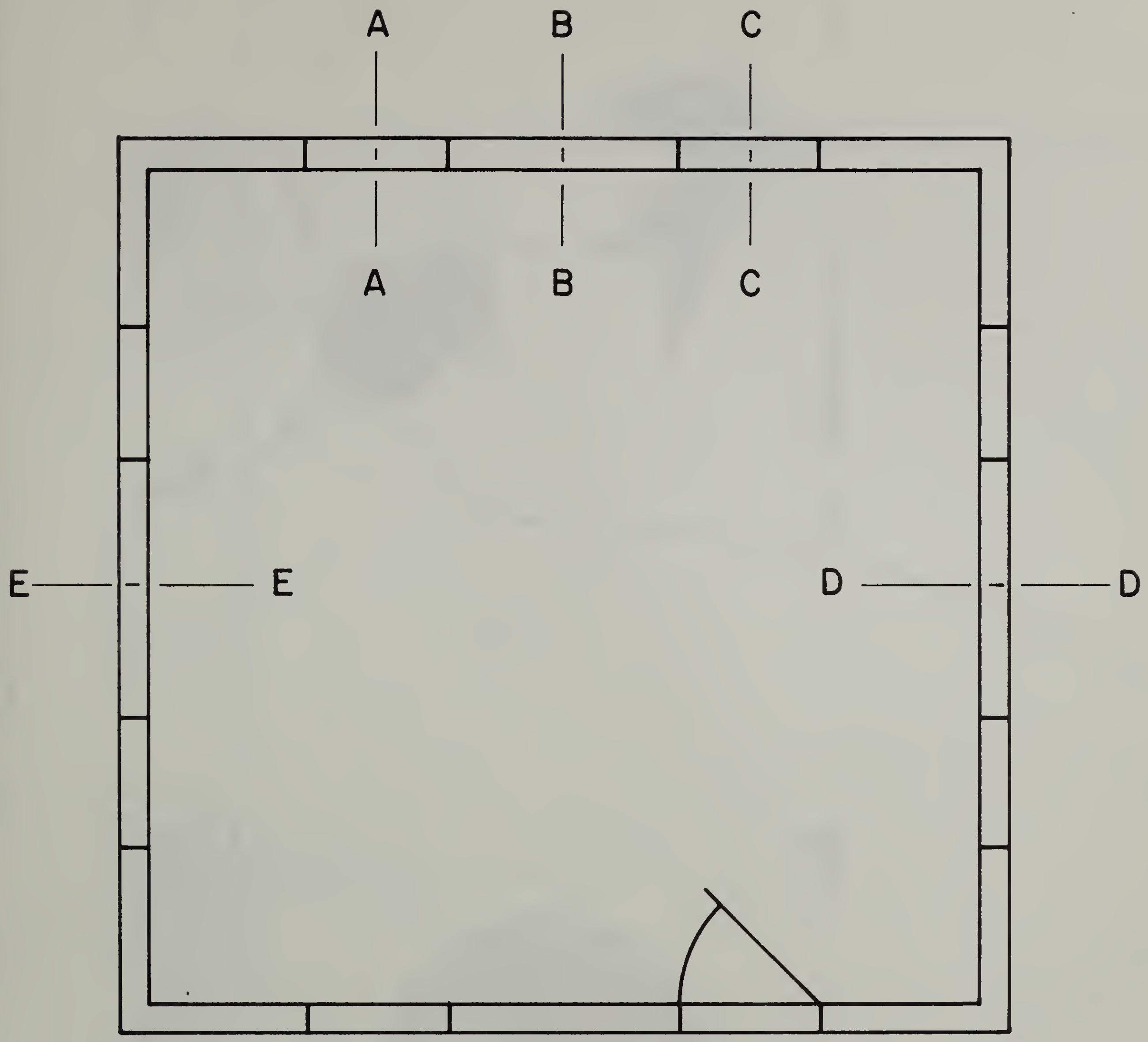


Figure 6 Plan view of thermocouple locations

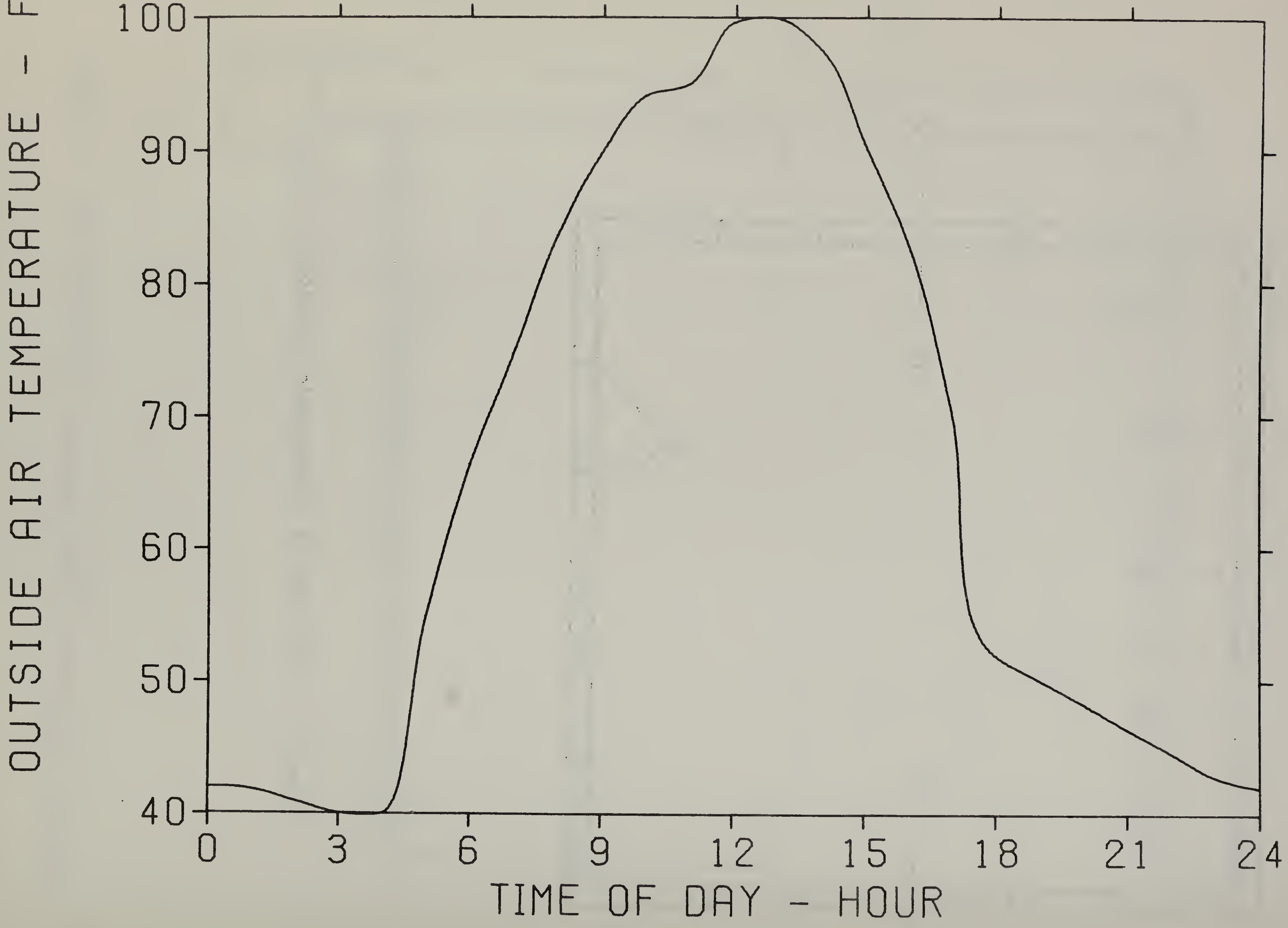


Figure 7 Outside sol-air temperature cycle

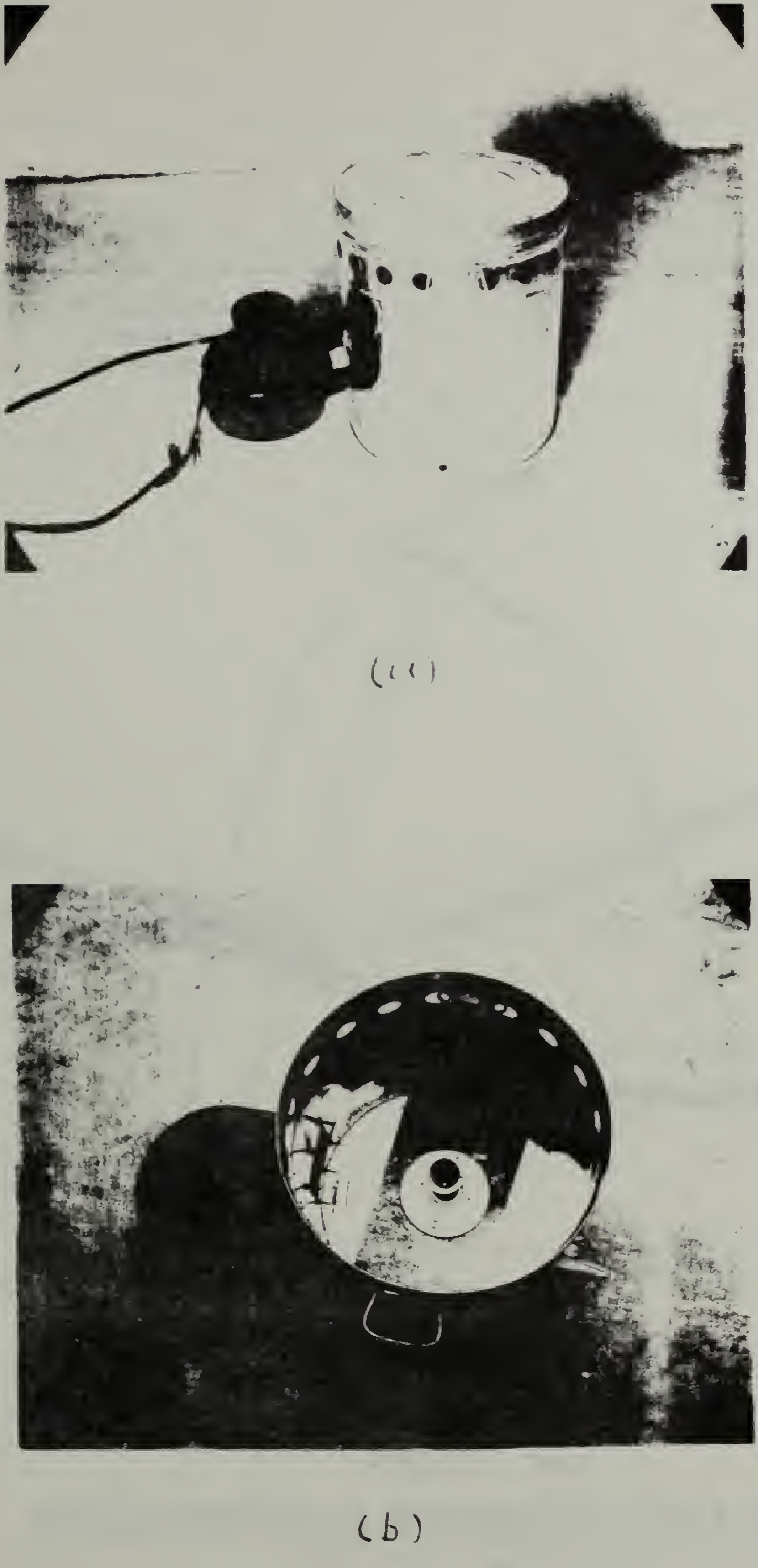


Figure 8 (a) Fan heater
(b) Fan heater with top cover removed

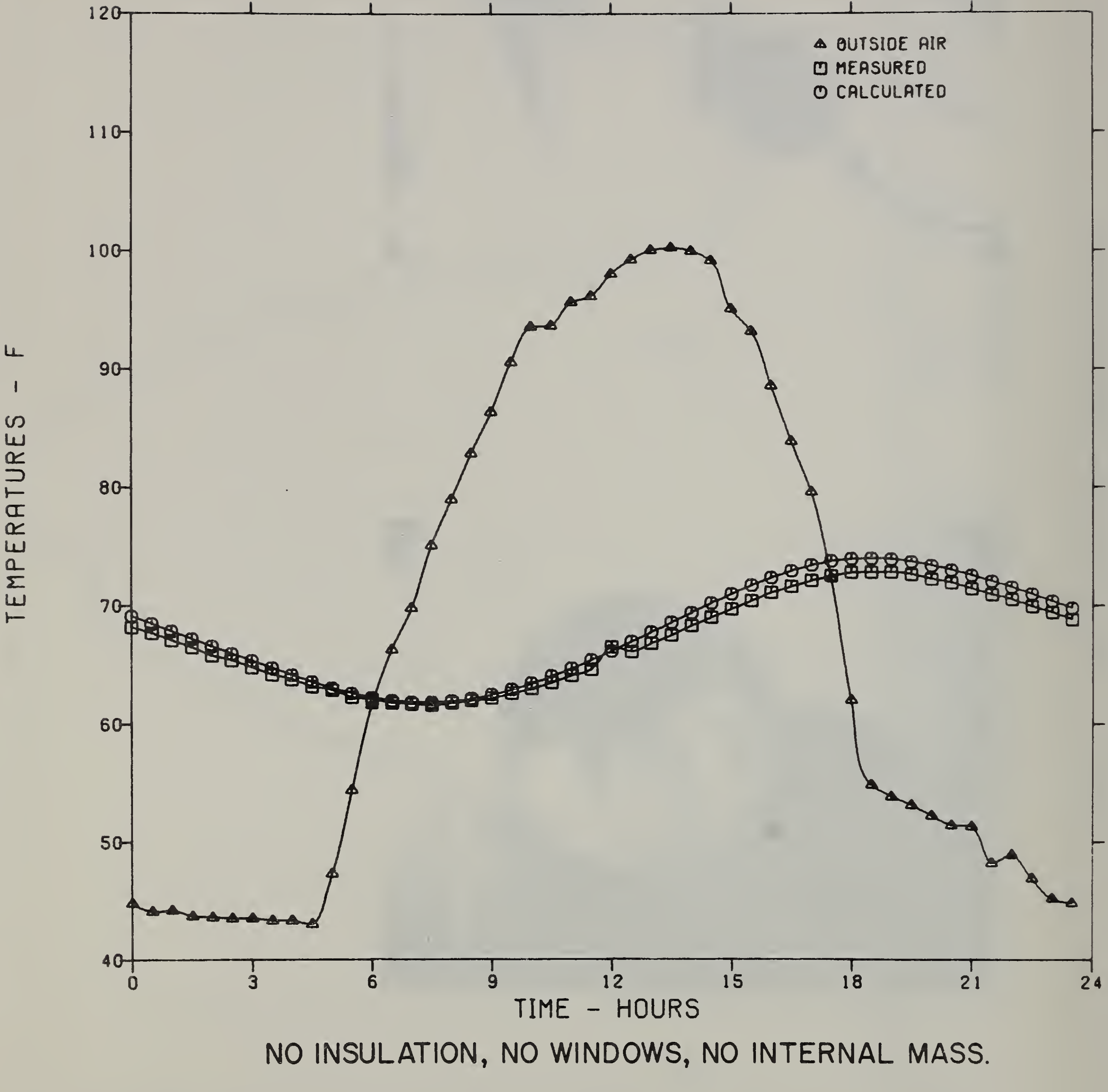


Figure 9 Comparison between measured and calculated inside air temperatures for floating test 1

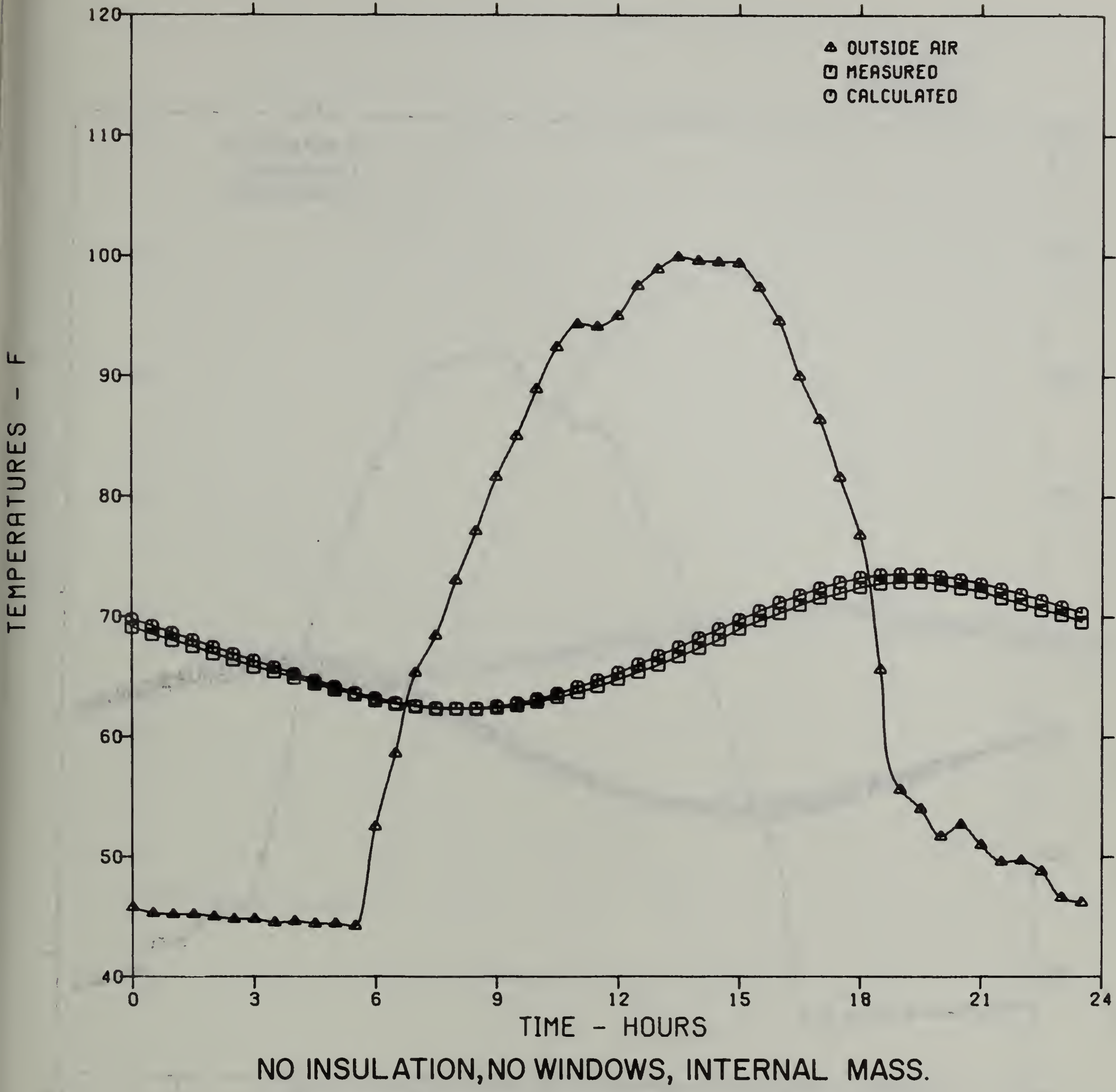
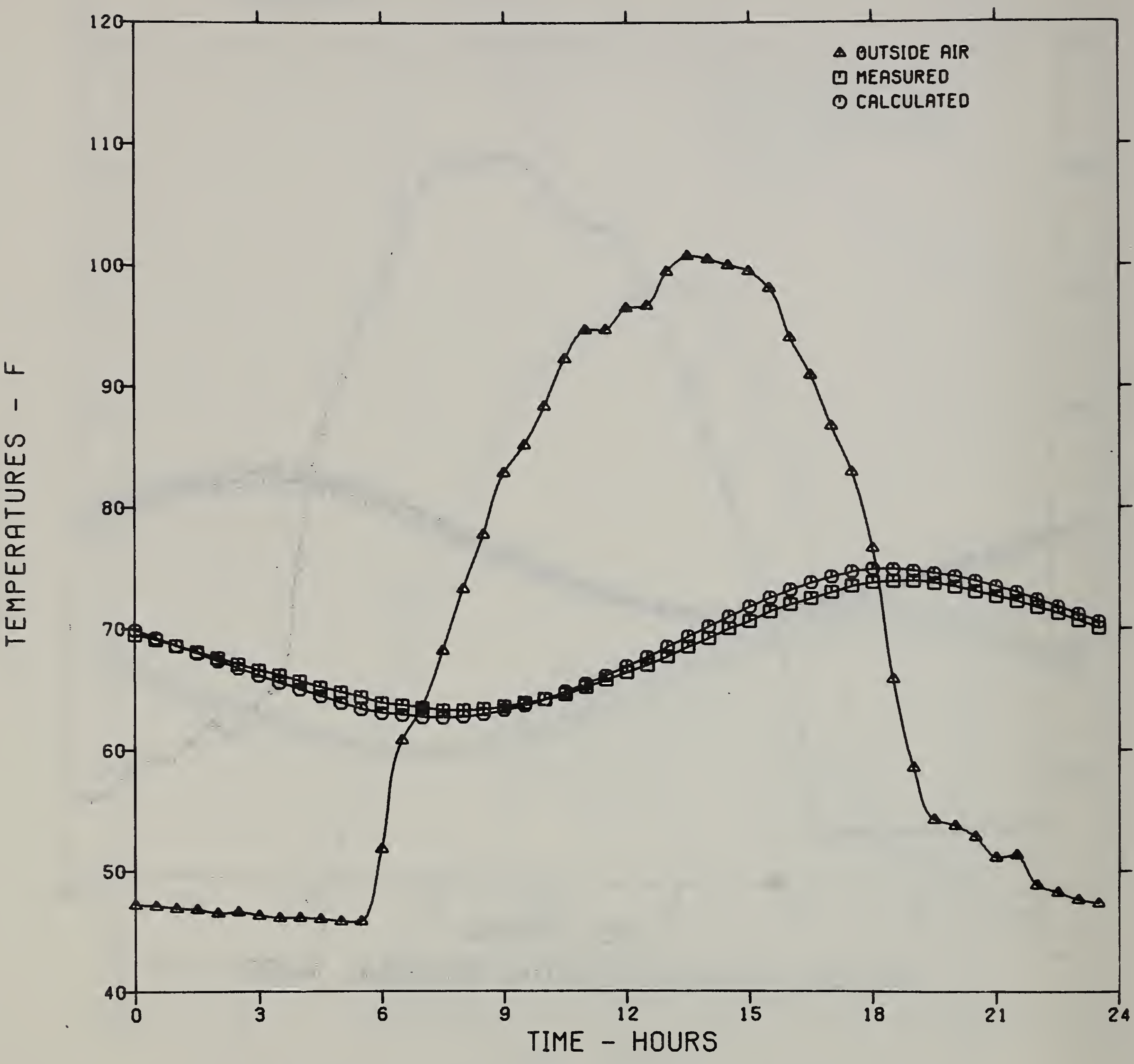


Figure 10 Comparison between measured and calculated inside air temperatures for floating test 2



NO INSULATION, WINDOWS, NO INTERNAL MASS.

Figure 11 Comparison between measured and calculated inside air temperatures for floating test 3

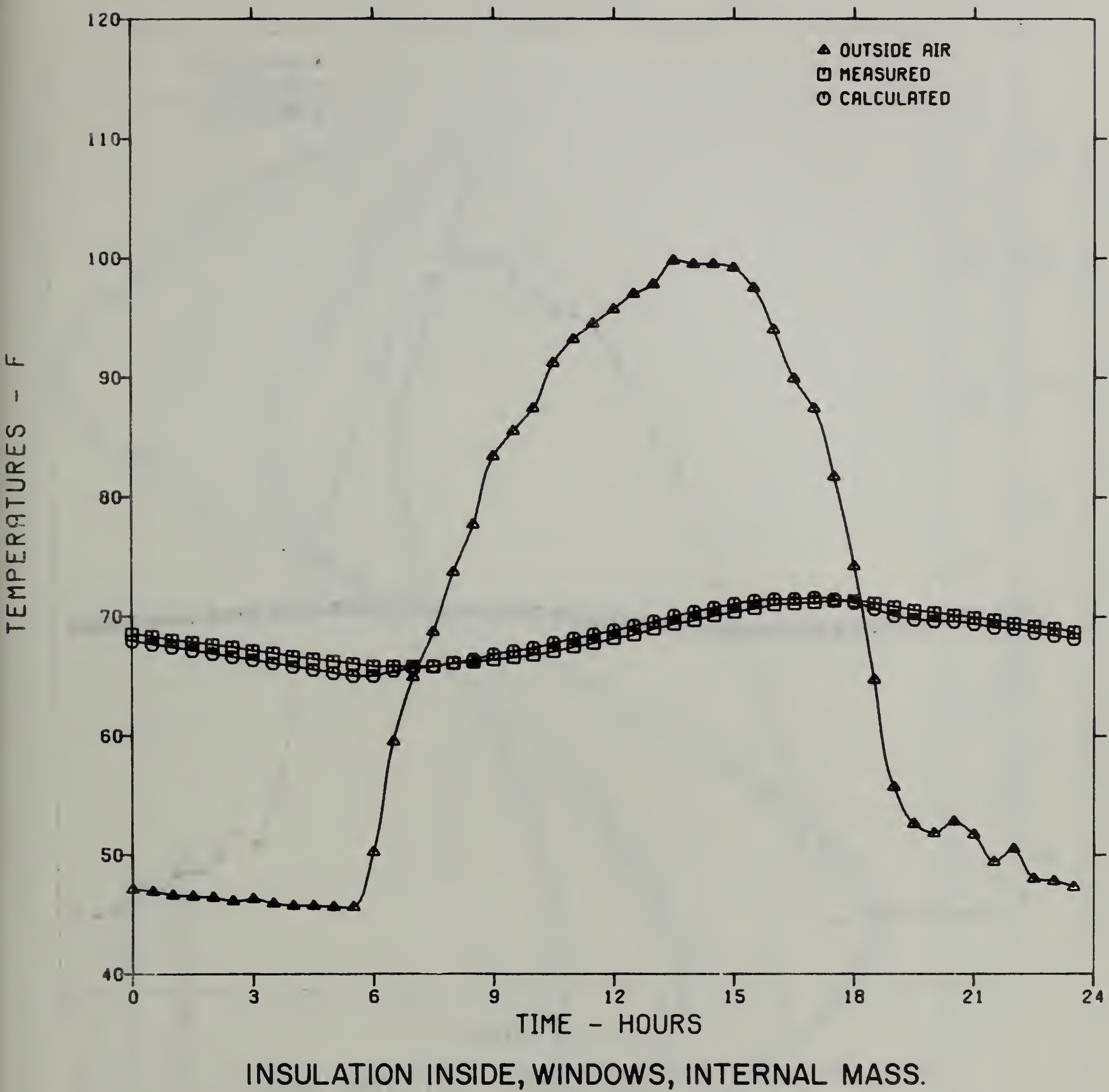


Figure 12 Comparison between measured and calculated inside air temperatures for floating test 4

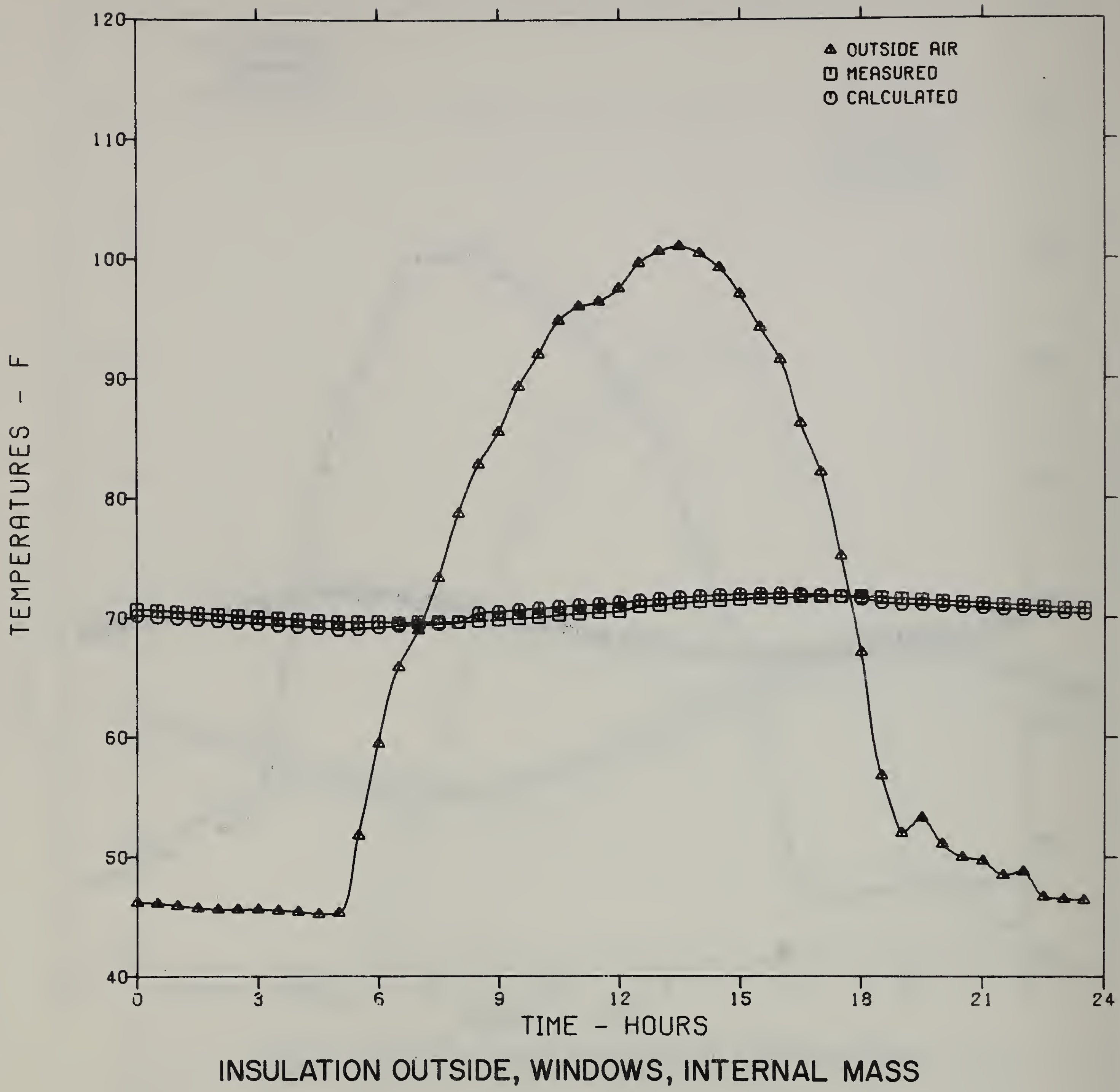


Figure 13 Comparison between measured and calculated inside air temperatures for floating test 5

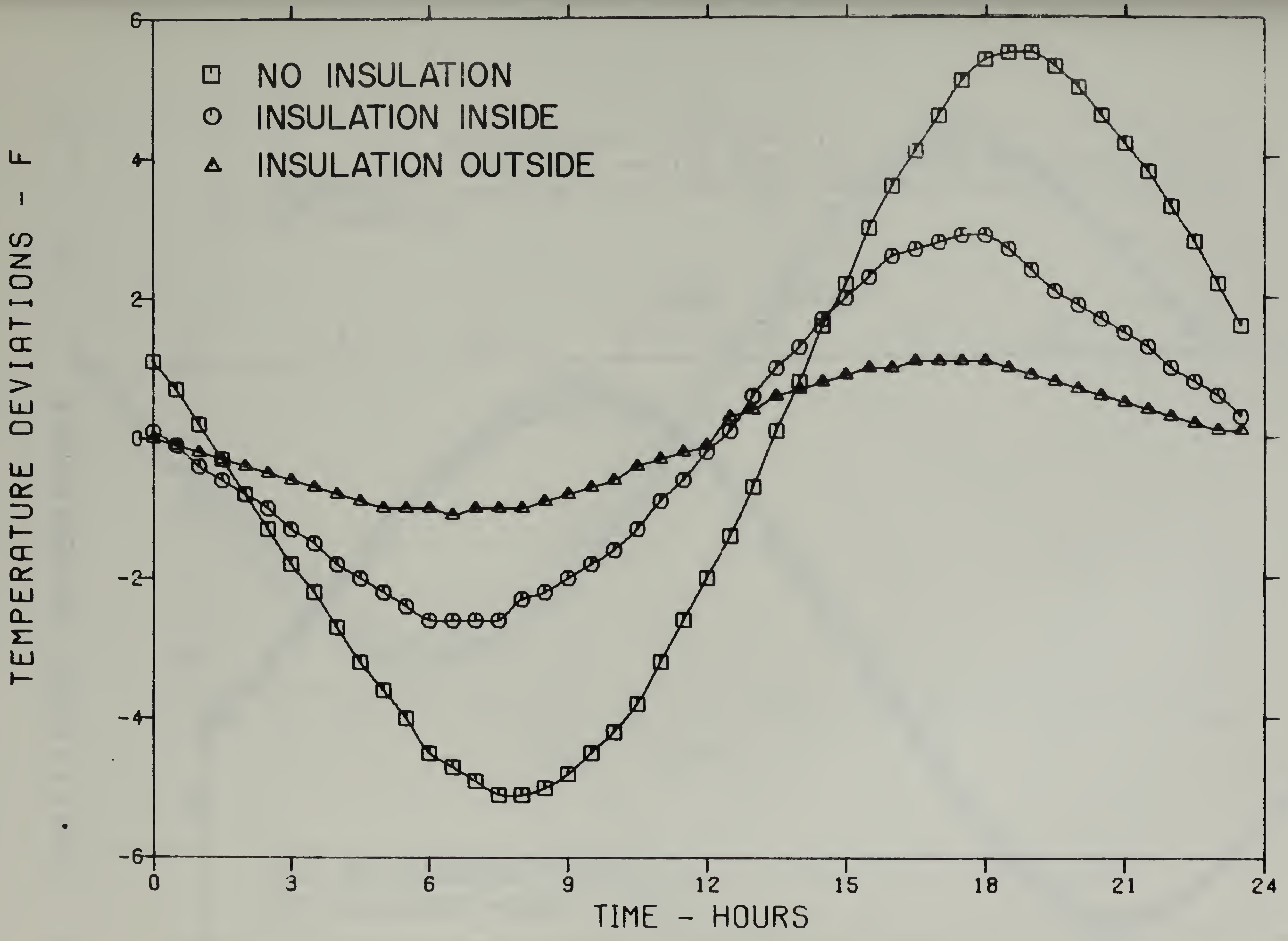


Figure 14   Comparison of inside air temperature deviations from daily average inside air temperature for identical houses for cases of no insulation, insulation inside, and insulation outside

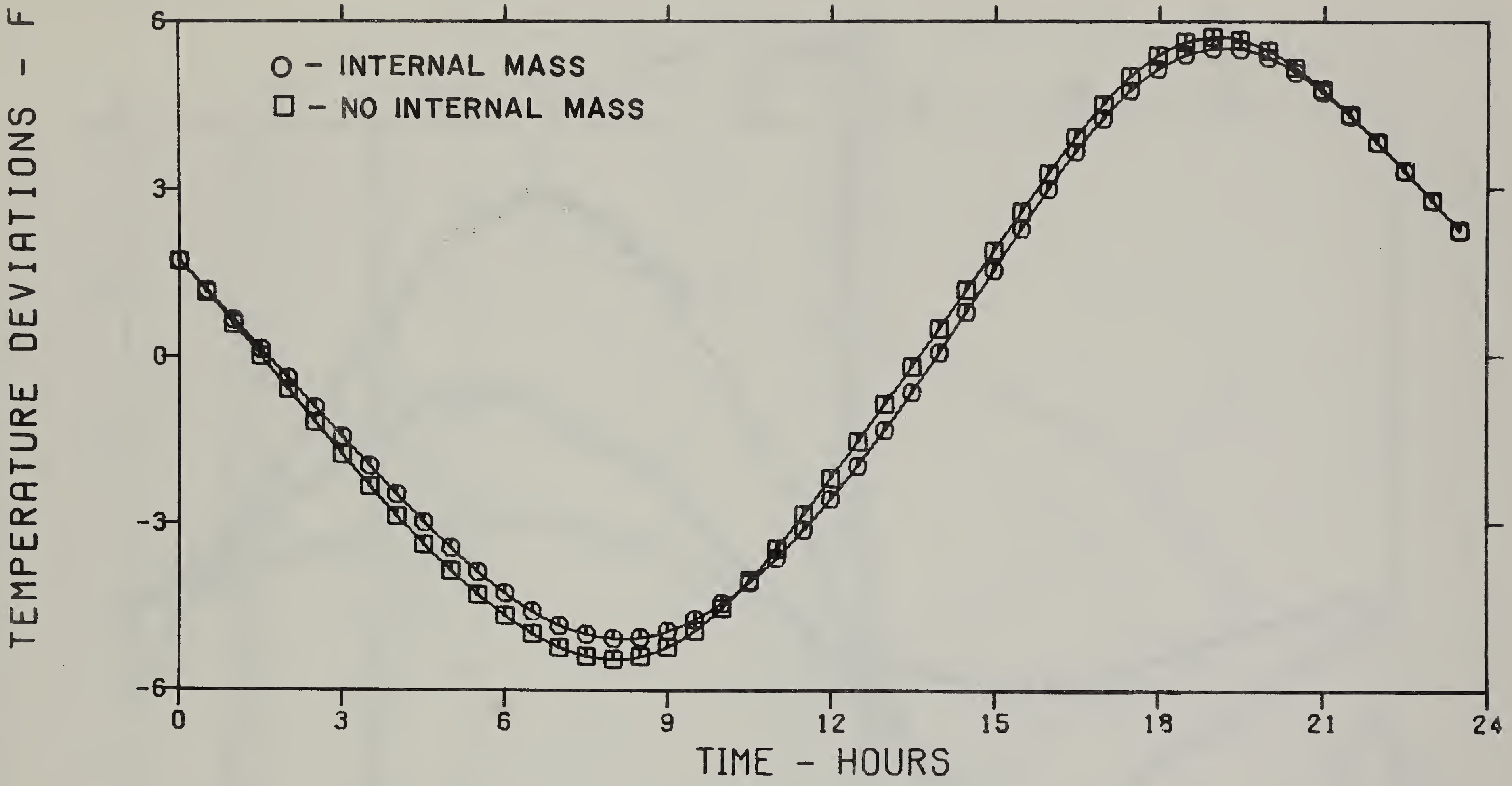


Figure 15 Comparison of the inside air temperature deviations from daily average for identical houses with internal mass (test 2) and without internal mass (test 1)

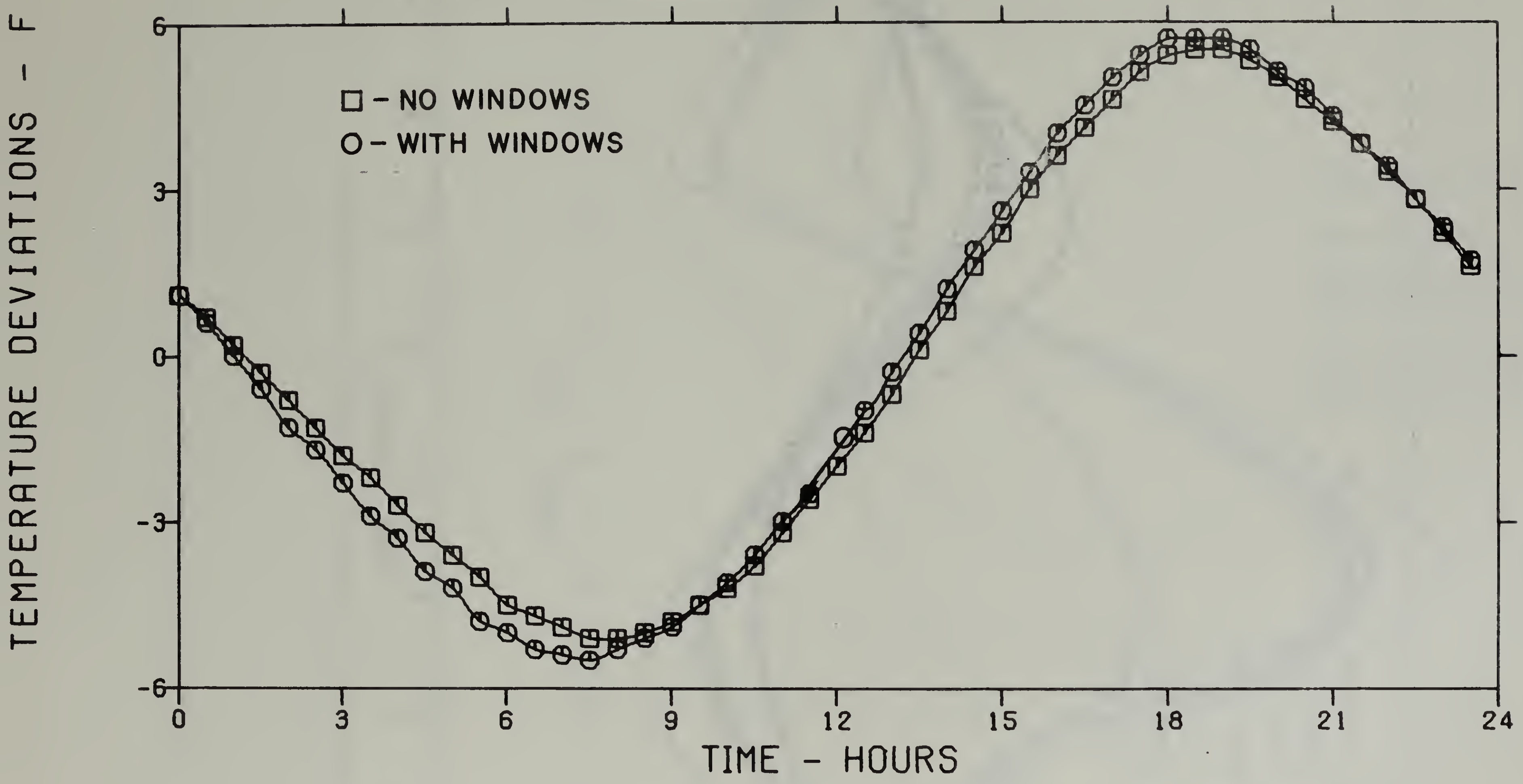


Figure 16 Comparison of the inside air temperature deviations from daily average inside air temperature for identical uninsulated houses with windows (test 3) and without windows (test 1)

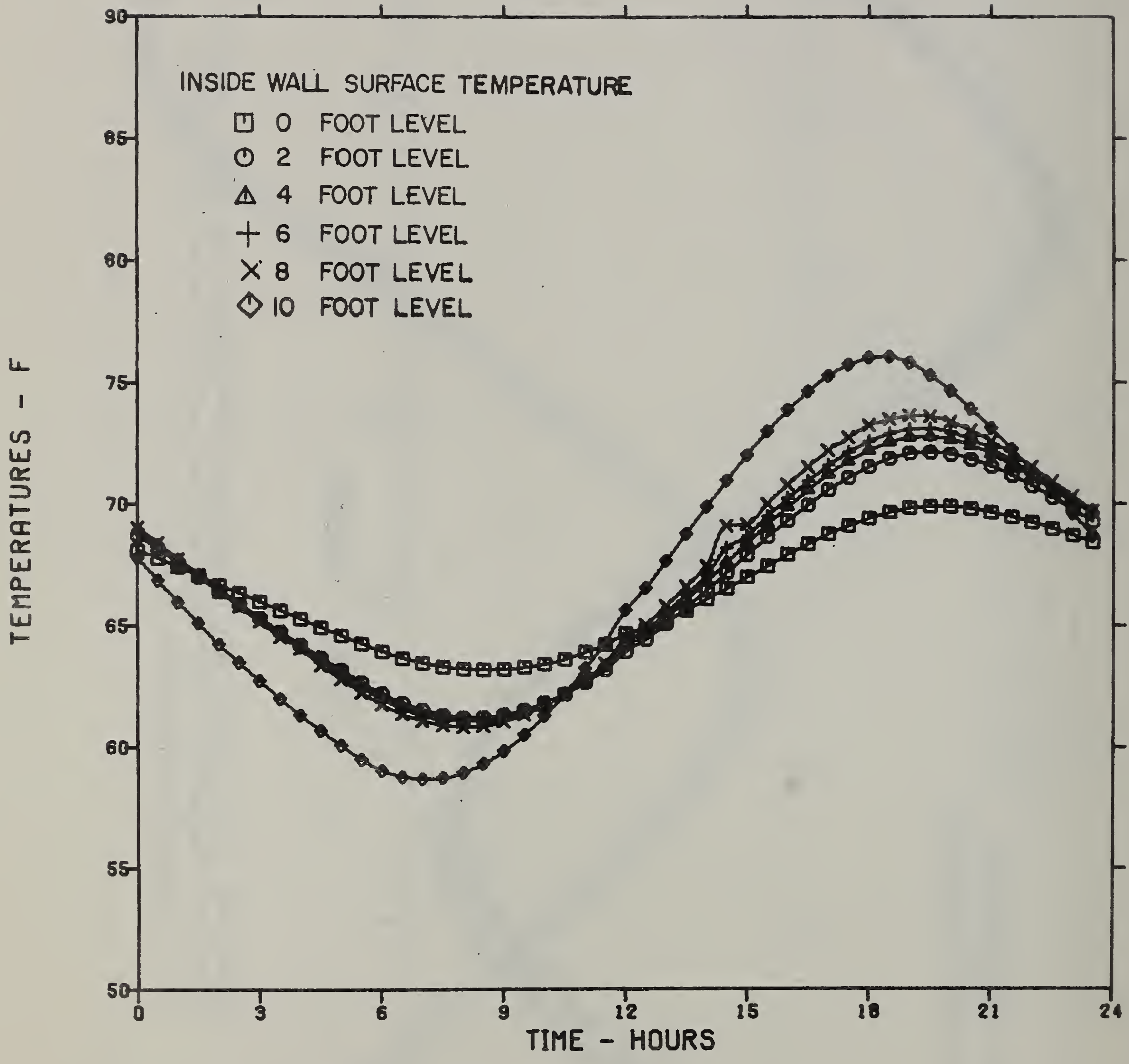


Figure 17 Variations of inside wall surface temperatures for test 1

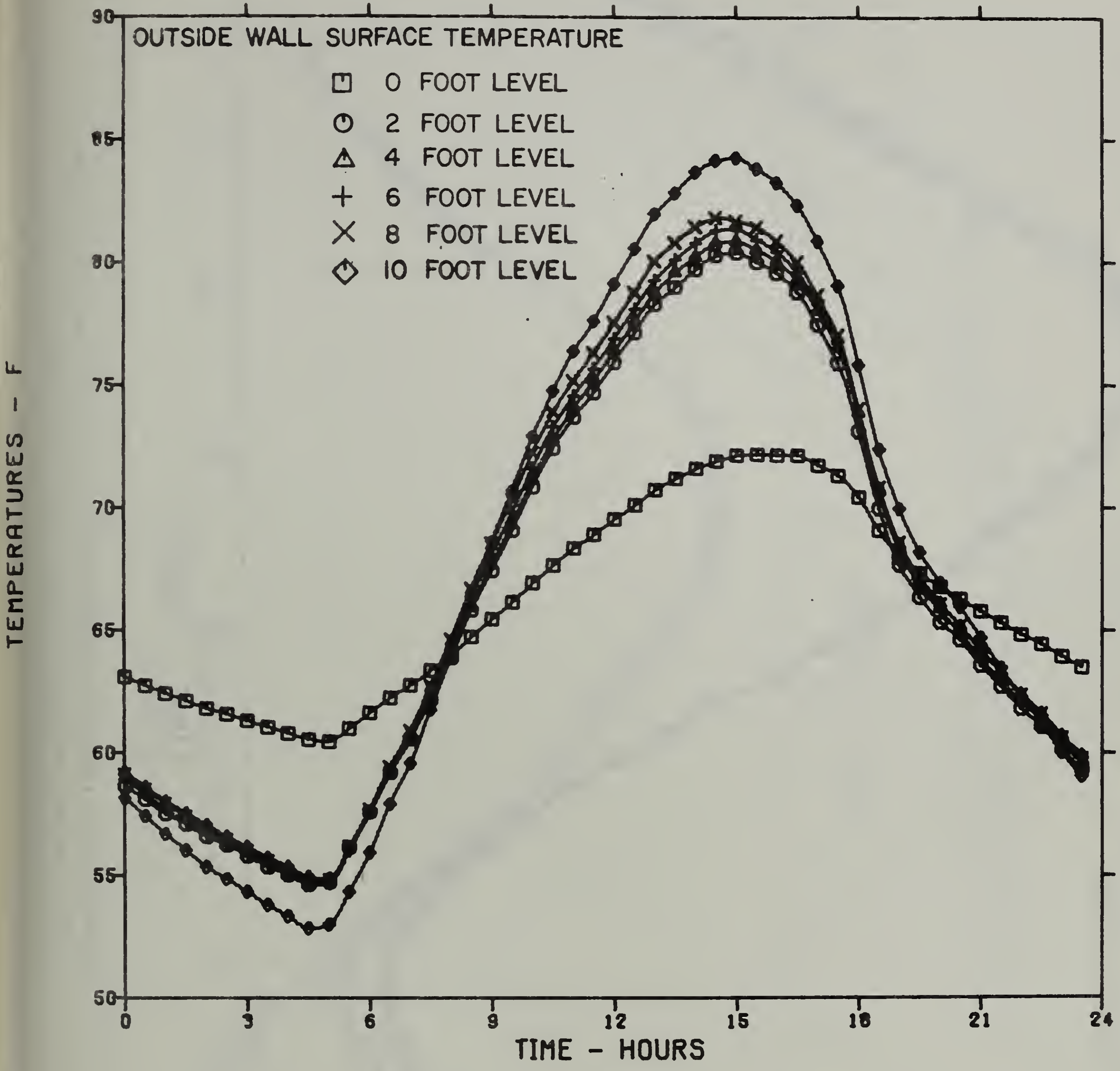


Figure 18 Variations of outside wall surface temperatures for test 1

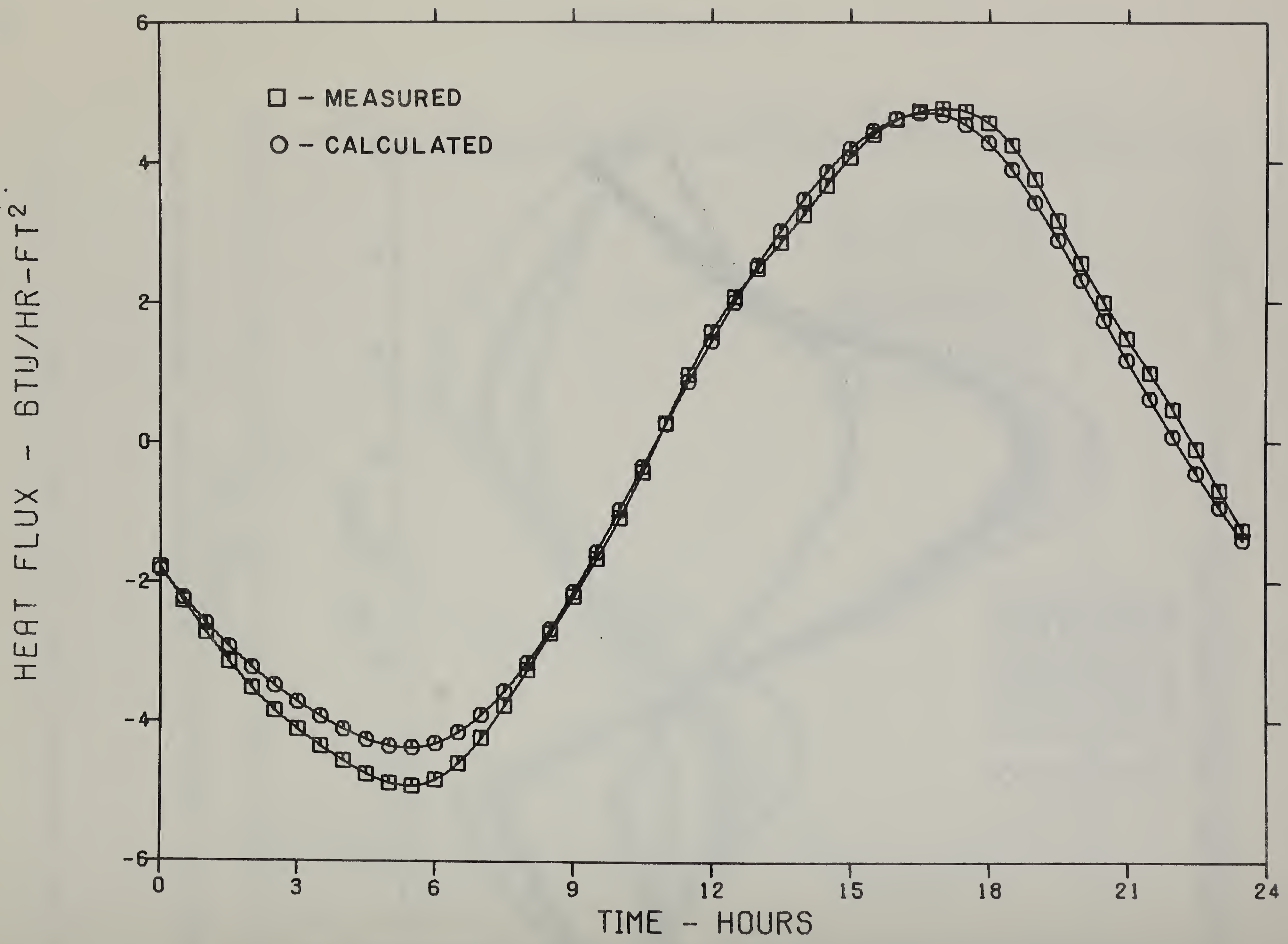


Figure 19 Comparison between the measured and calculated heat fluxes at the inside surface of the floor for test 1

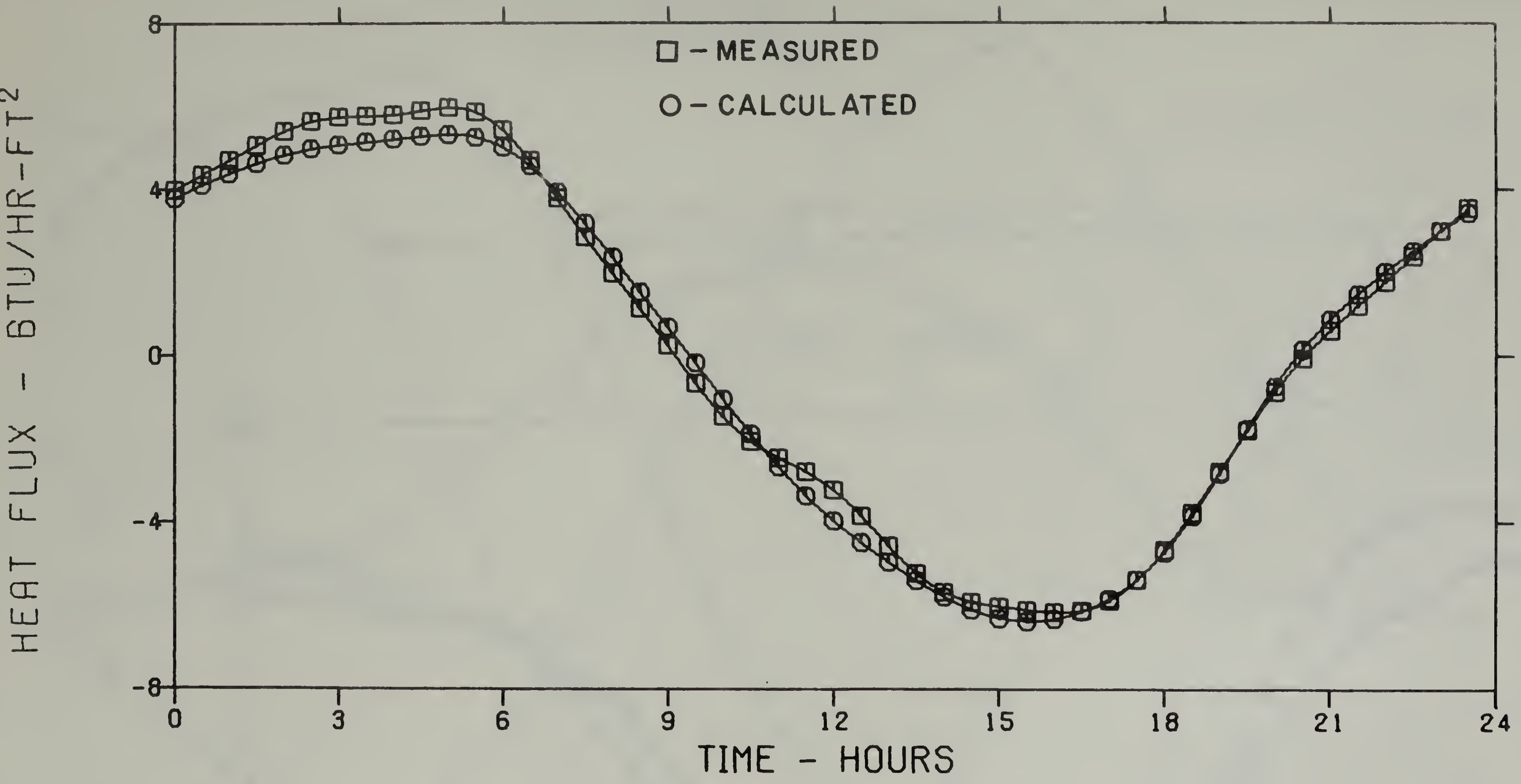


Figure 20 Comparison between the measured and calculated heat fluxes at the inside surface of the roof for test 1

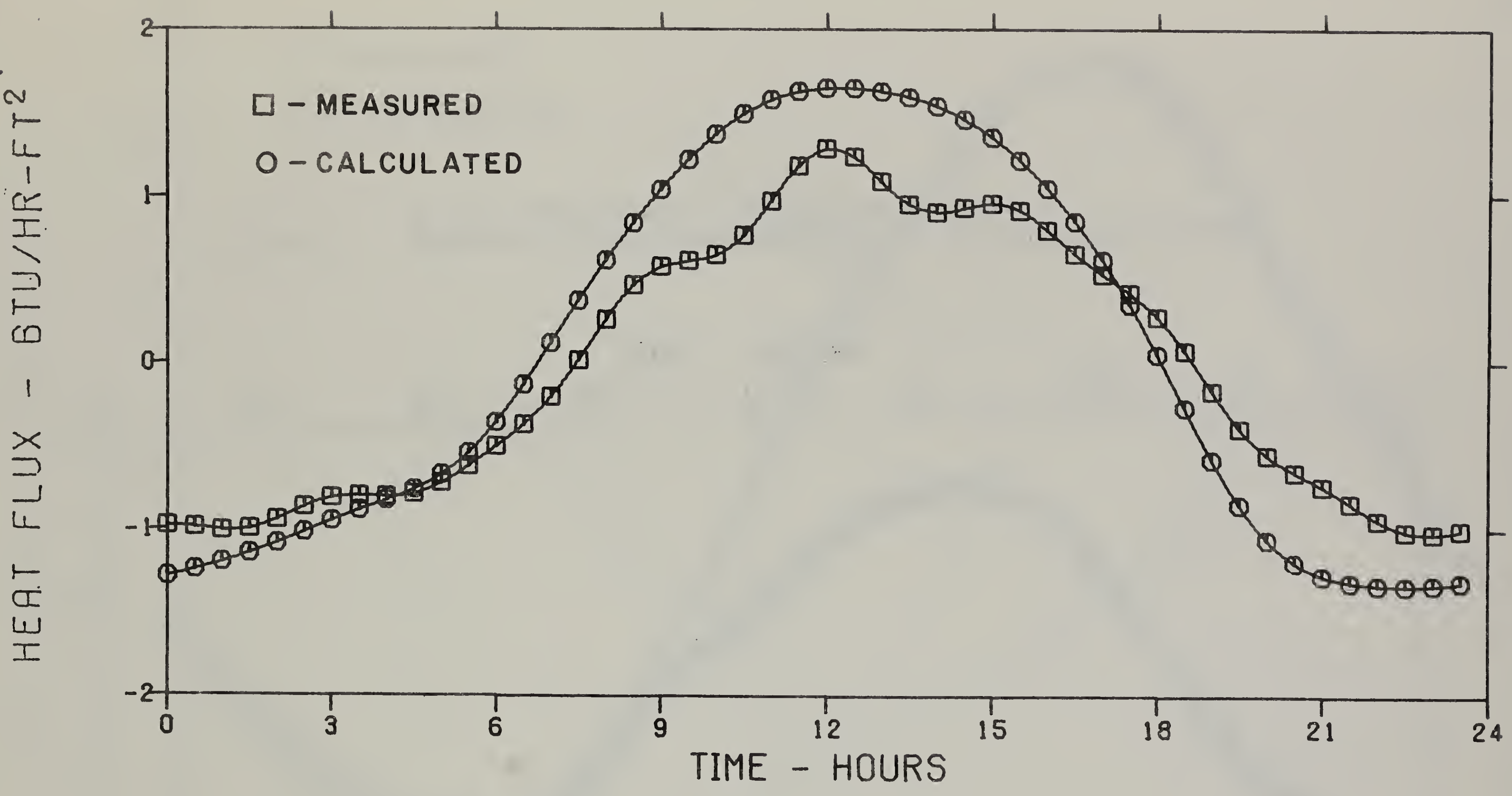


Figure 21 Comparison between the measured and calculated heat fluxes at the inside surface of the wall for test 1

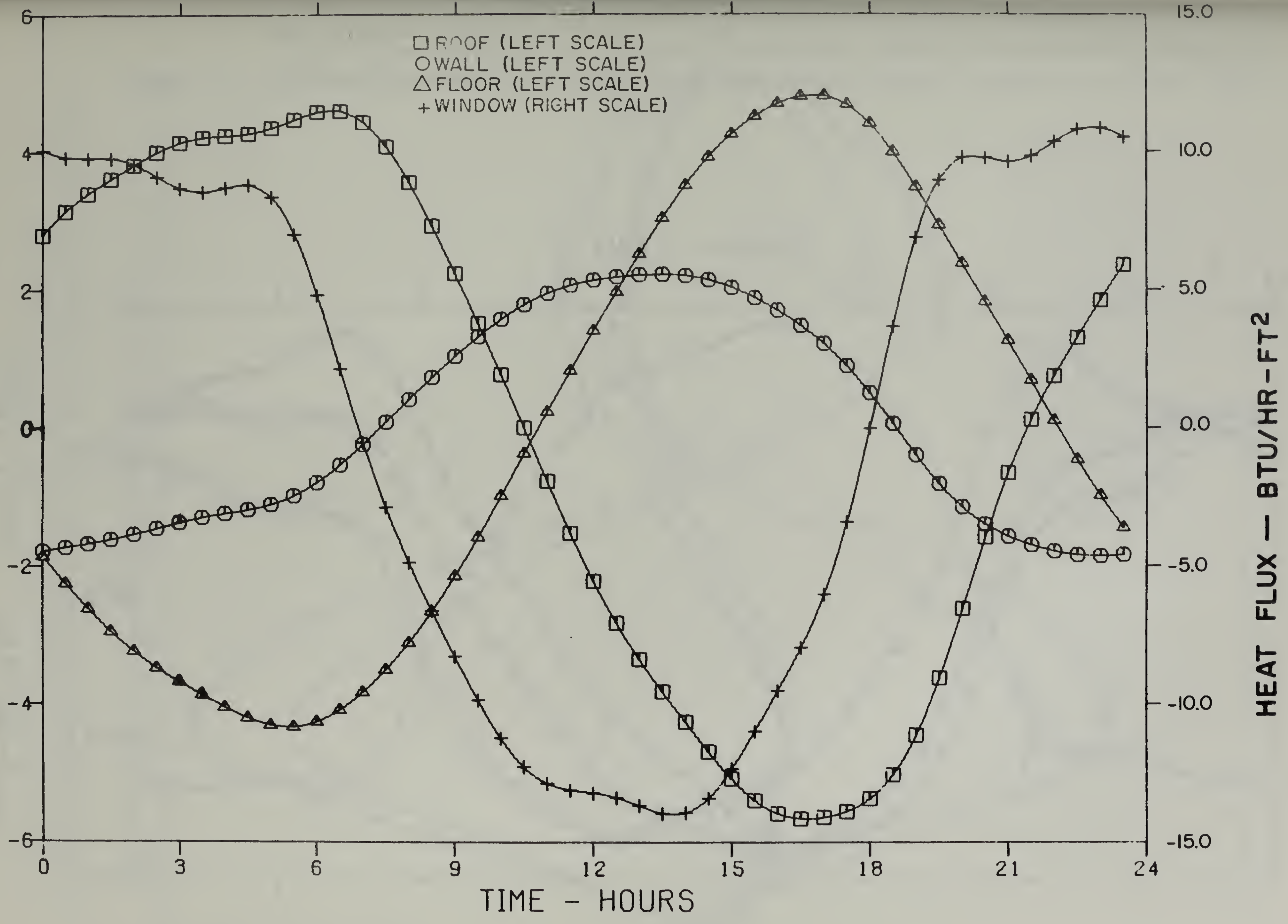


Figure 22 Computed variations of the heat flow rates at the inside surfaces of the roof, walls, floor, and the window for the case of no insulation (test 3)

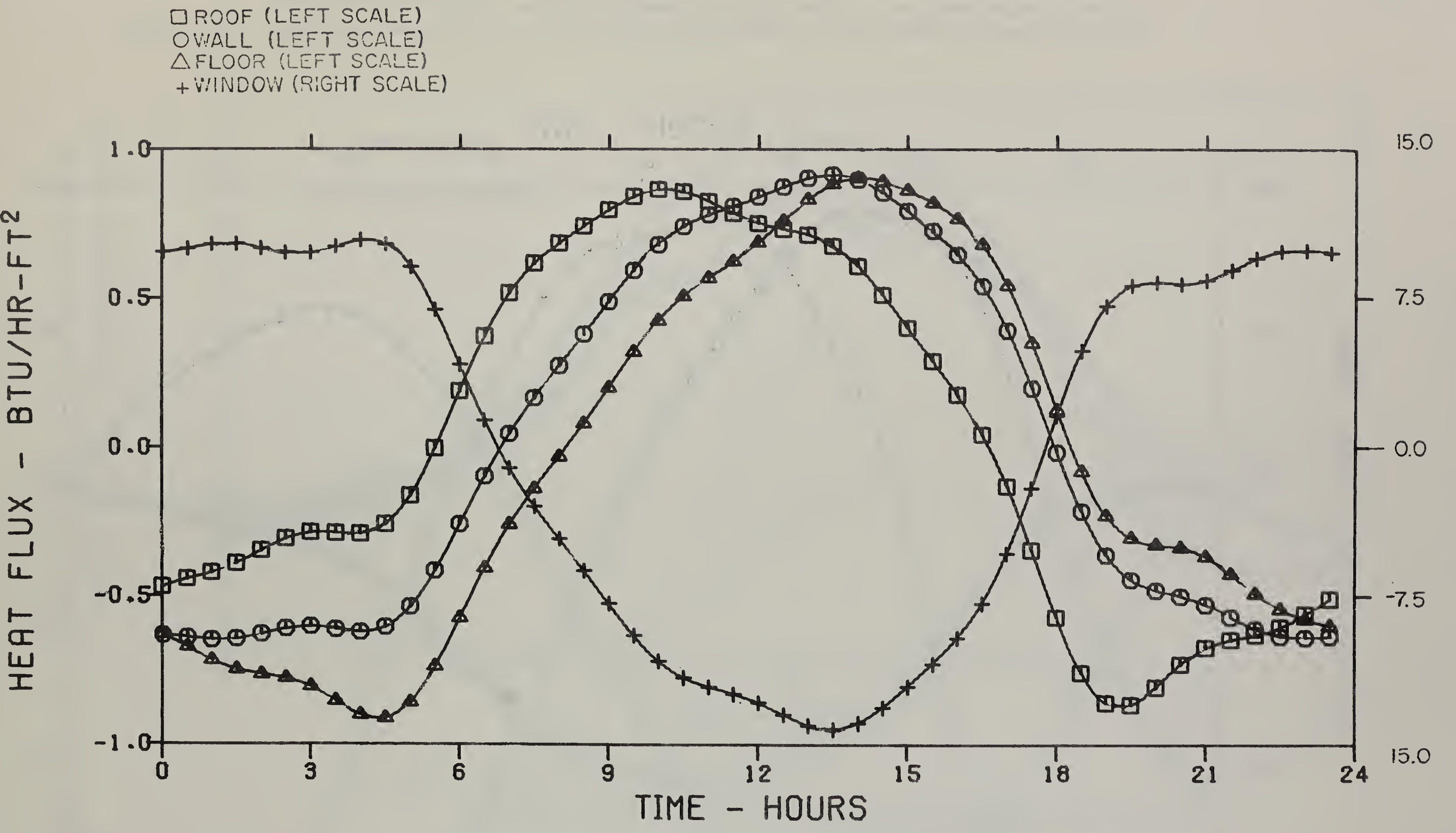


Figure 23 Computed variations of the heat flow rates at the inside surfaces of the roof, walls, floor, and the windows for the case of insulation placed on the outside surfaces of the building (test 5)

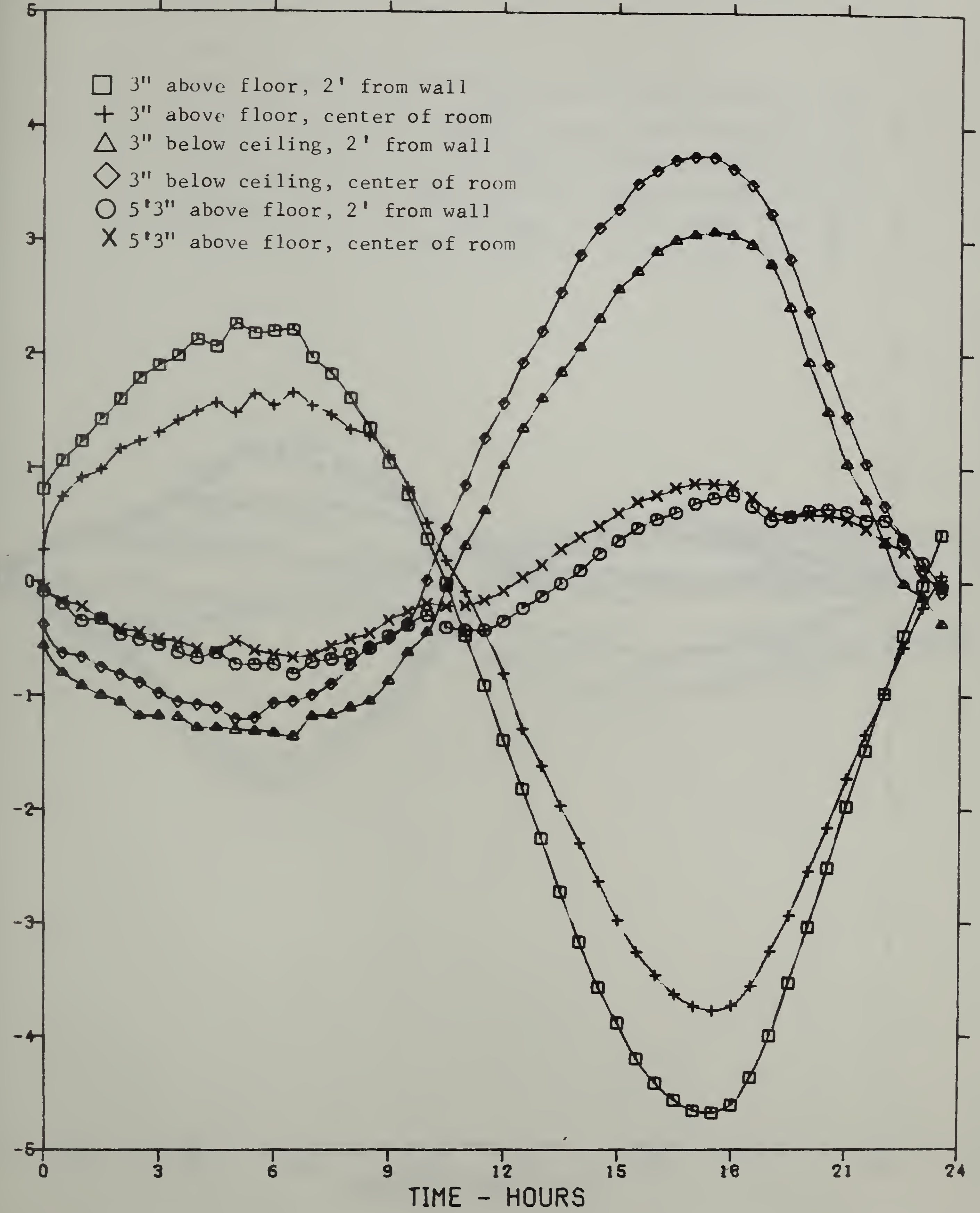


Figure 24 Deviations of the inside air temperature from instantaneous average of the six indoor air thermocouples for the case of no insulation (test 3)

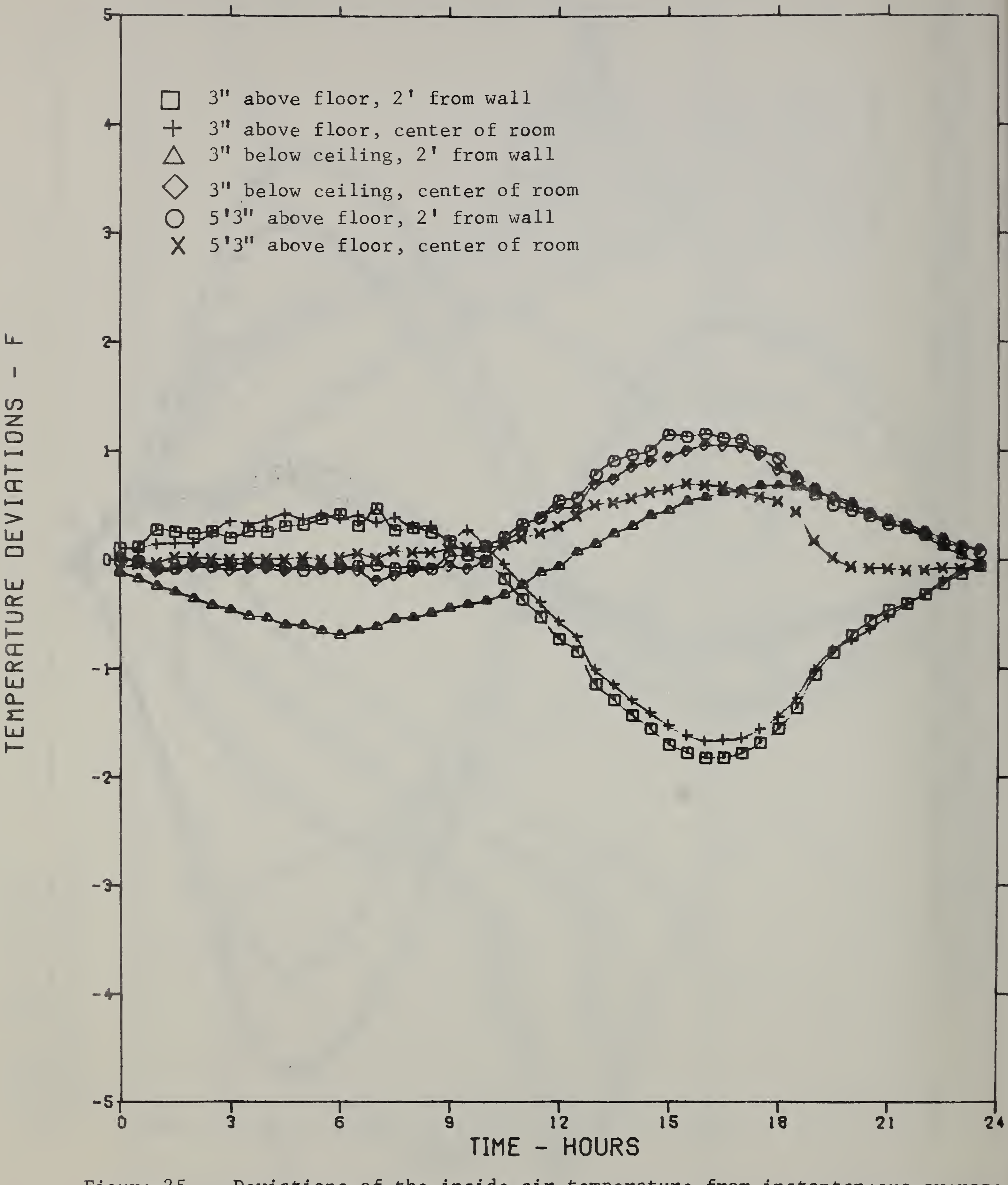


Figure 25 Deviations of the inside air temperature from instantaneous average of the six indoor air thermocouples for the case of insulation placed on the outside surfaces of the building (test 5)

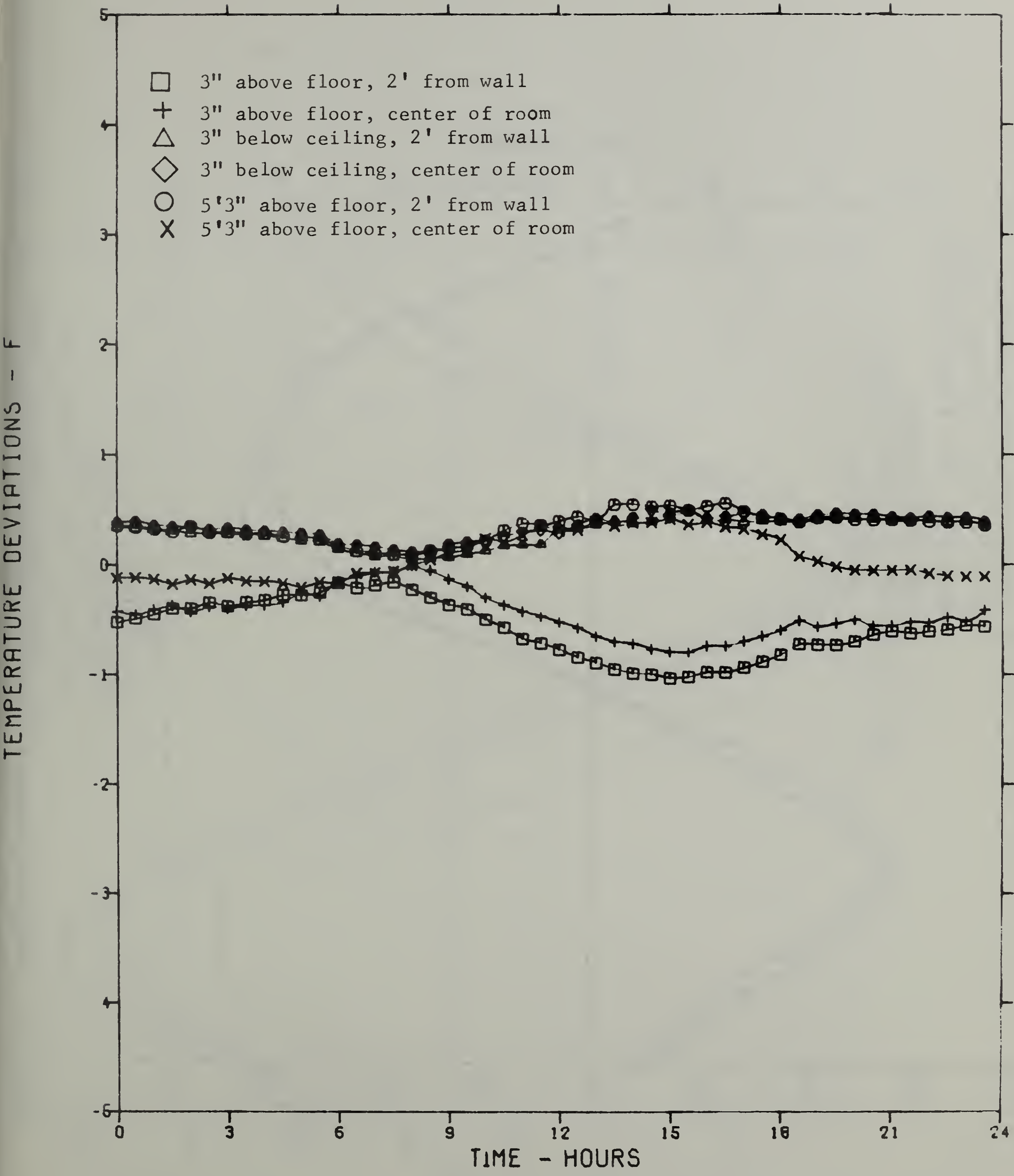


Figure 26 Deviations of the inside air temperature from daily average of the six indoor air thermocouples for the case of insulation placed on the inside surfaces of the building (test 4)

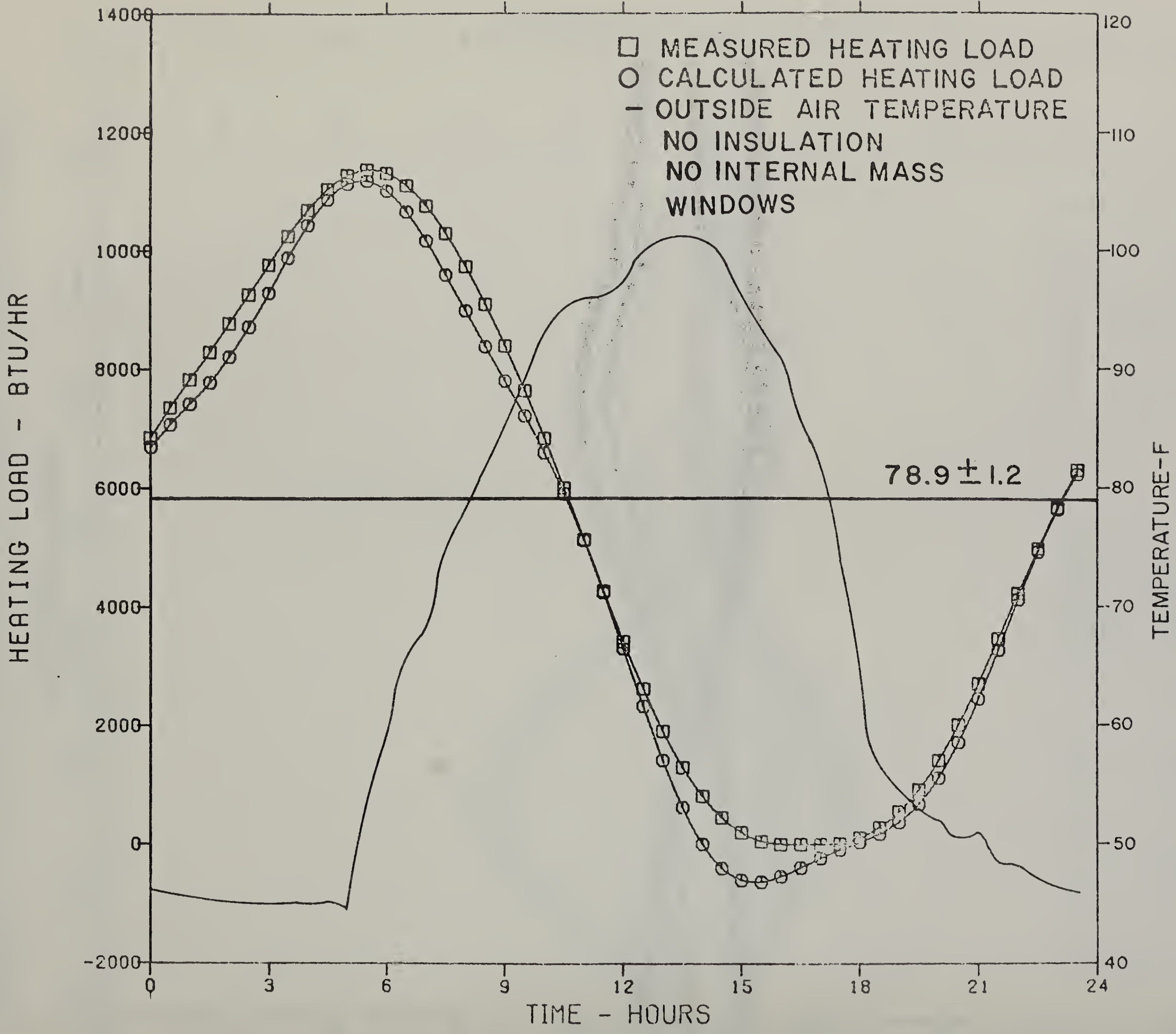


Figure 27 Comparison between the measured and calculated heating loads for test

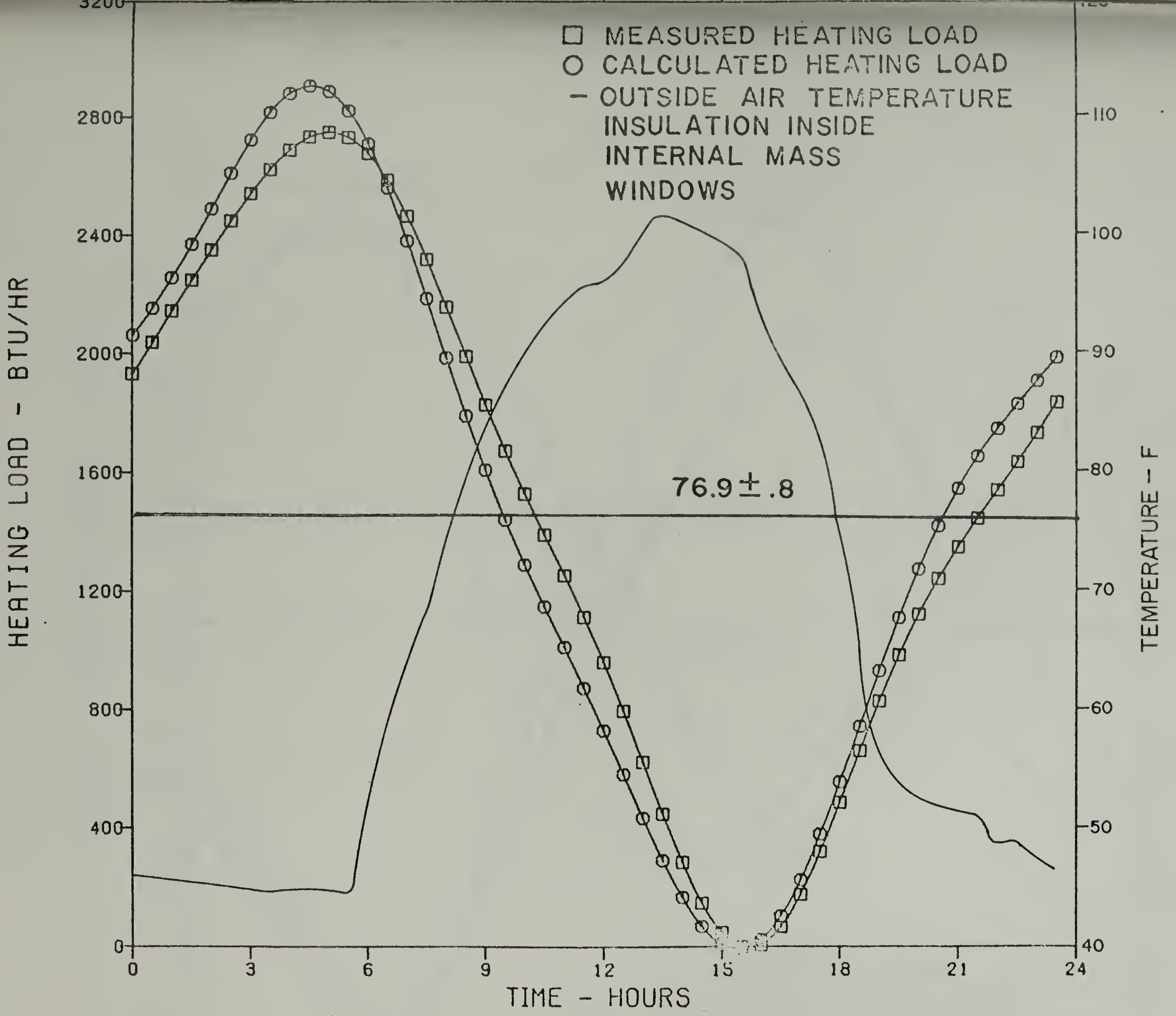


Figure 28 Comparison between the measured and calculated heating loads for test 7

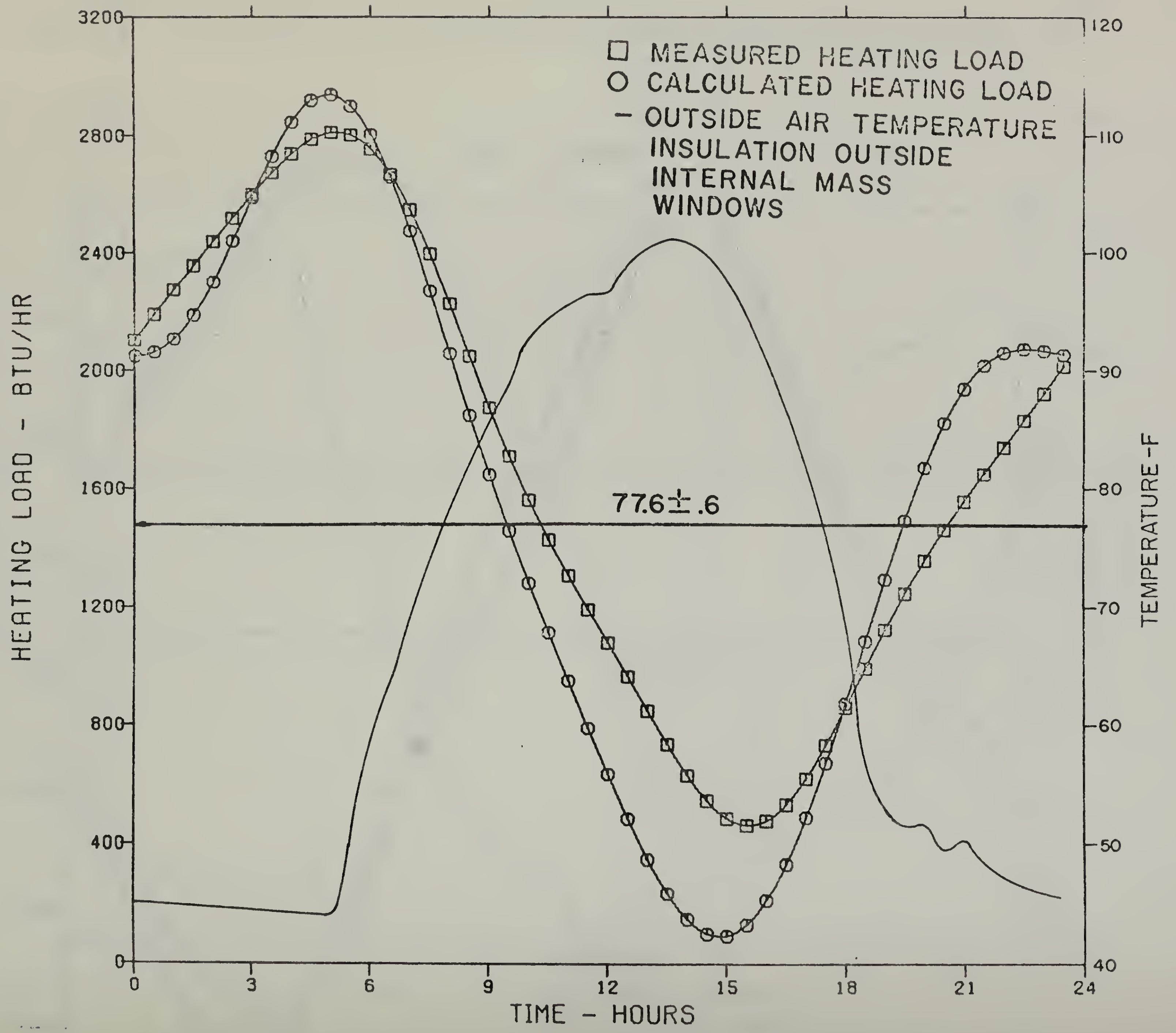


Figure 29 Comparison between the measured and calculated heating loads for test 8

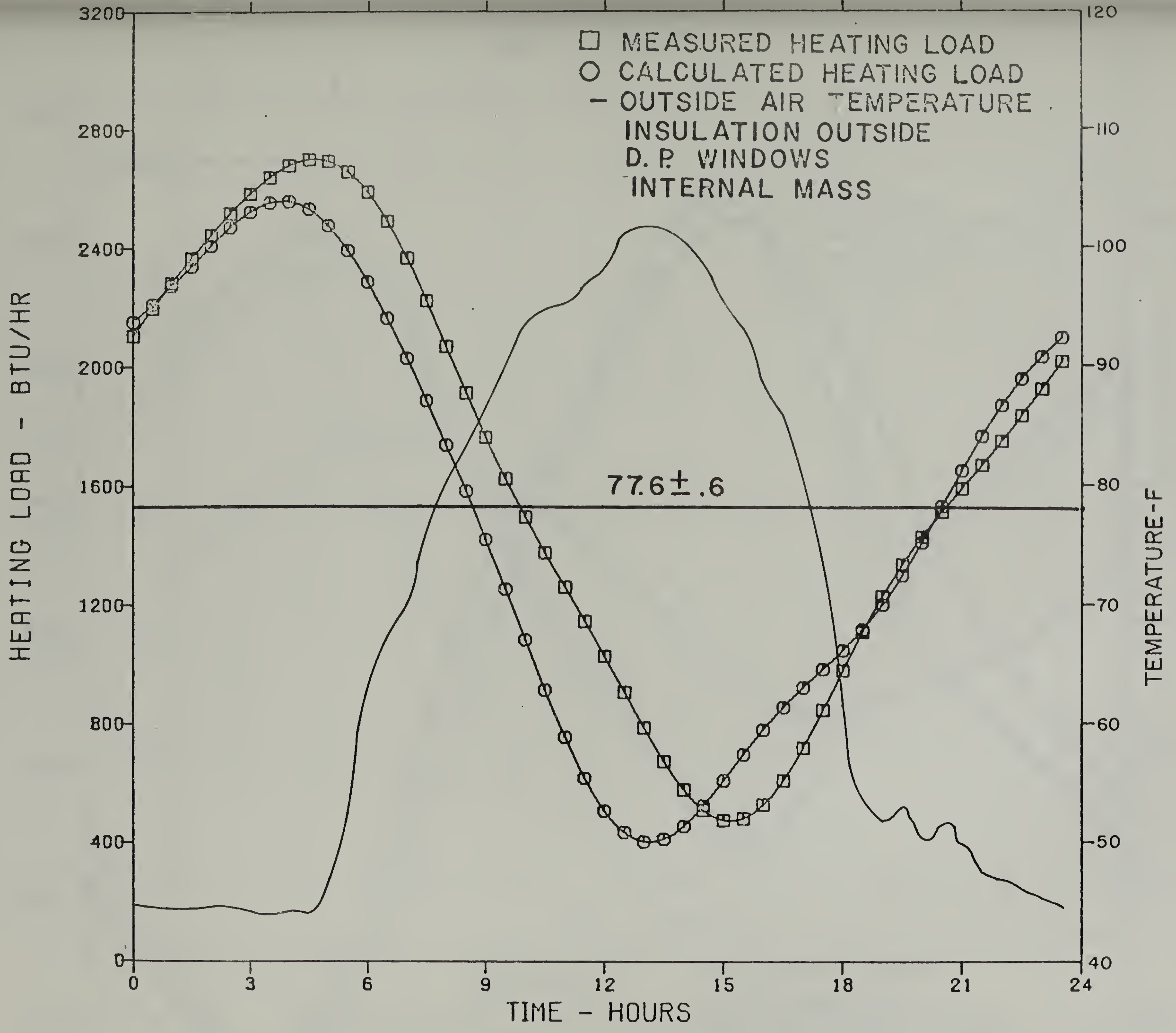
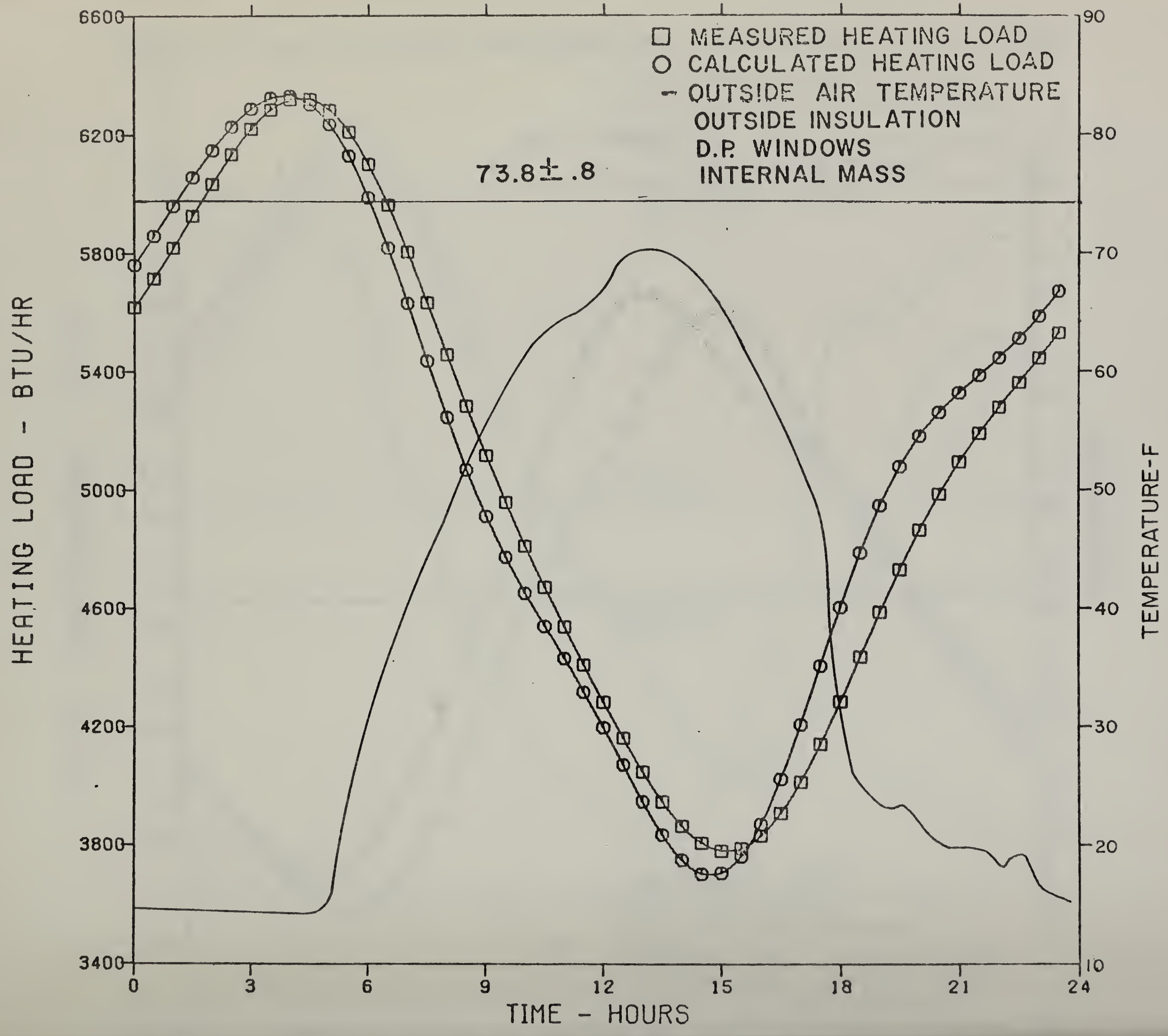
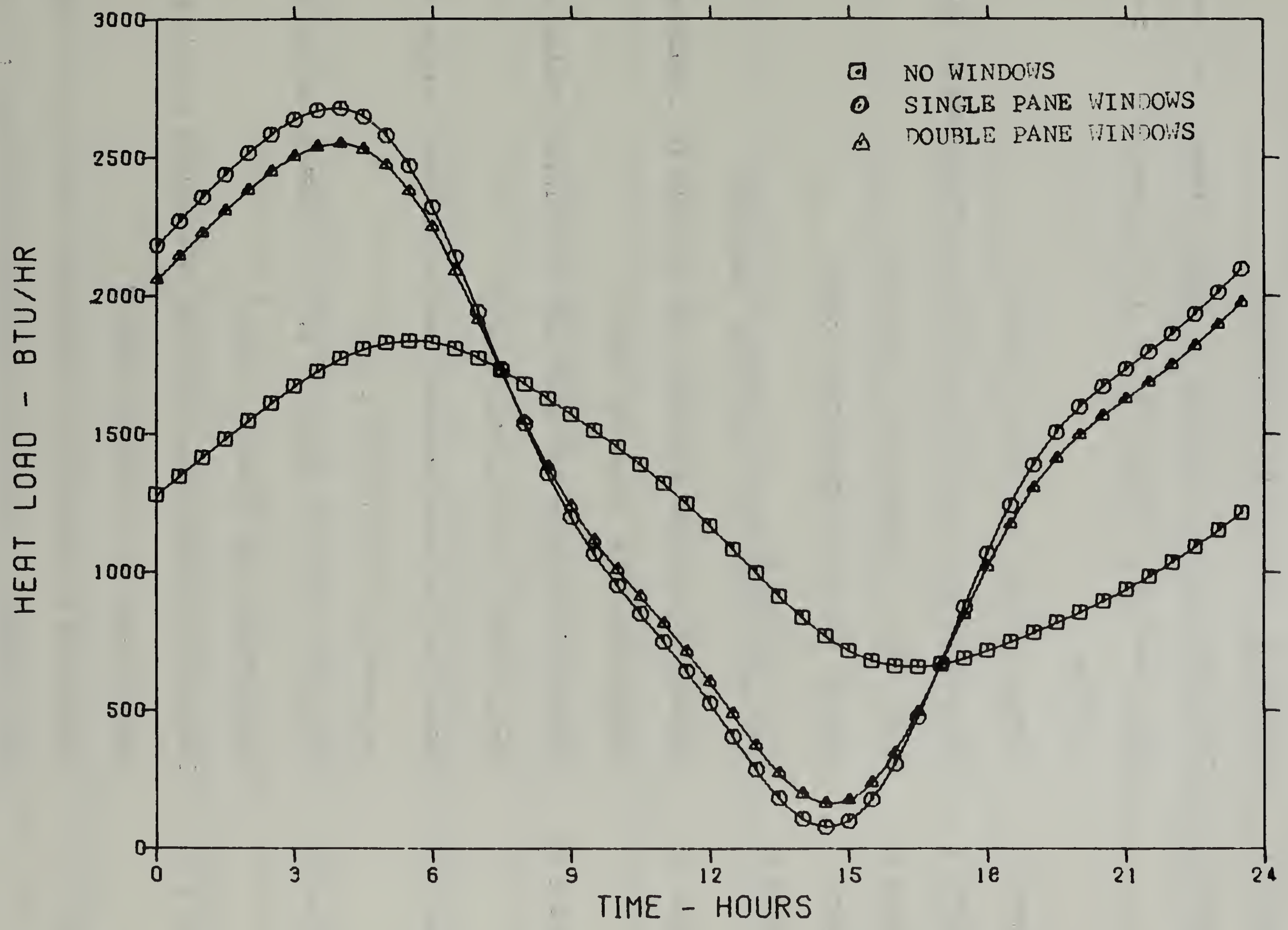


Figure 30 Comparison between the measured and calculated heating loads for test 9


□ MEASURED HEATING LOAD
○ CALCULATED HEATING LOAD
– OUTSIDE AIR TEMPERATURE
OUTSIDE INSULATION
D.P. WINDOWS
INTERNAL MASS
73.8±.8
HEATING LOAD - BTU/HR
6600
6200
5800
5400
5000
4600
4200
3800
3400
TEMPERATURE-F
90
80
70
60
50
40
30
20
10
0
3
6
9
12
15
18
21
24
TIME - HOURS



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Appendix A

Air Infiltration Measurements on the NBS Prototype Building

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1. Introduction

In the early stages of the project on thermal performance of the experimental structure, measurements were made to determine the magnitude of air exchange between the structure and the surrounding chamber during the process of cyclic temperature changes. Since wind forces were negligible during the testing period, the major driving force influencing the exchange of air was the thermal difference between the air inside of the structure and that of the surrounding air in the chamber.

2. Analysis and Instrumentation

The instrumentation used in the determination of the air exchange rates was developed at the National Bureau of Standards[1], and the process of measurement was that of the tracer gas method using helium as the tracer gas.

The rate of change in concentration of a tracer gas caused by exchange or infiltration of outside air under a steady-state temperature difference is expressed by the formula:

$$-V\ (dc/dt) = Kc \qquad (1)$$

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[1] Coblentz, C. W., and Achenbach, P. R., "Design and Performance of a Portable Infiltration Meter", Transactions, American Society of Heating and Air Conditioning Engineers, Vol. 63, 1957.

where V = volume of enclosure

c = concentration of tracer gas at time t

K = average volume of air infiltration per unit time for the time interval

t = time

When $c = c_o$ at time = o, the solution of Equation 1 is as follows:

$$c = c_o e^{-Kt/V} \tag{2}$$

or

$$Kt/V = \log_e (c_o/c) \tag{3}$$

Equation 3 shows that the number of air changes occurring during time t is equal to the natural logarithm of the ratio of the tracer gas concentrations at the beginning and at the end of the time interval.

3. Procedure and Results

Prior to the test, the apparatus was calibrated and brought into equilibrium with its surroundings, then helium, the tracer gas, was released into the room. As the helium was introduced it was mixed with the room air by means of a portable fan and the final mixture of air and helium contained about 1/2% of helium by volume.

Four helium sensing elements were distributed within the space. Each sensor was positioned 3 feet above floor level and 4 feet from an outside wall near each of the four corners. Air temperature measurements of the two spaces were recorded during the test.

Initially a test was made to determine the amount of air exchange through the structure with the surrounding environmental chamber prior to cutting openings for the glass windows. Later additional tests were made to determine the rate of air exchange when glass windows were introduced into the structure. The windows were of a fixed type and were caulked in place. The door was closed for all tests.

Measurements were made at the time of day when the air in the environmental chamber was lowest and unchanging, providing a maximum temperature difference and air exchange between the inside and outside. Measurements of air exchange were made when the tightly fitting weather-stripped door was normally closed and when all cracks around the door were taped.

For the building without windows the measured values of air exchange were 0.03 and 0.06 air changes per hour for the conditions of the taped and untaped door, respectively. These air exchange rates for the basic structure are very small. In fact, they are the smallest ever measured at NBS. They do provide a minimum value for comparison with other tests and show that heat gain or loss to the structure was almost solely by heat conduction and the influence of air leakage for the test without windows was practically negligible.

After the windows were installed, single glass only, additional measurements were made to determine the exchange rate under these conditions. The same procedure was followed and approximately the same temperature difference was observed. Under these conditions, but with the windows installed, the door not taped and no insulation on the walls, the measured value was 0.38 air changes per hour, a significant increase over the first tests having no window openings.

Appendix B

Noise Transmission Measurements of the NBS Prototype Building

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1. Objectives of Tests

Measurements were made of the attenuation of outdoor noise provided by the prototype concrete block structure constructed in the NBS high-bay environmental laboratory in order to establish the feasibility of noise reduction testing in such a space and to determine the sound transmission characteristics corresponding to four different conditions of the structure.

2. Building Variations Tested

The building construction during the first series of tests was a simple concrete block cubicle with a 20' x 20' floor plan and a 10 ft high ceiling (outside dimensions). The walls were made of 8" x 8" x 16" solid concrete blocks. A concrete slab floor and a flat four-inch thick pre-cast concrete slab roof completed the enclosure. A two-inch thick solid wooden door (foam rubber gasketed) provided the only break in the otherwise solid shell of the structure.

The test structure configurations employed during the noise transmission tests were as follows:

1. Concrete shell with a single wooden door (described above).
2. Seven 32" x 40" x 3/32" single-pane windows installed as shown in Figure 1 (bottom of sills 40 in. above floor).
3. Two-inch thick rigid polystyrene thermal insulation applied to the inside walls and ceiling.
4. Insulation removed from inside the structure and similar material used to cover the outside walls and roof.

3. Test Procedures

Figure B-1 shows the location of each of the five microphones of the receiving room array (inside the house) and the six microphones of the source room array (outside the house). The microphone systems employed one-inch pressure-type condenser microphone cartridges with attached preamplifiers. Each array was powered by a six-channel microphone energizer and multiplexer which scanned the microphone array at a rate of five channels per second. The multiplexer output was fed into a one-third octave band-pass filter set. The filtered signal was measured by means of a precision sound level meter or a graphic level recorder (see Table B-1).

Calibration of the measurement system was performed using a calibrated pistonphone--a precision sound source which produces a sound pressure level of 124 ± .2 dB at a frequency of 250 Hz at the microphone diaphragm.

The signal for the noise transmission tests was provided by four speakers energized with pink random noise*. These speakers were located opposite the outside corners of the house as shown in Figure B-1. The noise reduction provided by the house at each test frequency was determined by subtracting the one-third octave band sound pressure level measured in the receiving room from the corresponding level measured in the source room.

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* Pink random noise is white noise passed through a network which weights at -3 dB per octave.

4. Results

The curves plotted in Figure B-2 present the measured noise reduction provided by the house for each of the four variations in construction. As shown, the use of windows caused an average loss of sound isolation of about 10 db for frequencies above 200 Hz. The addition of thermal insulation either on the inside or the outside improved the acoustic performance but not enough to overcome the loss from windows.

Data was gathered at frequencies below 500 hertz but the short integration times used in the r.m.s. detection system, along with difficulties encountered in achieving a uniform sound field in the test space rendered the measurements inconclusive for frequencies below 500 hertz. Specifically, measurements of the sound distribution inside and around the house with the speakers energized revealed differences in the range of 4-12 db for frequencies below 200 Hz in the sound pressure levels measured at microphones in the same array in the receiving room and for frequencies below 500 Hz in the source room. Differences of this magnitude render a spatial average achieved by a five or six microphone array of little value.

Table B-1 Instrumentation for Noise Reduction Measurements*

1. Brüel and Kjaer Model 4220 Pistonphone
2. Brüel and Kjaer Model 4132 Pressure Microphone
3. Brüel and Kjaer Model 2619 FET Preamplifiers
4. Brüel and Kjaer Model 221 Microphone Energizer and Multiplexer
5. Brüel and Kjaer Model 1612 Band-pass Filter Set
6. Brüel and Kjaer Model 2204 Precision Sound Level Meter (used during design stages 1, 2, and 3).
7. Brüel and Kjaer Model 2305 Graphic Level Recorder (used during design stages 3 and 4).
8. Kudelski (Nagra III) tape recording of pink noise used as signal source in design stages 1, 2, and 3.
9. Brüel and Kjaer Model 1024 Sine Random Generator used as pink noise source in design stage 4.

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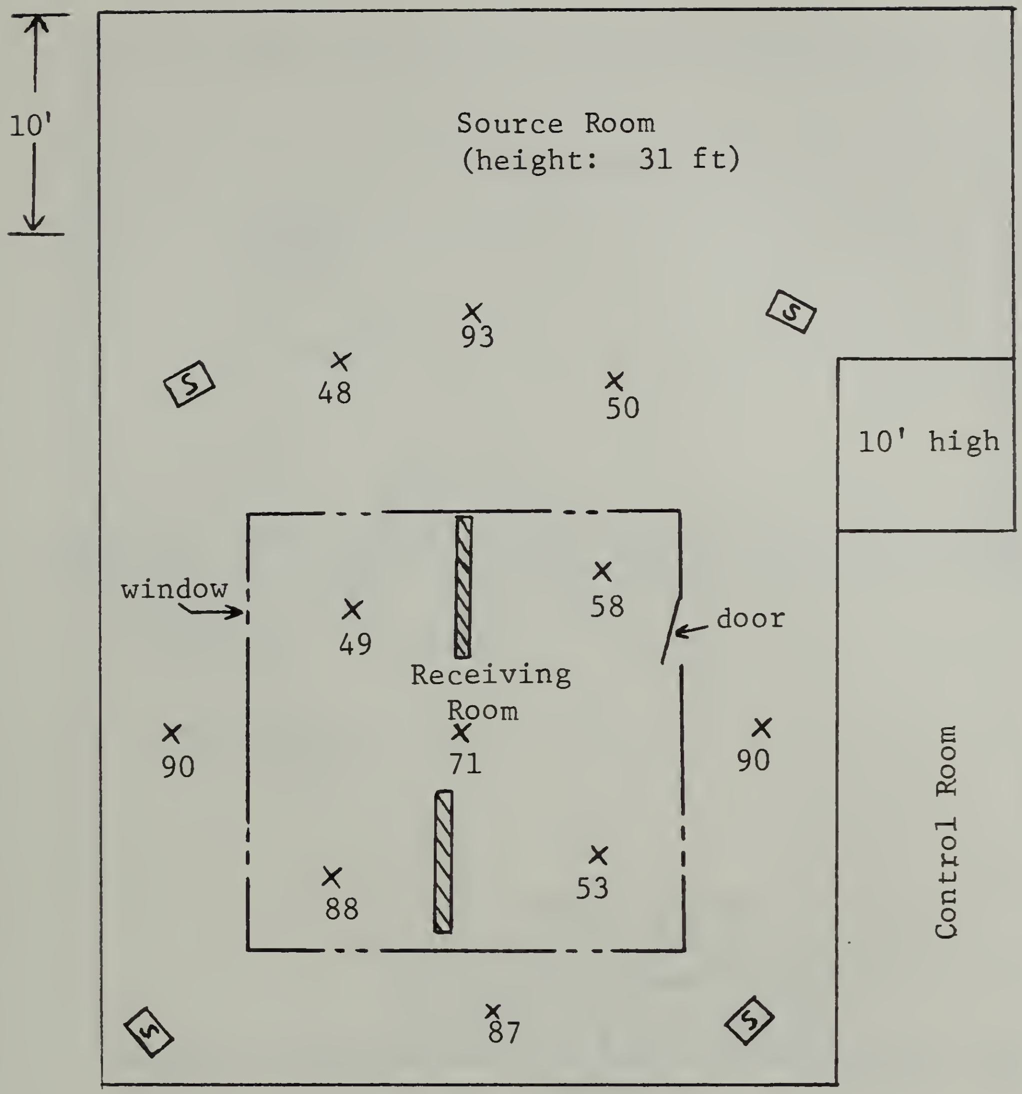
* Commercial instruments are identified in this report in order to adequately specify the experimental procedure. In no case does such identification imply recommendations or endorsement by the National Bureau of Standards, nor does it imply that the equipment identified is necessarily the best available for the purpose.



× microphone (height given in inches)

[S] speaker

▨ concrete block stack 38 in. high

Figure B-1 Floor plan of NBS High-bay Environmental Laboratory and prototype concrete block building. Microphone and speaker positions used for the noise reduction tests are indicated.

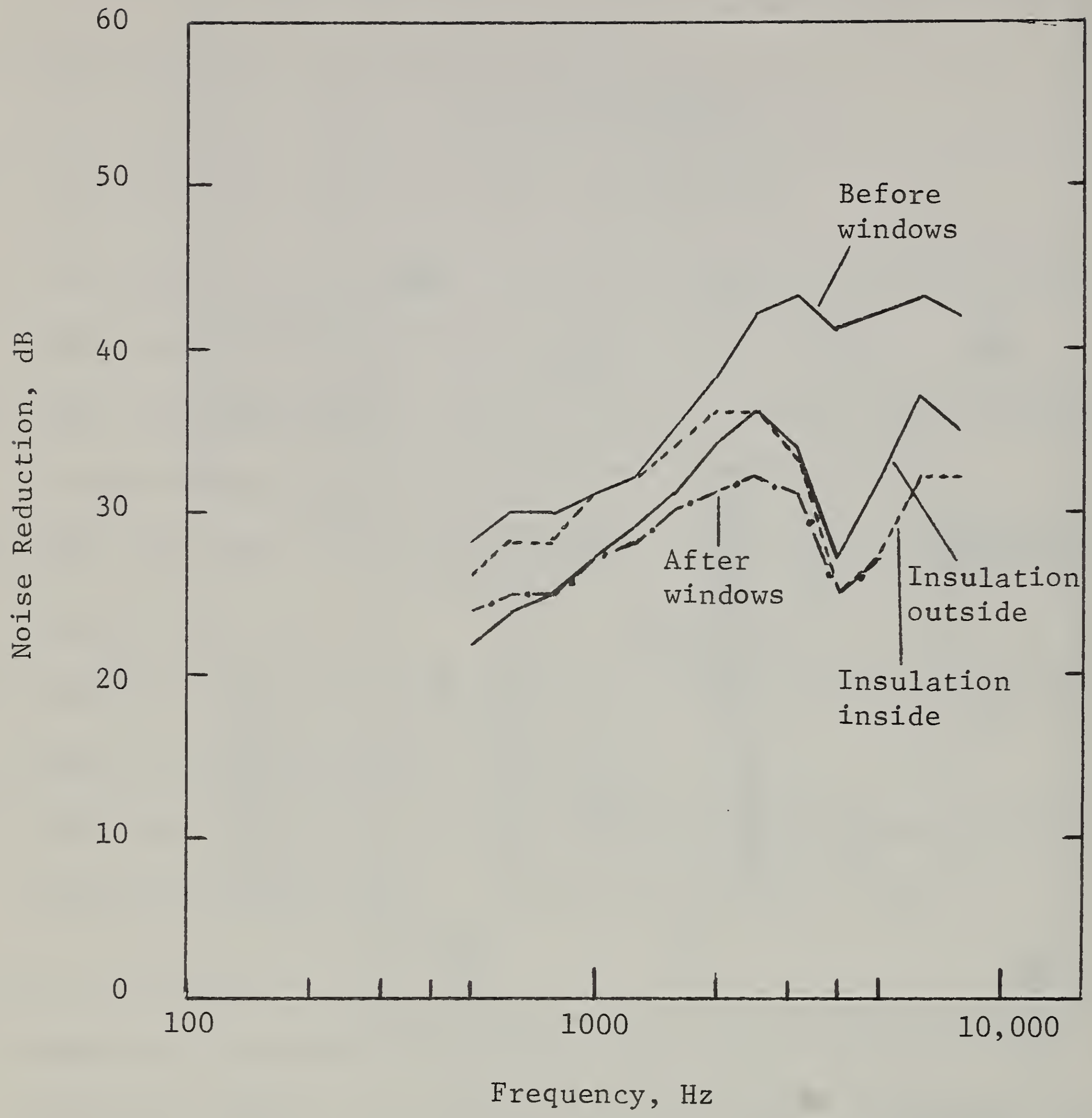


Figure B-2 Noise reduction versus frequency for various construction modifications of the concrete block building in the High-bay Environmental Laboratory.

Appendix C

Computer Programs (NBSLD) to Obtain Heating and Cooling Loads and to Estimate Room Air Temperature Change Using Thermal Response Factors

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National Bureau of Standards

Computer Programs (NBSLD) to Obtain Heating and Cooling Loads and to Estimate Room Air Temperature Change Using Thermal Response Factors

1. Introduction

The NBS computer programs called NBSLD are a group of routines to permit the determination of heating and cooling loads of a room based upon a calculation methodology proposed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Task Group on Energy Requirements.

For a given 24-hour weather pattern the program calculates heat exchange due to solar and sky thermal radiation through windows, heat conduction through walls and roofs, heat convection due to air infiltration and internal heat generation. Heat exchange is computed for every hour and later converted into the room heating or cooling load in conjunction with weighting factors. Details of these calculation procedures and the theoretical background for the weighting factors' application are given here. They are available in the 1971 ASHRAE publication entitled "Procedures for Determining Heating and Cooling Loads for Computerized Calculation of Energy Requirements". This publication was prepared by the ASHRAE Task Group on Energy Requirements with the assistance of the National Bureau of Standards and the National Research Council of Canada.

The ASHRAE Task Group procedure incorporates what is considered to be the most up-to-date computation methodology for evaluating the dynamic aspects of building heat conduction by the response factor method. Since the algorithms employed in this procedure are new and rather complex, their use has been limited.

Presented in this report is the Fortran listing of the NBS program of the ASHRAE Task Group algorithms to illustrate the use of this modern and powerful technique on small computers.

All of the routines are, therefore, written in a close accordance with the ASHRAE Task Group algorithms and made into many subroutines, each of which could be used independently for other programs.

Attached are the Fortran listings of NBSLD. The program in the form of punched cards or on magnetic tape is available from the Environmental Engineering Section of NBS including assistance for its use, if desired. Figure 1 shows the logic network for NBSLD.

1. ABCD2, ABCDP2, DERVT, GPF, MULT, RESF, RESFX, RESPTK: These routines are parts of response factor calculation package and are needed for the accurate evaluation of thermal time lag, damping, heat storage in exterior facing surfaces as well as the internal furnishings.
2. DPF: Calculates dew point temperature when the partial vapor pressure is known.
3. GLASS: Calculates solar heat gain through glass when given the shading coefficient, orientation type of glass, type of fenestration.

4. OUTSID: This routine calculates the outside surface temperature and wall heat gain by taking into account solar heating, back radiation to the sky, convective heat loss to the ambient air and transient heat conduction.
5. PSY1: This is a simplified psychrometric routine that determines the thermodynamic properties of moist air when given dry-bulb temperature, wet-bulb temperature and barometric pressure.
6. PSY2: This is the same as PSY1 except that the dew point temperature is used instead of the wet-bulb temperature.
7. PVSF: This routine determines the saturated vapor pressure as a function of temperature.
8. SHG: This is the ASHRAE routine for calculating solar heat gain through glass.
9. SUN: Calculates basic sun data such as angles, cloud cover, direct and diffuse radiation needed for solar heat gain and solar heating of the building exterior surfaces.
10. TAR: Calculates transmission and absorption characteristics of glass.
11. WBF: Approximates the wet-bulb temperature when provided with the enthalpy of moist air and the barometric pressure.
12. WF: Determines the cooling load by multiplying the heat gain by the ASHRAE weighting factors. (This routine was not used in the version listed in this report because it incorporates the basic calculation used for deriving the weighting factors.)

13. RMTMP: Determines the room temperature as a balance of heat gains and cooling capacity of an air conditioning unit. Since this routine is not available in ASHRAE Task Group Algorithms, detail is given in the following pages.

14. SOLVP: Solves simultaneous linear algebraic equations needed in RMTMP.

15. WEATHE, WD, DEC0DE: This package is a weather decoding program and was not included in this version because the weather input to this version is implicitly defined in the following section on input data.

16. CCM: This routine modifies the solar radiation for a cloudless sky by the instantaneous cloud cover. (This routine is not included in this version.)

17. FO: This routine calculates the outside surface heat transfer coefficients from the weather data. (This routine is not included in this version where the coefficients are considered to be input data.)

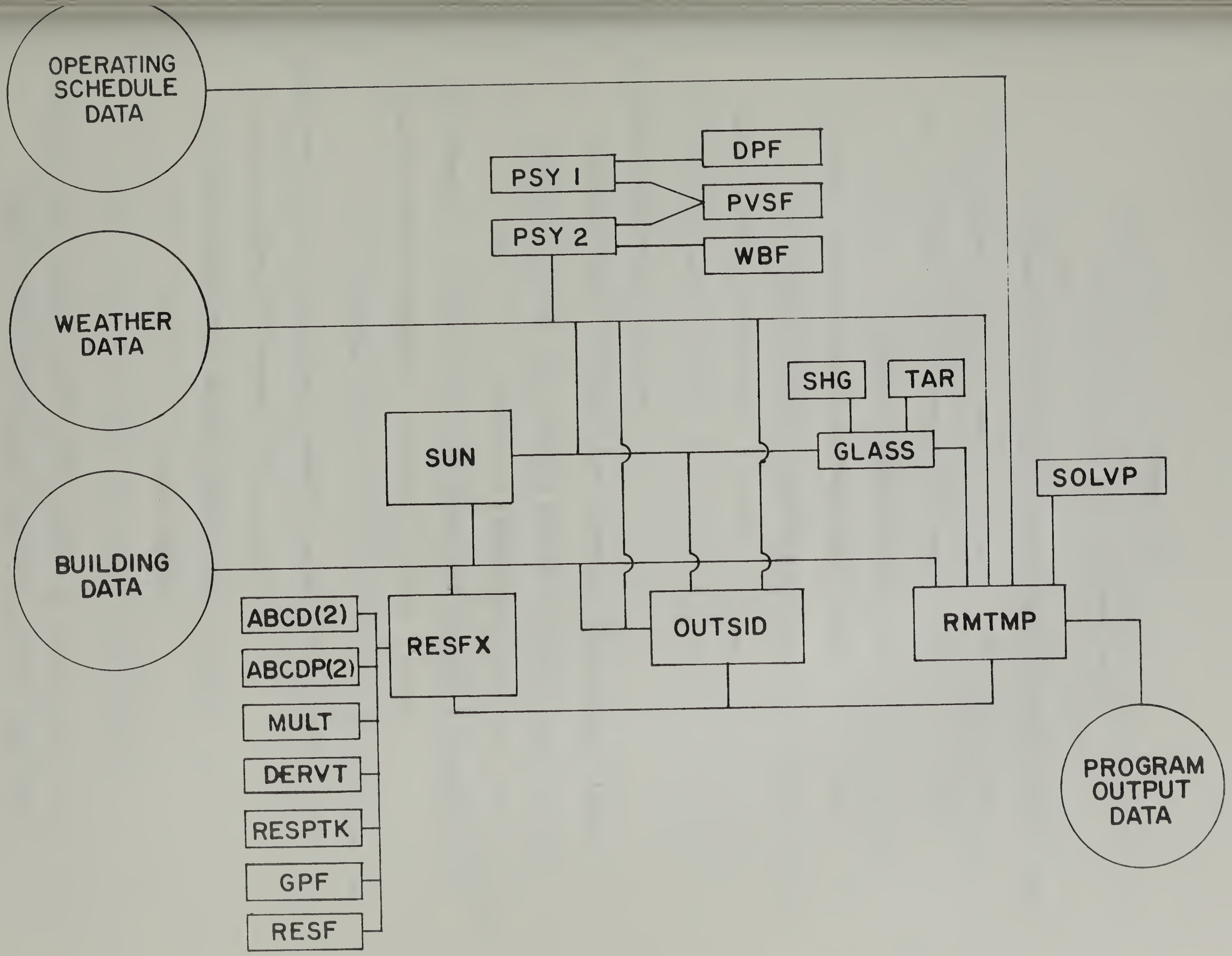

Figure 1 Logic network for NBSLD

2. RMTMP

Room Temperature Calculation Routine

Input: NS = number of heat transfer surfaces in the room

(S(I), I = 1, NS) = area of the heat transfer surfaces, ft^2

(M(I), I = 1, NS) = number of response factor terms for each heat transfer surface

(IX(I), I = 1, NS) = index for the thermal storage effect for each heat transfer surface

IX(J) = 1 for thermal storage surface

IX(J) = 0 for non-thermal storage surfaces such as windows and door

(CR(I), I = 1, NS) = common ratio for the thermal response factor of each heat transfer surface

M(I) = 1, CR(I) = 0 if IX(J) = 0

((X(I, J), Y(I, J) for I = 1, NS), J = 1, M(I)) thermal response factors for each surface

X(I, 1), Y(I, 1) = overall thermal conductance of the non-thermal storage surface and all the other response factor terms should be treated as zero if IX(I) = 0.

Note: For the calculation of X(I,J), Y(I,J), the surface heat transfer coefficients (both inside and outside) are not included.

((TØ(I,t-J) for I = 1,NS), J = 1,M(I)) = outside surface temperature history, °F

((TI(I,t-J) for I = 1,NS), J = 1,M(I)) = inside surface temperature history, °F

TA = air temperature of the room

(H(I), I = 1,NS) = convection coefficient of the interior surface, °F

(F(I,K), I = 1,NS), K = 1,NS) = radiant heat exchange factors between surfaces I and K, where F(I,K) = 0 if I = K

(R(I,t), I = 1,NS) = heat input per unit indoor surface at time t to the surface, such as solar heat or radiation heat from the lighting, equipment and occupants to the surface

(E(I), I = 1,NS) = emissivity of the surface

Q(I,t-1) = heat flow at the Ith surface at the previous time period or time = (t-1)Δ, Btu/hr, ft^2

Δ = time increment

t = time index for the elasped time tΔ hours

CFML = outdoor air leakage, CFM

CFMV = ventilation air rate, CFM/°F (at time tΔ)

DB(t) = outdoor air temperature, °F

TV(t) = ventilation air temperature, °F (at time tΔ)

QEQUP: convective component of internal heat from equipment, Btu/hr

Q0CPS: convective component of internal sensible heat from occupants, Btu/hr

QLITE: convective component of heat from lights suspended in air, Btu/hr

1. Basic heat balance equation at the I surface (at time $t\Delta$)

$$Q(I,t) = \sum_{J=1}^{M(I)} \{X(I,J) * TI(I,t-J+1) - Y(I,J) * T0(I,t-J+1)\}$$

$$+ CR(I) * Q(I,t-1)$$

$$= H(I) * (TA(t) - TI(1,t)) + \sum_{K=1}^{Ns} G(I,K) * (TI(K,t)$$

$$- TI(I,t)) + R(I,t)$$

where $G(I,K) = 4 * E(I) * F(I,K) * (TA + 460)^3 * 0.1714E-8$

2. Total heat balance for the room air

$$\sum_{I=1}^{Ns} S(I) * (TI(I,t) - TA(t)) + 1.08 * CFM * (DB(t$$

$$* (DB(t) - TA(t))$$

$$+ 1.08 * CFMV * (TV(t) - TA(t))$$

$$+ QEQUP + QOCPS + QLITE = 0$$

3. Letting matrix elements

$$A(I,I) = X(I,1) + H(I) + \sum_{K=1}^{Ns} G(I,K)$$

$$A(I,K) = -G(I,K),\ A(K,I) = -G(K,I),\ \text{for } I = 1,\ NS$$

$$A(I,\ Ns+1) = -H(I)$$

$$B(I) = -\sum_{J=2}^{M(I)} X(I,J) * TI(I,t-J) + \sum_{J=1}^{M(I)} Y(I,J) * T0(I,t-J)$$

$$- CR(I) * Q(I,t-1) + R(I,t)$$

$$A(Ns+1,K) = S(K) * H(K) \text{ for } K = 1,\ Ns$$

$$A(Ns+1,\ Ns+1) = -1.08 * (CFML + CFMV) - \sum_{K=1}^{Ns} H(K) * S(K)$$

$$B(Ns+1) = -QEQUP - Q0CPS - QLITE - 1.08 * (CFML * DB(t)$$

$$+ CFMV * TV(t))$$

TI(I,t) and TA can be obtained by solving the following Ns+1 simultaneous equations

$$\begin{bmatrix} A(1,1),\ A(1,2)\ \ldots\ A(1,Ns+1) \\ A(2,1),\ A(2,2)\ \ldots\ A(2,Ns+1) \\ \vdots \\ A(Ns,1),\ A(Ns,2)\ \ldots\ A(Ns,Ns) \\ A(Ns+1),\ A(Ns+1,2)\ \ldots\ A(Ns+1,Ns+1) \end{bmatrix} * \begin{bmatrix} TI(1,t) \\ TI(2,t) \\ \vdots \\ TI(Ns,t) \\ TA \end{bmatrix} = \begin{bmatrix} B(1) \\ B(2) \\ \vdots \\ B(Ns) \\ B(Ns+1) \end{bmatrix}$$

3. Input Data Needed for the Fortran Listing of NBSLD

Input data needed for the heating/cooling load calculation are listed on the following pages but not necessarily in the card reading sequence of the Fortran version listed in this report.

Building Number (BLDGNO)
Ceiling Height (HT)
Floor Area (AG)
Number of Floors (N0FLR)
Number of Occupants (QCU)
Winter Window Overall Heat Transfer Coefficient (UGW)
Ground Floor Heat Transfer Coefficient (UG)
Air Change Per Hour (AIRCHG)

Latitude (LAT)
Longitude (L0NG)
Time Zone Number (TZN)
Month (M0NTH)
Day (DAY)
Elapsed Hour Since Midnight of January 1st (ELAPS)

Electric Power to the Light Watts Per Square Foot of Floor (QLITY)
Electrical Power to Equipment, Watts Per Square Foot of Floor Area (QEQPX)
Ventilation Air Rate (CFMV)
Air Leakage Rate (CFML)

Maximum Temperature of the Design Day (DBMAX)
Daily Temperature Range of the Design Day (RANGE)
Design Indoor Temperature Condition (DBIN)
Design Outdoor Wet-Bulb Temperature (WBMAX)
Design Indoor Wet-Bulb Temperature (WBID)
Design Winter Outdoor Temperature (DBMWT)
Design Summer Ground Temperature (TG)
Design Winter Ground Temperature (TGW)

Total Number of Exterior Surfaces to be Considered for the Heat Gain Calculation (NEXP)
Index for the Room Temperature Calculation
Index for the Standard ASHRAE Task Group Calculation in the Special and Detailed NBS Calculation

Repeat the following cards for NEXP times

Type of Heat Transfer Exposures (ITYPE)

1. Roofs
2. Walls
3. Windows
4. Doors
5. Floors

Type of Response Factors to be Used (IRF)

1. Heavy roof construction
2. Light weight roof
3. Heavy weight exterior walls
4. Light weight exterior walls
5. Heavy ceiling/floor
6. Light ceiling/floor
7. Heavy partition wall
8. Light partition wall

U Value of the Exposures (U)

Area of the Exposures (A)

Orientation of the Exposures (AZW)

0.	South facing
90.	West facing
180.	North facing
-90.	East facing

Radiant Heat Exchange Factors Among Exposure Surfaces

If the construction of roof, wall and floor is non-standard, the following information is needed in addition to the standard data indicated above.

Roof, Wall, Floor Data

1 Time increment of the temperature data

2 Number of roof layers (NR)

3 Thermal resistance of the roof inside surface

4 ℓ, k, ρ, c, and resistance of the 1st layer counted from inside surface ... (NR-2) Cards

5 Thermal resistance outside surface of the roof

6 Description of the 1st layer of the roof

7 Description of the 2nd layer of the roof

8 Description of the NRth layer of the roof

9 Number of wall layers (NW)

10 Thermal resistance of the inside surface

11 ℓ, k, ρ, c and resistance of the 1st layer counted from inside (NW-2) Cards

12 Thermal resistance of the outside surface layer

13 Description of the 1st layer of the wall

14 Description of the 2nd layer of the wall

15 Description of the NWth layer of the wall

16 Number of layer of the floor and the semi-infinite layer (NF) index (if basement floor)

17 Thermal resistance of the inside surface ℓ, k, ρ, c and Res of the 1st layer of the floor counted from the inside surface

18 ℓ, k, ρ, c and Res of the 2nd layer of the floor (NF-1) Cards

19 k, ρ, and c of the earth ... if basement floor

20 Description of the 1st layer

21 Description of the 2nd layer

22 Description of the NFth layer

```
C     BASE HEATING/COOLING LOAD CALCULATION PROGRAM
C     INCLUDING THE ROOM TEMPERATURE  CHANGE PREDICTIONS
C     I=EXPOSURE NUMBER,I=1,2,-NEXP
C     ITYPE(I),EXPOSURE TYPE NUMBER
C     1  ROOF
C     2   EXPOSED WALLS
C     3  WINDOWS
C     4  DOORS
C     5   GROUND HEAT TRANSFER SURFACES
C     6   FURNISHINGS,PARTITION WALLS,PARTY WALLS AND FLOOR/CEILINGS
C       7   OPEN SURFACE
C     8   EXPOSED FLOORS
C     PB   BAROMETRIC PRESSURE  IN OF HG
C     ITEMP=  TEMPERATURE RISE INDEX
C     IHT(I) HEAT TRANSFER INDEX
C     AVEHTG--AVERAGE HEAT GAIN FOR SITE
C     TSITHT--TOTAL SITE HEAT GAIN FOR 24 HOURS
C     IHT=-1  GLASS SURFACE(TRANSPARENT)
C     IHT=0  OPAQUE
C     IHT=1  OTHERWISE
C     QI--HEAT FLOW THROUGH EACH EXPOSURE
C     QSUM--SENSIBLE HEAT GAIN
C     QTLAT--LATENT HEAT GAIN
C     TOTHT--TOTAL HEAT GAIN
C     QC--SENSIBLE COOLING LOAD
C     SITEQS--ENTIRE SITE SENSIBLE HEAT GAIN
C     SITEQL--ENTIRE SITE LATENT HEAT GAIN
C     SITETH--ENTIRE SITE TOTAL HEAT GAIN
C     BLDMAX--BUILDING MAX HEAT GAIN
C     QSUMT--AVERAGE HEAT GAIN
C     SITELD--ENTIRE SITE COOLING LOAD
C     SITMAX--SITE MAX HEAT GAIN
C     AVESIT--SITE AVERAGE HEAT GAIN
C     SQWINT--SITE HEAT LOSS
C     IRF(I) RESPONSE FACTOR NUMBER APPLICABLE TO THE SURFACE
C     ABSP(I) SURFACE SOLAR HEAT COEFFICENT
C      SHADE(I)   SHADING COEFFICIENTS
C     U(I) EXPOSURE U VALUE
C     UT(I)--U VALUE WITHOUT EXTERNAL SURFACE RESISTANCE
C     H(I) EXPOSURE EXTERIOR SURFACE THERMAL CONDUCTANCE
C     A(I) EXPOSURE AREA
C     WAZ(I) WALL AZIMUTH ANGLE MEASURED CLOCKWISE FROM SOUTH
C     TG--GROUND TEMPERATURE FOR COOLING LOAD CALCULATION
C     TV = VENTILATION AIR TEMPERATURE
C     UG--GROUND HEAT TRANSFER COEFFICIENT
C     AG--GROUND HEAT TRANSFER SURFACE(=0 WHEN NO GROUND FLOOR)
C     TGW--WINTER GROUND TEMP
C     DBMWT--WINTER OUTDOOR TEMP
C     LAT=LATITUDE DEGREE
C     LONG=LONGITUDE DEGREE
C     TZN--TIME ZONE NUMBER
C     MONTH--MONTH OF YEAR
C     DAY--DAY
C     QLITX--MAXIMUM LIGHTING LOAD IN WATT/FT2
```

```
 QEQPX--MAX EQUIP LOAD IN WATT/FT2
 NEXP--NUMBER OF EXTERIOR HEAT TRANSFER SURFACES
 BLDGNO--BUILDING NUMBER
 HT--BUILDING OR DWELLING UNIT HEIGHT
 QPSX--MAX OCCUPANT SENSIBLE LOAD BTU/HR,PERSON
 QPLX--MAX OCCUPANT LATENT LOAD BTU/HR,PERSON
 DP--DEWPOINT TEMP, F
 QCU--MAX NUMBER OF OCCUPANTS
 ELAPS=DAYS ELAPSED SINCE JAN. 1
 UGLAS--WINTER GLASS HEAT TRANSFER COEFFICIENT
 HI-----INNER SURFACE CONVECTIVE HEAT TRANSFER COEFFICIENT
 HR   INNER SURFACE RADIATIVE HEAT TRANSFER COEFFICIENT
 G,GG   RADATION HEAT EXCHANGE SURFACES   SHAPE FACTORS
 X,Y,Z   RESPONSE FACORS
 THESE RESPONSE FACORS SHOULD NOT INCLDE  OUTSIDE SURFACE
 THERMAL RESISTANCE WHEN ITEMP.EQ.0
 THEY SHOUD NOT INCLUDE BOTH THE OUTSIDE AND INSIDE THERMAL
 RESISTANCES WHEN ITEMP.EQ.1
 CFML     AIR LEAKAGE
 CFMV   VENTILATION
 R   A FRACTION OF LIGHTING POWER  THAT GOES INTO FLOOR
 DBMAX   DESIGN OUTDOOR DRY-BULB TEMPERATURE
 RANGE   DAILY RANGE OF THE OUTDOOR TEMPERATURE
 WBMAX   DESIGN OUTDOOR WET-BULB TEMPERATURE
 WBID   DESIGN INDOOR WET-BULB TEMPERATURE
 DBIN   DESIGN INDOOR DRY-BULB TEMPRATURE
 ITK   INDEX TO CALCULATE ROOM TEMPERATURE RISE WHEN NOT AIR CONDIT
 ITK=1 WHEN NOT AIR CONDITIONED
 ITEMP  INDEX TO USE  ASHRAE WEIGHTING FACTOR
 IF ITEMP=0  ASHARE WEIGHTING FACTOR
 COMMON /CC/ X(10,100),Y(10,100),Z(10,100),ITYPE(10),IHT(10),IRF(10
1),ABSP(10),U(10),H(10),HI(10),A(10),UT(10),TOS(10,48),TIS(10,48),G
2(10,10),TOY(48),DB(24),QLITE(24),QEQUP(24),QOCPS(24),QI(10),CR(10)
3,NR(10),QGLAS(10,24),ITHST
 DIMENSION XX(100,10),YY(100,10),ZZ(100,10),TNEW(24),TIX(24),TI(48)
1,QOCUP(24),QTL(24),XDUM(100),YDUM(100),ZDUM(100),TDUM(100),QO(10)
 REAL LG(8),LX(8),LIS(8),QG(8),QX(8),QIS(8),QGZ(8),QXZ(8),QISZ(8),S
1ITEQS(24),SITEQL(24),SITETH(24),SITELD(24),TIF(10)
 DIMENSION QLITX(24),QEQUX(24),QDESIN(10,24),QPEOPL(24),QDES(10)
 DIMENSION QSUN(10,24),QSKY(10,24),SHADE(10),AZW(10)
 DIMENSION NAMEBD(6),VT(10),DR(10),MR(10),QGX(10)
 DIMENSION DBNBS(24)/.26,.20,.15,.10,.05,.0,.03,.1,.19,.30,.43,.57,
1.69,.80,.90,.96,.99,1.0,.97,.90,.75,.57,.43,.33/
 REAL LAT,LONG,MONTH,NOFLR
 DIMENSION LTYPE(10),GG(10,10)
 COMMON /SOL/ LAT,LONG,TZN,WAZ,WT,CN,DST,LPYR,S(35)
 READ (5,900) QLITX
 READ (5,900) QEQUX
 READ (5,900) QOCUP
 SIGMA=0.1714E-8
 HR=4.*(535.**3)*SIGMA
 DO 790 IJKLMN=1,20
 READ (5,910,END=800) NAMEBD
 READ (5,880) IROT,ISKIP
 IF (NAMEBD(1).EQ.' ') GO TO 800
 IF (ISKIP.NE.0) GO TO 30
 DO 10 I=1,10
 DO 10 J=1,100
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      X(I,J)=0.
      Y(I,J)=0.
10    Z(I,J)=0.
      DO 20 J=1,24
      SITEQS(J)=0.
      SITEQL(J)=0.
      SITETH(J)=0.
      SITELD(J)=0.
20    CONTINUE
      SQWINT=0.
      CALL RESFX (X,Y,Z,XX,YY,ZZ,MR,DR,VT,10)
      WRITE (6,820)
      PB=29.92
      READ (5,900) LAT,LONG,TZN,MONTH,DAY,ELAPS,UG,UGLAS
      WRITE (6,850)
      WRITE (6,840) LAT,LONG,TZN,MONTH,DAY,ELAPS,UG,UGLAS
      READ (5,900) QLITY,QEQPX,CFMV,CFML
      WRITE (6,860)
      WRITE (6,840) QLITY,QEQPX,CFMV,CFML
      READ (5,900) DBMAX,RANGE,DBIN,WBMAX,WBID,DBMWT,TG,TGW,TV
      WRITE (6,870)
      WRITE (6,840) DBMAX,RANGE,DBIN,WBMAX,WBID,DBMWT,TG,TGW,TV
      CALL PSY1 (DBMAX,WBMAX,PB,DP,PV,WOUT,HOUT,VOUT,RHOUT)
      CALL PSY1 (DBIN,WBID,PB,DPID,PV,WID,HIND,VIN,RHIN)
      WV=WOUT
      WIN=WID
      WA=WOUT
      TIO=DBIN
30    READ (5,900) ROOMNO,HT,AG,NOFLR,QCU,AIRCHG
      WRITE (6,830)
      WRITE (6,840) ROOMNO,HT,AG,NOFLR,QCU,AIRCHG
      READ (5,890) NEXP,ITK,ITEMP,ITHST
      DO 110 I=1,NEXP
      READ (5,920) ITYPE(I),IRF(I),U(I),A(I),AZW(I),DUM,SHADE(I),ABSP(I)
      READ (5,900) (G(I,J),J=1,NEXP)
      LTYPE(I)=ITYPE(I)
      IF (ITYPE(I).EQ.7) GO TO 110
      K=IRF(I)
      IF (Y(K,1).GT.1.) IRF(I)=10
      NR(I)=MR(K)
      UT(I)=VT(K)
      CR(I)=DR(K)
      IF (NR(I).GT.48) NR(I)=48
      IF (ITYPE(I).EQ.3) ABSP(I)=0.
      IF (ITYPE(I).EQ.5) ABSP(I)=0.
      IF (ITYPE(I).EQ.6) ABSP(I)=0.
      IHT(I)=1
      IF (ITYPE(I).EQ.3) IHT(I)=-1
      H(I)=4.08
      HI(I)=0.542
      IF (ITYPE(I).EQ.6) H(I)=0.
      IF (ITYPE(I).EQ.5) HI(I)=0.162
      IF (U(I)) 40,40,50
40    RU=1./UT(I)+1./HI(I)
      IF (ITYPE(I).NE.6) RU=RU+1./H(I)
      U(I)=1./RU
50    CONTINUE
      IF (X(K,2)) 110,60,110
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60    IF (H(I)) 70,80,70
70    R=1./U(I)-1./H(I)
      GO TO 90
80    R=1./U(I)
90    UT(I)=1./R
      IF (ITEMP.NE.0) UT(I)=1./(R-1./(HI(I)+0.9))
      IF (UT(I)) 100,100,110
100   UT(I)=100.
110   CONTINUE
      WRITE (6,1170)
      DO 120 I=1,NEXP
      AZW(I)=AZW(I)+IROT
      IF (AZW(I).GT.180.) AZW(I)=AZW(I)-360.
      WRITE (6,930) I,ITYPE(I),IHT(I),IRF(I),ABSP(I),U(I),H(I),A(I),AZW(
     1I),SHADE(I),UT(I)
120   CONTINUE
      NEXP1=NEXP-1
      NEXP2=NEXP-2
      DO 160 I=1,NEXP
      GSUM=0.
      NEX=NEXP1
      IF (I.EQ.NEXP) NEX=NEXP2
      MEX=NEX+1
      DO 130 J=1,NEX
      IF (I.GT.J) G(I,J)=G(J,I)*A(J)/A(I)
130   GSUM=GSUM+G(I,J)
      IF (GSUM-1.) 140,150,150
140   G(I,MEX)=1.-GSUM
      GO TO 160
150   G(I,MEX)=0.
160   CONTINUE
      WRITE (6,1180)
      WRITE (6,1190)
      DO 170 I=1,NEXP
      WRITE (6,1200) I,(G(I,J),J=1,NEXP)
170   CONTINUE
      DO 180 I=1,NEXP
      DO 180 J=1,NEXP
180   G(I,J)=HR*G(I,J)
      II=0
      DO 200 I=1,NEXP
      IF (ITYPE(I).EQ.7) GO TO 200
      II=II+1
      ITYPE(II)=ITYPE(I)
      IRF(II)=IRF(I)
      U(II)=U(I)
      A(II)=A(I)
      AZW(II)=AZW(I)
      SHADE(II)=SHADE(I)
      ABSP(II)=ABSP(I)
      NR(II)=NR(I)
      UT(II)=UT(I)
      CR(II)=CR(I)
      IHT(II)=IHT(I)
      H(II)=H(I)
      HI(II)=HI(I)
      JJ=0
      DO 190 J=1,NEXP
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      IF (LTYPE(J).EQ.7) GO TO 190
      JJ=JJ+1
      GG(II,JJ)=G(I,J)
190   CONTINUE
200   CONTINUE
      NEXP=II
      WRITE (6,1210)
      DO 210 I=1,NEXP
      DO 210 J=1,NEXP
210   G(I,J)=GG(I,J)
      WRITE (6,1180)
      WRITE (6,1190)
      DO 220 I=1,NEXP
220   WRITE (6,1200) I,(G(I,J),J=1,NEXP)
      WRITE (6,1170)
      DO 230 I=1,NEXP
230   WRITE (6,930) I,ITYPE(I),IHT(I),IRF(I),ABSP(I),U(I),H(I),A(I),AZM(
     1I),SHADE(I),UT(I)
      R=0.5
      WRITE (6,940)
      DO 240 I=1,24
240   DB(I)=(DBMAX-RANGE)+(RANGE*DBNBS(I))
      SUM=0.
      DO 250 I=1,24
250   SUM=SUM+DB(I)
      DBM=SUM/24.
      WRITE (6,950) (DB(I),I=1,24),DBM
      DO 260 I=1,24
260   TIX(I)=TIO
      SUM=0.
      DO 270 I=1,24
270   SUM=SUM+TIX(I)
      TIM=SUM/24.
      WRITE (6,960) (TIX(I),I=1,24),TIM
      WRITE (6,970) QLITX
      WRITE (6,980) QEQUX
      WRITE (6,990) QOCUP
      CFMWT=AG*HT/60.*AIRCHG
      CFML=0.5*CFMWT
      CFM=CFML+CFMV
      QLITO=QLITY*AG*3.413*NOFLR
      QEQPO=QEQPX*AG*3.413*NOFLR
      DO 280 J=1,24
      QLITE(J)=QLITX(J)*QLITO
      QEQUP(J)=QEQUX(J)*QEQPO
      QTL(J)=4840.*CFM*WOUT
280   CONTINUE
      DO 290 I=1,9
      QO(I)=0.
      QI(I)=0.
290   TNEW(I)=0.
C     DBM=TIM= REFERENCE TEMPERATURE
      DBM=TIM
      S(1)=LAT
      S(2)=LONG
      S(3)=TZN
      S(4)=ELAPS
      S(6)=1.
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      S(7)=0.2
      S(8)=1.0
      S(33)=1.
      WRITE (6,1220)
      DO 350 I=1,NEXP
      IF (ITYPE(I).LT.5) GO TO 310
      DO 300 J=1,24
      QSUN(I,J)=0.
      QGLAS(I,J)=0.
  300 QSKY(I,J)=0.
      GO TO 340
  310 WAZ=AZW(I)
      S(9)=WAZ
      S(10)=90.
      IF (ITYPE(I).EQ.1) S(10)=0.
      DO 330 J=1,24
      QSKY(I,J)=0.
      IF (ITYPE(I).EQ.1) QSKY(I,J)=20.
      TIME=J
      S(5)=TIME
      CALL SUN
      IF (S(25).GT.0.) GO TO 320
      QSUN(I,J)=0.
      QGLAS(I,J)=0.
      GO TO 330
  320 QSUN(I,J)=S(25)*ABSP(I)
      QGLAS(I,J)=0
      IF (IHT(I).GT.0) GO TO 330
      CALL GLASS (SHADE(I),1.,1.,QGLAS(I,J))
  330 CONTINUE
  340 WRITE (6,1000) I
      WRITE (6,1010) (QSUN(I,J),J=1,24)
  350 WRITE (6,1010) (QGLAS(I,J),J=1,24)
      DO 360 J=1,24
      TI(J)=TIX(24-J+1)-TIM
      DO 360 I=1,NEXP
  360 TOS(I,J)=DB(24-J+1)-DBM
      DO 370 J=25,48
      TI(J)=TI(J-24)
      DO 370 I=1,NEXP
  370 TOS(I,J)=TOS(I,J-24)
      IF (ITEMP.NE.0) GO TO 390
      DO 380 L=1,8
      LG(L)=0.
      LX(L)=0.
      LIS(L)=0.
      QG(L)=0.
      QX(L)=0.
  380 QIS(L)=0.
  390 CONTINUE
      DO 400 I=1,NEXP
      DO 400 J=1,48
  400 TIS(I,J)=0.
      TA=TIM
      DO 720 N=1,7
      IF (N.NE.7) GO TO 410
      QSUMT=0.
      BLDMAX=0.
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410   CONTINUE
      DO 720 NK=1,24
      DO 440 I=1,NEXP
      DO 420 NTT=2,48
420   TOY(NTT)=TOS(I,NTT-1)
      DO 430 NTT=2,48
430   TOS(I,NTT)=TOY(NTT)
440   CONTINUE
      IF (ITEMP.NE.0) GO TO 490
      TA=TIX(NK)
      DO 450 L=2,8
      QGZ(L)=QG(L-1)
      QXZ(L)=QX(L-1)
      QISZ(L)=QIS(L-1)
450   CONTINUE
      DO 460 L=2,8
      QG(L)=QGZ(L)
      QX(L)=QXZ(L)
      QIS(L)=QISZ(L)
460   CONTINUE
      DO 470 NTT=2,48
470   TOY(NTT)=TI(NTT-1)
      DO 480 NTT=2,48
480   TI(NTT)=TOY(NTT)
      SUMQG=0.
490   CONTINUE
      DO 540 I=1,NEXP
      K=IRF(I)
      DO 500 J=1,48
      XDUM(J)=X(K,J)
      YDUM(J)=Y(K,J)
      ZDUM(J)=Z(K,J)
      TDUM(J)=TOS(I,J)
      IF (ITYPE(I).EQ.6) TDUM(J)=TIS(I,J)
      IF (ITYPE(I).EQ.5) TDUM(J)=TG-TIM
      IF (ITEMP.NE.0) TI(J)=TIS(I,J)
      IF (TDUM(J).GT.100..OR.TI(J).GT.100.) GO TO 760
      IF (TDUM(J).LT.-100..OR.TI(J).LT.-100.) GO TO 760
500   CONTINUE
      UX=U(I)
      IF (H(I)) 520,520,510
510   RX=1./U(I)-1./H(I)
      UX=1./RX
520   CONTINUE
      CALL OUTSID (XDUM,YDUM,ZDUM,CR(I),UX,H(I),DB(NK),TIM,QO(I),QI(I),Q
     1SUN(I,NK),QSKY(I,NK),TDUM,TI,TNEWO,TA,ITEMP)
      DO 530 J=1,48
530   TOS(I,J)=TDUM(J)
      TNEW(I)=TNEWO+TIM
540   CONTINUE
      QOCPS(NK)=QOCUP(NK)*10.*(100.-TA)*QCU
      QOCPL=10.*(TA-60.)*QOCUP(NK)*QCU
      IF (TA-100.) 560,550,550
550   QOCPS(NK)=0.
      QOCPL=400.*QOCUP(NK)*QCU
      GO TO 580
560   IF (TA-60.) 570,580,580
570   QOCPS(NK)=400.*QOCUP(NK)*QCU
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```
      QOCPL=0.
580   QPEOPL(NK)=QOCPL
      SUML=QTL(NK)-4840.*CFM*WIN+QOCPL
      QTLAT=-SUML
C     QSUM     INSTANTANEOUS HEAT GAIN
C     SUMQG    INSTANTANEOUS SOLAR HEAT GAIN
C     QI       CONDUCTION HEAT TRANSFER
      QSUM=1.08*CFML*(TA-DB(NK))+1.08*CFMV*(TA-TV)-QLITE(NK)-QEQUP(NK)-Q
     1OCPS(NK)
      DO 590 I=1,NEXP
590   QSUM=QSUM+A(I)*(QI(I)-QGLAS(I,NK))
      IF (N.NE.5) GO TO 650
      IF (NK.NE.1) GO TO 600
      WRITE (6,1020) NAMEBD
600   CONTINUE
      WRITE (6,1030) NK,(TNEW(I),I=1,9),DB(NK)
      IF (ITEMP) 720,720,650
610   IF (NK.NE.1) GO TO 620
      WRITE (6,1040) NAMEBD
620   CONTINUE
      TOTHT=QL+QTLAT
      WRITE (6,1050) NK,(QI(I),I=1,9),QSUM,QTLAT,QL,TOTHT
      DO 630 I=1,NEXP
      QDESIN(I,NK)=QI(I)*A(I)
630   CONTINUE
      SITEQS(NK)=SITEQS(NK)+QSUM
      SITEQL(NK)=SITEQL(NK)+QTLAT
      SITETH(NK)=SITETH(NK)+TOTHT
      SITELD(NK)=SITELD(NK)+QL
      IF (QL.GT.BLDMAX) GO TO 640
      BLDMAX=QL
      TOTHTX=TOTHT
      IMAX=NK
640   IF (N.EQ.7) QSUMT=QSUMT+TOTHT
      GO TO 720
650   DO 680 I=1,NEXP
      DO 660 NTT=2,48
660   TOY(NTT)=TIS(I,NTT-1)
      DO 670 NTT=2,48
670   TIS(I,NTT)=TOY(NTT)
680   CONTINUE
      TV=DB(NK)
      CALL RMTMP (NEXP,NK,TV,CFML,CFMV,R,TIM,TA,TIF,QL,ITK)
      IF (TA.GT.TIM) GO TO 690
      DPI=DPID
      WBIN=WBID
      HIN=HIND
      WIN=WID
      GO TO 700
690   CONTINUE
      QOCPL=QOCPL/1060.
      WI=(4.5*CFML*WA+4.5*CFMV*WV+QOCPL)/(4.5*CFML+4.5*CFMV)
      PVI=PB*WI/(0.622+WI)
      DPI=DPF(PVI)
      CALL PSY2 (TA,DPI,PB,WBIN,PVI,WIN,HIN,VIN,RHIN)
700   CONTINUE
      IF (N.LT.6) GO TO 720
      IF (N.EQ.7) GO TO 610
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      IF (NK.NE.1) GO TO 710
      WRITE (6,1060) NAMEBD
710   WRITE (6,1070) NK,(TIF(I),I=1,9),TA,WBIN
720   CONTINUE
      QSUMT=QSUMT/24.
      QWINT=1.08*CFMWT*(TIM-DBMWT)+UG*(TIM-TGW)*AG
      QWINT=1.08*CFMWT*(TIM-DBMWT)
      DO 740 I=1,NEXP
      IF (IHT(I).LT.0) U(I)=UGLAS
      IF (ITYPE(I).NE.5) GO TO 730
      QWINT=QWINT+UG*A(I)*(TIM-TGW)
      GO TO 740
730   IF (ITYPE(I).EQ.6) GO TO 740
      IF (ITYPE(I).EQ.7) GO TO 740
      QWINT=QWINT+A(I)*U(I)*(TIM-DBMWT)
740   CONTINUE
      SQWINT=SQWINT+QWINT
      WRITE (6,1140) QWINT,TOTHTX,QSUMT
      IF (ITK.NE.0) GO TO 790
      DO 750 I=1,NEXP
      QGX(I)=QGLAS(I,IMAX)*A(I)
750   QDES(I)=QDESIN(I,IMAX)
      CFM=CFML+CFMV
      CALL OUTPUT (DBMAX,WBMAX,DBIN,WBID,WOUT,WIN,QGX,CFM,QLITE(IMAX),QO
     1CPS(IMAX),QPEOPL(IMAX),QDES,AZW,ITYPE,NEXP,NAMEBD)
      GO TO 790
760   WRITE (6,1080) N
      WRITE (6,1090)
      DO 770 J=1,48
770   WRITE (6,1110) J,(TOS(I,J),I=1,10)
      WRITE (6,1080) N
      WRITE (6,1100)
      DO 780 J=1,48
780   WRITE (6,1110) J,(TIS(I,J),I=1,10)
790   CONTINUE
800   CONTINUE
      WRITE (6,1120)
      WRITE (6,1130)
      SITMAX=0.
      TSAVE=0.
      TSITHT=0.
      DO 810 I=1,24
      SQLLD=SITEQL(I)+SITELD(I)
      TSITHT=TSITHT+SITETH(I)
      IF (SITETH(I).LT.SITMAX) SITMAX=SITETH(I)
      IF (SQLLD.LT.TSAVE) TSAVE=SQLLD
      WRITE (6,1150) I,SITEQS(I),SITEQL(I),SITETH(I),SITELD(I),SQLLD
810   CONTINUE
      AVEHTG=TSITHT/24.
      WRITE (6,1160) SQWINT,SITMAX,AVEHTG,TSAVE
      WRITE (6,1120)
      STOP
C
C
820   FORMAT (1H1)
830   FORMAT (8H1 BLDGNO,8X'HT',8X'AG',5X'NOFLR',7X'QCU',4X'AIRCHG')
840   FORMAT (10F10.1)
850   FORMAT (7X'LAT',6X'LONG',7X'TZN',5X'MONTH',7X'DAY',5X'ELAPS',8X'UG
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     1',5X'UGLAS')
860   FORMAT (5X'QLITY',5X'QEQPX',6X'CFMV',6X'CFML')
870   FORMAT (5X'DBMAX'5X'RANGE',6X'DBIN',5X'WBMAX',6X'WBID',5X'DBMWT',8
     1X'TG',7X'TGW',8X'TV')
880   FORMAT (10I7)
890   FORMAT (10I7)
900   FORMAT (10F7.0)
910   FORMAT (6A6)
920   FORMAT (2I7,6F7.0)
930   FORMAT (I3,3I10,8F10.2)
940   FORMAT ('1  ENVIRONMENTAL DATA')
950   FORMAT ('0DB TEMP'/12F10.2/12F10.2/'0MEAN VALUE='F10.3)
960   FORMAT ('0TI'/12F10.2/12F10.2/'0MEAN VALUE='F10.3)
970   FORMAT ('0WLITE'/(12F10.3))
980   FORMAT ('0WEQUP'/(12F10.3))
990   FORMAT ('0WOCUP'/(12F10.3))
1000  FORMAT (I10,F10.0)
1010  FORMAT (24F5.0)
1020  FORMAT (1H120X'EXPOSURE SURFACE TEMPERATURE, DEGREES F  FOR 'A6//
     17X'TIME'5X'(1)'7X'(2)'7X'(3)'7X'(4)'7X'(5)'7X'(6)'7X'(7)'7X'(8)'7X
     2'(9)'7X'DB')
1030  FORMAT (I10,10F10.2)
1040  FORMAT (1H130X6A6///7X'TIME'14X'EXPOSURE HEAT FLUX '40X' HEAT GAIN
     1S '3X' SENSIBLE LOAD'1X' TOTAL LOAD'/30X'BTU/HR,FT2'45X'BTU/HR'12X
     2'BTU/HR'5X'BTU/HR'/'0'81X'SENSIBLE'3X'LATENT'/14X'(1)'4X'(2)'4X'(3
     3)'4X'(4)'4X'(5)'4X'(6)'4X'(7)'4X'(8)'4X'(9)'7X'HEAT'7X'HEAT'/)
1050  FORMAT (I10,9F7.2,4X,4G10.4)
1060  FORMAT (1H120X' INSIDE SURFACE TEMPERATURE, DEGREE F FOR '6A6//7X'
     1TIME'5X'(1)'7X'(2)'7X'(3)'7X'(4)'7X'(5)'7X'(6)'7X'(7)'7X'(8)'7X'(9
     2)'7X'TA'8X'WB'/)
1070  FORMAT (I10,11F10.2)
1080  FORMAT ('1 CINVERSION ERROR AT N='I10)
1090  FORMAT ('0   TOS')
1100  FORMAT ('0  TIS')
1110  FORMAT (I10,10F10.2)
1120  FORMAT (1H1)
1130  FORMAT (30X'SITE SUMMARY'//7X'TIME'9X'HEAT GAINS'15X'TOTAL HEAT'4X
     1'COOLING LOAD'7X'TOTAL'/22X'BTU/HR'19X'BTU/HR'9X'BTU/HR'7X'COOLING
     2 LOAD'//14X'SENSIBLE HEAT'3X'LATENT HEAT'//)
1140  FORMAT (////' HEAT LOSS'10X'COOLING LOAD'7X'AVERAGE HEAT GAIN'3X//
     11X3(G10.4,10X))
1150  FORMAT (6(G10.4,5X))
1160  FORMAT (////' HEAT LOSS'10X'MAX HEAT GAIN'7X'AVERAGE HEAT GAIN'3X'
     1MAX TOTAL COOL LOAD'//1X4(G10.4,10X))
1170  FORMAT ('0 SURFACE NO ITYPE'4X,'IHT'7X,'IRF'7X,'ABSP'6X,'U'9X,'H'9
     1X,'A'9X,'WAZ'5X,'SHADE'8X,'UT')
1180  FORMAT ('0    RADIATION INTERCHANGE FACTORS')
1190  FORMAT ('0 SURFACE           1           2           3           4
     1 5           6           7           8           9          10')
1200  FORMAT (I10,10F10.3)
1210  FORMAT ('0 MODIFIED SURFACE  DATA')
1220  FORMAT ('1  SOLAR DATA (QSUN/QGLASS)')
      END
```

```
      SUBROUTINE ABCD2 (Z,K,L,G,A,B,C,D,NL)
      DIMENSION AX(10),BX(10),CX(10),DX(10),G(10)
      REAL K(10),L(10)
      PI=4.*ATAN(1.)
      PP=PI*0.5
      DO 50 I=1,NL
      IF (G(I)) 40,40,10
10    IF (Z) 30,30,20
20    ZQ=SQRT(Z/G(I))
      ZQL=ZQ*L(I)
      CO=SIN(ZQL)
      C1=COS(ZQL)
      S1=CO/ZQL
      S2=(S1-C1)/ZQL/ZQL
      AX(I)=C1
      BX(I)=L(I)/K(I)*S1
      CX(I)=-ZQL*K(I)/L(I)*CO
      DX(I)=C1
      GO TO 50
30    AX(I)=1.
      CX(I)=0.
      DX(I)=1.
      BX(I)=L(I)/K(I)
      GO TO 50
40    AX(I)=1.
      BX(I)=1/K(1)
      CX(I)=0.
      DX(I)=1.
50    CONTINUE
      A=AX(1)
      B=BX(1)
      C=CX(1)
      D=DX(1)
      IF (NL.LT.2) GO TO 60
      CALL MULT (AX,BX,CX,DX,A,B,C,D,NL)
60    RETURN
      END
```

```
      SUBROUTINE ABCDP2 (Z,K,L,G,AP,BP,CP,DP)
      REAL K,L
      PI=4.*ATAN(1.)
      IF (G) 30,30,10
10    PP=PI/4./G
      IF (Z) 40,40,20
20    ZQ=SQRT(Z/G)
      ZQL=ZQ*L
      X=L*L*0.5/G
      RES=L/K
      C0=SIN(ZQL)
      C1=COS(ZQL)
      S1=C0/ZQL
      S2=(S1-C1)/ZQL/ZQL
      AP=X*S1
      BP=X*RES*S2
      CP=X*(S1+C1)/RES
      DP=X*S1
      GO TO 50
30    AP=0.
      BP=0.
      CP=0.
      DP=0.
      GO TO 50
40    CONTINUE
      X=L*L*0.5/G
      AP=X
      BP=X*L/K/3
      CP=K/L*X*2.
      DP=X
      GO TO 50
50    RETURN
      END
```

```
      SUBROUTINE DERVT (A,B,C,D,AP,BP,CP,DP,APP,BPP,CPP,DPP,N)
      DIMENSION A(N),B(N),C(N),D(N),AP(N),BP(N),CP(N),DP(N),AT(10),BT(10
     1),CT(10),DT(10),ATT(10),BTT(10),CTT(10),DTT(10)
      DO 30 I=1,N
      DO 20 J=1,N
      IF (I.EQ.J) GO TO 10
      AT(J)=A(J)
      BT(J)=B(J)
      CT(J)=C(J)
      DT(J)=D(J)
      GO TO 20
10    AT(J)=AP(J)
      BT(J)=BP(J)
      CT(J)=CP(J)
      DT(J)=DP(J)
20    CONTINUE
30    CALL MULT (AT,BT,CT,DT,ATT(I),BTT(I),CTT(I),DTT(I),N)
      APP=ATT(1)
      BPP=BTT(1)
      CPP=CTT(1)
      DPP=DTT(1)
      DO 40 I=2,N
      APP=APP+ATT(I)
      BPP=BPP+BTT(I)
      CPP=CPP+CTT(I)
40    DPP=DPP+DTT(I)
      RETURN
      END
```

```
      FUNCTION DPF (PV)
C     THIS SUBROUTINE CALCULATES DEW-POINT TEMPERATURE FOR GIVEN VAPOR PRE
      Y=LOG(PV)
      IF (PV.GT.0.1836) GO TO 10
      DPF=71.98+24.873*Y+0.8927*Y*Y
      GO TO 20
10    DPF=79.047+30.579*Y+1.8893*Y*Y
20    RETURN
      END
```

```
SUBROUTINE GLASS (SHDCF,GLTYP,GLAZE,SHGF)
DIMENSION TR(9),SH(25)
COMMON /SOL/ LAT,LONG,TZN,WAZ,WT,CN,DST,LPYR,S(35)
TR(7)=S(19)
TR(8)=GLTYP
TR(9)=GLAZE
CALL TAR (TR)
SH(1)=S(24)
SH(2)=S(22)
SH(3)=S(23)
SH(4)=S(19)
SH(5)=0.5
SH(6)=0.5
SH(7)=0.25
SH(8)=0.
SH(9)=0.7
SH(10)=1.0
SH(11)=SHDCF
SH(12)=TR(1)
SH(13)=TR(2)
SH(14)=TR(3)
SH(15)=TR(5)
SH(16)=TR(4)
SH(17)=TR(6)
CALL SHG (SH)
SHGF=SH(18)
RETURN
END
```

```
      SUBROUTINE GPF (U,ZL,Z)
      DIMENSION Z(1)
      PI=4.*ATAN(1.)
      SQTPI=SQRT(PI)
      PI2=2./PI
      EB=0.001
      DB=0.1
      WRITE (6,30)
      WRITE (6,40)
      Z(1)=2*ZL*SQRT(U)/SQTPI
      ZZ=Z(1)
      Z(2)=Z(1)*(SQRT(2.)-2.)
      DO 10 K=3,50
      ZK=K
10    Z(K)=Z(1)*(SQRT(ZK)-2.*SQRT(ZK-1)+SQRT(ZK-2.))
      DO 20 K=1,50
20    WRITE (6,50) K,Z(K)
      RETURN
C
C
30    FORMAT (50H0  RESPONSE FACTORS FOR  SEMI-INFINITE BED                  )
40    FORMAT (50H0          K       Z(K)                                     )
50    FORMAT (1I10,3F10.5)
      END
```

```
      SUBROUTINE MULT (A,B,C,D,AT,BT,CT,DT,N)
      DIMENSION A(N),B(N),C(N),D(N)
      ATT=A(1)
      BTT=B(1)
      CTT=C(1)
      DTT=D(1)
      IF (N.LT.2) GO TO 20
      DO 10 J=2,N
      AT=ATT*A(J)+BTT*C(J)
      BT=ATT*B(J)+BTT*D(J)
      CT=CTT*A(J)+DTT*C(J)
      DT=CTT*B(J)+DTT*D(J)
      ATT=AT
      BTT=BT
      CTT=CT
10    DTT=DT
      GO TO 30
20    AT=ATT
      BT=BTT
      CT=CTT
      DT=DTT
30    RETURN
      END
```

```
      SUBROUTINE OUTPUT (DB,WB,DBI,WBI,WA,WI,QGX,CFML,QLITE,QOCS,QOCL,Q,
     1WAZ,ITYPE,NEXP,NAME)
      DIMENSION Q(10),WAZ(10),ITYPE(10),NAME(6),QGX(10)
      QWS=0.
      QWW=0.
      QWN=0.
      QWE=0.
      QGS=0.
      QGE=0.
      QGW=0.
      QGN=0.
      QDS=0.
      QDW=0.
      QDE=0.
      QDN=0.
      WRITE (6,20) (NAME(I),I=1,6)
      WRITE (6,30) DB,WB,WA
      WRITE (6,40) DBI,WBI,WI
      DBD=DB-DBI
      WD=WA-WI
      WRITE (6,50)
      WRITE (6,60) DBD,WD
      DO 10 I=1,NEXP
      Q(I)=-Q(I)
      II=ITYPE(I)
      IF (II.EQ.3) Q(I)=Q(I)+QGX(I)
      IWAZ=WAZ(I)
      IF (II.EQ.1) QROOF=Q(I)
      IF (II.EQ.5) QFLOOR=Q(I)
      IF (II.EQ.6) QFLOOR=QFLOOR+Q(I)
      IF (II.EQ.2.AND.IWAZ.EQ.0) QWS=Q(I)
      IF (II.EQ.2.AND.IWAZ.EQ.90) QWW=Q(I)
      IF (II.EQ.2.AND.IWAZ.EQ.-90) QWE=Q(I)
      IF (II.EQ.2.AND.IWAZ.EQ.180) QWN=Q(I)
      IF (II.EQ.3.AND.IWAZ.EQ.0) QGS=Q(I)
      IF (II.EQ.3.AND.IWAZ.EQ.90) QGW=Q(I)
      IF (II.EQ.3.AND.IWAZ.EQ.-90) QGE=Q(I)
      IF (II.EQ.3.AND.IWAZ.EQ.180) QGN=Q(I)
      IF (II.EQ.4.AND.IWAZ.EQ.0) QDS=Q(I)
      IF (II.EQ.4.AND.IWAZ.EQ.90) QDW=Q(I)
      IF (II.EQ.4.AND.IWAZ.EQ.-90) QDE=Q(I)
0     IF (II.EQ.4.AND.IWAZ.EQ.180) QDN=Q(I)
      WRITE (6,350)
      WRITE (6,70) QROOF
      WRITE (6,80) QWS
      WRITE (6,90) QWE
      WRITE (6,100) QWW
      WRITE (6,110) QWN
      WRITE (6,180)
      WRITE (6,190) QDS
      WRITE (6,200) QDE
      WRITE (6,220) QDW
      WRITE (6,210) QDN
      WRITE (6,120) QFLOOR
```

```
      WRITE (6,130)
      WRITE (6,140) QGS
      WRITE (6,150) QGE
      WRITE (6,160) QGN
      WRITE (6,170) QGW
      QINFIL=1.08*CFML*DBD
      WATT=QLITE/3.415
      WRITE (6,340)
      SUM=QROOF+QWS+QWE+QWW+QWN+QFLOOR+QDS+QDE+QDW+QDN+QGS+QGW+QGE+QGN
      WRITE (6,270) SUM
      WRITE (6,230)
      WRITE (6,250) WATT,QLITE
      WRITE (6,260) QOCS
      WRITE (6,240) CFML,DBD,QINFIL
      WRITE (6,340)
      SUM=SUM+QLITE+QINFIL+QOCS
      WRITE (6,280) SUM
      QINFIL=4840.*WD*CFML
      WRITE (6,320) CFML,WD,QINFIL
      WRITE (6,330) QOCL
      WRITE (6,340)
      SUML=QINFIL+QOCL
      WRITE (6,290) SUML
      SUMT=SUM+SUML
      WRITE (6,300)
      WRITE (6,310) SUMT
      RETURN
C
C
20    FORMAT (1H110X'SUMMARY OF CALCULATIONS FOR'6A6)
30    FORMAT ('0 OUTDOOR CONDITIONS.....'F5.1,' DB'F10.1,'WB'F10.4,'HUMI
     1DTY RATIO')
40    FORMAT ('0 SPACE CONDITIONS........'F5.1,' DB'F10.1,'WB'F10.4,'HUMI
     1DTY RATIO')
50    FORMAT (24X'-----',20X'-----')
60    FORMAT ('0 DIFFERENCE...............'F5.1,F25.4)
70    FORMAT (' ROOF       ='36X,F10.0)
80    FORMAT (' SOUTH WALL='36X,F10.0)
90    FORMAT (' EAST WALL ='36X,F10.0)
100   FORMAT (' NORTH WALL='36X,F10.0)
110   FORMAT (' WEST WALL ='36X,F10.0)
120   FORMAT (' FLOOR      ='36X,F10.0)
130   FORMAT ('0 SOLAR HEAT GAIN AND TRANSMISSION THROUGH GLASS')
140   FORMAT (' SOUTH      ='36X,F10.0)
150   FORMAT (' EAST       ='36X,F10.0)
160   FORMAT (' NORTH      ='36X,F10.0)
170   FORMAT (' WEST       ='36X,F10.0)
180   FORMAT ('0DOORS')
190   FORMAT (' SOUTH      ='36X,F10.0)
200   FORMAT (' EAST       ='36X,F10.0)
210   FORMAT (' NORTH      ='36X,F10.0)
220   FORMAT (' WEST       ='36X,F10.0)
230   FORMAT ('0 INTERNAL LOAD')
240   FORMAT (' INFILTRATION'F10.0,'CFMX 1.08 X 'F10.1,F13.0)
250   FORMAT (' LIGHTS'F10.1,'X 3.41='23X,F10.0)
260   FORMAT ('0PEOPLE = '37X,F10.0)
270   FORMAT (48X,F10.0)
280   FORMAT ('0  TOTAL SENSIBLE SPACE LOAD'20X,F10.0)
```

```
290   FORMAT ('0  TOATL LATENT SPACE LOAD'20X,F10.0)
300   FORMAT ('0---------------------------------------------------------'
     1)
310   FORMAT ('    GRAND TOTAL LOAD '30X,F10.0)
320   FORMAT ('0INFILTRATION'F5.1,'CFM X 4840 X'F6.4,'='10X,F10.0)
330   FORMAT (' PEOPLE =   '27X,F20.0)
340   FORMAT (50X,'-----------')
      END
```

```
      SUBROUTINE OUTSID (X,Y,Z,CR,UX,FO,DB,TIM,QO,QI,QSUN,QSKY,TO,TI,TON
     1EW,TA,ITEMP)
      DIMENSION TO(1),TI(1),X(1),Y(1),Z(1)
      XNUM=QSUN-QSKY+FO*(DB-TIM)
      IF (X(2)) 50,10,50
10    IF (FO) 20,20,30
20    TONEW=TO(1)
      GO TO 40
30    TAM=TA-TIM
      TONEW=(XNUM+UX*TAM)/(UX+FO)
40    CONTINUE
      QO=UX*(TAM-TONEW)
      IF (ITEMP.EQ.0) QI=QO
      TO(1)=TONEW
      RETURN
50    SUMZ=0.
      SUMY=Y(1)*TI(1)
      SUMX=X(1)*TI(1)
      SUMXY=0.
      DO 60 J=2,48
      SUMY=SUMY+Y(J)*TI(J)
      SUMX=SUMX+X(J)*TI(J)
      SUMXY=SUMXY+Y(J)*TO(J-1)
60    SUMZ=SUMZ+Z(J)*TO(J-1)
      XNUM=SUMY-SUMZ+CR*QO+XNUM
      TONEW=XNUM/(Z(1)+FO)
      IF (FO) 70,70,80
70    TONEW=TO(1)
80    TO(1)=TONEW
      SUMZ=SUMZ+Z(1)*TO(1)
      SUMXY=SUMXY+Y(1)*TO(1)
      QO=SUMY-SUMZ+CR*QO
      IF (ITEMP.EQ.0) QI=SUMX-SUMXY+CR*QI
      RETURN
      END
```

```
      SUBROUTINE PSY1 (DB,WB,PB,DP,PV,W,H,V,RH)
     THIS SUBROUTINE CALCULATES VAPOR PRESSURE(PV),HUMIDITY RATIO (W)
     ENTHALPY(H),VOLUME(V),RELATIVE HUMIDITY(RH) AND DDEW-POINT
     TEMPERATURE WHEN THE DRY-BULB TEMPERATURE(DB),WET-BULB TEMPERATUR
     (WB) AND BAROMETRIC PRESSURE(PB) ARE GIVEN
      PVP=PVSF(WB)
      IF (DB-WB) 30,30,10
 0    WSTAR=0.622*PVP/(PB-PVP)
      IF (WB-32.) 20,20,40
20    PV=PVP-5.704E-4*PB*(DB-WB)/1.8
      GO TO 50
30    PV=PVP
      GO TO 50
40    CDB=(DB-32.)/1.8
      CWB=(WB-32.)/1.8
      HL=597.31+0.4409*CDB-CWB
      CH=0.2402+0.4409*WSTAR
      EX=(WSTAR-CH*(CDB-CWB)/HL)/0.622
      PV=PB*EX/(1.+EX)
50    W=0.622*PV/(PB-PV)
      V=0.754*(DB+459.7)*(1+7000*W/4360)/PB
      H=0.24*DB+(1061+0.444*DB)*W
      DP=DPF(PV)
      RH=PV/PVSF(DB)
      RETURN
      END
```

```
      SUBROUTINE PSY2 (DB,DP,PB,WB,PV,W,H,V,RH)
C    THIS SUBROUTINE CALCULATES THE FOLLOWINGS WHEN DRY-BULB TEMPERATURE
C    (DB),DEW-POINT TEMPERATURE(DP),AND BAROMETRIC PRESSURE(PB) ARE GIVEN
C    WB    WET-BULB TEMPERATURE
C    W     HUMIDITY RATIO
C     H    ENTHALPY
C     V    VOLUME
C    PV    VAPOR PRESSURE
C    RH    RELATIVE HUMIDITY
      IF (DP-DB) 20,10,10
10    DP=DB
20    PV=PVSF(DP)
      PV=PVSF(DP)
      PVS=PVSF(DB)
      RH=PV/PVS
      W=0.622*PV/(PB-PV)
      V=0.754*(DB+459.7)*(1+7000*W/4360)/PB
      H=0.24*DB+(1061+0.444*DB)*W
      WB=WBF(H,PB)
      RETURN
      END
```

```
      FUNCTION PVSF (X)
      DIMENSION A(6)/-7.90298,5.02808,-1.3816E-7,11.344,8.1328E-3,-3.491
     149/,B(4)/-9.09718,-3.56654,0.876793,0.0060273/,P(4)
      T=(X+459.688)/1.8
      IF (T.LT.273.16) GO TO 10
      Z=373.16/T
      P(1)=A(1)*(Z-1)
      P(2)=A(2)*LOG10(Z)
      Z1=A(4)*(1-1/Z)
      P(3)=A(3)*(10**Z1-1)
      Z1=A(6)*(Z-1)
      P(4)=A(5)*(10**Z1-1)
      GO TO 20
10    Z=273.16/T
      P(1)=B(1)*(Z-1)
      P(2)=B(2)*LOG10(Z)
      P(3)=B(3)*(1-1/Z)
      P(4)=LOG10(B(4))
20    SUM=0
      DO 30 I=1,4
30    SUM=SUM+P(I)
      PVSF=29.921*10**SUM
      RETURN
      END
```

```
      SUBROUTINE RESF (XX,YY,ZZ,IRUN)
C     THIS PROGRAM IS DEVELOPED BY T.KUSUDA OF THE NATIONAL BUREAU OF
C     STANDARDS FOR CALCULTING THE THERMAL RESPONSE FACTORS FOR
C     COMPOSITE WALLS,FLOORS,ROOFS,BASEMENT WALLS BASEMENT FLOORS
C     AND INTERNAL FURNISHINGS OF SIMPLE SHAPES
C     RESPONSE FACTORS ARE USED IN THE FOLLOWING MANNER
C     X,Y,Z ARE RESPONSE FACTORS
C    QI=X*TI-Y*TO*GMA   INSIDE WHERE R IS MINIMUM
C     QO=Y*TI-Z*TO   OUTSIDE WHERE R IS MAXIMUM
C     TI    INSIDE TEMPERARURE WHERE R IS MINIMUM
C     TO    OUTSIDE TEMPERATURE WHERE R IS MAXIMUM
C     K  THERMAL CONDUCTIVITY
C     G  THERMAL DIFFUSIVITY
C     L  THICKNESS
C    IN=0   FINITE THICK WALL
C    IN=1   SEMI-FINITE WALL
C    IN=2   SOLID OBJECT
C    IF RESPONSE FACTORS OF THE SOLID CYLINDER OR SPHERE OF HOMOGENEOUS
C    PROPETY ARE DESIRED, TREAT THE PROBLEM OF MULTILAYER BUT WITH THE
C    IDENTICAL PROPERTIES FOR ALL THE LAYERS EXCEPT THE RADIUS
      REAL K(10),G(10),L(10),KG
      DIMENSION X(100),Y(100),Z(100),C(10),D(10),RES(10),RMK(10,4)
      DIMENSION RMKG(4),F(100),XX(100,1),YY(100,1),ZZ(100,1),FF(100,20)
10    READ (5,240) DELTAT
      IRUN=0
20    READ (5,230) NLAYR,IN
      IF (NLAYR.EQ.0) GO TO 200
      IRUN=IRUN+1
      IF (NLAYR.GT.10) GO TO 200
      NNLAYR=NLAYR+1
      IF (NLAYR.EQ.0) GO TO 40
      DO 30 I=1,NLAYR
30    READ (5,240) L(I),K(I),D(I),C(I),RES(I)
      IF (IN.EQ.2.AND.IM.EQ.0) GO TO 50
C    READ K,RHO, AND C OF GROUND IF IN=1
C     FOLLOWINGS ARE GROUND THERMAL CONDUCTIVITY, DENSITY AND SP.HT IF
C     IN=2,  OTHERWISE THE SAME PROPERTIES OF THE  INTERNAL SLAB
40    IF (IN.NE.0) READ (5,240) KG,DG,CG
C    AG  THERMAL DIFFUSIVITY  OF EARTH
      IF (IN.NE.0) AG=KG/CG/DG
      IF (NLAYR.EQ.0) GO TO 100
      IF (IN.EQ.2) READ (5,330) (RMKG(J),J=1,4)
50    DO 60 I=1,NLAYR
60    READ (5,330) (RMK(I,J),J=1,4)
      IF (IN.EQ.1) READ (5,330) (RMKG(J),J=1,4)
      DO 90 I=1,NLAYR
      IF (L(I)) 80,70,80
70    G(I)=0.
      K(I)=1./RES(I)
      GO TO 90
80    G(I)=K(I)/C(I)/D(I)
90    CONTINUE
100   WRITE (6,350)
      CALL RESPTK (K,L,G,AG,KG,X,Y,Z,NLAYR,DELTAT,NRT,CR,UT,IN,F)
```

```
      WRITE (6,220) IRUN
      WRITE (6,360)
      WRITE (6,250)
      WRITE (6,260)
      WRITE (6,210)
      IF (NLAYR.EQ.0) GO TO 130
      IF (IN.EQ.2.AND.IM.NE.0) WRITE (6,370) KG,DG,CG,(RMKG(J),J=1,4)
      DO 120 I=1,NLAYR
      IF (L(I)) 120,110,120
10    K(I)=0.
20    WRITE (6,270) I,L(I),K(I),D(I),C(I),RES(I),(RMK(I,J),J=1,4)
      IF (IN.EQ.1) WRITE (6,370) KG,DG,CG,(RMKG(J),J=1,4)
30    WRITE (6,290) DELTAT
      WRITE (6,280) UT
      WRITE (6,300)
      WRITE (6,210)
      IF (IN.NE.0) GO TO 150
      WRITE (6,310)
      XX(1,IRUN)=FLOAT(NRT)
      YY(1,IRUN)=FLOAT(NRT)
      ZZ(1,IRUN)=FLOAT(NRT)
      XX(2,IRUN)=CR
      YY(2,IRUN)=CR
      ZZ(2,IRUN)=CR
      XX(NRT+3,IRUN)=UT
      DO 140 N=1,NRT
      XX(N+2,IRUN)=X(N)
      YY(N+2,IRUN)=Y(N)
      ZZ(N+2,IRUN)=Z(N)
      JN=N-1
40    WRITE (6,320) JN,X(N),Y(N),Z(N)
      GO TO 190
50    WRITE (6,380)
      IF (IN.EQ.1) GO TO 170
      IF (IN.EQ.2) GO TO 170
      XX(1,IRUN)=FLOAT(NRT)
      XX(2,IRUN)=CR
      XX(NRT+3,IRUN)=UT
      DO 160 N=1,NRT
      JN=N-1
      X(N)=-X(N)
      XX(N+2,IRUN)=X(N)
60    WRITE (6,390) JN,X(N)
      GO TO 190
70    DO 180 N=1,NRT
      JN=N-1
      FF(N+2,IRUN)=F(N)
80    WRITE (6,390) JN,F(N)
      FF(1,IRUN)=FLOAT(NRT)
      FF(2,IRUN)=CR
      FF(NRT+3,IRUN)=UT
90    WRITE (6,210)
      WRITE (6,210)
      WRITE (6,340) CR
      GO TO 20
00    RETURN
```

```
210   FORMAT (2H0 )
220   FORMAT (10H1   IRUN= I10)
230   FORMAT (10I7)
240   FORMAT (10F7.0)
250   FORMAT (77H0  LAYER     L(I)      K(I)        (I)      C(I)    RES(
     1I)   DESCRIPTION       )
260   FORMAT (77H   NO
     1     OF LAYERS         )
270   FORMAT (1I6,1F11.3,1F10.3,1F10.2,1F10.3,1F8.2,2X,4A6)
280   FORMAT (58H0                              THERMAL CONDUCTANCE
     1 U=1F7.3)
290   FORMAT (49H0                               TIME INCREMENT DT=1F3.0)
300   FORMAT (50H0                                  RESPONSE FACTORS)
310   FORMAT (120H0                J                    X              Y
     1             Z
     2)
320   FORMAT (1I17,1F23.4,2F15.4)
330   FORMAT (4A6)
340   FORMAT (44H0                           COMMON RATIO  CR=1F7.5)
350   FORMAT (2H1 )
360   FORMAT (50H0  WALL COMPOSITION                                )
370   FORMAT (1F27.3,1F10.2,1F10.3,10X,4A6)
380   FORMAT (50H0           J                    F                 )
390   FORMAT (1I24,1F21.5)
      END
```

```
      SUBROUTINE RESFX (X,Y,Z,XX,YY,ZZ,NR,CR,UT,NEXP)
      DIMENSION XX(100,10),YY(100,10),ZZ(100,10),X(10,100),Y(10,100),Z(1
     10,100),NR(10),CR(10),UT(10)
      DO 10 K=1,10
      DO 10 J=1,100
      XX(J,K)=0
      YY(J,K)=0
10    ZZ(J,K)=0
      CALL RESF (XX,YY,ZZ,IRUN)
      DO 30 K=1,NEXP
      I=K
      IF (K.GT.IRUN) GO TO 30
      X(I,1)=XX(3,K)
      Y(I,1)=YY(3,K)
      Z(I,1)=ZZ(3,K)
      NR(I)=XX(1,K)
      CR(I)=XX(2,K)
      JJJ=NR(I)+3
      UT(I)=XX(JJJ,K)
      NMAX=NR(I)
      DO 20 J=2,NMAX
      J3=J+2
      J2=J+1
      X(I,J)=XX(J3,K)-XX(J2,K)*CR(I)
      Y(I,J)=YY(J3,K)-YY(J2,K)*CR(I)
20    Z(I,J)=ZZ(J3,K)-ZZ(J2,K)*CR(I)
30    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE RESPTK (K,L,G,AG,KG,X,Y,Z,NL,DT,NR,CR,U,IS,F)
      DIMENSION K(10),L(10),G(10),X(100),Y(100),Z(100),AP(10),BP(10),CP(
     110),DP(10),A(10),B(10),C(10),D(10),ZR1(3),ZR2(3),RB(3),RAP(3),ROOT
     2(100),RA(3,100),ZRK(3,100),RX(100),RY(100),AZ(100),F(100)
      REAL K,L,KG
      PI=4.*ATAN(1.)
      M3=3
      IF (IS.NE.1) GO TO 10
      ZL=KG/10.
      UY=100./AG/DT
      CALL GPF (UY,ZL,AZ)
      IF (IS.EQ.1.AND.NL.EQ.0) GO TO 330
10    CALL ABCD2 (0.,K,L,G,AX,BX,CX,DX,NL)
      RB(1)=DX
      RB(2)=1.
      RB(3)=AX
      U=1./BX
      DO 20 I=1,NL
      PX=0
      CALL ABCDP2 (PX,K(I),L(I),G(I),AP(I),BP(I),CP(I),DP(I))
20    CALL ABCD2 (PX,K(I),L(I),G(I),A(I),B(I),C(I),D(I),1)
      IF (NL.LT.2) GO TO 30
      CALL DERVT (A,B,C,D,AP,BP,CP,DP,APP,BPP,CPP,DPP,NL)
      GO TO 40
30    APP=AP(1)
      BPP=BP(1)
      CPP=CP(1)
      DPP=DP(1)
40    RAP(1)=DPP
      RAP(2)=0.
      RAP(3)=APP
      DO 50 I=1,3
      C1=RAP(I)/BX/DT
      C2=RB(I)*BPP/BX/BX/DT
      ZR2(I)=-C1+C2
50    ZR1(I)=-ZR2(I)+RB(I)/BX
      WRITE (6,480)
      WRITE (6,490) (ZR1(I),I=1,M3)
      WRITE (6,490) (ZR2(I),I=1,M3)
C   ROOTS OF B(P)=0.
      NMAX=10
      TESTMX=40.
      PX=0.001
      DP0=0.1/DT
      DLX=0.0001
      N=0
      WRITE (6,500)
60    DL=DP0
      CALL ABCD2 (PX,K,L,G,AX,BX,CX,DX,NL)
70    PXP=PX+DL
      CALL ABCD2 (PXP,K,L,G,AXP,BXP,CXP,DXP,NL)
      IF (BX*BXP) 90,110,80
80    PX=PXP
      BX=BXP
```

```
      TESTX=PX*DT
      IF (TESTX-TESTMX) 70,170,170
90    IF (DL-DLX) 140,140,100
100   DL=DL/2.
      GO TO 70
110   IF (BX) 130,120,130
120   RXX=PX
      GO TO 150
130   RXX=PXP
      GO TO 150
140   AB=ABS(BX/BXP)
      RXX=(PX+AB*PXP)/(1.+AB)
150   N=N+1
      ROOT(N)=RXX
      IF (N.GT.1) DPO=ROOT(N)-ROOT(N-1)
      NRT=N
      WRITE (6,510) N,ROOT(N)
      PX=RXX+DLX
      TESTX=RXX*DT
      IF (TESTX-TESTMX) 160,160,170
160   IF (N.LT.NMAX) GO TO 60
170   WRITE (6,520)
      IF (ROOT(NRT)-100.) 190,180,180
180   NRT=NRT-1
190   DO 250 JJ=1,NRT
      PX=ROOT(JJ)
      DO 200 J=1,NL
      CALL ABCD2 (PX,K(J),L(J),G(J),A(J),B(J),C(J),D(J),1)
200   CALL ABCDP2 (PX,K(J),L(J),G(J),AP(J),BP(J),CP(J),DP(J))
      CALL ABCD2 (PX,K,L,G,AX,BX,CX,DX,NL)
      IF (NL.LT.2) GO TO 210
      CALL DERVT (A,B,C,D,AP,BP,CP,DP,APP,BPP,CPP,DPP,NL)
      GO TO 220
210   APP=AP(1)
      BPP=BP(1)
      CPP=CP(1)
      DPP=DP(1)
220   PY=BPP*PX*PX*DT
      RA(1,JJ)=DX/PY
      RA(2,JJ)=1./PY
      RA(3,JJ)=AX/PY
      PZ=PX*DT
      IF (PZ-20.) 240,240,230
230   RX(JJ)=0.
      RY(JJ)=25.E16
      GO TO 250
240   RX(JJ)=EXP(-PZ)
      RY(JJ)=(1.-EXP(PZ))**2
250   WRITE (6,530) ROOT(JJ),(RA(M,JJ),M=1,M3)
      DO 260 JJ=1,NRT
      DO 260 M=1,M3
      ZR1(M)=RA(M,JJ)*RX(JJ)+ZR1(M)
260   ZR2(M)=RA(M,JJ)*(RX(JJ)*RX(JJ)-2.*RX(JJ))+ZR2(M)
      II=1
      III=2
      WRITE (6,540)
      WRITE (6,550)
      IF (ZR1(2).LT.0) ZR1(2)=0.
```

```
      WRITE (6,560) II,(ZR1(M),M=1,M3)
      WRITE (6,560) III,(ZR2(M),M=1,M3)
      DO 270 M=1,M3
      ZRK(M,1)=ZR1(M)
270   ZRK(M,2)=ZR2(M)
      NT=100
      DO 300 N=3,NT
      NR=N
      DO 280 M=1,M3
280   ZRK(M,N)=0.
      DO 290 M=1,M3
      DO 290 JJ=1,NRT
      PZ=(RX(JJ))**N
290   ZRK(M,N)=ZRK(M,N)+PZ*RY(JJ)*RA(M,JJ)
      WRITE (6,560) N,(ZRK(M,N),M=1,M3)
      IF (N.LT.5) GO TO 300
      TEST1=ZRK(1,N)/ZRK(1,N-1)
      TEST2=ZRK(1,N-1)/ZRK(1,N-2)
      TEST3=ABS(TEST1-TEST2)
      IF (TEST3-0.00001) 310,310,300
300   CONTINUE
310   DO 320 N=1,NR
      X(N)=ZRK(1,N)
      Y(N)=ZRK(2,N)
320   Z(N)=ZRK(3,N)
      CR=TEST2
      WRITE (6,570) CR
      IF (IS.EQ.2) GO TO 450
      IF (IS.NE.1) GO TO 470
330   IF (NL.EQ.0) GO TO 390
      GF=2*KG/SQRT(DT*AG*PI)
      IF (NR.LT.50) GO TO 350
      DO 340 J=50,NR
      ZJ=J
340   AZ(J)=GF*(SQRT(ZJ)-2.*SQRT(ZJ-1.)+SQRT(ZJ-2.))
      NRR=NR
      GO TO 370
350   DO 360 J=NR,50
      Z(J+1)=Z(J)*CR
      X(J+1)=X(J)*CR
360   Y(J+1)=Y(J)*CR
      NRR=50
370   DO 380 J=1,NRR
380   F(J)=X(J)-Y(J)*Y(J)/(Z(J)+AZ(J))
      NR=NRR
      GO TO 410
390   DO 400 J=1,NR
400   F(J)=AZ(J)
410   WRITE (6,580)
      CR1=1.
      DO 430 J=1,50
      CR=F(J+1)/F(J)
      TESTCR=ABS(CR-CR1)
      IF (TESTCR-0.00001) 440,440,420
420   CR1=CR
      JJ=J-1
430   WRITE (6,590) JJ,F(J)
440   NR=J
```

```
      CR=CR1
      GO TO 470
450   WRITE (6,580)
      DO 460 J=1,NR
      F(J)=X(J)+Z(J)-2.*Y(J)
      JJ=J-1
460   WRITE (6,590) JJ,F(J)
470   RETURN
C
C
480   FORMAT (50H0  RESIDUES AT P=0                                )
490   FORMAT (3F20.6)
500   FORMAT (50H0  ROOTS OF B(P)=0                                )
510   FORMAT (I10,1F20.6)
520   FORMAT (50H0  RESUDUES AT  P=ROOT(N)                         )
530   FORMAT (4F20.6)
540   FORMAT (50H0  RESPONSE FACTORS OF  FINITE SLAB               )
550   FORMAT (120H0        J                X(J)                Y(J)
     1            Z(J)
     2)
560   FORMAT (I10,3F20.6)
570   FORMAT (10H0      CR=1F10.6)
580   FORMAT (50H0        J               F                        )
590   FORMAT (1I10,1F20.5)
      END
```

```
      SUBROUTINE RMTMP (NEXP,NX,TV,CFML,CFMV,R,TIM,TA,TIF,QL,ITK)
      COMMON /CC/ X(10,100),Y(10,100),Z(10,100),ITYPE(10),IHT(10),IRF(10
     1),ABSP(10),U(10),H(10),HI(10),A(10),UT(10),TOS(10,48),TIS(10,48),G
     2(10,10),TOY(48),DB(24),QLITE(24),QEQUP(24),QOCPS(24),QI(10),CR(10)
     3,NR(10),QGLAS(10,24),ITHST
      DIMENSION AA(20,20),BB(20),TT(20),TIF(20),A2(20,20),B2(20),B3(20),
     1GSUM(20)
      DBNX=DB(NX)-TIM
      TU=TV-TIM
      NEXP2=NEXP+1
      DO 10 I=1,NEXP2
      BB(I)=0.
      B2(I)=0.
      DO 10 J=1,NEXP2
      A2(I,J)=0.
10    AA(I,J)=0.
      SHG=0.
      HSUM=0.
      ASUM=0.
      ASUMT=0.
      DO 70 I=1,NEXP
      SHG=SHG+QGLAS(I,NX)*A(I)
      ASUMT=ASUMT+A(I)
      GSUM(I)=0.
      DO 20 J=1,NEXP
20    GSUM(I)=GSUM(I)+G(I,J)
      IF (ITYPE(I).NE.3) ASUM=ASUM+A(I)
      HSUM=HSUM+HI(I)*A(I)
      IR=IRF(I)
      CRX=CR(I)
      IF (X(IR,2)) 40,30,40
30    X(IR,1)=UT(I)
      Y(IR,1)=UT(I)
      CRX=0.
      Z(IR,1)=UT(I)
40    AA(I,I)=X(IR,1)+HI(I)+GSUM(I)
      DO 50 J=1,NEXP
      IF (I.EQ.J) GO TO 50
      AA(I,J)=-G(I,J)
50    CONTINUE
      AA(I,NEXP2)=-HI(I)
      SUMY=Y(IR,1)*TOS(I,1)
      SUMX=0.
      DO 60 J=2,48
      SUMY=SUMY+Y(IR,J)*TOS(I,J)
60    SUMX=SUMX+X(IR,J)*TIS(I,J)
      B3(I)=SUMY-CRX*QI(I)-SUMX
70    AA(NEXP2,I)=A(I)*HI(I)
      QLT=QLITE(NX)/ASUMT*R
      DO 80 I=1,NEXP
      SHF=SHG/ASUM
      IF (ITYPE(I).EQ.3) SHF=0.
80    BB(I)=B3(I)+SHF+QLT
      AA(NEXP2,NEXP2)=-1.08*(CFML+CFMV)-HSUM
```

```
      SUBROUTINE SHG (SH)
      DIMENSION SH(20)
C     SH(1)=INTENSITY OF DIRECT NORMAL SOLAR RADIATION
C     SH(2)=INTENSITY OF DIFFUSE SKY RADIATION
C     SH(3)=INTENSITY OF GROUND REFLECTED DIFFUSE RADIATION
C     SH(4)=COSINE OF INCIDENCE OF DIRECT SOLAR RADIATION
C     SH(5)=FORM FACTOR BETWEEN THE WINDOW AND THE SKY
C     SH(6)=FORM FACTOR BETWEEN THE WINDOW AND THE GROUND
C     SH(7)=THERMAL RESISTANCE AT OUTSIDE SURFACE
C     SH(8)=THERMAL RESISTANCE AT THE AIR SPACE (DOUBLE GLAZING)
C     SH(9)=THERMAL RESISTANCE AT THE INNER SURFACE
C     SH(10)=SUNLIT AREA  FACTOR
C     SH(11)=SHADING  COEFFICIENT ,NON-ZERO VALUE WILL BE GIVEN  ONLY
C            WHEN THE WINDOW IS SHADED BY DRAPES OR BLINDS OR IF IT HAS
C            AN INTERPANE SEPARATION OF MORE THAN 1-INCH
C     SH(12)=TRANSMISSION FACTOR FOR DIRECT RADIATION
C     SH(13)=TRANSMISSION FACTOR FOR DIFFUSE RADIATION
C     SH(14)=ABSORPTION FACTOR FOR DIRECT RADIATION (OUTER PANE)
C     SH(15)=ABSORPTION FACTOR FOR DIRECT RADIATION (INNER PANE)
C     SH(16)=ABSORPTION FACTOR FOR DIFFUSE RADIATION(OUTER PANE)
C     SH(17)=ABSORPTION FACTOR FOR DIFFUSE RADIATION(INNER PANE)
C     SH(18)=SOLAR HEAT GAIN
      COMMON /SOL/ LAT,LONG,TZN,WAZ,WT,CN,DST,LPYR,S(35)
      REAL NI,NO
      NI=(SH(7)+SH(8))/(SH(7)+SH(8)+SH(9))
      NO=(SH(7))/(SH(7)+SH(8)+SH(9))
      D=SH(10)*SH(1)*SH(4)*(SH(12)+NO*SH(14)+NI*SH(15))
      DD=(SH(2)*SH(5)+SH(3)*SH(6))*(SH(13)+NO*SH(16)*NI*SH(17))
      IF (SH(11)) 20,10,20
10    SH(18)=D+DD
      GO TO 30
20    SH(18)=(D+DD)*SH(11)
30    RETURN
      END
```

```
      SUBROUTINE SOLVP (M,N,C,D,X,I)
C    THIS IS A ROUTINE FOR SOLVING  SIMULTANEOUS LINEAR  EQUATIONS
C     THE ROUTINE WAS DEVELOPED BY B.A. PEAVY OF NBS
C     ROUTINE FAILS WHEN ANY OF THE DIAGONAL ELEMENTS IS ZERO
      DIMENSION A(100,101),C(I,1),D(1),X(1)
      DO 10 IX=1,M
      DO 10 IY=1,M
10    A(IX,IY)=C(IX,IY)
      DO 20 IZ=1,M
20    A(IZ,N)=D(IZ)
      L=1
30    AA=A(L,L)
      DO 40 K=L,N
40    A(L,K)=A(L,K)/AA
      DO 60 K=1,M
      IF (K.EQ.L) GO TO 60
      AA=-A(K,L)
      DO 50 IA=L,N
50    A(K,IA)=A(K,IA)+AA*A(L,IA)
60    CONTINUE
      L=L+1
      IF (L.LE.M) GO TO 30
      DO 70 IP=1,M
70    X(IP)=A(IP,N)
      RETURN
      END
```

```
      SUBROUTINE SUN
      DIMENSION A0(5)/.302,-.0002,368.44,.1717,0.0905/,A1(5)/-22.93,.419
     17,24.52,-.0344,-.0410/,A2(5)/-.229,-3.2265,-1.14,.0032,.0073/,A3(5
     2)/-.243,-.0903,-1.09,.0024,.0015/,B1(5)/3.851,-7.351,.58,-.0043,-.
     30034/,B2(5)/.002,-9.3912,-.18,0.,0.0004/,B3(5)/-.055,-.3361,.28,-.
     4008,-.0006/
      COMMON /SOL/ LAT,LONG,TZM,WAZ,WT,CN,DST,LPYR,S(35)
      REAL LATD,LONG,MERID,LOND
C     S(1)= LATITUDE,DEGREES(+NORTH,-SOUTH)
C     S(2)= LONGITUDE,DEGREES(+WEST,-EAST)
C     S(3)= TIME ZONE NUMBER
C              STANDARD  TIME          DAYLIGHT  SAVING TIME
C      ATLANTIC       4                      3
C      EASTERN        5                      4
C      CENTRAL        6                      5
C      MOUNTAIN       7                      6
C      PACIFIC        8                      7
C     S(4)= DAYS(FROM START OF YEAR)
C     S(5)= TIME,HOUR AFTER MIDNIGHT)
C     S(6)= DAYLIGHT SAVING TIME INDICATOR
C     S(7)= GROUND REFLECTIVITY
C     S(8)= CLEARNESS NUMBER
C     S(9)= WALL AZIMUTH ANGLE, DEGREES FROM SOUTH
C     S(10)=WALL TILT    ANGLE, DEGREES FROM HORIZON
C     S(11)=SUN RISE TIME  (HOURS AFTER MIDNIGHT)
C     S(12)=SUN SET TIME
C     S(13)=COSZ    DIRECTION COSINES
C     S(14)=COSN    DIRECTION COSINES
C     S(15)=COS(S)  DIRECTION COSINES)
C     S(16)=ALPHA   DIRECTION COSINES NORMAL TO SURFACE
C     S(17)=BETA
C     S(18)=GAMMA
C     S(19)=COS(ETA)COSINE OF INCIDENCE ANGLE
C     S(20)=SOLAR ALTITUDE ANGLE
C     S(21)=SOLAR AZIMUTH  ANGLE
C     S(22)=DIFFUSE SKY RADIATION ON HORIZONTAL SURFACE
C     S(23)=DIFFUSE GROUND REFLECTED RADIATION
C     S(24)=DIRECT NORMAL RADIATION
C     S(25)=TOTAL SOLAR RADIATION INTENSITY
C     S(26)=DIFFUSE SKY RADIATION INTENSITY
C     S(27)=GROUND REFLECTED DIFFUSE RADIATION INTENSITY
C     S(28)=SUN DECLINATION ANGLE,DEGREES
C     S(29)=EQUATION OF TIME ,HOURS
C     S(30)=A     SOLAR FACTOR
C     S(31)=      SOLAR FACTOR
C     S(32)=      SOLAR FACTOR
C     S(33)=      CLOUD COVER MODIFIER
C     S(34)    INTENSITY OF DIRECT SOLAR RADIATION ON SURFACE
C     S(35)     HOUR ANGLE,DEGREE
      PI=3.1415927
      X=2*PI/366.*S(4)
      C1=COS(X)
      C2=COS(2*X)
      C3=COS(3*X)
```

```
      S1=SIN(X)
      S2=SIN(2*X)
      S3=SIN(3*X)
      DO 10 K=1,5
      KS=(K-1)+28
10    S(KS)=A0(K)+A1(K)*C1+A2(K)*C2+A3(K)*C3+B1(K)*S1+B2(K)*S2+B3(K)*S3
      S(29)=S(29)/60.
      LATD=S(1)
      LONG=S(2)
      MERID=15*S(3)
      LOND=LONG-MERID
      Y=S(28)*PI/180.
      YY=LATD*PI/180.
      HP=-TAN(Y)*TAN(YY)
      TR=12/PI*ACOS(HP)
      S(11)=(12-TR)-S(29)+LOND/15.
      S(12)=24.-S(11)
      H=15*(S(5)-12+S(3)+S(29)-S(6))-S(2)
      S(35)=H
      S13=SIN(YY)*SIN(Y)+COS(YY)*COS(Y)*COS(H*PI/180.)
      S(13)=S13
      HP1=180.*ACOS(HP)/PI
      X1=ABS(HP1)
      X2=ABS(H)
      IF (X1-X2) 130,20,20
20    S(14)=COS(Y)*SIN(H*PI/180.)
      S(15)=SQRT(1.-S(13)*S(13)-S(14)*S(14))
      STEST=S(15)
      STEST1=COS(H*PI/180.)-TAN(Y)/TAN(YY)
      IF (STEST1) 40,30,30
30    S(15)=STEST
      GO TO 50
40    S(15)=-STEST
50    S(20)=ASIN(S(13))
      IF (S(15)) 70,60,60
60    S(21)=ASIN(S(14)/COS(S(20)))
      GO TO 80
70    S(21)=PI-ASIN(S(14)/COS(S(20)))
80    S(20)=180.*S(20)/PI
      S(21)=180.*S(21)/PI
      S(24)=S(30)*S(8)*S(33)*EXP(-S(31)/S(13))
      S(22)=S(32)*S(24)/S(8)/S(8)
      S(23)=S(7)*(S(22)+S(24)*S(13))
      WT=S(10)*PI/180.
      S(16)=COS(WT)
      WA=S(9)*PI/180.
      S(16)=COS(WT)
      S(17)=SIN(WA)*SIN(WT)
      S(18)=COS(WA)*SIN(WT)
      S(19)=S(16)*S(13)+S(17)*S(14)+S(18)*S(15)
      S(34)=S(24)*S(19)
      Y=0.45
      IF (S(19)+0.2) 100,100,90
90    Y=0.55+0.437*S(19)+0.313*S(19)**2
100   IF (S(19)) 110,110,120
110   S(19)=0.
      S(34)=0.
120   CONTINUE
```

```
      S(26)=S(22)*Y
      S(27)=S(23)*(1-S(16))/2.
      S(25)=S(34)+S(26)+S(27)
      GO TO 150
130   DO 140 J=14,26
140   S(J)=0.
      S(34)=0
150   RETURN
      END
```

```
      SUBROUTINE TAR (TR)
      REAL A1(6)/0.01154,0.77674,-3.94657,8.57881,-8.38135,3.01188/
      REAL A2(6)/0.01636,1.40783,-6.79030,14.37378,-13.83357,4.92439/
      REAL A3(6)/0.01837,1.92497,-8.89134,18.40197,-17.48648,6.17544/
      REAL A4(6)/0.09902,2.35417,-10.4715,21.24322,-19.95978,6.99964/
      REAL A5(6)/0.01712,3.50839,-13.8639,26.34330,-23.84846,8.17372/
      REAL A6(6)/0.01406,4.15958,-15.0628,27.18492,-23.88518,8.03650/
      REAL A7(6)/0.01153,4.55946,-15.4329,26.70568,-22.87993,7.57795/
      REAL A8(6)/0.00962,4.81911,-15.4714,25.86516,-21.69106,7.08714/
      REAL T1(6)/-0.00885,2.71235,-0.62062,-7.07329,9.75995,-3.89922/
      REAL T2(6)/-0.01114,2.39371,0.42978,-8.98262,11.51798,-4.52064/
      REAL T3(6)/-0.01200,2.13036,1.13833,-10.07925,12.44161,-4.83285/
      REAL T4(6)/-0.01218,1.90950,1.61391,-10.64872,12.83698,-4.95199/
      REAL T5(6)/-0.01056,1.29711,2.28615,-10.37132,11.95884,-4.54880/
      REAL T6(6)/-0.00835,0.92766,2.15721,-8.71429,9.87152,-3.73328/
      REAL T7(6)/-0.00646,0.68256,1.82499,-6.95325,7.80647,-2.94454/
      REAL T8(6)/-0.00496,0.51043,1.47607,-5.41985,6.00546,-2.28162/
      REAL AO1(6)/0.01407,1.06226,-5.59131,12.15034,-11.78092,4.20070/
      REAL AO2(6)/0.01819,1.86277,-9.24831,19.49443,-18.56094,6.53940/
      REAL AO3(6)/0.01905,2.47900,-11.7427,24.14037,-22.64299,7.89954/
      REAL AO4(6)/0.01862,2.96400,-13.4870,27.13020,-25.11877,8.68895/
      REAL AO5(6)/0.01423,4.14384,-16.66709,31.30484,-27.81955,9.36959/
      REAL AO6(6)/0.01056,4.71447,-17.33454,30.91781,-26.63898,8.79495/
      REAL AO7(6)/0.00819,5.01768,-17.21228,29.46388,-24.76915,8.05040/
      REAL AO8(6)/0.00670,5.18781,-16.84820,27.90292,-22.99619,7.38140/
      REAL AI1(6)/0.00228,0.34559,-1.19908,2.22336,-2.05287,0.72376/
      REAL AI2(6)/0.00123,0.29788,-0.92256,1.58171,-1.40040,0.48316/
      REAL AI3(6)/0.00061,0.26017,-0.72713,1.14950,-0.97138,0.32705/
      REAL AI4(6)/0.00035,0.22974,-0.58381,0.84626,-0.67666,0.22102/
      REAL AI5(6)/-0.00009,0.15049,-0.27590,0.25618,-0.12919,0.02859/
      REAL AI6(6)/-0.00016,0.10579,-0.15035,0.06487,0.02759,-0.02317/
      REAL AI7(6)/-0.00015,0.07717,-0.09059,0.00050,0.06711,-0.03394/
      REAL AI8(6)/-0.00012,0.05746,-0.05878,-0.01855,0.06837,-0.03191/
      REAL TD1(6)/-0.00401,0.74050,7.20350,-20.11763,19.68824,-6.74585/
      REAL TD2(6)/-0.00438,0.57818,7.42065,-20.26848,19.79706,-6.79619/
      REAL TD3(6)/-0.00428,0.45797,7.41367,-19.92004,19.40969,-6.66603/
      REAL TD4(6)/-0.00401,0.36698,7.27324,-19.29364,18.75408,-6.43968/
      REAL TD5(6)/-0.00279,0.16468,6.17715,-15.84811,15.28302,-5.23666/
      REAL TD6(6)/-0.00192,0.08180,4.94753,-12.43481,11.92495,-4.07787/
      REAL TD7(6)/-0.00136,0.04419,3.87529,-9.59069,9.16022,-3.12776/
      REAL TD8(6)/-0.00098,0.02576,3.00400,-4.33834,6.98747,-2.38328/
      DIMENSION TR(9),A(8,6),T(8,6),AO(8,6),AI(8,6),TD(8,6)
C     TR(1)= TRANSMISSION FACTOR ,DIRECT
C     TR(2)= TRANSMISSION FACTOR ,DIFFUSE
C     TR(3)= ABSORPTION FACTOR   ,DIRECT, OUTER
C     TR(4)=                     ,DIFFUSE,OUTER
C     TR(5)=                     ,DIRECT ,INNER
C     TR(6)=                     ,DIFFUSE,INNER
C     TR(7)= COSINE OF INCIDENT ANGLE
C      TR(8)=TYPE OF GLASS
C      TR(9)=ID   CODE FOR THE GLAZING
C     ID   =1    SINGLE  GLAZING
C     ID   =2    DOUBLE  GLAZING
      DO 10 J=1,6
```

```
      A(1,J)=A1(J)
      A(2,J)=A2(J)
      A(3,J)=A3(J)
      A(4,J)=A4(J)
      A(5,J)=A5(J)
      A(6,J)=A6(J)
      A(7,J)=A7(J)
      A(8,J)=A8(J)
      T(1,J)=T1(J)
      T(2,J)=T2(J)
      T(3,J)=T3(J)
      T(4,J)=T4(J)
      T(5,J)=T5(J)
      T(6,J)=T6(J)
      T(7,J)=T7(J)
      T(8,J)=T8(J)
      A0(1,J)=A01(J)
      A0(2,J)=A02(J)
      A0(3,J)=A03(J)
      A0(4,J)=A04(J)
      A0(5,J)=A05(J)
      A0(6,J)=A06(J)
      A0(7,J)=A07(J)
      A0(8,J)=A08(J)
      AI(1,J)=AI1(J)
      AI(2,J)=AI2(J)
      AI(3,J)=AI3(J)
      AI(4,J)=AI4(J)
      AI(5,J)=AI5(J)
      AI(6,J)=AI6(J)
      AI(7,J)=AI7(J)
      AI(8,J)=AI8(J)
      TD(1,J)=TD1(J)
      TD(2,J)=TD2(J)
      TD(3,J)=TD3(J)
      TD(4,J)=TD4(J)
      TD(5,J)=TD5(J)
      TD(6,J)=TD6(J)
      TD(7,J)=TD7(J)
10    TD(8,J)=TD8(J)
      ETA=TR(7)
      L=TR(8)
      ID=TR(9)
      IF (ID.EQ.2) GO TO 30
      TR(1)=T(L,1)
      TR(2)=T(L,1)/2.
      TR(3)=A(L,1)
      TR(4)=A(L,1)/2.
      DO 20 J=2,6
      TR(1)=TR(1)+T(L,J)*(ETA**(J-1))
      TR(2)=TR(2)+T(L,J)/(J+1)
      TR(3)=TR(3)+A(L,J)*(ETA**(J-1))
20    TR(4)=TR(4)+A(L,J)/(J+1)
      TR(5)=0
      TR(6)=0
      GO TO 50
30    TR(1)=TD(L,1)
      TR(2)=TD(L,1)/2.
```

```
      TR(3)=AO(L,1)
      TR(4)=AO(L,1)/2.
      TR(5)=AI(L,1)
      TR(6)=AI(L,1)/2.
      DO 40 J=2,6
      X=ETA**(J-1)
      TR(1)=TR(1)+TD(L,J)*X
      TR(2)=TR(2)+TD(L,J)/(J+1)
      TR(3)=TR(3)+AO(L,J)*X
      TR(4)=TR(4)+AO(L,J)/(J+1)
      TR(5)=TR(5)+AI(L,J)*X
40    TR(6)=TR(6)+AI(L,J)/(J+1)
50    TR(2)=2*TR(2)
      TR(4)=2*TR(4)
      TR(6)=2*TR(6)
      RETURN
      END
```

```
      FUNCTION WBF (H,PB)
C   THIS PROGRAM APPROXIMATES THE WET-BULB TEMPERATURE WHEN
C    ENTHALPY IS GIVEN
      IF (PB-29.92) 10,30,10
10    Y=LOG(H)
      IF (H.GT.11.758) GO TO 20
      WBF=0.6041+3.4841*Y+1.3601*Y*Y+0.97307*Y*Y*Y
      GO TO 100
20    WBF=30.9185-39.68200*Y+20.5841*Y*Y-1.758*Y*Y*Y
      GO TO 100
30    WB1=150.
      PV1=PVSF(WB1)
      W1=0.622*PV1/(PB-PV1)
      X1=0.24*WB1+(1061+0.444*WB1)*W1
      Y1=H-X1
40    WB2=WB1-1
      PV2=PVSF(WB2)
      W2=0.622*PV2/(PB-PV2)
      X2=0.24*WB2+(1061+0.444*WB2)*W2
      Y2=H-X2
      IF (Y1*Y2) 90,60,50
50    WB1=WB2
      Y1=Y2
      GO TO 40
60    IF (Y1) 80,70,80
70    WBF=WB1
      GO TO 100
80    WBF=WB2
      GO TO 100
90    Z=ABS(Y1/Y2)
      WBF=(WB2*Z+WB1)/(1+Z)
100   RETURN
      END
```

```
      SUBROUTINE WF (QG,QX,QIS,LG,LX,LIS,QL)
C     THIS ROUTINE TAKES HEAT GAINS TO HEAT LOSS BY WEIGHTING FACTOR
C     QG--HISTORY OF SOLAR HEAT GAIN
C     QX--HISTORY OF LONG WAVE LENGTH HEAT GAIN
C     QIS--HISTORY OF LIGHTING POWER INPUT
      REAL QG(8),QX(8),QIS(8),LG(8),LX(8),LIS(8)
      REAL AG(8)/0.2060,-0.3988,0.2247,-0.0245,-0.0026,-0.0006,-0.0002,-
     10.0001/
      REAL BG(8)/1.000,-2.4586,2.0078,-0.5447,0.,0.,0.,0./
      REAL AX(8)/0.6258,-1.2492,0.7932,-0.1573,-0.0003,0.,0.,0./
      REAL BX(8)/1.000,-2.0676,1.3651,-0.2837,0.,0.,0.,0./
      REAL AIS(8)/0.2902,-0.1866,0.,0.,0.,0.,0.,0./
      REAL BIS(8)/1.000,-0.8781,0.,0.,0.,0.,0.,0./
      DIMENSION QZG(8),QZX(8),QZIS(8)
      DO 10 L=2,8
      QZG(L)=LG(L-1)
      QZX(L)=LX(L-1)
      QZIS(L)=LIS(L-1)
10    CONTINUE
      DO 20 L=2,8
      LG(L)=QZG(L)
      LX(L)=QZX(L)
      LIS(L)=QZIS(L)
20    CONTINUE
      SUMAG=AG(1)*QG(1)
      SUMBG=0.
      SUMAX=AX(1)*QX(1)
      SUMBX=0.
      SUMAIS=AIS(1)*QIS(1)
      SUMBIS=0.
      DO 30 L=2,8
      SUMAG=SUMAG+AG(L)*QG(L)
      SUMBG=SUMBG+BG(L)*LG(L)
      SUMAX=SUMAX+AX(L)*QX(L)
      SUMBX=SUMBX+BX(L)*LX(L)
      SUMAIS=SUMAIS+AIS(L)*QIS(L)
      SUMBIS=SUMBIS+BIS(L)*LIS(L)
30    CONTINUE
      LG(1)=SUMAG-SUMBG
      LX(1)=SUMAX-SUMBX
      LIS(1)=SUMAIS-SUMBIS
      QL=LG(1)+LX(1)+LIS(1)
      RETURN
      END
```

Appendix D

Computer Program Used in Evaluation for the Prototype Building

T. Kusuda
D. M. Burch
Environmental Engineering Section
Sensory Environment Branch
Building Research Division
Institute for Applied Technology
National Bureau of Standards

```
C     THIS PROGRAM CHECKS THE NBS INSIDEOUT HOUSE
C     XX,YY,ZZ  ARE RESPONSE FACTORS CALCULATED BT RESPTK
C     WHICH HAS BEEN DEVELOPED BY T.KUSUDA OF NBS
C     X,Y,Z ARE AUGUMENTED RESPONSE FACTORS TO SHORTEN THE CALCULATION
C     A(1)  AREA OF THE ROOF IN SQ.FT
C     A(2)  AREA OF THE WALLS  IN SQ. FT
C     A(3)  AREA OF THE FLOOR IN SQ. FT
C     A(4)  AREA OF THE INTERNAL FURNISHINGS
C     CFM  AIR LEAKAGE IN CU.FT.PER MIN.
C     UD  OVERALL HEAT TRANSFER COEFFICEINT OF THE DOOR IN BTH/HR,SQ.FT.,F
C     AD  AREA OF THE DOOR IN SQ.FT.
C      UW   OVERALL HEAT TRANSFER COEFFICIENT FOR WINDOWS
C      AW   TOTAL WINDOW AREA  SQ.FT
C     TG  GROUND TEMPERATURE IN F
C     TA  ASSUMED INITIAL AIR TEMPERATURE AT TIME ZERO IN F
      PARAMETER R=4,S=100,T=48,U=T+1,V=2*T
      DIMENSION X(R,S),Y(R,S),Z(R,S),XX(S,R),YY(S,R),ZZ(S,R),CR(R),Q(R),
     1TO (S),TI(S),TOX(T),A(R),SUM(R),TOY(S),TIME(T),TIX(T)
 3001 DO 700 K=1,R
      DO 700 J=1,S
      XX(J,K)=0.
      YY(J,K)=0.
  700 ZZ(J,K)=0.
      CALL RESF (IRUN,XX,YY,ZZ,DEL)
      DO 1 I=1,IRUN
      X(I,1)=XX(3,I)
      Y(I,1)=YY(3,I)
      Z(I,1)=ZZ(3,I)
      CR(I)=XX(2,I)
      NMAX=XX(1,I)
      DO  1  J=2,NMAY
      J3=J+2
      J2=J+1
      X(I,J)=XX(J3,I)-XX(J2,I)*CR(I)
      Y(I,J)=YY(J3,I)-YY(J2,I)*CR(I)
    1 Z(I,J)=ZZ(J3,I)-ZZ(J2,I)*CR(I)
  603 WRITE(6,605)
  100 FORMAT(11F7.0)
 3000 READ(5,100) RUN
      WRITE(6,8007) RUN
 8007 FORMAT(1H1'RUN NO='F10.0)
      IF(RUN) 6000,6000,7000
 7000 DEN=0.
      DO 102 I=1,T
      TIME(I)=DEN
  102 DEN=DEN+DEL
      READ (5,101) (TOX(I),I=1,T)
      READ (5,101) (TIX(I),I=1,T)
      READ (5,100) (A(I),I=1,R),CFM,UD,AD,UW,AW,TG,TA
101   FORMAT(12F6.1)
      WRITE(6,4000)
 4000 FORMAT(30H0  OUTDOOR TEMPERATURE CYCLE                                )
      WRITE (6,609)(TOX(I),I=1,T)
      IF(TIX(1)) 8001,8002,8001
 8001 WRITE(6,8003)
      WRITE (6,609) (TIX(I),I=1,T)
      NTI=1
```

```
8003 FORMAT(1H0'INSIDE AIR TEMPERATURE CYCLE')
 609 FORMAT(12F10.2)
     GO TO 8010
8002 NTI=0
 605 FORMAT(2H0   )
 606 FORMAT(120H0      A(1)        A(2)        A(3)        A(4)        CFM
    1   UD)        AD          UW          AW          TG          TA          )
8010 CONTINUE
     WRITE(6,606)
     WRITE(6,609) (A(I),I=1,R),CFM,UD,AD,UW,AW,TG,TA
     DO 500 J=1,T
     IF(NTI.NE.0)TI(J)=TIX(T-J+1)
 500 TO(J)=TOX(T-J+1)
     DO 501 J=U,V
     IF(NTI.NE.0)TI(J)=TI(J-T)
 501 TO(J)=TO(J-T)
     IF(NTI.NE.0) GO TO 8004
     DO 2 I=1,V
   2 TI(I)=TA
8004 DO 502 J=1,V
     TO(J)=TO(J)-TG
 502 TI(J)=TI(J)-TG
     DO 503 J=1,T
     IF(NTI.NE.0) TIX(J)=TIX(J)-TG
 503 TOX(J)=TOX(J)-TG
     DO 4 I=1,2
     Q(I)=0.
     DO 5 J=1,V
   5 Q(I)=Q(I)+(XX(J+2,I)*TI(J)-YY(J+2,I)*TO(J))
   4 CONTINUE
     DO 6 I=3,4
     Q(I)=0.
     DO 6 J=1,V
   6 Q(I)=Q(I)+XX(J+2,I)*TI(J)
5001 FORMAT(2H1   )
     WRITE(6,5001)
     WRITE(6,5000)
5000 FORMAT(10X,25H          TEMPERATURES,F          ,30X,30H     HEAT  FLOWS
    1,BTU/HR                                                                   )
     WRITE(6,400)
 400 FORMAT('  TIME',8X'TO',8X'TI',6X'ROOF',6X'WALL',5X'FLOOR',4X'SOLID
    1 ',6X'DOOR',4X'WINDOW',5X'INFIL',7X'NET')
     DO 200 N=1,10
     DO 200 NK=1,T
     L=(N-1)*T+NK
     IF(NTI.NE.0) TINEW=TIX(NK)
     TNEW=TOX(NK)
     DO 10 NTT=2,V
  10 TOY(NTT)=TO(NTT-1)
     DO 11 NTT=2,V
  11 TO(NTT)=TOY(NTT)
     DO 12 NTT=2,V
  12 TOY(NTT)=TI(NTT-1)
     DO 13 NTT=2,V
  13 TI(NTT)=TOY(NTT)
     TO(1)=TNEW
     IF(NTI.NE.0) TI(1)=TINEW
     DO 7 I=1,2
     SUM(I)=Q(I)*CR(I)-Y(I,1)*TO(1)
```

```
      NMAX=XY(1,I)
      DO 8 J=2,NMAX
    8 SUM(I)=SUM(I)+(X(I,J)*TI(J)-Y(I,J)*TO(J))
    7 SUM(I)=SUM(I)*A(I)
      DO 20 I=3,4
      SUM(I)=CR(I)*Q(I)
      NMAX=XY(1,I)
      DO 9 J=2,NMAX
    9 SUM(I)=SUM(I)+Y(I,J)*TI(J)
   20 SUM(I)=SUM(I)*A(I)
      IF(NTI.NE.0) GO TO 8005
      DEN=UD*AD+UW*AW+1.08*CFM
      DEM=DEN
      DO 15 I=1,R
   15 DEN=DEN+A(I)*X(I,1)
      XNEM=DEM*TO(1)
      DO 16 I=1,R
   16 XNEM=XNEM-SUM(I)
      TI(1)=XNEM/DEN
 8005 DO 17 I=1,R
   17 Q(I)=SUM(I)+A(I)*X(I,1)*TI(1)
      QD=UD*AD*(TI(1)-TO(1))
      QW=UW*AW*(TI(1)-TO(1))
      QI=1.08*CFM*(TI(1)-TO(1))
      TON=TO(1)+TG
      TIN=TI(1)+TG
      SUMQ=QD+QW+QI
      DO 8006 I=1,R
 8006 SUMQ=SUMQ+Q(I)
      DO 201 I=1,R
      IF(A(I)) 201,201,202
  202 Q(I)=Q(I)/A(I)
  201 CONTINUE
      IF(N.NE.10) GO TO 200
      WRITE (6,300) NK,TON,TIN,(Q(I),I=1,R),QD,QW,QI,SUMQ
C      TON   OUTSISE AIR TEMPETARURE
C     TIN   INSIDE AIR TEMPERATURE
C     Q(I),I=1,4)    HEAT FLUX  IN BTU PER HOUR,SQ.FT
C      QD   TOTOAL HEAT TRANSFER THROUGH DOOR
C      QW   TOTAL HEAT TRANSFER THROUGH WINDOWS
C      QI   TOTAL HEAT TRANSFER  DUE TO INFILTRATION
  200 CONTINUE
  300 FORMAT(I5,10F10.2)
      GO TO 3000
 6000 STOP
      END
```

```
@I FOR,* LD100,LD100
C     THIS PROGRAM IS DEVELOPED BY T.KUSUDA OF THE NATIONAL BUREAU OF
C     STANDARDS FOR CALCULTING THE THERMAL RESPONSE FACTORS FOR
C     COMPOSITE WALLS,FLOORS,ROOFS,BASEMENT WALLS BASEMENT FLOORS
C     AND INTERNAL FURNISHINGS OF SIMPLE SHAPES
C     RESPONSE FACTORS ARE USED IN THE FOLLOWING MANNER
C     X,Y,Z ARE RESPONSE FACTORS
C     QO=Y*TI-Z*TO   OUTSIDE WHERE R IS MAXIMUM
C     TI   INSIDE TEMPERARURE WHERE R IS MINIMUM
C     TO   OUTSIDE TEMPERATURE WHERE R IS MAXIMUM
C     K  THERMAL CONDUCTIVITY
C     G  THERMAL DIFFUSIVITY
C     L  THICKNESS
C   IM=0 OR BLABK  PLANE WALL
C   IM=1  CYLINDRICAL WALL
C   IM=2 SPHERICAL WALL
C   IN=0   FINITE THICK WALL
C   IN=1   SEMI-FINITE WALL
C   IN=2   SOLID OBJECT
C   IF RESPONSE FACTORS OF THE SOLID CYLINDER OR SPHERE OF HOMOGENEOUS
C   PROPETY ARE DESIRED, TREAT THE PROBLEM OF MULTILAYER BUT WITH THE
C   IDENTICAL PROPERTIES FOR ALL THE LAYERS EXCEPT THE RADIUS
C    IF IHEAT=0  NO TEMPERATURE DATA THUS NO HEAT CALCULATION
C    IF IHEAT=1  PERIODIC BOUNDATRY CONDITIONS
  400 FORMAT(2H0  )
      PARAMETER S=100,T=10,U=T+1,TV=2*T
      REAL K(T),G(T),L(T),KG
      DIMENSION X(S),Y(S),Z(S),C(T),D(T),R(U),RES(T),RMK(T,T),RMKG(T),
     1F(S),XX(S,TV),YY(S,TV),ZZ(S,TV)
    1 FORMAT(10I7)
    2 FORMAT(10F7.0)
  100 FORMAT (14H0 EXPOSURE NO= I10)
  101 FORMAT(77H0  LAYER     L(I)      K(I)       (I)       C(I)    RES(I
     1)   DESCRIPTION                                                   )
  102 FORMAT(77H   NO
     2    OF LAYERS                                                     )
  103 FORMAT(1I6,1F11.3,1F10.3,1F10.2,1F10.3,1F8.2,2X,4A6)
  104 FORMAT(58H0                             THERMAL CONDUCTANCE
     3U=1F7.3)
  105 FORMAT(49H0                              TIME INCREMENT DT=1F3.1 )
  106 FORMAT(50H0                                 RESPONSE FACTORS     )
  107 FORMAT(120H0               J                    X              Y
     1            Z                                                     )
  108 FORMAT(1I17,1F23.4,2F15.4)
  112 FORMAT(4A6)
  117 FORMAT(44H0                          COMMON RATIO  CR=1F7.5)
  700 READ(5,2) DELTAT
      IRUN=0
  500 READ(5,1) NLAYR,NTEST,IM,IN
      IF(NLAYR.EQ.0) GO TO 800
      IRUN=IRUN+1
      IF(NLAYR.GT.10) GO TO 600
      NNLAYR=NLAYR+1
      IF(NLAYR.EQ.0) GO TO 500
      DO 200 I=1,NLAYR
```

```
200 READ(5,2) L(I),K(I),D(I),C(I),RES(I)
    IF(IN.EQ.2.AND.IM.EQ.0) GO TO 301
500 IF(IN.NE.0) READ(5,2)KG,DG,CG
    IF(IN.NE.0) AG=KG/CG/DG
    IF(NLAYR.EQ.0) GO TO 501
    IF(IM.EQ.0) GO TO 301
    READ(5,2)(R(I),I=1,NNLAYR)
    GO TO 302
301 R(1)=10.
    DO 303 I=2,NNLAYR
303 R(I)=R(I-1)+L(I)
302 IF(IN.EQ.2.AND.IM.NE.0) READ(5,112)(RMKG(J),J=1,4)
    DO 113 I=1,NLAYR
113 READ(5,112)(RMK(I,J),J=1,4)
    IF(IN.EQ.1) READ(5,112) (RMKG(J),J=1,4)
    DO 109 I=1,NLAYR
    IF(L(I)) 110,111,110
111 G(I)=0.
    K(I)=1./RES(I)
    GO TO 109
110 G(I)=K(I)/C(I)/D(I)
109 CONTINUE
501 GMA=(R(NNLAYR)/R(1))**IM
    CALL RESPTK(K,L,R,G,AG,KG,X,Y,Z,NLAYR,DELTAT,NRT,CR,UT,IM,IN,F)
    XX(1,IRUN)=FLOAT(NRT)
    YY(1,IRUN)=FLOAT(NRT)
    ZZ(1,IRUN)=FLOAT(NRT)
    XX(2,IRUN)=CR
    YY(2,IRUN)=CR
    ZZ(2,IRUN)=CR
    XX(NRT+3,IRUN)=UT
    YY(NRT+3,IRUN)=UT
    ZZ(NRT+3,IRUN)=UT
    WRITE(6,100) IRUN
    IF(IM.EQ.0) WRITE(6,701)
701 FORMAT(50H0  PLANE WALL                                     )
    IF(IM.EQ.1) WRITE(6,702)
702 FORMAT(50H0  CYLINDRICAL WALL                               )
    IF(IM.EQ.2) WRITE(6,703)
703 FORMAT(50H0  SPHERICAL WALL                                 )
    WRITE(6,101)
    WRITE(6,102)
    WRITE(6,400)
     IF(NLAYR.EQ.0) GO TO 502
    IF (IN.EQ.2.AND.IM.NE.0) WRITE (6,120) KG,DG,CG,(RMKG(J),J=1,4)
    DO 202 I=1,NLAYR
    IF(L(I)) 202,203,202
203 K(I)=0.
202 WRITE(6,103) I,L(I),K(I),D(I),C(I),RES(I),(RMK(I,J),J=1,4)
    IF(IN.EQ.1) WRITE(6,120) KG,DG,CG,(RMKG(J),J=1,4)
120 FORMAT(1F27.3,1F10.2,1F10.3,10X,4A6)
502 CONTINUE
    IF(IN.NE.0) GO TO 1535
    DO 114 N=1,NRT
    JN=N-1
    XX(N+2,IRUN)=X(N)
    YY(N+2,IRUN)=Y(N)
```

```
      ZZ(N+2,IRUN)=Z(N)
  114 CONTINUE
      GO TO 504
 1535 CONTINUE
  555 FORMAT(50H0                       J               F             )
      IF(IN.EQ.1) GO TO 9999
      GO TO 9998
9999  SIGN=1.0
      GO TO 505
9998  IF(IN.EQ.2.AND.IM.EQ.0) GO TO 9997
      GO TO 9996
9997  SIGN=-1.0
      GO TO 505
9996  CONTINUE
      DO 506 N=1,NRT
      JN=N-1
      X(N)=-X(N)
      XX(N+2,IRUN)=X(N)
  506 CONTINUE
      GO TO 504
  505 DO 509 N=1,NRT
      XX(N+2,IRUN)=SIGN*F(N)
      JN=N-1
  509 CONTINUE
  508 FORMAT(1124,1F21.5)
  504 CONTINUE
      GO TO 300
  600 CONTINUE
  800 RETURN
      END
```

```
@1 FOR,* RESP,RESP
      SUBROUTINE RESP (IRUN,XX,YY,ZZ,DELTAT)
C     THIS PROGRAM IS DEVELOPED BY T.KUSUDA OF THE NATIONAL BUREAU OF
C     STANDARDS FOR CALCULTING THE THERMAL RESPONSE FACTORS FOR
C     COMPOSITE WALLS,FLOORS,ROOFS,BASEMENT WALLS BASEMENT FLOORS
C     AND INTERNAL FURNISHINGS OF SIMPLE SHAPES
C     RESPONSE FACTORS ARE USED IN THE FOLLOWING MANNER
C     X,Y,Z ARE RESPONSE FACTORS
C    QI=X*TI-Y*TO*GMA    INSIDE WHERE R IS MINIMUM
C    QI=X*TI-Y*TO*GMA    INSIDE WHERE R IS MINIMUM
C     QO=Y*TI-Z*TO    OUTSIDE WHERE R IS MAXIMUM
C     TI    INSIDE TEMPERARURE WHERE R IS MINIMUM
C     TO    OUTSIDE TEMPERATURE WHERE R IS MAXIMUM
C     K  THERMAL CONDUCTIVITY
C     G  THERMAL DIFFUSIVITY
C     L  THICKNESS
C   IM=0 OR BLABK  PLANE WALL
C   IM=1  CYLINDRICAL WALL
C   IM=2 SPHERICAL WALL
C   IN=0    FINITE THICK WALL
C   IN=1    SEMI-FINITE WALL
C   IN=2    SOLID OBJECT
C   IF RESPONSE FACTORS OF THE SOLID CYLINDER OR SPHERE OF HOMOGENEOUS
C   PROPETY ARE DESIRED, TREAT THE PROBLEM OF MULTILAYER BUT WITH THE
C   IDENTICAL PROPERTIES FOR ALL THE LAYERS EXCEPT THE RADIUS
C    IF IHEAT=0  NO TEMPERATURE DATA THUS NO HEAT CALCULATION
C    IF IHEAT=1  PERIODIC BOUNDATRY CONDITIONS
  400 FORMAT(2H0   )
      REAL K(10),G(10),L(10),R(11),KG
      DIMENSION X(200),Y(200),Z(200),TI(1000),TO(1000),C(10),D(10),RES(1
     10),RMK(10,4),RMKG(4),F(200)
    1 FORMAT(10I7)
    2 FORMAT(10F7.0)
  100 FORMAT(10H1          )
  101 FORMAT(77H0  LAYER     L(I)      K(T)       (I)      C(I)   RES(I
     1)    DESCRIPTION                                                )
  102 FORMAT(77H    NO
     2    OF LAYERS                                                   )
  103 FORMAT(1I6,1F11.3,1F10.3,1F10.2,1F10.3,1F8.2,2X,4A6)
  104 FORMAT(58H0                            THERMAL CONDUCTANCE
     3U=1F7.3)
  105 FORMAT(49H0                             TIME INCREMENT DT=1F3.0 )
  106 FORMAT(50H0                                RESPONSE FACTORS     )
  107 FORMAT(120H0               J                    X              Y
     1             Z                                                  )
  108 FORMAT(1I17,1F23.4,2F15.4)
  112 FORMAT(4A6)
  117 FORMAT(44H0                          COMMON RATIO  CR=1F7.5)
      READ(5,1) IHEAT
      IF(IHEAT.NE.0) CALL TDATA(TO,TI,NP,IHEAT)
  700 READ(5,2) DELTAT
  500 READ(5,1) NLAYR,NTEST,IM,IN
      IF(NLAYR.GT.10) GO TO 600
      NNLAYR=NLAYR+1
      IF(NLAYR.EQ.0) GO TO 500
      DO 200 I=1,NLAYR
```

```
200  READ(5,2) L(I),K(I),D(I),C(I),RES(I)
     IF(IN.EQ.2.AND.IM.EQ.0) GO TO 301
500  IF(IN.NE.0) READ(5,2)KG,DG,CG
     IF(IN.NE.0) AG=KG/CG/DG
     IF(NLAYR.EQ.0) GO TO 501
     IF(IM.EQ.0) GO TO 301
     READ(5,2)(R(I),I=1,NNLAYR)
     GO TO 302
301  R(1)=10.
     DO 303 I=2,NNLAYR
303  R(I)=R(I-1)+L(I)
302  IF(IN.EQ.2.AND.IM.NE.0) READ(5,112)(RMKG(J),J=1,4)
     DO 113 I=1,NLAYR
113  READ(5,112)(RMK(I,J),J=1,4)
     IF(IN.EQ.1) READ(5,112) (RMKG(J),J=1,4)
     DO 109 I=1,NLAYR
     IF(L(I)) 110,111,110
111  G(I)=0.
     K(I)=1./RES(I)
     GO TO 109
110  G(I)=K(I)/C(I)/D(I)
109  CONTINUE
501  GMA=(R(NNLAYR)/R(1))**IM
     WRITE(6,207)
207  FORMAT(2H1     )
     CALL RESPTK(K,L,R,G,AG,KG,X,Y,Z,NLAYR,DELTAT,NRT,CR,UT,IM,IN,F)
     WRITE(6,100)
     IF(IM.EQ.0) WRITE(6,701)
701  FORMAT(50H0  PLANE WALL                                     )
     IF(IM.EQ.1) WRITE(6,702)
702  FORMAT(50H0  CYLINDRICAL WALL                               )
     IF(IM.EQ.2) WRITE(6,703)
703  FORMAT(50H0  SPHERICAL WALL                                 )
     WRITE(6,101)
     WRITE(6,102)
     WRITE(6,400)
      IF(NLAYR.EQ.0) GO TO 502
     IF(IN.EQ.2) WRITE(6,120) KG,DG,CG,(RMKG(J),J=1,4)
     DO 202 I=1,NLAYR
     IF(L(I)) 202,203,202
203  K(I)=0.
202  WRITE(6,103) I,L(I),K(I),D(I),C(I),RES(I),(RMK(I,J),J=1,4)
     IF(IN.EQ.1) WRITE(6,120) KG,DG,CG,(RMKG(J),J=1,4)
120  FORMAT(1F27.3,1F10.2,1F10.3,10X,4A6)
502  WRITE(6,105) DELTAT
     WRITE(6,104)UT
     WRITE(6,106)
     WRITE(6,400)
     IF(IN.NE.0) GO TO 1535
     WRITE(6,107)
     DO 114 N=1,NRT
     JN=N-1
114  WRITE(6,108)JN,X(N),Y(N),Z(N)
     GO TO 504
1535 WRITE(6,555)
555  FORMAT(50H0                     J              F             )
     IF(IN.EQ.1) GO TO 505
```

```
      IF(IN.EQ.2.AND.IM.EQ.0) GO TO 505
      DO 506 N=1,NRT
      JN=N-1
      X(N)=-X(N)
  506 WRITE(6,508) JN,X(N)
      GO TO 504
  505 DO 509 N=1,NRT
      JN=N-1
  509 WRITE(6,508) JN,F(N)
  508 FORMAT(1I24,1F21.5)
  504 WRITE(6,400)
      WRITE(6,400)
      WRITE(6,117) CR
      IF(NTEST.EQ.0) GO TO 300
      CALL HEAT(X,Y,Z,TI,TO,DELTAT,NP,NRT,GMA,CR)
      GO TO 300
  600 STOP
      END
```

```
@1 FOR,* A,A
      SUBROUTINE RESPTK(K,L,R,G,AG,KG,X,Y,Z,NL,DT,NR,CR,J,IM,IS,F)
C     CALCULATES RESPONSE FACTORS BY MARING USE OF THICKNESS, THERMAL
C     CONDUCTIVITY, DENSITY, AND SPECIFIC HEAT OF EACH LAYER OF
C     COMPOSITE WALL
      DIMENSION K(10),L(10),R(10),G(10),X(100),Y(100),Z(100),AP(10),BP(1
     10),CP(10),DP(10),A(10),B(10),C(10),D(10),ZR1(3),ZR2(3),RB(3),RAP(3
     2),ROOT(100),RA(3,100),ZRK(3,100),RX(100),RY(100),AZ(100)
     3,F(100)
      REAL K,L,KG
      PI=3.1415927
      M3=3
      IF(IS.EQ.2.AND.IM.NE.0) M3=1
      IF(IS.NE.1) GO TO 613
  608 ZL=KG/R(NL+1)
      DY=R(NL+1)**2/AG/DT
      CALL GPF(DY,ZL,IM,AZ )
      IF(IS.EQ.1.AND.NL.EQ.0)  GO TO 901
  613 CALL ABCD2(0.,K,L,R,G,AX,BX,CX,DX,IM,NL)
      RB(1)=DX
      RB(2)=1.
      RB(3)=AX
      J=1./BX
      DO 1 I=1,NL
      PX=0
      CALL ABCDP2(PX,K(I),L(I),R(I),G(I),AP(I),BP(I),CP(I),DP(I),IM)
    1 CALL  ABCD2(PX,K(I),L(I),R(I),G(I),A(I),B(I),C(I),D(I),IM,1)
      IF(NL.LT.2) GO TO 502
      CALL DERVT(A,B,C,D,AP,BP,CP,DP,APP,BPP,CPP,DPP,NL)
      GO TO 503
  502 APP=AP(1)
      BPP=BP(1)
```

```
      CPP=CP(1)
      DPP=DP(1)
  503 IF(IS.NE.2) GO TO 501
      IF(IM.EQ.0) GO TO 501
      CALL SOLID(0.,R(1),KG,AG,IM,HF,HFP)
      ZR1(1)=(-CPP+HFP*AX)/DX/DT
      ZR2(1)=-ZR1(1)
 1400 FORMAT(4F20.5)
      GO TO 1212
  501 RAP(1)=DPP
      RAP(2)=0.
      RAP(3)=APP
      DO 2 I=1,3
      C1=RAP(I)/BX/DT
      C2 = RB(I)*BPP/BX/BX/DT
      ZR2(I)=-C1+C2
    2 ZR1(I)=-ZR2(I)+RB(I)/BX
 1212 CONTINUE
  100 FORMAT(3F20.6)
C    ROOTS OF B(P)=0.
  212 NMAX=40
      IF(IS.EQ.2.AND.IM.NE.0) NMAX=100
      PX=0.001
      DPO=0.1/DT
      IF(IS.EQ.2.AND.IM.NE.0) DPO=3.1416*3.1416*AG/R(1)/R(1)*0.25
      DLX=0.0001
      IF(IS.EQ.2.AND.IM.NE.0)DLX=DPO/1000
      N=0
   11 DL=DPO
      CALL ABCD2(PX,K,L,R,G,AX,BX,CX,DX,IM,NL)
      IF(IS.EQ.2.AND.IM.NE.0) CALL SOLDX(PX,R(1),KG,AG,IM,BX,DX,TEST1)
   15 PXP=PX+DL
      CALL ABCD2(PXP,K,L,R,G,AXP,BXP,CXP,DXP,IM,NL)
      IF(IS.NE.2) GO TO 213
      IF(IM.EQ.0) GO TO 213
      CALL SOLDX(PXP,R(1),KG,AG,IM,BXP,DXP,TEST2)
      IF(TEST1*TEST2) 112,113,114
  114 PX=PXP
      TEST1=TEST2
      GO TO 15
  112 IF(DL-DLX) 130,130,117
  117 DL=DL/2.
      GO TO 15
  113 IF(TEST1) 118,119,118
  119 RXX=PX
      GO TO 31
  118 RXX=PXP
      GO TO 31
  130 AB=ABS(TEST1/TEST2)
      RXX=(PX+AB*PXP)/(1+AB)
      GO TO 31
  213 IF(BX*BXP) 12,13,14
   14 PX=PXP
      BX=BXP
      TESTX=PX*DT
      IF(TESTX-100.)15,43,43
   12 IF(DL-DLX)30,30,17
```

```
  17 DL=DL/2.
     GO TO 15
  13 IF(BX) 18,19,18
  19 RXX=PX
     GO TO 31
  18 RXX=PXP
     GO TO 31
  30 AB=ABS(BX/BXP)
     RXX=(PX+AB*PXP)/(1.+AB)
  31 N=N+1
     ROOT(N)=RXX
     IF(N.GT.1) DPO=ROOT(N)-ROOT(N-1)
     NRT=N
  41 FORMAT(I10,1F20.6)
     PX=RXX+DLX
     TESTMX=40
     TESTX=RXX*DT
     IF(TESTX-TESTMX)42,42,43
  42 IF(N.LT.NMAX) GO TO 11
  43 CONTINUE
     DO 600 JJ=1,NRT
     PX=ROOT(JJ)
     DO 51 J=1,NL
     CALL ABCD2(PX,K(J),L(J),R(J),G(J),A(J),B(J),C(J),D(J),IM,1)
  51 CALL ABCDP2(PX,K(J),L(J),R(J),G(J),AP(J),BP(J),CP(J),DP(J),IM)
     CALL ABCD2(PX,K,L,R,G,AX,BX,CX,DX,IM,NL)
     IF(NL.LT.2) GO TO 504
     CALL DERVT(A,B,C,D,AP,BP,CP,DP,APP,BPP,CPP,DPP,NL)
     GO TO 505
 504 APP=AP(1)
     BPP=BP(1)
     CPP=CP(1)
     DPP=DP(1)
 505 IF(IS.NE.2) GO TO 214
     IF(IM.EQ.0) GO TO 214
     CALL SOLID(PX,R(1),KG,AG,IM,HF,HFP)
     IF(HF) 401,400,401
 401 PYS     =(HF*AX-CX)/PX/PX/(DPP-HFP*BX-HF*BPP)/DT
     GO TO 402
 400 PYS=0.
 402 RA(1,JJ)=PYS
     GO TO 601
 214 PY=BPP*PX*PX*DT
     RA(1,JJ)=DX/PY
     RA(2,JJ)=1./PY
     RA(3,JJ)=AX/PY
 601 PZ=PX*DT
     IF (PZ.LT.40.) GO TO 52
     RX(JJ) = .0
     RY(JJ) = 1.E30
     GO TO 600
  52 RX(JJ)=EXP(-PZ)
   5 RY(JJ)=(1.-EXP(PZ))**2
 600 CONTINUE
  54 FORMAT(4F20.6)
     DO 154 JJ=1,NRT
     DO 154 M=1,M3
```

```
      ZR1(M)= RA(M,JJ)*RX(JJ)+ZR1(M)
  154 ZR2(M) = RA(M,JJ)*RX(JJ)*(RX(JJ)-2.)+ZR2(M)
      II=1
      III=2
   80 FORMAT(50H0  RESPONSE FACTORS OF  FINITE SLAB                     )
   81 FORMAT(120H0         J                    X(J)                Y(J)
     1              Z(J)                                                )
  701 FORMAT(120H1  RESPONSE FACTORS FOR SOLID CYLINDRICAL OBJECTS
     1                                                                  )
  702 FORMAT(120H1     RESPONSE FACTORS FOR SOLID  SPHERICAL OBJECTS
     1                                                                  )
      IF(ZR1(2).LT.0) ZR1(2)=0.
      DO 67 M=1,M3
      ZRK(M,1)=ZR1(M)
   67 ZRK(M,2)=ZR2(M)
   55 FORMAT(I10,3F20.6)
      NT=100
      DO 58 N=3,NT
      NR=N
      DO 61 M=1,M3
   61 ZRK(M,N)=0.
      DO 57 M=1,M3
      DO 57 JJ=1,NRT
      PZ=(RX(JJ))**N
   57 ZRK(M,N)=ZRK(M,N)+PZ*RY(JJ)*RA(M,JJ)
      IF(N.LT.5) GO TO 58
      TEST1=ZRK(1,N)/ZRK(1,N-1)
      TEST2=ZRK(1,N-1)/ZRK(1,N-2)
      TEST3=ABS(TEST1-TEST2)
      IF(TEST3-0.00001) 59,59,58
   58 CONTINUE
   59 DO 60  N=1,NR
      X(N)=ZRK(1,N)
      Y(N)=ZRK(2,N)
   60 Z(N)=ZRK(3,N)
      CR=TEST2
   62 FORMAT(10H0       CR=1F10.6)
      IF(IS.EQ.2.AND.IM.EQ.0) GO TO 800
      IF(IS.NE.1) GO TO 900
  901 IF(NL.EQ.0) GO TO 905
      GF=2*KG/SQRT(DT*AG*PI)
      IF(NR.LT.50) GO TO 610
      DO 204 J=50,NR
      ZJ=J
  204 AZ(J)=GF*(SQRT(ZJ)-2.*SQRT(ZJ-1.)+SQRT(ZJ-2.))
      NRR=NR
      GO TO 300
  610 DO 301 J=NR,50
      Z(J+1)=Z(J)*CR
      X(J+1)=X(J)*CR
  301 Y(J+1)=Y(J)*CR
      NRR=50
  300 DO 205 J=1,NRR
  205 F(J)=X(J)-Y(J)*Y(J)/(Z(J)+AZ(J))
      NR=NRR
      GO TO 906
```

```
905 DO 904 J=1,NR
904 F(J)=AZ(J)
906 CONTINUE
207 FORMAT(50H0           J                    F                                      )
    CR1=1.
    DO 208 J=1,50
    CR=F(J+1)/F(J)
    TESTCR=ABS(CR-CR1)
    IF(TESTCR-0.00001) 611,611,612
612 CR1=CR
    JJ=J-1
208 CONTINUE
209 FORMAT(1I10,1F20.5)
611 NR=J
    CR=CR1
    GO TO 900
600 CONTINUE
    DO 210 J=1,NR
    F(J)=2*Y(J)-(X(J)+Z(J))
    JJ=J-1
210 CONTINUE
900 RETURN
    END


@I FOR,* B,B

      SUBROUTINE DERVT(A,B,C,D,AP,BP,CP,DP,APP,BPP,CPP,DPP,N)
C     COMPUTES DERIVATIVE OF MATRIX ELEMENTS FOR PLANE LAYER
      DIMENSION A(N),B(N),C(N),D(N),AP(N),BP(N),CP(N),DP(N),AT(10),BT(10
     1),CT(10),DT(10),ATT(10),BTT(10),CTT(10),DTT(10)
      DO 1 I=1,N
      DO 2 J=1,N
      IF(I.EQ.J) GO TO 3
      AT(J)=A(J)
      BT(J)=B(J)
      CT(J)=C(J)
      DT(J)=D(J)
      GO TO 2
    3 AT(J)=AP(J)
      BT(J)=BP(J)
      CT(J)=CP(J)
      DT(J)=DP(J)
    2 CONTINUE
    1 CALL MULT(AT,BT,CT,DT,ATT(I),BTT(I),CTT(I),DTT(I),N)
      APP=ATT(1)
      BPP=BTT(1)
      CPP=CTT(1)
      DPP=DTT(1)
      DO 4 I=2,N
      APP=APP+ATT(I)
      BPP=BPP+BTT(I)
      CPP=CPP+CTT(I)
    4 DPP=DPP+DTT(I)
      RETURN
      END
```

```
@I FOR,* C,C
      SUBROUTINE ABCD2(Z,K,L,R,G,A,B,C,D,IM,NL)
C     COMPUTES MATRIX ELEMENT FOR MULTI-LAYER PLANE AS SHOWN IN TABLE I
C     OF KUSUDA'S PAPER
      DIMENSION AX(10),BX(10),CX(10),DX(10),R(10),G(10)
      DOUBLE PRECISION   DBEJ,DBEY,ZQ1,ZQ2
      REAL K(10),L(10),J01,J02,J11,J12
      PI=3.1415927
      PP=PI*0.5
      IF(NL.LT.2) R(2)=R(1)+L(1)
      DO 4 I=1,NL
      IF(G(I)) 103,103,102
  102 IF(Z) 1,1,101
  101 ZQ=SQRT(Z/G(I))
      ZQ1=ZQ*R(I)
      ZQ2=ZQ*R(I+1)
      ZQL=ZQ*L(I)
      IF(IM.NE.1) GO TO 3
      J01=DBEJ(ZQ1,0)
      J11=DBEJ(ZQ1,1)
      J02=DBEJ(ZQ2,0)
      J12=DBEJ(ZQ2,1)
      Y01=DBEY(ZQ1,0)
      Y11=DBEY(ZQ1,1)
      Y02=DBEY(ZQ2,0)
      Y12=DBEY(ZQ2,1)
      AX(I)=-PP*ZQ2*(J01*Y12-Y01*J12)
      BX(I)=PP*R(I+1)/K(I)*(-Y01*J02+J01*Y02)
      CX(I)=K(I)/R(I+1)*(-J11*Y12+Y11*J12)*PP*ZQ2*ZQ2
      DX(I)=PP*ZQ2*(J11*Y02-Y11*J02)
      GO TO 4
    3 CO=SIN(ZQL)
      C1=COS(ZQL)
      S1=CO/ZQL
      S2=(S1-C1)/ZQL/ZQL
      IF(IM.EQ.2) GO TO 5
      AX(I)=C1
      BX(I)=L(I)/K(I)*S1
      CX(I)=-ZQL*K(I)/L(I)*CO
      DX(I)=C1
      GO TO 4
    5 GM=R(I+1)/R(I)
      AX(I)=GM*(C1-L(I)/R(I+1)*S1)
      BX(I)=L(I)/K(I)*GM*S1
      CX(I)=L(I)*L(I)/R(I)/R(I)*K(I)/L(I)*(-(ZQ1*ZQ2+1)*S1+C1)
      DX(I)=GM*(C1+L(I)/R(I)*S1)
      GO TO 4
    1 AX(I)=1.
      CX(I)=0.
      DX(I)=(R(I+1)/R(I))**IM
      IF(IM.EQ.0) BX(I)=L(I)/K(I)
      IF(IM.EQ.1) BX(I)=R(I+1)/K(I)*LOG(R(I+1)/R(I))
      IF(IM.EQ.2) BX(I)=L(I)/K(I)*(R(I+1)/R(I))
      GO TO 4
  103 AX(I)=1.
```

```
      BP=RES*X*R1*S2/R
      ZP1=ZQ1
      ZP2=ZQ2
      CP=X*(L/R)**2/RES*((2.*R*R1/L/L+1)*S1-(ZP1*ZP2+1.)*S2)
      DP=X*(R1/R*S1+(L/R)*(R1/R)*S2)
      GO TO 4
    5 AP=X*S1
      BP=X*RES*S2
      CP=X*(S1+C1)/RES
      DP=X*S1
      GO TO 4
  103 AP=0.
      BP=0.
      CP=0.
      DP=0.
      GO TO 4
  101 IF(IM.NE.0) GO TO 6
      X=L*L*0.5/G
      AP=X
      BP=X*L/K/3
      CP=K/L*X*2.
      DP=X
      GO TO 4
    6 IF(IM.NE.1) GO TO 7
      R1=R+L
      AP=(0.5*(R*R-R1*R1)+R1*R1*LOG(R1/R))*0.5/G
      BP=R1/4/G/K*((R1*R1+R*R)*LOG(R1/R)-(R1*R1-R*R))
      CP=K/R*0.5/G*(R1*R1-R*R)
      DP=0.5/G*(0.5*(R1*R1-R*R)*R1/R-R*R1*LOG(R1/R))
      GO TO 4
    7 X=L*L*0.5/G
      R1=R+L
      AP=X/3.*(2*R1/R+1.)
      BP=L/K*R1/R*X/3.
      CP=K/L*X*L/R*L/R*(2.*R*R1/L/L+0.666667)
      DP=X/3.*R1/R*(R1/R+2)
    4 RETURN
      END



@1 FOR,* D,D
      SUBROUTINE ABCDP2(Z,K,L,R,G,AP,BP,CP,DP,IM)
C     COMPUTES MATRIX ELEMENT FOR SINGLE-LAYER PLANE AS SHOWN IN TABLE I
C     OF KUSUDA'S PAPER
      DOUBLE PRECISION ZQ1,ZQ2,DBEJ,DBEY
      REAL K,L,J01,J02,J11,J12
      PI=3.1415927
      IF(G) 103,103,104
  104 PP=PI/4./G
      IF(Z) 101,101,105
  105 ZQ=SQRT(Z/G)
      ZQL=ZQ*L
      ZQ1=ZQ*R
      ZQ2=ZQ1+ZQL
      IF(IM.NE.1) GO TO 3
      X=R*(R+L)
```

```
      Y=(R+L)**2
      Z1=(R+L)/K
      J01=DBEJ(ZQ1,0)
      J02=DBEJ(ZQ2,0)
      J11=DBEJ(ZQ1,1)
      J12=DBEJ(ZQ2,1)
      Y01=DBEY(ZQ1,0)
      Y02=DBEY(ZQ2,0)
      Y11=DBEY(ZQ1,1)
      Y12=DBEY(ZQ2,1)
      AP=(-X*(J11*Y12-Y11*J12)+Y*(J01*Y02-Y01*J02))*PP
      BP=(X*(J11*Y02-Y11*J02)*Z1/ZQ2+Y*(J01*Y12-Y01*J12)*Z1/ZQ2)*PP
      CP=PP*ZQ2/Z1*(X*(J01*Y12-Y01*J12)+Y*(J11*Y02-Y11*J02))
      DP=(X*(-J01*Y02+Y01*J02)-Y*(-J11*Y12+Y11*J12))*PP
      GO TO 4
    3 X=L*L*0.5/G
      R1=R+L
      RES=L/K
      C0=SIN(ZQL)
      C1=COS(ZQL)
      S1=C0/ZQL
      S2=(S1-C1)/ZQL/ZQL
      IF(IM.EQ.0) GO TO 5
      AP=X*(R1*S1/R-L*S2/R)
      BX(I)=L/K(I)
      CX(I)=0.
      DX(I)=(R(I+1)/R(I))**IM
    4 CONTINUE
      A=AX(1)
      B=BX(1)
      C=CX(1)
      D=DX(1)
      IF(NL.LT.2) GO TO 6
      CALL MULT(AX,BX,CX,DX,A,B,C,D,NL)
    6 RETURN
      END
```

```
@1 FOR,* E,E
C     ROUTINE TO PERFORM MATRIX MULTIPLICATION
      SUBROUTINE MULT(A,B,C,D,AT,BT,CT,DT,N)
      DIMENSION A(N),B(N),C(N),D(N)
      ATT=A(1)
      BTT=B(1)
      CTT=C(1)
      DTT=D(1)
      IF(N.LT.2) GO TO 3
      DO 1 J=2,N
      AT=ATT*A(J)+BTT*C(J)
      BT=ATT*B(J)+BTT*D(J)
      CT=CTT*A(J)+DTT*C(J)
      DT=CTT*B(J)+DTT*D(J)
      ATT=AT
      BTT=BT
      CTT=CT
```

```
    1 DTT=DT
      GO TO 4
    3 AT=ATT
      BT=BTT
      CT=CTT
      DT=DTT
    4 RETURN
      END
```

```
@I FOR,* F,F
      SUBROUTINE SOLID(Z,R1,KG,AG,IM,HF,HFP)
C     COMPUTES RESPONSE FACTORS FOR SOLID MATERIAL
      REAL KG,J01,J11
      DOUBLE PRECISION DBEJ,ZQD
      ZQ=SQRT(Z/AG)
      ZQ1=ZQ*R1
      ZQD=ZQ1
      ZA=R1*R1/AG
      CON=KG/R1
      IF(Z) 2,1,2
    2 IF(IM.NE.1) GO TO 100
      J01=DBEJ(ZQD,0)
      TX=ABS(J01)
      IF(TX-0.00001) 4,4,5
    5 J11=DBEJ(ZQD,1)
      HF=CON*ZQ1*J11/J01
      HF1=J11/J01/ZQ1
      HF2=(J01*J01+J11*J11-J01*J11/ZQ1)/J01/J01
      HFP=-CON*0.5*ZA*(HF1+HF2)
      GO TO 300
  100 C=COS(ZQ1)
      S=SIN(ZQ1)/ZQ1
      TX=ABS(SIN(ZQ1))
      IF(TX-0.00001) 4,4,3
    3 HF=-CON*(C/S-1)
      HFP=-CON*0.5*ZA*(1+C*(C-S)/S/S/ZQ1/ZQ1)
      GO TO 300
    1 HF=0.
      IF(IM.EQ.2) HFP=-CON*ZA/3.
      IF(IM.EQ.1) HFP=-0.5*CON*ZA
      GO TO 300
    4 HF=0.
      HFP=0.
  300 RETURN
      END
```

```
@I FOR,* J,J
      SUBROUTINE GPF(U,ZL,IM,Z)
C     COMPUTES RESPONSE FACTORS FOR GROUND HEAT TRANSFER
      DIMENSION Z(100),ZT(5000),ZS(5000)
      DOUBLE PRECISION DBEJ,DBEY,ZQ
      PI=3.1415927
```

```
      SQTPI=SQRT(PI)
      PI2=2./PI
      EB=0.001
      DB=0.1
      Z(1)=2*ZL*SQRT(U)/SQTPI
      ZZ=Z(1)
      Z(2)=Z(1)*(SQRT(2.)-2.)
      DO 2 K=3,50
      ZK=K
    2 Z(K)=Z(1)*(SQRT(ZK)-2.*SQRT(ZK-1)+SQRT(ZK-2.))
      IF(IM.EQ.0) GO TO 70
      IF(IM.EQ.1) GO TO 1
      Z(1)=Z(1)+ZL
      GO TO 70
    1 X=PI2   *LOG(0.5*EB )+0.36746691
      SUN=PI*0.5*(ATAN(X)+0.5*PI)
      IX=0
      B=EB-DB
      DO 17 L=1,5000
      B=B+DB
    8 ZQ=B
      IF(IX.EQ.10) GO TO 30
      ZJO=DBEJ(ZQ,0)
      ZYO=DBEY(ZQ,0)
      TESTX=ZJO*ZJO+ZYO*ZYO
      TESTY=PI2/B
      TESTZ=ABS(TESTX-TESTY)
      IF(TESTZ-0.00001) 30,30,31
   31 ZZ=B*B*B*TESTX
      GO TO 32
   30 ZZ=B*B*PI2
      IX=10
   32 ZT(L)=1./ZZ
      LT=L
      TEST=ABS(ZT(L))*10
      IF(TEST-0.0001) 11,11,17
   17 CONTINUE
   11 LTY=LT/2
      LTX=LTY*2-1
      BMAX=EB+(LTX-1)*DB
      BB=1./BMAX
      ZJ=1./U
      SUT=SUN*ZJ
      B=EB-DB
      DO 28 L=1,LT
      B=B+DB
      ZB=B*B*ZJ
    6 ZP=EXP(-ZB)
   28 ZS(L)=(1.-ZP)*ZT(L)
      CALL SIMS(ZS,DB ,SUM,LTX)
      GK=(SUM+SUT)*PI2   +BB
      GG=GK*PI2
      Z(1)=GG*ZL*U
   70 CONTINUE
      RETURN
      END
```

Appendix E

Input and Output for the Response Factor Program

The Response Factor program (Appendix D) analyses the thermal performance of the inside space of the prototype building under a prescribed outdoor air temperature cycle. When the inside air temperature is thermostated, this program calculates the rate of heat loss from the building at prescribed time intervals. If the inside room air temperature is not controlled and floats in response to the outdoor air temperature cycle, the program then calculates time dependent variations of the inside room air temperature. Following this discussion is a sample set of data input and the print-out of corresponding computer results.

A description of a sample set of data input is given below:

Card Sequence	
1	Time increment of the temperature data in hours
2	Number of roof layers (includes the thermal resistances of the inside and outside surfaces)
3	Thermal resistance at inside surface of roof
4	Thickness, thermal conductivity, density, and specific heat of roof
5	Thermal resistance at outside surface of roof
6	Description of the inside surface of the roof
7	Description of roof

8 Description of the outside surface of roof

9 Number of wall layers

10 Thermal resistance at inside surface of wall

11 Thickness, thermal conductivity, density, and specific heat of wall

12 Thermal resistance of the outside surface of wall

13 Description of the inside surface of wall

14 Description of wall

15 Description of the outside surface of wall

16 Number of layers of the floor and the semi-infinite layer index (if basement floor)

17 Thermal resistance at inside surface of floor

18 Thickness, thermal conductivity, density, and specific heat of the first solid layer of the floor counted from the inside surface

19 Thickness, thermal conductivity, density, and specific heat of the second solid layer

20 Thermal conductivity, density, and specific heat of the earth

21 Description of the inside surface of floor

22 Description of the first solid layer

23 Description of the second solid layer

24 Description of the semi-infinite earth layer

25 Number of layers for inner mass

26 Thermal resistance at the outside surface of the interior mass

27	Thickness, density, specific heat, and thermal conductivity of the internal mass
28	Thermal resistance at the other outside surface of internal mass
29	Description of the outside surface of interior mass
30	Description of the interior mass
31	Description of the other outside surface of interior mass
32	Blank card (necessary to show end of above data)
33	Run no. card
34-37	Outside air temperature
38-41	Inside air temperature
42	Roof area, wall area, floor area, inner mass surface area, air flow (ventilation on air leakage), conductance of door, door area, conductance of window, window area, ground temperature, average inside air temperature

Components possessing significant heat capacity (such as walls, roof, etc.) are described in cards 2 through 31, while components having negligible heat capacity are described on card 42. Some various options available in the Response Factor program are discussed below.

Additional layers can be readily handled. For example, if the roof contains a second layer, then the number of layers given in card 2 would be increased to four. Also, a card giving the thermal and physical properties of this additional layer and a card giving a description of this layer would be inserted in proper sequence (from inside to outside). Additional layers in any component would be handled in a similar manner. If the additional layer is an air insulating layer, then only an average value of the thermal resistance of the air layer would be specified on the card giving layer properties. Another option is a floor which has no semi-infinite layer (such as the floor of a room of a multi-story building). This case may be handled by omitting the semi-infinite layer index on card 16 and removing the card giving the properties of the earth and the card giving the layer description of the earth. Another option is the case of a building without a component (such as a room without windows). This case is handled by setting the area of that component (given on card 42) equal to zero. And finally, the option for determination of the inside room air temperature (floating test) is handled by inserting four blank cards for the inside air temperature (cards 38 through 41).

A print-out of the computer results follows the sample set of input data. The first page of the print-out of results gives the description and composition of each building component having significant heat capacity. The second page gives the run number, outside air temperature cycle, the inside air temperature cycle (if thermostated), and the data input given on card 42. And finally, the third page of the print-out of the computer results gives the inside and outside air temperatures, the heat fluxes from the room at the inside surfaces of the building components in Btu hr^{-1} ft^{-2}, the air infiltration loss, and the net heat loss from the room at prescribed time intervals, in Btu hr^{-1}.

Sample Set of Data Input

```
0.50
     3
                                 0.92
.33    .80    150.    .20        0.0
                                 0.50
 INSIDE  SURFACE
 4-IN CONCRETE
 OUTSIDE SURFACE
     3
                                 1.00
0.625  0.29   100.    0.18       0.0
                                 0.50
 INSIDE SURFACE
 8-IN LT. CONCRETE
 OUTSIDE SURFACE
     3       0        0        1
                                 0.92
0.1666 0.80   160.    0.18       0.0
0.1666 0.018  2.50    0.27       0.0
0.5    120.   0.2
 INSIDE  SURFACE
 2-IN CONCRETE
 2-IN expanded polystyrene
 GROUND
     3                         2
                                 1.0
0.623  0.29   100.    0.18       0.0
                                 1.0
 OUTSIDE SURFACE
 7.5-IN LT WT CONCRETE
 OUTSIDE SURFACE
 (BLANK CARD)
10.0
78.2  82.1  85.7  89.6  93.1  95.4  96.2  96.2  97.6  100.3 101.0 101.5
101.3 99.4  96.5  93.6  91.0  86.0  82.3  74.5  64.0  56.6  54.7  52.9
52.2  50.3  51.1  48.6  48.4  47.1  46.6  46.3  46.3  46.0  45.8  45.5
45.3  45.2  45.2  45.3  45.0  45.2  44.6  53.7  59.2  65.8  68.4  74.8
77.9  78.9  78.8  79.1  78.3  78.7  79.0  78.5  78.3  79.1  78.4  78.8
78.6  78.8  79.1  79.4  79.7  80.0  80.2  80.2  80.2  79.9  79.4  79.0
78.7  78.7  78.8  78.9  78.7  79.0  79.1  79.1  78.5  78.9  78.9  78.0
78.2  79.0  78.0  79.1  79.0  79.0  79.0  78.2  79.3  79.0  79.1  79.1
350.   673.   350.   0.0    21.0   0.25   20.5   0.45   64.0   70.9   79.0
 (BLANK CARD)
```

```
XPOSURE NO=          1

PLANE WALL

LAYER      L(I)       K(I)         (I)         C(I)      RES(I)    DESCRIPTION
NO                                                                  OF LAYERS


  1        .000       .000         .00         .000        .92    INSIDE  SURFACE
  2        .330       .800      150.00         .200        .00    4-IN CONCRETE
  3        .000       .000         .00         .000        .68    OUTSIDE SURFACE

XPOSURE NO=          2

PLANE WALL

LAYER      L(I)       K(I)         (I)         C(I)      RES(I)    DESCRIPTION
NO                                                                  OF LAYERS


  1        .000       .000         .00         .000       1.00    INSIDE SURFACE
  2        .625       .290      100.00         .180        .00    8-IN LT. CONCRETE
  3        .000       .000         .00         .000        .68    OUTSIDE SURFACE

XPOSURE NO=          3

PLANE WALL

LAYER      L(I)       K(I)         (I)         C(I)      RES(I)    DESCRIPTION
NO                                                                  OF LAYERS


  1        .000       .000         .00         .000        .92    INSIDE  SURFACE
  2        .167       .800      160.00         .130        .00    2-IN CONCRETE
  3        .167       .018        2.50         .270        .00    2-IN expanded polystyrene
                      .500      120.00         .200               GROUND

XPOSURE NO=          4

PLANE WALL

LAYER      L(I)       K(I)         (I)         C(I)      RES(I)    DESCRIPTION
NO                                                                  OF LAYERS


  1        .000       .000         .00         .000       1.00    OUTSIDE SURFACE
  2        .623       .290      100.00         .180        .00    7.5-IN LT WT CONCRETE
  3        .000       .000         .00         .000       1.00    OUTSIDE SURFACE
```

```
RUN NO=       10.

 OUTDOOR TEMPERATURE CYCLE
  75.20     82.10     85.70     89.60     93.10     95.40     96.20     96.20     97.60    100.30    101.00    101.50
 101.30     99.40     96.50     93.60     91.00     85.00     82.30     74.50     64.00     56.60     54.70     52.90
  52.20     50.30     51.10     49.60     48.40     47.10     46.60     46.30     46.30     46.00     45.80     45.50
  45.30     45.20     45.20     45.30     45.00     45.20     44.60     53.70     59.20     65.80     68.40     74.80

INSIDE AIR TEMPERATURE CYCLE
  77.90     78.90     79.30     79.10     78.30     78.70     79.00     78.50     78.30     79.10     78.40     78.80
  75.60     78.80     79.10     79.40     79.70     80.00     81.20     80.20     80.20     79.90     79.40     79.00
  78.70     78.70     78.80     78.90     78.70     79.00     79.10     79.10     78.50     78.90     78.90     78.00
  75.20     79.00     78.90     79.10     79.00     79.00     79.00     78.20     79.30     79.00     79.10     79.10

   A(1)      A(2)      A(3)      A(4)       CFM        JD        AD        UW        AW        TG        TA
 350.00    573.00    350.00       .00     21.00       .25     20.50       .45     64.00     70.90     79.00
```

```
                 TEMPERATURES,F                                                   HEAT  FLOWS,BTU/HR
TIME        TO        TI      ROOF      WALL     FLOOR     SOLID      DOOR    WINDOW     INFIL        NET
   1     78.20     77.90     10.94      5.49      -.16       .00     -1.54     -8.64     -6.80    7393.63
   2     82.10     78.90     10.87      5.32       .91       .00    -15.40    -92.16    -72.58    8194.47
   3     85.70     78.80      9.51      5.07       .80       .00    -35.35   -198.72   -156.49    7306.44
   4     89.60     79.10      8.51      6.13      1.09       .00    -53.81   -302.40   -238.14    6391.25
   5     93.10     78.30      6.34      5.20       .28       .00    -75.85   -426.24   -335.66    4992.88
   6     95.40     78.70      5.37      5.39       .73       .00    -85.59   -480.96   -378.76    4756.74
   7     96.20     79.00      4.23      5.18      1.02       .00    -88.15   -495.36   -390.10    4350.07
   8     96.20     78.50      2.37      4.33       .51       .00    -90.71   -509.76   -401.44    2923.10
   9     97.60     78.30       .95      3.78       .35       .00    -98.91   -555.84   -437.72    1907.04
  10    100.30     79.10       .61      4.09      1.17       .00   -108.65   -610.56   -480.82    2117.30
  11    101.00     78.40     -1.25      2.89       .45       .00   -115.83   -650.88   -512.57     389.30
  12    101.50     78.80     -1.91      2.79       .88       .00   -116.34   -653.76   -514.84     233.35
  13    101.30     78.60     -3.13      2.12       .67       .00   -116.34   -653.76   -514.84    -713.96
  14     99.40     78.80     -3.33      1.92       .88       .00   -105.57   -593.28   -467.21    -971.34
  15     96.50     79.10     -4.31      1.58      1.16       .00    -89.17   -501.12   -394.63   -1024.95
  16     93.50     79.40     -4.61      1.32      1.41       .00    -72.78   -408.96   -322.06   -1033.87
  17     91.00     79.70     -4.71      1.07      1.54       .00    -57.91   -325.44   -256.28    -994.12
  18     86.00     80.00     -4.63       .84      1.84       .00    -30.75   -172.80   -136.08    -746.31
  19     82.30     80.20     -4.43       .57      1.93       .00    -10.76    -60.48    -47.63    -608.42
  20     74.50     80.20     -4.21       .20      1.82       .00     29.21    164.16    129.28    -378.66
  21     64.00     80.20     -3.68      -.09      1.73       .00     83.02    466.56    367.42     171.78
  22     56.60     79.90     -3.04      -.54      1.35       .00    119.41    671.04    528.44     363.11
  23     54.70     79.40     -2.21     -1.03       .92       .00    126.59    711.36    560.20     221.51
  24     52.90     79.00     -1.10     -1.28       .44       .00    133.76    751.68    591.95     381.87
  25     52.20     78.70       .10     -1.34       .20       .00    135.81    763.20    601.02     703.66
  26     50.30     78.70      1.53     -1.05       .27       .00    145.55    817.92    644.11    1526.91
  27     51.10     78.80      2.96      -.64       .42       .00    141.96    797.76    628.24    2318.58
  28     48.60     78.90      4.27      -.20       .56       .00    155.29    872.64    687.20    3267.17
  29     48.40     78.70      5.20       .01       .39       .00    155.29    872.64    687.20    3680.95
  30     47.10     79.00      6.57       .68       .73       .00    163.49    918.72    723.49    4818.50
  31     46.60     79.10      7.65      1.15       .83       .00    166.56    936.00    737.10    5580.69
  32     46.30     79.10      8.55      1.54       .83       .00    168.10    944.64    743.90    6180.64
  33     46.30     78.50      8.82      1.45       .25       .00    165.02    927.36    730.30    5977.00
  34     46.00     78.90     10.03      2.24       .70       .00    168.61    947.52    746.17    7127.70
  35     45.80     78.90     10.71      2.62       .71       .00    169.64    953.28    750.71    7635.45
  36     45.50     78.00     10.47      2.27      -.15       .00    166.56    936.00    737.10    6979.67
  37     45.30     78.20     11.31      2.91       .15       .00    168.61    947.52    746.17    7829.32
  38     45.20     79.00     12.64      3.33       .99       .00    173.23    973.44    766.58    9329.01
  39     45.20     78.00     12.10      3.39      -.01       .00    168.10    944.64    743.90    8368.98
  40     45.30     79.10     13.66      4.68      1.15       .00    173.23    973.44    766.58   10247.80
  41     45.00     79.00     13.89      4.91      1.00       .00    174.25    979.20    771.12   10375.53
  42     45.20     79.00     14.21      5.07       .99       .00    173.23    973.44    766.58   10543.40
  43     44.60     79.00     14.50      5.32       .97       .00    176.30    990.72    780.19   10939.93
  44     53.70     78.20     13.93      4.91       .18       .00    125.55    705.60    555.66    9644.44
  45     59.20     79.30     15.13      6.12      1.31       .00    103.01    578.88    455.87   11008.56
  46     65.80     79.00     14.46      6.00       .36       .00     67.65    380.16    299.38   10179.79
  47     68.40     79.10     13.94      6.25      1.04       .00     54.84    308.16    242.68   10953.10
  48     74.80     79.10     13.11      6.34      1.02       .00     22.04    123.84     97.52    9450.41
```

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